Thesis

Attention meets emotion : temporal unfolding of attentional processes to emotionally relevant information

ROESCH, Etienne

Abstract

We investigated the interplay of the perception of emotion and the allocation of attentional resources. We contrasted predictions taken from basic emotion theories and appraisal theories, and hypothesized that emotionally relevant information attracts attention, thus biasing perception. We used the modulation of the attentional blink and psychophysical methods, and examined the perception of static, and dynamic, fearful, happy and neutral facial expressions. We showed that the time course of the AB can be decomposed into several periods, each of which is differentially sensitive to emotion-laden information. In a paradigm designed to measure the minimum display duration necessary to make a correct gender decision on emotion-laden faces, we showed that, on average and across all emotions, participants need the face to be displayed for 50 msec, and that they make significantly less mistake when the face is fearful or happy. Results emphasise the importance of inter-individual differences.

Reference

ROESCH, Etienne. *Attention meets emotion : temporal unfolding of attentional processes to emotionally relevant information*. Thèse de doctorat : Univ. Genève, 2009, no. FPSE 439

URN : urn:nbn:ch:unige-163821
DOI : 10.13097/archive-ouverte/unige:16382

UNIVERSITÉ DE GENÈVE
FACULTÉ DE PSYCHOLOGIE ET DES SCIENCES DE L'ÉDUCATION

Section de Psychologie

Sous la direction du Prof. Klaus R. Scherer et du Prof. David Sander

---

ATTENTION MEETS EMOTION: TEMPORAL UNFOLDING OF ATTENTIONAL PROCESSES TO EMOTIONALLY RELEVANT INFORMATION

THÈSE

Présentée à la
Faculté de Psychologie et des Sciences de l'éducation
de l'Université de Genève
pour obtenir le grade de Docteur en Psychologie

par

Etienne B. ROESCH

de

Thionville (France)

Thèse N° 439

GENÈVE

Octobre 2009

UNIVERSITÉ DE GENÈVE
FACULTÉ DE PSYCHOLOGIE ET DES SCIENCES DE L'ÉDUCATION

Section de Psychologie

ATTENTION MEETS EMOTION:

TEMPORAL UNFOLDING OF ATTENTIONAL PROCESSES TO EMOTIONALLY RELEVANT INFORMATION

THÈSE

Présentée par

Etienne B. ROESCH

JURY DE THÈSE

Dr. Tom Johnstone

Prof. Dirk Kerzel

Prof. David Sander (*Directeur de thèse*)

Prof. Klaus R. Scherer (*Directeur de thèse*)

Prof. Patrik Vuilleumier

To my family.
To Mina.

Acknowledgements

I am for ever in debt to many people, without whom the completion of this thesis would not have been possible...

First of all, I would like to thank Klaus Scherer and David Sander, who not only provided me with support and guidance throughout this work, but also introduced me to the fascinating world of research and shared their enthusiasm for inter-disciplinarity. I would like to thank Patrik Vuilleumier and Dirk Kerzel, for serving in my thesis committee, and for the many discussions that shaped my work and my understanding of how the brain does what it does. I would like to thank Tom Johnstone, for his warm smiles and unbounded support, and for having accepted to be part of the final jury.

I am grateful to the 698 participants who generously donated a moment of their busy lives, and endured an "experiment" to build Science, without complaining (much).

I am obliged to Andreas, Christopher, Fabien, Martijn, Mina, and Nienke for reading and commenting on this manuscript.

I would like to thank the colleagues and friends who provided me with the smiles required to get through the downs and build upon the ups of the Ph.D., Alison, Arnaud & Mehdi & Karim, Astrid, Chiara, Christelle, Christian, Christopher & Ginevra, Cristina (mwã!), Murray and everyone in the Cognitive Robotics group at Imperial College, David & Véro, Didier & Andrei, Del & Seb & Tancred, Fridtjof, Irene, Joana, Joanna, Katia, Kerstin, Lionel, Lucas, Marc, Marcello, Martijn, Michael, Natascha, Nele, Nienke, PN & Tony (HVRd'I), Seba, Sophie, Stéphane, Sylvain, Tanja, Tobias, Venera, and all the others. I would like to thank Alexandre, Antoine, Edouard, Harry, Jean-Paul, Michel and all of our Friends for everything and more.

I dedicate this work to my parents, Hélène and Paul, and to my beloved brothers, Guillaume and Mathieu. I owe you everything. If it was not for you, I would not have attempted this journey.

The last words go to the love of my life. Mina, you have shared every moment of this work. You have explored every affective dimension, discussed every appraisal, and empathised with every subjective feeling that occurred during this part of my life. I thank you for putting up with all this, and for always pushing me to go beyond the limits. I thank you for believing in me, and for sharing your life with me. You are my home. I am the luckiest man in the world.

Thank you, each one of you.

Contents

List of abbreviations

AB	Attentional blink (Raymond et al., 1992)
ACC	Anterior cingulate cortex
AU	Action unit
ANN	Artificial neural network
CPM	Component process model (Scherer, 2001)
CPU	Central processing unit
EEG	Electro–encephalography
FACS	Facial action coding system (Ekman et al., 2002)
GPU	Graphics processing unit
GWT	Global workspace theory (Baars, 1988)
MEG	Magneto–encephalography
fMRI	Functional magnetic resonance imaging
LC–NE	Locus coeruleus–norepinephrine (a.k.a. dopamine, noradrenergic system)
PFC	Pre-frontal cortex
PRP	Psychological refractory period (Pashler, 1984)
PG	Parietal gyri
RP	Repetition blindness (Kanwisher, 1987)
TE/TEO	Inferior temporal areas / Temporo–occipital areas

List of Figures

List of Tables

Chapter 1

Emotion theories and attention

Abstract: What are emotions? What is attention? What is the link between the two and, more importantly, what can we learn from one about the other? In this chapter, we will describe the distinctive nature of the link between emotion and attention as perceived through the lenses of three major classes of emotion theories. Each class of theories provides a number of models that illuminate this link in a particular way. We will use selected models to formulate the general hypotheses that formed the foundation for the experimental work presented in this thesis.

A major task of the organism is to cope with and survive in its environment. To achieve this goal, a major constraint of the cognitive system is the limited resources that need to be allocated to the processing of the perceived environment. Evolutionary pressure provided organisms with two mechanisms to take on this task: emotion and attention. The former evaluates the significance of the stimuli perceived by the organism, while the latter sustains the further processing of selected stimuli. Combined, these two mechanisms guide perception, resolve conflicts and avoid interference, allowing the brain to cope with subsets of the available information. In this chapter, we will define the link between emotion and attention as perceived through the lenses of major emotion theories: dimensional theories, basic emotion theories, and appraisal theories of emotion.

To scholarly define what emotions are, one needs to take a grand perspective over a few hundred years of research. Trying to reconcile the various theories and definitions that have been proposed is a task that has proved to be difficult (Kleinginna & Kleinginna, 1981). Much like the folk tale of the blind men and the elephant[1], each researcher studies a very specific aspect of emotions, and conclusions are sometimes in complete disagreement. To circumscribe the study of emotion through the study of attention is to see emotions in the light of their evolutionary functions (Izard, 1979; Tooby & Cosmides, 1990). Emotions ensure the required level of readiness to respond to events of significance to the organism's survival, by decoupling perception from behaviour (Scherer, 1984). In their own ways, emotion theories propose a description of the mechanisms underlying this function.

1.1 Through the lens of dimensional theories: Orthogonal systems motivate the orienting of attention

1.1.1 Spinoza and Wundt's legacies

Generally, dimensional theories represent a particular affective phenomenon as a set of coordinates in a low-dimensional space; thus allowing the differentiation of a wide range of phenomena while acknowledging the infinite richness of emotional experience. Consequently, a major task for dimensional theorists is to define the dimensions that best represent this space. This challenge leads to further questions about the optimal number and the nature of such dimensions. Early dimensional theories often don't directly address the link between emotion and attention. Yet, attention is often implicitly referred to in the functional description of the orthogonal dimensions proposed by each model. The orienting of attention is thus often accounted for by the common effect of the evaluative systems supporting each dimension.

The idea that the emotion domain can be reduced to a small number of dimensions may have first been introduced by the 18th century Dutch philosopher Baruch Spinoza. According to him, not only are emotions pleasant or unpleasant, but they are also weak or strong, and short-lived or persistent (Osgood, 1957). Wundt (1896) rejuvenated the idea, and proposed to structure the space of feelings[2] along three dimensions: pleasure–displeasure, arousal–rest, and tension–relaxation (Figure 1.1, panel a).

After Wundt, many theorists proposed low-dimensional models to account for the full range of

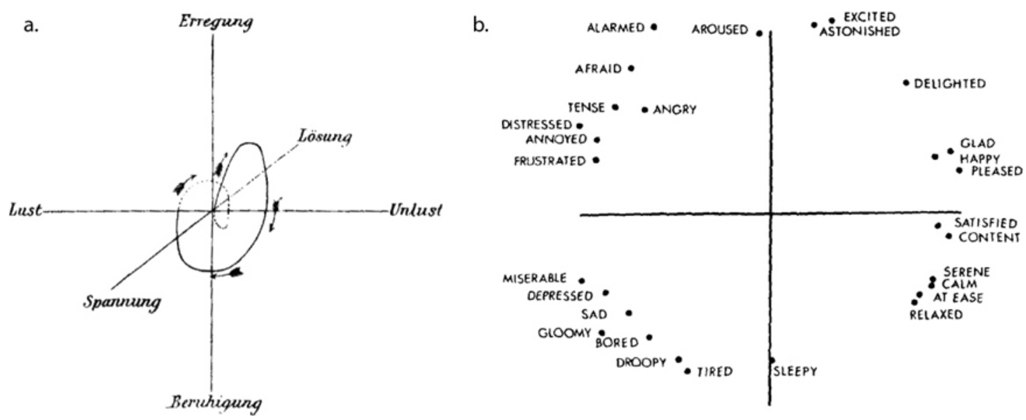

Figure 1.1: Panel a. The three-dimensional space of feelings ("Gefühle") proposed by Wundt (1896). Panel b. The circumplex model of affect (Russell, 1980).

emotional experience. Assuming that the meaning of emotional words transcends emotional experience, Schlosberg (1952), Osgood et al. (1975), and Russell & Mehrabian (1977) came to the conclusion that the emotional domain comprises three orthogonal dimensions: pleasure–displeasure, levels of arousal, and dominance–submissiveness. In other words, they argued not only that emotional words can be used to probe the space of emotional experience, but that this space can also be reduced to a minimal set of three dimensions. Using different sorting and scaling techniques on a selection of 28 emotional words, Russell (1980) concluded that this space could be reduced to a two-dimensional representation along the dimensions of valence and arousal (see also Plutchik, 1962, 1980). This model was very appealing in that it conveniently represented a broad range of emotional phenomenon on a circle, dubbed a circumplex model of affect (Figure 1.1, panel b). These results were then replicated in a cross-cultural context (Russell, 1983), and extended to the perception of prototypical emotional facial expressions across cultures (Russell et al., 1989).

Russell made two fundamental claims that contributed to establish dimensional models in general, and his two-dimensional circumplex in particular, in the scientific community (Russell, 1980, 2003; Russell & Feldman Barett, 1999): a) the valence/arousal circumplex is an integrative model that represents the structure of affective experience, and b) it also represents the cognitive structure underlying affect. Some researchers took these claims quite literally, and attempted the description of the functional systems implementing these two dimensions in the nervous system, as we will see in the next section. These fundamental claims have been very appealing to a wide range of disciplines. The conceptual economy obtained from representing emotional constructs in such a two-dimensional space is indeed useful in many respects: In clinical settings, for instance, it eases the diagnostic process (Davidson, 1998); in affective computing (Picard, 1997), where engineers build artifacts that can sense and express emotions, a low-dimensional representation reduces the complexity of the computations.

Recent results however challenge the notion that a minimal two-dimensional space is sufficient to fully represent the emotion domain. In an effort to best fit the semantic space of emotion terms, we[3] constructed a novel instrument based on the predictions formulated in the framework of major emotion theories. This instrument comprehensively gathers 144 features, representing the six components explicitly assumed by most emotion theorists as centrally relevant to the domain of emotion. We used this instrument to evaluate the semantic space of 24 prototypical emotion words, in three different Indo-European cultures. We found robust evidence for at least four dimensions, which accounted for 75.5% of the total variance. In order of importance: evaluation–pleasantness (35.3%), potency–control (22.8%), activation–arousal (11.4%), and unpredictability of the occurring event (6.0%). Whereas the first three dimensions resemble the space suggested half a century ago, the fourth dimension, unpredictability, is not reported by most studies. This latter dimension reflects the urgent reaction to novel stimuli and unfamiliar situations. Of most interest, it renders an explicit continuum differentiating the semantic spaces of surprise, fear, and anxiety.

It is most likely that fear and anxiety share a common evolutionary path. Yet, these are conceptually different affective phenomena, which differ with respect to the object of attention and the associated behavioural response: When fear is elicited by threatening objects in the vicinity of the organism, often requiring an immediate response, anxiety is often elicited by objects characterised by a looser probability of occurrence, in a more or less distant future. One can easily distinguish the implication of attentional processes in the prediction and perception of forecoming threats, as emphasised in a number of studies addressing the influence of attention in the etiology and maintenance of anxiety disorders (Epstein, 1972; Eysenck, 1992; Wells & Matthews, 1994). This new dimension thus constitutes a fruitful extension of traditional dimensional theories, especially with regards to the link between emotion and other processing systems like attention.

In the family of dimensional theories, one model stands out by formulating possible mechanisms for the interaction of affective phenomenon with other systems, like attention. It is embodied into the concept of core affect (Russell & Feldman Barett, 1999; Russell, 2003). In the next section, we will introduce this conceptualisation, and formulate predictions that can be made about the link between emotion and attention in this theoretical framework.

1.1.2 The "core affect" hypothesis: Attention will be drawn by information that activates interacting bi-dimensional neurophysiological systems

Russell and colleagues extended the interpretation of the circumplex model of affect into the concept of core affect (Russell & Feldman Barett, 1999; Russell, 2003), which they define as a "neurophysiological state that is consciously accessible as a simple, nonreflective feeling that is an integral blend of hedonic (pleasure-displeasure) and arousal (sleepy-activated) values" (2003, p. 147). This conceptualisation attempts to go beyond the folk concepts of emotion and feeling, and propose a "psychological currency" (p. 153) to represent the neurophysiological mechanisms that give rise to emotion. The core affect hypothesis suggests that prototypical emotions, say fear, are blends of activations from several neurophysiological systems – expressed in the bi-dimensional space of valence and arousal – that cannot be reduced to atomic objects. Several varieties of the same prototypical emotion may exist, which cannot be accounted for by the activation of a single emotional system, say a fear system[4]. Through the concept of core affect, Russell and colleagues thus attempts to define the fundamental bricks that compose the emotional system and sustain the richness of affective phenomena.

Core affect (i.e., as a neurophysiological state) is object-free, but becomes directed *at* an object after a process of attribution. A key mechanism is that the organism constantly looks for the causes to any change in core affect, which reacts and depends on all information available, perceptual and cognitive, of course, but also hormonal or physiological. Through this mechanism, core affect informs, facilitates and guides all other systems of cognitive processing, like attention (Russell, 2003).

The biological substrate underlying core affect is not well described, and best perceived through the bi-dimensional space it represents, the circumplex model of affect (Russell, 2003). Each of these orthogonal dimensions is a topic of research in its own right, and a growing number of studies investigate their behavioural and neuroimaging correlates, as well as their link to attention.

The concept of valence

The concept of valence relates to the hedonic value of pleasure–displeasure (Russell & Feldman Barett, 1999; Russell, 2003). It is part of all formal definitions of emotions, and central to most, if not all theories of emotion (see Colombetti, 2005, for a review). Feldman Barett (2006) defines it as an invariant feature of emotion and affective life in general, and suggests it is one of the "basic building block" of emotion that derives from the organism's ability to engage in a process of valuation, i.e., deciding whether an object is helpful or harmful. She notes that individuals differ in their ability to monitor, perceive and report the details of their emotional life, and suggests that this trait of "emotional granularity", is grounded on valence as a basic principle engaged in personality (Feldman Barett, 2006, p. 37).

Psychophysiological correlates of valenced information processing have been under thorough scrutiny since the beginning of the discipline. In 1990, Lang et al. examined startle-reflex responses evoked during the passive viewing and the recall of emotion-laden images. In several experiments, they showed that startle responses are enhanced during the perception of aversive images, and diminished during the perception of pleasant images. By controlling for the level of intensity/arousal of the images, they studied the specificity of this valence-based response, and proposed that emotions are organised on a bi-phasic continuum, spanning aversive and appetitive contents. They further integrate this view in a theory linking emotion to attention, and suggest that affective valence information is a basic category of information processing, informing and guiding attention and perception (Russell, 2003).

The investigation of valence and its bipolar organisation is closely related to the study of motivational systems underlying the functions of approach and withdrawal (Davidson, 1992; Davidson & Irwin, 1999; Cacioppo & Gardner, 1999). Two systems are proposed to mediate each of these action tendencies: The approach system would implement appetitive behaviours as well as a number of positive emotions, like enthusiasm and pride. The withdrawal system would implement aversion-related behaviours and emotions, like fear and disgust. The former would motivate getting closer to the source of the emotion, whereas the latter would motivate withdrawal. Numerous neuroimaging studies attempted the description of the neural circuitry implementing these two systems, and pointed at brain structures like the PFC, the ACC and the amygdala. An other important result of this thread of research is the investigation of the cerebral lateralisation, as structures in the left hemisphere seem to be more involved in the processing of approach-related emotions, whereas structures in the right hemisphere seem to be more involved in the processing of avoidance-related emotions (Davidson, 2000, 2001, see also Borod & Madigan, 2000, for a different interpretation). The cerebral asymmetry of these processes has been used in to characterise emotional disorders, like depression (e.g. Davidson, Pizzagalli, et al., 2002) and anxiety (e.g. Davidson, Lewis, et al., 2002).

The concept of arousal

The concept of arousal is one of the most notorious concepts in psychology and neuroscience (Cacioppo et al., 1996). It has been thought to influence and motivate a wide range of phenomena, and its influence can be traced back to the early days of psychology. A putative definition would see arousal as "a general and initially perceptible energising physiological state that is the prepotent physiological determinant of social behaviour" (Cacioppo et al., 1996, p. 72).

At the beginning of the 20th century, Duffy argued that behaviour could be described as variations in either the direction of the behaviour or the intensity of behaviour (1934; 1957). In particular, she was amongst the first to claim that the intensity of behaviour could be abstracted and, as such, investigated in isolation from the other variables constituting behaviour. Reporting that the arousal elicited by occurring stimuli has a distinctive effect over the physiology of individuals, she advocated several methods to address the systems involved in emotional activation. The concept of arousal indeed brings together a wide variety of research traditions and methodologies, as it illuminates very different levels of analysis, spanning neural and social perspectives.

A large body of literature indeed shows that different levels of investigations (e.g. perception, peripheral and central activation) generally correlate with valence and arousal. Lang et al. (1993, 1998) for instance showed that valence and arousal ratings of emotional pictures robustly correlate across participants; a finding which has been replicated across cultures (Hamm et al., 2003). At the neural level, Lane et al. (1999) demonstrated distinct modulatory effects of valence and arousal on the activation of the visual cortex, which they attributed to early top-down influence from the amygdala.

Arousal is believed to motivate the orienting of attention to salient objects of the environment (Hebb, 1955; Lang et al., 1997, 2000; Lane et al., 1999). For Levenson (1999; 2003), for instance, it constitutes the core system in emotion: The arousal system promotes the detection and identification of incoming stimuli, supports the selection of an appropriate response by maintaining the organism in the appropriate level of readiness, and eases the organism into a state of physiological calm ("deactivation") when action is no longer necessary. Evidence suggesting arousal is a critical aspect of attentional orienting comes from studies addressing the modulation of the attentional blink in rapid serial visual presentations. In these paradigms, participants have only limited access to the meaning of the target words, yet arousing emotional words seem to benefit from a processing bias and survive this particular attentional deficit regardless of their valence (Anderson, 2005; Keil & Ihssen, 2004).

1.2 Through the lens of basic emotion theories: emotion-specific, and evolutionary justified mechanisms underlie selective attention

1.2.1 Darwin's legacy

This theoretical tradition originated after Charles Darwin's seminal work on emotional expression (Darwin, 1872). By comparing the emotional facial expressions of humans and animals throughout the world, Darwin proposed that the configural patterns of facial muscles expressing emotions were due to a "principle of serviceable associated habits" (Darwin, 1872, p. 34). According to this principle, universal emotional expressions did not evolve for the sole purpose of communicating, but rather as an incidental product due to particular actions associated with strong emotions. According to him, prototypical facial expressions find their origins in the phylogeny of the species, and would be the remainder of particular actions that led to evolutionary advantages for the species. The purpose of the facial expression of disgust, for instance, would be to expel from the mouth a piece of food appraised as dangerous for the organism (see also Rozin & Fallon, 1987; Wiens et al., 2008), and the purpose of the facial expression of fear would be to gather as much sensory information as possible (see also Susskind et al., 2008).

Tomkins (1962), Ekman (1992, 1999, 2004), Izard (1992, 2007) and others, extended Darwin's work, and formalised a full theoretical account on emotional systems. Primarily, these views posit a finite number of basic emotions, which emerged in response to evolutionary pressure. These discrete entities possess unique properties, distinguishing one from the others, and are believed to be mediated by separate and distinct brain substrates (Ekman, 2003; Izard, 2007). A basic emotion occurs rapidly, and automatically, upon perception and classification of a stimulus as belonging to specific classes of events.

The classes of these events are of upmost importance, as some results emphasise the universality of the themes representing these events across cultures (Boucher & Brant, 1981; Matsumoto et al., 1988; Scherer et al., 1983). Ekman (2004, p. 125) refers to these automatic appraising mechanisms as "autoappraisers [...] scanning continuously, out of our conscious awareness, watching out for the themes and variations of the events that have been relevant to our survival." To ensure an adaptive function to the processes in the daily life, supporting the acquisition of new information, for instance, he further proposes that autoappraisers query and update some kind of an "emotional alert database" (2004, p. 125), collecting information about goals and direct concerns for the individual.

Proponents of the basic emotion theories argued for a long time about the number of such basic emotions, varying from six to over ten. A consensus seems to have been reached however, in the form of a list of six emotions: anger, disgust, fear, joy/happiness, sadness and surprise (Ekman, 2003; Izard, 2007). These six emotions are considered fundamental, as they can be combined and blended into more complex emotions (e.g., shame or guilt).

By setting the emphasis on the adaptive role of emotions in dealing with key survival issues, basic emotion theorists argue that emotional systems evolved concurrently, providing individuals with better ways of handling their environment. Amongst which is the quick selective attention to elements of the environment carrying some relevance for the individual's survival, in preparation for an appropriate response.

1.2.2 The "fear module" hypothesis: Attention will preferentially be drawn by fear-related stimuli

In this context, fear is often presented as the most important emotion. Not only does it explicitly refer to objects of major value for survival, it has a special importance in our modern society due to the prevalence of anxiety disorders (for a review, see Bishop, 2007). In an early work, Seligman (1970, 1971) showed that certain threatening stimuli (e.g., snakes, spiders) were more susceptible to fearful conditioning than other types of stimuli. To explain his results, he formulated the preparedness hypothesis, according to which this ease of associability would be due to the threatening contexts encountered throughout the evolution of the species, rather than to individual features of the stimuli. In other words, evolutionary pressure would have favoured the associative mechanisms that would provide individuals with the ability to easily recognise threatening situations.

Influenced by Fodor's modular approach (1983), Öhman and colleagues extended this work and developed the concept of the fear module (Öhman & Mineka, 2001; Mineka & Öhman, 2002): a particular module dedicated to the detection of fear-related situations (Figure 1.2). This selectivity to the sole class of threatening events is justified by the need for minimal neural processing to capture attention, and to promote rapid defencive response (Öhman & Wiens, 2004). The ease of associability through conditioning described by Seligman would thus ensure that the range of stimuli that activates the fear module can be expanded to specific, new threatening stimuli of the

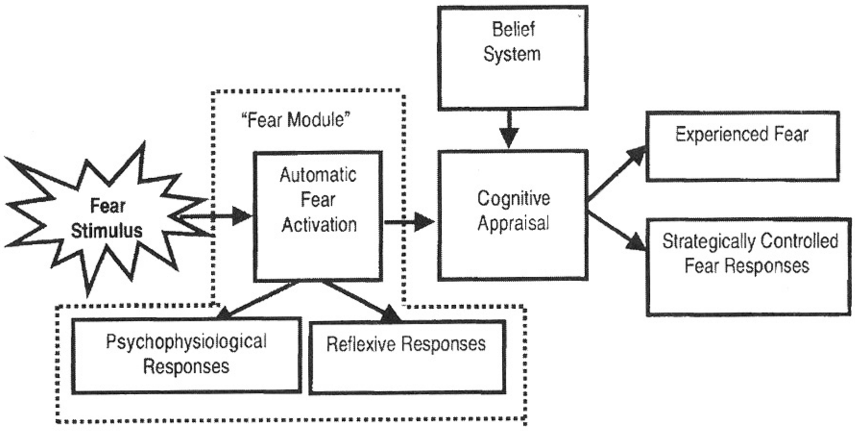

Figure 1.2: The fear module (Öhman & Wiens, 2004). Upon perception of a fear-related stimulus, the fear module activates a cascade of events meant to prepare the individual for immediate, appropriate response.

environment (Öhman et al., 1975, 1976). This particular module would not require any conscious recognition of the perceived stimulus. It is also proposed to be encapsulated, that is independent from other modules. Once activated, it would behave in a ballistic fashion, relatively impenetrable to higher-order influences. Finally, it would be centred around the amygdala. This brain structure is indeed in a very good place in the perceptual processing stream for this task (LeDoux, 1996).

According to this hypothesis, anxiety disorders and phobias can be explained by both the natural inclination of our species towards a specific class of threatening events (Seligman, 1970, 1971; Öhman & Mineka, 2001), and the particular malfunction of the processes involved in the detection of threatening stimuli, or the learning of fearful reactions (Mineka & Öhman, 2002; Juth et al., 2005). The formal object of this module was originally proposed to be restricted to any stimulus of the environment that has been experienced through a phylogenetic contingency with physical harm (e.g., reptile predators, aggressive social encounters). This claim has later been refined to include ontogenetic threat stimuli as well (Brosch & Sharma, 2005; Blanchette, 2006; Flykt et al., 2007). In this framework, the experienced contingencies between threat and harm is believed to have resulted in hardwired connections in the brain, located in the amygdala, supporting reflexive-like behaviours (automatic, fast, pre-attentive and preconscious) promoting the survival of the individual.

A general prediction can thus be made: any threatening stimulus will yield to an orienting reflex in preparation for an immediate response (Mogg & Bradley, 1998, 1999). This prediction is supported by a growing amount of data pointing at an advantage for detecting threatening stimuli (e.g., Flykt et al., 2007; Brosch & Sharma, 2005). In a series of experiments using the visual search paradigm, for instance, Öhman and colleagues showed that participants were faster at detecting a schematic face expressing anger within a board of smiling faces, than at detecting a smiling face within a board of angry faces (Öhman et al., 2001). They later demonstrated that this effect was enhanced in socially anxious participants (Juth et al., 2005). They report, however, that when they used pictures of faces in place of schematic faces, healthy participants were faster and more accurate at detecting happy faces than angry faces. They explain this effect by arguing that schematic faces were more controlled (e.g., in terms of intensity and expressiveness) compared to the schematic pictures they used. Results to a memory task comparing both types of stimuli indeed suggest that the pictures of smiling faces were more easily processed and recognised than schematic faces (Juth et al., 2005).

The scope of the fear module is explicitly restricted to threatening stimuli, and does not account for the perception or response to stimuli belonging to other classes of emotions. An implicit corollary to this hypothesis would be that there exist similar dedicated processing systems for the other so-called basic emotions, as described by Ekman (2003), or Izard (2007). Given the evolutionary value for survival of threatening stimuli, it is expected that modules concerned with positive stimuli would yield to less prominent orienting reflexes than the fear module.

1.3 Through the lens of appraisal theories of emotions: pre-attentive, emotion non-specific mechanisms yield to the unfolding of attention

1.3.1 Arnold's legacy

Appraisal theories of emotion originated after the work of Magda Arnold (1960) who first argued that organisms constantly evaluate the relevance of environmental changes against a finite number of criteria. She dubbed these evaluative processes "appraisals" (p. 73), referring to the rapid, automatic, unconscious, and ballistic evaluations involved in this recurrent process (see also Lazarus, 1966). In this framework, an appraisal is viewed as a continuous process filtering the significance of the events occurring in the environment. A number of appraisal processes interact, generating emotions[5], and thereby influencing the course of perception and action of the organism.

A central tenet of appraisal theories sees emotions as adaptive mechanisms meant to decouple perception and behaviour (Scherer, 1984). As such, emotions represent a flexible, evolutionary justified alternative to pre-wired reflexive responses, providing the organism with the ability to respond to a greater range of situations. The elicitation and differentiation of emotions occur through the integration of the many appraisals. In other words, the process causally linking a stimulus to an emotional response is divided into multiple appraisals, which are common to every emotions. These processes evaluate the perceived object from the environment against a finite number of criteria. The integration of these appraisals yields the genesis of a particular emotion. Unlike basic emotion theories, appraisal theories do not posit a finite number of emotions, as the appraised space can virtually contain an infinite number of emotional states.

Several theories attempt to define the very appraisal criteria involved in the recurrent evaluative process (see Table 1.1). A general picture emerges in the form of central appraisal themes spanning from low-level perceptual features (novelty, attentional grabbing) to higher-level features involving the individual's motivations and her social environment (goals, agency, norms and standards).

The integration of the appraisals results in action tendencies that are experienced as emotions (Ellsworth & Scherer, 2003; Frijda, 2005). These action tendencies are concerned with the appropriate reaction to the occurring event, and as such it is not surprising to see that attention (in a broad sense) is central to most appraisal theories. "Attention is tied to what the event means" (Frijda, 2005, p. 475), and it is attention that will drive the cascading appraisal process, setting the ground for the level of action-readiness required for an appropriate reaction.

1.3.2 The component process model: Attention will be drawn by relevant stimuli

The idea that it is attention that will drive the unfolding appraising process is central to the component process model (CPM; Scherer, 2001; Sander & Scherer, 2005). In this model, Scherer defines the nature and the functions of the cognitive evaluations yielding the genesis of an emotion. These evaluations are described in terms of objectives encompassing the main information domains that are required to the determination and ignition of appropriate reactions to a particular situation. The following objectives are being proposed:

1. Relevance – Is the stimulus relevant for the individual? Does it require attention deployment, further information processing?
2. Implication – What are the potential consequences of the stimulus for the individual?

Frijda (1986)	Roseman (1984)	Scherer (2001)	Smith & Ellsworth (1985)
Change		Relevance • Novelty (suddenness, familiarity, predictability)	Attentional activity
Familiarity			
Certainty	Certainty	• Intrinsic pleasantness	Certainty
Valence		• Goal/need relevance	Pleasantness
Focality	Appetitive/aversive motives		Importance
		Implication	
Intent/Self-other	Agency	• Causality: agent	Human agency
		• Causality: motive • Outcome probability • Discrepancy from expectation • Conduciveness • Urgency	
		Coping • Control • Power • Adjustment	
Value relevance		Normative significance • Internal standards compatibility • External standards compatibility	Legitimacy

Attention-related appraisals (Change through Importance rows)

Table 1.1: Comparison of appraisal criteria postulated by different theorists, adapted from Ellsworth & Scherer (2003). Appraisals related to attentional processes are generally proposed to occur at the beginning of the evaluative sequence.

3. Coping – Does the individual have sufficient resources to cope with the consequences of the event?

4. Normative significance – How does the stimulus relate to the individual's social or personal norms and standards?

Each of these objectives encompasses more subtle cognitive appraisals, dubbed stimulus evaluation checks (SECs), the interaction of which yields to the differentiation of the ensuing emotion. One can see these checks as dedicated processes evaluating the occurring stimulus in regards to specific criteria. Throughout the appraising process, the evaluative function of the checks increases in complexity. The significance of the occurring event to the organism is built up, and constantly re-appraised, through recursive evaluation cycles (see also Lazarus, 1966, 1991).

Core to this theory is the proposal that appraisals occur sequentially (Grandjean & Scherer, 2008) and influence in turn each of the five components of emotion (Figure 1.3). In addition, each appraisal interacts with higher-order cognitive systems, like attention, memory or motivation. The appraisal objective concerned with relevance starts the unfolding sequence of appraising processes. It is proposed to gather evaluations of the novelty of the stimulus, its intrinsic pleasantness, and its relevance for the goals and needs of the individual. The result of these (low-level) appraisals determine whether the individual's limited resources should be allocated to the further processing of the occurring stimulus. In other words, the appraisal of relevance determines the amount of processing resources to be allocated, driving attention to the important information in the environment. This first series of appraisal checks thus occur pre-attentively, rapidly tuning the appraising system to sustain the extensive processing of the perceived stimulus.

The concept of relevance is central to the CPM, being the first step in the sequence of appraisals (Figure 1.3). It is of particular importance as it is believed to determine the amount of cognitive resources to be allocated to the unfolding processing of the perceived stimulus. This mechanism is evolutionarily justified in that it provides the organism with the economy of available resources, only allocating processing resources to important stimuli, thus allowing for rapid responses. In general, any stimulus that could potentially influence the goals, satisfy the needs, or maintain the individual, or her in-group members, in a sustained level of well-being is considered relevant (Scherer, 2001).

The extent to which an event will be considered relevant depends heavily on the context in which it occurs. A facial expression of fear, for instance, will represent a relevant information for the

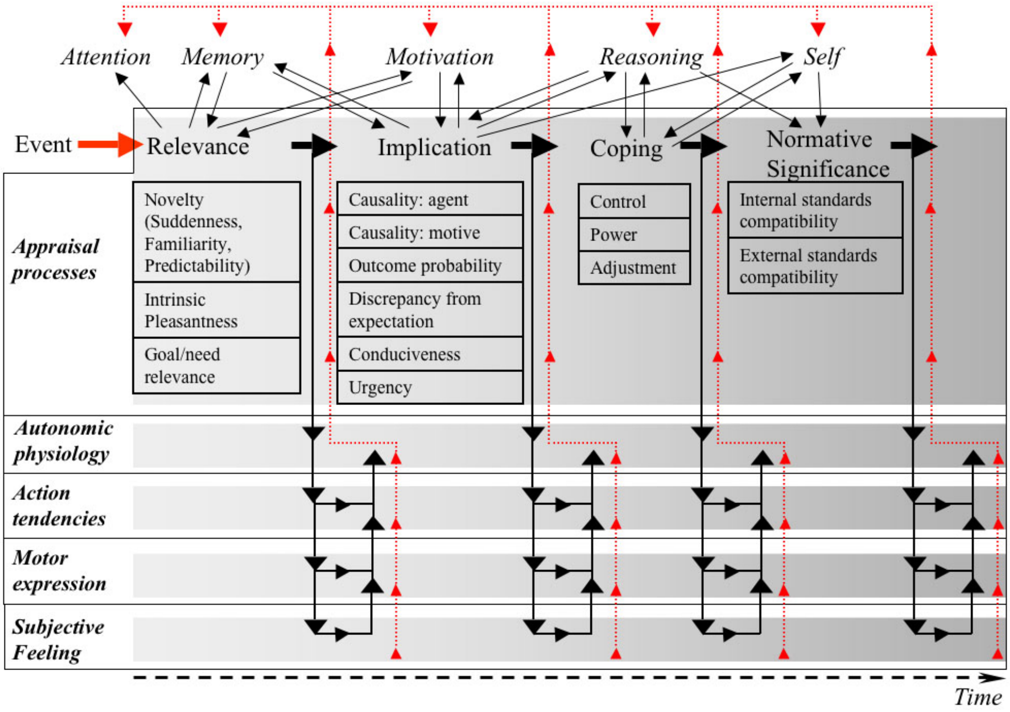

Figure 1.3: The component process model (Scherer, 2001; Sander & Scherer, 2005). Represented are the five components of emotion (vertical) as well as the sequence of appraisals (horizontal) and the interaction between subsystems that gradually shape the emotion, supporting the genesis of a particular feeling.

individual, signalling the occurrence of a negative event, obstructing the goals of the individual, or a potential danger. The degree to which the individual will process this information, allocating more or less resources to its processing, depends on her goals, her needs, and the present situation. If it occurs during a safari in the savanna, it will have a different importance than if it appears on the stage of a London theatre. The ensuing reactions include the orienting of attention towards the stimulus event, the allocation of cognitive resources to its further processing, and the preparation of the organism to a behavioural response.

The concept of relevance contrasts evidently with the proposal for a fear module, and several authors propose a different reading of the results supposedly demonstrating processing biases of threat-related material (Sander et al., 2003; Vuilleumier, 2005; Fitzgerald et al., 2006; Cunningham et al., 2008). A fundamental criticism to these results concerns the fact that most studies addressed the biases of phobic populations toward phobia-related material. By definition, such material is relevant to those populations, consequently these results may have suffered from the confounding factor of relevance.

1.4 Conclusion

In summary, each class of emotion theories sheds a different light on what emotions are, and how the link between emotions and attention is promoted:

In the framework of dimensional theories of emotion, the orienting of attention to salient stimuli of the environment is motivated by the joint effect of orthogonal evaluative systems. Results suggest that the valence and arousal elicited by occurring stimuli plays a critical role in the detection and identification of salient objects of the environment, providing grounds for the general hypothesis that attention will preferentially be drawn by stimuli that activate valence-based and arousal-based systems.

Basic emotion theories describe emotions as discrete objects implemented in distinct networks of brain areas. The fear module in particular describes the cascade of events leading to the orienting of attention to fear-related stimuli in preparation for an appropriate response. According to this model, attention will thus preferentially be drawn by fear-related stimuli.

Appraisal theories describe the processes common to every emotion involved in the evaluation of occurring events. The component process model in particular suggests that the unfolding of attention is driven by the evaluation of the relevance of the occurring event for the individual, including but not restricted to fear-related stimuli.

What do we learn about attention from emotion? Generally, emotion theories suggest that the attentional process as a whole is more than just a filter for concomitant perceptions. At some level, they all try to account for the orienting of attention, which then influences perception and behaviour in return. In this context, attention seems inseparable from, and complementary to emotion, promoting survival by providing the means of selecting the important information in the environment.

What do we learn about emotion from attention? From the accounts of emotion theories on attention, it can generally be understood that some level of emotion is appraised very rapidly, pre-attentively, and before full-blown conscious recognition. Emotion modulates attention, most likely through the afferent influence of subcortical areas over primary perceptual areas. Most emotion theory describe early influence of emotion over attention, and it thus seems probable that there is some dedicated emotional content at every levels of the processing, from perception through attention orienting, to recognition and action.

As the boundary between emotional and attentional systems gets blurrier and blurrier, it seems more suitable to speak of emotional attention (Vuilleumier, 2005). A key point to the study of this compound of systems is the temporal aspect intrinsic to the unfolding of the processing, yielding to questions of the sort "What influences what? When? And, how?". A big part of the work presented in this thesis was to review and elaborate suitable experimental means towards answering these questions.

Chapter 2

Recasting the link between emotion and attention

Abstract: What methods do researchers use to study the link between emotion and attention? What conclusions can be drawn, and how can we move forward? In this chapter, after quickly reviewing some of the most common methods to investigate the link between emotion and attention, we will introduce temporal attention as a way to specifically address the unfolding processing of emotion-laden stimuli. As an illustration, we will describe the attentional blink, an attentional deficit spreading over a few hundred milliseconds that can be used to probe the stages of processing ensuing perception. We will then review the results showing a modulation of this particular effect by emotional material.

"Attention is an emergent property of many neural mechanisms working to resolve competition for visual processing and control of behaviour" (Desimone & Duncan, 1995, p. 194; see also, Desimone, 1998; Duncan, 1997). As the organism is faced with virtually an infinite number of elements in the environment, it needs to select the ones that are most relevant for its current course of conduct. Perceived elements thus compete throughout the many levels of processing of the cognitive system. Attention refers to the outcome of this competition, where a particular stimulus takes priority over the others and benefits from sustained processing.

Attention, however, cannot be regarded as a unitary phenomenon. A great range of data indeed suggests that it is the result of several concurrent processes (see Allport, 1992; Driver, 2001; Raz & Buhle, 2006). If that is so, where in the flow of information can the link between emotion and attention be found? The diversity of paradigms being used to address what has been coined emotional attention (Vuilleumier, 2005) allowed to tap into very different attentional phenomena. Results generally suggest that perception and attention are enhanced for emotional material, and a number of behavioural observations as well as a growing body of neuroimaging data seem to show that emotional information is given priority at several stages of the processing (Table 2.1).

In this chapter, we will go through the main results of the research explicitly addressing the link between emotion and attention. By defining the particular experimental contexts within which conclusions are drawn, we will assess the limits of current methodologies. We will then define temporal attention as the temporal counterpart of the traditional "static" views on attention, and conclude that by explicitly setting the focus on the unfolding processing, temporal attention is an ideal tool to study emotional processes.

2.1 Static perspectives on the interplay between emotion and attention

2.1.1 Emotion modulates spatial attention

Spatial attention refers to the ability to select a particular piece of information in the static 3D space. This line of research has witnessed an increase in literature over the past 20 years, and recent results show that the emotional salience plays a critical part in how the mind selects information. Spatial attention is typically addressed by means of experimental paradigms in which participants are presented with several visual stimuli at the same time. The aim of those paradigms is to assess the extent to which emotional stimuli attract, hold, or pull away attention to, or from a particular spatial location, that is promoting or hindering the participants' performance on an orthogonal task (e.g. E. Fox et al., 2001; Salemink et al., 2007; Öhman et al., 2001; Juth et al., 2005, ; see also Section 1.2).

For instance, in a version of the dot-probe paradigm (MacLeod et al., 1986), participants are presented with two facial expressions, flashing simultaneously in the left and right visual fields. One of the faces usually portrays an emotion (cue), whereas the other acts as a control. A neutral

Attentional phenomena	Paradigms	Method	Results	Interpretations	Criticisms
Spatial attention	Dot-probe	Spatial pre-cueing of target by an emotional cue	• Faster identification of probes when emotional cue in same spatial location (e.g., Bradley & Mogg, 1997; Pourtois et al., 2004; Santesso et al., 2008) • Slower identification of probes when emotional cue in opposite spatial location (e.g., Fox et al., 2001)	• Emotion modulates spatial attention	• Fails to distinguish fast orienting from slow disengagement (Fox et al., 2001; Saleminck et al., 2007) • Inconsistent results due to : – Emotional material – Experimental specifics, e.g. SOA, stimulus display duration (e.g. Amir et al., 1998)
	Visual search	Detection of a target embedded in search array	• Faster to detect emotional target in neutral array than neutral target in array of emotional stimuli (e.g., Hansen et al., 1988; Fox et al., 2000; Öhman et al., 2001; Juth et al., 2005)	• Emotion facilitates detection in static 3D space	• Effects depend on categories of stimuli (Tipples et al., 2002; Lipp et al., 2004, 2006) • Effects may be task-dependent (e.g. Horstmann & Becker., 2009) • Search advantage for emotional targets is dependent of array size
Selective awareness	Masking (backward, crowding)	Limited processing of targets prevented by mask (often yields to inability to report target)	• Emotional probe yields better perception than neutral probe (e.g., Esteves et al, 1993; Pessoa et al, 2007) • Unreported emotional probe can sometimes modulate subsequent measurement (e.g., Öhman et al., 1998; Morris et al., 1998)	• Emotion enhances perception	• Need distinction between objective and subjective awareness (Pessoa et al., 2005; Szczepanowski et al., 2007) • Big inter-individual differences
Automaticity and interference	Emotional Stroop task, Flanker tasks	Identification (feature, object) of targets interfered by emotional distractor	• Slower feature (e.g., color) identification on emotional targets (e.g., Fox et al., 1996; Phaf et al., 2007) • Slower target identification when flanked by emotional distractors (e.g., Fenske et al., 2003; Horstmann et al., 2006)	• Emotion takes precedence over concurrent processes • Emotion cannot be ignored even if it is irrelevant to the task	• Largest effects occur only in blocked presentation, suggesting a strong contribution of slow interference (McKenna et al., 2004; Phaf et al., 2007) • Effects only found in conscious presentation (Phaf et al., 2007)
Temporal attention	Rapid Serial Visual Presentation (PRP, AB), Repetition blindness, Change blindness	Rapid attentional resource allocation over time	• Enhanced response toward emotional targets (e.g., Fox et al., 2005) • Stronger interference of emotional targets over subsequent targets (e.g., Vaquero et al., 2006; Mathewson et al., 2008)	• Emotional stimuli benefit from processing biases throughout several stages of processing	• Relatively new paradigms; few results • Sensitive paradigms due to experimental specifics, e.g. SOA, stimulus display duration

Table 2.1: Comparative table of selected paradigms used to address emotional attention. Note 1: Results are always stronger in patient populations. Note 2: Studies usually don't address positive stimuli, and only use so-called threatening stimuli. PRP: Psychological Refractory Period; AB: Attentional Blink. (Original work elaborated in the course of this thesis.)

probe (target requiring a response, e.g. the orientation of a bar) follows immediately the faces, appearing in the location previously occupied by one of the faces. If attention is selectively drawn by emotion, probes presented in the location of the cue should be identified faster than probes presented in the location of control faces. Studies using this paradigm report that the non-clinical population showed hypervigilance toward threat-related stimuli (e.g. E. Fox et al., 2001; E. Fox, 2002; Lipp & Derakshan, 2005; Pourtois et al., 2004; Santesso et al., 2008), and stronger results have been found in patients with various anxiety disorders (e.g. MacLeod et al., 1986; Bradley et al., 1999; Mogg et al., 1992; Horenstein & Segui, 1997; Kroeze & van den Hout, 2000).

However, results are not always consistent, and the extent to which anxiety mediates this processing bias not well accounted for (Heinrichs & Hofmann, 2001; Schmukle, 2005, for a review), which led Mogg et al. (2000, p. 1074) to conclude that "the dot probe task appears to provide a relatively fragile index of anxiety-related attentional biases in non-clinical studies." Some studies have indeed found that angry faces drew attention of socially anxious participants (e.g. Mogg et al., 2004), while others reported that both angry and happy faces led participants to move their attention away from the faces (Mansell et al., 1999, 2003).

Inconsistencies can be explained in several ways. First, most studies used a single attentional bias index, and thus often fail to distinguish a fast orienting of attention towards the cue from a slow disengagement of attention away from the cue (see E. Fox et al., 2001; Salemink et al., 2007). Second, participants across studies are not presented with the same emotional material, which proves difficult to compare the results. The general notion of what is threatening remains unclear, and does not refer to a particular stimulus. Finally, depending on the specifics of their experimental settings (display durations of the stimuli, stimulus onset asynchrony–SOA / inter-stimuli intervals–ISI), it may also be that researchers probe very different stages of the attentional processing stream ; not to mention that different emotions may have different effects throughout these stages.

According to the hypervigilance-avoidance hypothesis (Amir et al., 1998; Cooper & Langton, 2006), patients suffering from social anxiety would be more prone to attend to threatening information during the early stages of the attentional processing stream, and would strategically shift their attention away from such information during later stages of the processing, in an effort to reduce their anxiety. Studies with anxious populations showed different results for different SOAs: hypervigilance has been found for shorter SOAs (100 ms: Amir et al. (1998); Cooper & Langton (2006) ; 250 ms: Derryberry & Reed (2002); 500 ms: Bradley et al. (1998); Mogg et al. (2004)). Whereas studies using longer SOAs have showed either avoidance (Cooper & Langton, 2006; Derryberry & Reed, 2002; Amir et al., 1998) or no attentional biases (Bradley et al., 1998; Mogg et al., 2004). Overall, it seems that pre-attentive processes may provide a significant advantage in the detection of threatening material and that, in experimental conditions emphasising a quick response (SOAs $\leq$ 200 ms), anxious participants may be prevented from strategically shifting their attention away from this material, unlike what is shown in experimental conditions with longer SOAs (Frewen et al., 2008).

2.1.2 Emotion enhances perception

Emotions are being described as decoupling mechanisms that provide the organism with a way of quickly detecting, and reacting to events in its environment. This further assumes that such emotional stimuli elicit distinct responses relatively early in the perceptual stream, pre-attentively, prior to conscious object recognition (Öhman & Wiens, 2004), and raises the question of the sensitivity of the perceptual system towards such stimuli.

Emotional awareness is often studied by means of backward masking paradigms (Breitmeyer & Ogmen, 2000; Wiens, 2006), which rule out conscious recognition as a factor in emotional processing. In this paradigm, a brief presentation of an emotional stimulus (target) is immediately followed by a visual mask that limits the processing of the target, and prevents its recognition. If the interval between the onsets of the two stimuli is sufficiently short, participants may not perceive the target stimulus, and report only seeing the mask.

In a series of experiments, Esteves & Öhman (1993) used this paradigm to investigate the recognition of emotional expressions (angry, happy, and neutral) masked by a neutral face (displayed for 30 msec). In experiment 1 and 2, the display duration of the face targets was gradually increased. For each presentation, groups of participants were instructed to judge the emotion, the sex, and the identity of the face targets. In addition, participants rated the certainty of their response as “something more”, “guess”, or “sure”. The dependent variable was the duration of the target for each of these response categories. Results for the three types of instruction were similar, which the authors interpreted as reflecting parallel processes. They also observed that faces portraying a happy facial expression resulted in lower subjective thresholds than those for the other expressions. However, in the second experiment, they found a recognition bias for angry faces for shorter display durations, and a recognition bias for happy faces for longer durations, which they interpreted as a pre-attentive bias for threatening cues before a complete analysis of the stimuli is reached. Experiment 3 and 4 addressed other parameters of the paradigm (e.g. the duration of the mask), and confirmed the results of the previous experiments. Overall the authors concluded that a display duration of approximately 100 msec was necessary for an accurate recognition of emotional facial expressions. In addition, they hypothesised that when information is scarce, the perceptual system tends to search for threatening cues because of their survival values.

Since then, hundreds of studies have used backward masking to tap into the processes underlying emotional awareness, often in relation to other attentional phenomena like priming, or inattentional blindness (see Enns & Di Lollo, 2000).

It is commonly accepted that a minimum display duration of 50 msec is required for conscious perception of a visual stimulus. A series of studies by Pessoa and colleagues used backward masking to study the limits and sensitivity of the perceptual system for fear perception (Pessoa et al., 2005; Szczepanowski & Pessoa, 2007). Their results, however, suggest that there is no universal awareness threshold for fear perception, and that this phenomenon is best understood in terms of objective (i.e., the participants' actual performance) versus subjective (i.e., their reported performance) awareness: Some participants could objectively detect a fearful face which was presented for a duration as short as 17 msec, but only a small proportion of them could subjectively discriminate above chance correct/incorrect responses. These results emphasise the high sensitivity of the perceptual system to threat-related information, and pose questions about the underlying mechanisms and inter-individual differences.

2.1.3 Emotion takes precedence over concurrent information

The competition for limited resources inevitably leads to the question of the interference between concurrent representations in the cognitive system. In this respect, an impressive body of data suggests that emotional information will be favoured over any other kind of information, even if it is irrelevant or at the expense of the current task; an aspect of emotional processing which has been heavily addressed using an emotional variant of the Stroop task (see also the variations of the flanker tasks, e.g. Fenske & Eastwood, 2003; Horstmann et al., 2006).

The original results by Stroop (1935) showed that naming a colour is delayed by the presence of irrelevant and conflicting information. More specifically, naming the colour of the ink of a word is delayed if the word refers to a different colour (e.g., the word "blue" written in red ink). These results were interpreted as reflecting the interference between concurrent and conflicting processes (MacLeod, 1991).

In a variant of this paradigm, naming the colour of a word or a picture is slowed down when it is emotional. Consistent results have been demonstrated in various clinical populations and also, to a lesser extent, in the non-clinical population. Reviewing the literature from 1974 to 1995, Williams et al. (1996, p. 19) concluded that "relatedness to current concern is necessary to explain [emotional] Stroop interference in nonclinical participants. However, in clinical patients, it is not sufficient. In patients, both the relevance to schemata and the negativity of the material is important in determining the extent to which colour naming will be disrupted." In other words, evidence suggests that situational and contextual state emotions are associated with individual differences in emotional Stroop interference (e.g., Gotlib & McCann, 1984). As can be expected, the frequency and intensity of ruminations in clinical populations, however, exacerbate this effect by increasing the accessibility (i.e., priming) of the themes tested in the task (Williams et al., 1996).

A common interpretation of the interference sees emotional processes as automatic[6], pre-attentive and preconscious (Mogg & Marden, 1990; E. Fox, 1996). The automatic processing of an emotional stimulus may momentarily consume most of the available processing resources, despite the current task, yielding to the transient slow down of the response.

Recent studies, however, depict a very confusing picture by demonstrating that the emotional Stroop interference might be due to both a fast and a slow component; the former referring to an automatic within-trial effect; the latter referring to a "carry-over" effect lasting for less than a second, perturbing the response in subsequent trials.

This novel interpretation has first been made by McKenna & Sharma (2004). In experiment 1 and 2, the authors showed that it was possible to reverse the emotional intrusion effect (i.e., reaction time longer for neutral words) by mixing threatening and neutral words in a pseudo-random fashion that would bias the probability of occurrence of subsequent targets in one way or the other. As noted by the authors, this effect by itself demonstrates that the interference cannot be explained on the sole account of a fast within-trial component. In experiment 3 and 4, the authors addressed the unfolding of the hypothesised slow component by measuring the carry-over effect of emotional targets over six subsequent neutral targets. Interestingly, results showed a strong carry-over effect of negative trials to the next immediate neutral trial, unlike positive and neutral targets. And, more importantly, there was no evidence in favour of a fast within-trial effect.

In accordance to these results, a meta-analysis of emotional Stroop studies by Phaf & Kan (2007) confirmed that the largest effects occurred in blocked presentations of consciously perceived emotional words. They note that an interference effect with emotional targets presented sub-consciously would constitute a strong evidence in favour of the automaticity of emotional processing. However, their meta-analysis indicated that the effect size for this kind of studies was virtually zero for most of the conditions they tested. If it is clear that emotion takes precedence over concurrent processes, these results cast more doubts on the ability to demonstrate automaticity with the Stroop task.

2.1.4 Intermediate conclusion: more than meets the eye?

Both emotion and attention provide the organism with the ability to attend, select and process the particular events from the environment that are most relevant for current concerns: Emotionally salient information modulates spatial attention, enhances perception and takes precedence over concurrent information, as shown by various experimental paradigms.

Reviewing the literature however suggests that these conclusions only represent the tip of the iceberg, and that a broader framework may be necessary to fully account for the mechanisms at play. In particular, the fact that different experimental setups (e.g., short versus long SOAs, blocked versus semi-randomised trials presentation) produce radically different, sometimes opposing results might appear as counter-intuitive at first glance but may in reality reflect different perspectives of the same phenomenon. By emphasising the temporal development of processing this thesis takes a wider perspective and investigates the unfolding of the actual computation.

2.2 Temporal attention and the Attentional Blink

Temporal attention results from the competition between many neural mechanisms over time. It is concerned with the coordination of the many stages of processing to resolve the competition for resources and prevent interference. Unlike "static" perspectives on attention, which often only address a single, short and finite moment in the processing of information, research on temporal attention emphasises the unfolding of the processing over time. The general aim of this area of research is thus to probe the very processes at play over time and to describe the flow of information from the onset of the stimulus event to the ignition of the appropriate reaction by the organism (e.g., conscious perception, report, identification). It generally asks the question: How do we prioritise the processing of certain information over time?

The concept of processing resources (and processing resources allocation) becomes apparent when considering the ability of the cognitive system to process several items at the same time. In an environment virtually containing an infinite number of items, it is remarkable that the processing can be successfully carried out even though several channels of information are perceived at the same time. However, there are only so many items that can be processed and often pieces of information interfere and compete for processing, rendering an actually parallel processing system somehow effectively serial. This further suggests that this ability to process parallel items can be exhausted in some way, and raises the question of the priority upon which the cognitive system selects the relevant information to be processed.

This concept remains ambiguous, however, as there is no such thing as "a bucket of resources" from which cognitive processing would derive. Arguably the number of information items that can be held in working memory (WM) does reflect some resource limitation, but the type of this information, its underlying structure and the maximum number of items that can be held in memory remains a heavily debated topic in itself. As a consequence, in addition to these provisions, the competition that can be demonstrated is therefore likely to reflect a processing bottleneck, which would arise from the competition between modular processes and the way the system is structured, more than a resource bottleneck.

Temporal attention is best addressed through experimental paradigms that emphasise the temporal unfolding of the processing. These paradigms address distinctive phenomena like the psychological refractory period effect (PRP; Pashler, 1984), repetition blindness (RB; Kanwisher, 1987), change blindness (Rensink et al., 1997), or the attentional blink (AB; Raymond et al., 1992). The latter in particular seems to form "a central method" (Shapiro, 2001, p. 3) providing researchers with the opportunity to tap into the underpinnings of the wide range of phenomena that generally compose temporal attention.

In a stream of rapid visual serial presentation (RSVP), participants are presented with rapidly flowing visual stimuli (presented at a frequency of ≈10 Hz), one replacing the other at the same spatial location on the screen (Weichselgartner & Sperling, 1987). Participants are asked to spot and perform tasks on one or more targets embedded within distracting stimuli (Figure 2.1, panel a). Varying the time interval between two targets renders it possible to measure the competition between the two targets: results in a typical dual task experiment indeed show that the perception and processing of a first target (T1) hinders the perception and processing of a second target (T2) if it appears within 200–400 milliseconds after T1 – thus the hindering of processing of the second target is being rhetorically referred to as an attentional blink (AB; Raymond et al., 1992).

The original study by Raymond et al. (1992) demonstrated that this effect was not due to perceptual factors alone, but reflected effective limitations of the attentional system: when instructed to

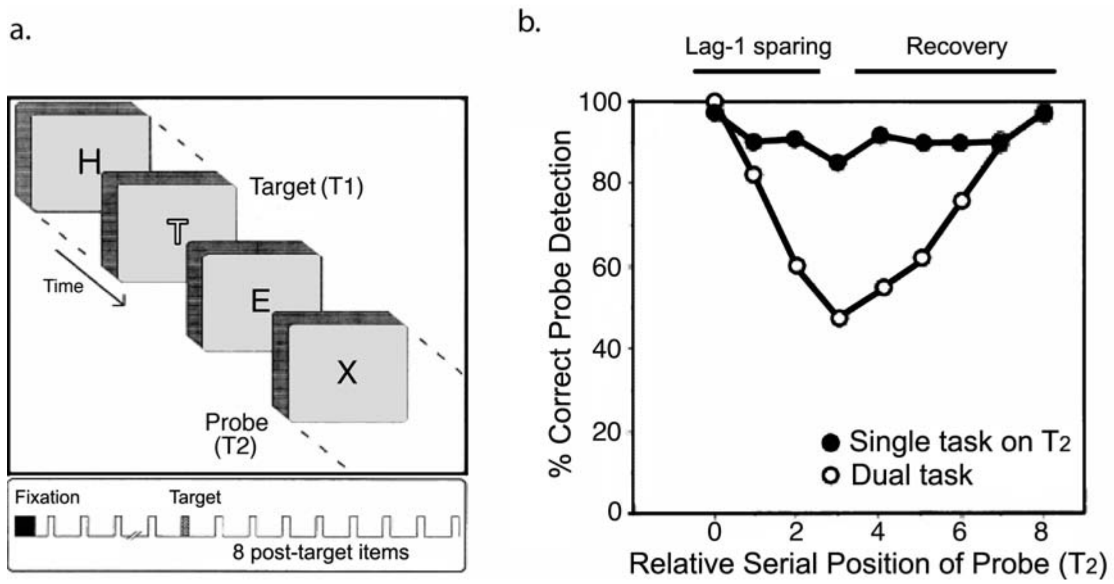

Figure 2.1: Adapted from Raymond et al. (1992) demonstrating the Attentional Blink. Panel a. Participants were asked to identify the white letter in a stream of black letters and to detect whether a black “X” was present in the following stimuli. Panel b. Traditional AB curve representing the percentage of correct response to probe (T2) detection given a correct response to target (T1) identification. Results show a U-shaped curve: Probes immediately following the target are spared – a period of time dubbed “Lag-1 sparing”. After the blink has occurred, the cognitive system slowly recovers. The single task condition is a control condition in which participants are asked to respond to T2 while ignoring T1.

ignore the first target, participants would not exhibit this particular deficit (Figure 2.1, panel b). Over the years, a great range of models have been proposed to account for this particular phenomenon. The methodology has evolved and researchers have addressed very specific questions, like the distinctive effect of the distractors (e.g. Most et al., 2007; Dux & Coltheart, 2005; Dux & Harris, 2007), or the extent to which the integration of the individual features of the targets support this phenomenon (e.g. Raymond et al., 1995; Raymond, 2003).

Recently, emotion researchers have used the modulation of the AB effect to address the extent to which particular types of stimuli can survive the “blink”. Under certain conditions, it is indeed shown that the traditional U-shaped curve demonstrating the AB flattens when emotional stimuli are used as targets (Anderson & Phelps, 2001). The general hypothesis is that emotional stimuli benefit from a processing bias that would ease their way through the stages of processing and defeat the blink. In what follows, we will first review the different theories accounting for the mechanisms underlying the AB, before reviewing the few results on the emotional AB.

2.2.1 Descriptive accounts: The AB reflects the dwell time of attention

In an early study, Duncan et al. (1994) used the AB curve to measure how long an object that must be identified continues to occupy attentional resources, that is the dwell time during which the processing of T1 impairs the processing of T2. In a series of experiments, Duncan et al. varied the complexity of the task performed by the participants on the targets, as well as the spatial location where the targets appeared to compare their results with results obtained in visual search paradigms. They concluded that the AB reflects the time during which the perceived target is a steady state available to conscious perception and report. They further proposed that the AB might refer to the amount of time required by the cognitive system to merge the information required for the task on T1. During this short period of the time, the cognitive system would be less available for the processing of the second target, thereby rendering a deficit of processing on T2.

With the same goal in mind, Vul, Nieuwenstein, & Kanwisher (2008) investigated the ability of the cognitive system to recover from the task on T1 by asking participants to recall the first distractor they remember after the occurrence of T1. Their analysis shows that attentional selection (on T1) can have up to three different effects: causing suppression, delay, or diffusion in a second attentional episode. In other words, they showed that the consequences of the primary allocation to the processing of a target can take three different forms and impair different dimensions of the processing on a subsequent attentional event. In addition, they showed that these three effects unfold over different time courses, which may indicate the implication of different cognitive processes that combine to form the commonly reported AB curve.

2.2.2 Interference theories: The AB reflects the competition and interference between incoming stimuli

Two different theories form the core of what has been dubbed interference theories (Shapiro, Raymond, & Arnell, 1997). They both describe the sequence of events yielding the AB, and put a particular emphasis on the competition occurring between T1 and T2. They differ, however, with regard to the moment in the sequence of processing during which this competition is believed to take place: whereas Raymond et al. (1992) sets the focus on early processes, Shapiro et al. (1994) sets the competition during the late retrieval of information from memory.

According to Raymond et al. (1992), the distinctive features of T1 initiate an attentional response (i.e., ”opening of an attentional gate”, p. 859; see also Maki & Mebane, 2006; Shih & Reeves, 2007), during which T1 will go through the processing steps yielding conscious report. If T2 appears soon enough, it will benefit from the opening of the attentional gate and undergo the same extensive processing leading to its identification (i.e., Lag-1 sparing), however this will result in some interference – as measured by the increasing probability of correct T1 identification over the lags (see also Hommel & Akyurek, 2005). In an effort to reduce conjunction errors impeding on the identification of the first target, the attentional system will set up a suppressive response (i.e., close the attentional gate), preventing T2 from entering processing all together. An important prediction of this model was the idea that the AB occurred in response to the extensive processing required by the identification of T1 perturbed by T2.

However, new results led Shapiro et al. (1994) to propose a refined model, as an AB was shown to occur even if the task on T1 did not require the identification of the target but only its perception. This second account of the AB is based on Duncan and Humphreys' general model of visual processing (1989), which divides visual processing in serial stages: The stage of "perceptual description" (p. 445) processes the incoming information, assigning each parallel, hierarchically structured representation a gain weight to the extent that it matches an internal description of the information required to achieve the current goal. The piece of information that has the biggest weight is then selected to enter Visual Short Term Memory for report. In this context, Shapiro et al. (1994) propose that the AB results from the interference during the late stage of information retrieval. T1 and T2 will have equivalent weighting and equivalent probability of entering VSTM (as they are both goal-relevant targets), which will impair the selection process, resulting in the AB. According to this theory, the AB is an "all-or-nothing" phenomenon that will occur independently of the cognitive load of the tasks on T1 and T2. However, this latter prediction is contradicted by results demonstrating a correlation between the magnitude of the AB and the difficulty of the tasks (Chun & Potter, 1995; Grandison et al., 1997; Jolicoeur, 1998, 1999; Seiffert & Di Lollo, 1997; Moore et al., 1996).

Interference theories constitute the first attempts at explaining the underpinnings of the AB. Even though later accounts on the AB differ significantly, this initial effort has been highly influential in many respects. Firstly, by describing this novel attentional phenomenon in terms of early and late selection, the authors shaped the way for research investigating a two-folded processing. Secondly, by attempting to define the computational units of the network of processes at play during the AB, the authors emphasised different aspects of the processing that are now being defined in other types of models (e.g. WM, integration of features). Finally, they also emphasised the role of the cognitive system in the prevention of conjunction errors and interference, and believed that the

AB could be used as a window into this competition between processes; a view which can be seen in more recent accounts.

2.2.3 Two-stage models: The AB reflects a processing bottleneck

Unlike interference theories, two-stage models assume that T1 and T2 do not interfere directly. Rather, they explain the AB by suggesting that each target triggers a sequence of ballistic processes, which take one and only one stimulus as input, and cannot overlap.

Chun & Potter (1995) proposed a two-stage model extending from Broadbent and Broadbent's serial model of visual identification (1987). According to Chun and Potter, the first stage of processing involves the rapid selection of potential candidate targets on the basis of independent features (e.g., colour, letter case). All perceived targets would enter this unconscious stage of processing, which could last up to 100 msec. The second stage consists of the capacity-limited processing involved in the consolidation of the to-be-reported target in visual short term memory, and its conscious identification. This second stage of processing would start upon completion of the first stage, and would only accept one item at a time. This would delay the processing of other targets occurring in the meantime, and explain the processing bottleneck responsible for the AB if T2 occurs during this short laps of time.

Chun (1997) later refined this two-stage model on the basis of results describing an other attentional phenomenon called the repetition blindness (RB; Kanwisher, 1987). This latter phenomenon refers to the transient inability to report the repetition of targets closely related in time. A typical example of this phenomenon would be the difficulty to notice the repetition of two words in an otherwise well constructed sentence: "It is difficult to detect repetitions of words, as seems to be indicated by the the 'repeated words' feature included in many word processor spell-checking programs" (Chun, 1997, p. 739; did you notice the repetition of "the"?). As highlighted by Chun, the AB and the RB share common features. Firstly, they both seem to reflect capacity limitations in attentional processing of targets, following the correct identification of the first target. And secondly, the magnitude of both effects vary systematically as a function of the temporal asynchrony between the two targets. They qualitatively differ, however, in the extent to which the individual item that immediately follows the first target can be processed correctly: In the AB, the second target can be processed if it appears immediately after T1, yielding to what is called the lag-1 sparing, whereas it cannot be processed at all in the RB. The obvious similarities between these two phenomena led Chun to apply the type-token distinction, as originally proposed by

Kanwisher (1987) to describe the RB, to the AB. This functional account of the two-stage model sees the first stage as the recognition and activation of the type of the incoming item, whereas the second stage of processing would be concerned with the individuation of the object as a particular spatio-temporal token that can consciously be reported. The two kinds of information, types and tokens, are proposed to be encoded and used in two distinct domains of the processing occurring in parallel fashion (Kanwisher, 1987; Chun, 1997). The reportability of the selected target depends on the binding of the activated type to the appropriate token. Chun (1997) thus proposes that the bottleneck of the AB lies in the transient impairment of the binding process due to the temporal adjacency of targets. In other words, in a similar way to the RB, the AB would occur when targets' types are recognised but fail to be individuated as tokens.

2.2.4 Neurocognitive theories and computational models

Most of what is known about the AB has been gathered through behavioural work. A few neuroimaging studies nonetheless provided useful information as to the structure of the brain circuitry involved in this particular deficit (Figure 2.2) and the dynamics of information processing expressed within this network of structures.

Hommel et al. (2006) describe a neurocognitive scenario involving a temporo-parieto-frontal network to account for the AB. They build upon two-stage models to circumscribe where in the brain the processing bottleneck lies. In this scenario, the stimulus processing begins with a nonselective stage in occipital areas, in which both targets and masks are encoded to the same extent. No effect of the lags has been reported showing the modulation of the early activation of these brain areas[7], which supports the claim that the AB does not purely reflect a perceptual phenomena. The second stage of the processing involves temporo-frontal areas: Stimuli are identified, and targeted by modulations originating from lateral-frontal and posterior-parietal areas. There, task-specific target stimuli undergo a more extensive task-related processing (Kessler et al., 2005). Different types of targets have been shown to activate different, content-specific temporal areas (Marois et al., 2004). Hommel et al. (2006) further suggest that temporal areas represent a kind of workspace where bottom-up information meets top-down influences to fulfil task-related goals.

A slightly different interpretation is provided by Dehaene and colleagues who used recordings of event-related potentials (ERP) to compare the temporal dynamics of seen and unseen (blinked) words in a typical AB experiment (Sergent & Dehaene, 2004). Describing the cortical activations of unseen words, the authors report a drop in the waveform of components peaking around 300

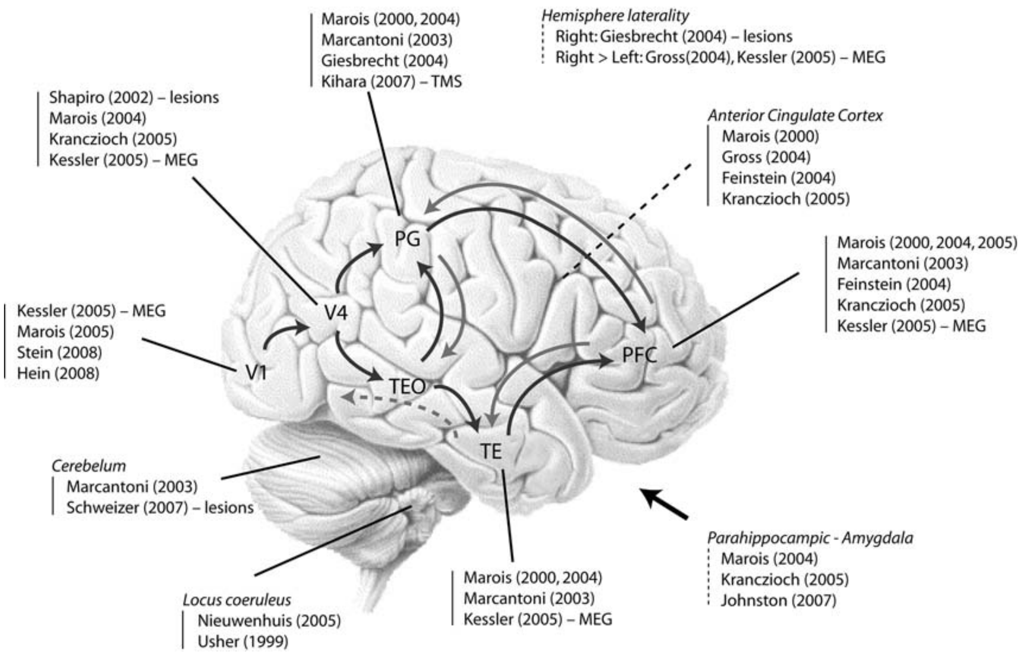

Figure 2.2: The "Attentional Blink matrix" superimposed on cortical areas underlying bottom-up (dark arrows) and top-down (light arrows) attentional influences (after Desimone & Duncan, 1995; Kanwisher & Wojciulik, 2000; Kastner & Ungerleider, 2000; Pessoa et al., 2002; Vuilleumier, 2005; Pessoa, 2008). Dashed lines indicate subcortical areas, and areas not visible on the drawing. PFC: Pre-Frontal Cortex; PG: Parietal Gyri; TE: Inferior Temporal areas; TEO: Temporo-Occipital areas; V1/V4: Visual cortices. Studies used fMRI if not otherwise specified. (Original work elaborated in the course of this thesis.)

milliseconds, which correlated with behavioural visibility ratings. Whereas ERP methodology cannot be used to make unambiguous inferences about brain localisations, estimations techniques allow one to roughly determine the sources of cortical electrical activity. Using this approach, the authors report that seen words, compared to unseen words, initiated an intense spread of activation within left temporal and inferior frontal regions (about 300 milliseconds after stimulus onset), which would then spread to lateral prefrontal and anterior cingulate cortices (about 440 milliseconds), before extending in more posterior regions (about 580 milliseconds). In their interpretation, these authors introduce the concept of a global workspace, which refers to the notion that the different high-level, specialised brain areas involved in the processing of visual stimuli interconnect to each other, to form a global workspace processing the stimuli into a unitary assembly supporting conscious reportability (Baars, 1988, 2002; Shanahan, 2007). Perceived stimuli would thus compete to recruit this global workspace that once activated, only affords exclusive access, leading to the inability to process subsequent stimuli for a transient period of time. Areas in the global workspace theoretically map onto the description of the processing streams involved in visual perception, from perceptual areas to higher associative areas of temporal, parietal, frontal, and cingulate cortex ; which is to say that the bottleneck described in AB studies would therefore lay in the influence of higher-level areas, like the PFC or more parietal areas, over the lower-level areas involved in the visual streams. Dehaene et al. (2003) constructed an artificial neural network model to put to test this hypothesis. They structured the model to represent early sensory regions and higher association areas. Results compared to their ERP results, suggesting that the competition between T1 and T2 may prevent the second target from reaching the stages of processing necessary for report (see also Shanahan, 2007).

An alternative hypothesis is proposed by Nieuwenhuis, Gilzenrat, et al. (2005). According to these authors, the AB may be explained by the particular biphasic response of the locus coeruleus–norepinephrine system (LC–NE). The LC is a tiny structure in the brain stem that has been implicated in the maintenance of arousal states (Robbins, 1997, see also Hebb, 1955) as well as in the regulation of cognitive performance (Aston-Jones et al., 1998, 1999; Aston-Jones & Cohen, 2005; Dayan & Yu, 2006). It is heavily activated during the processing of motivationally relevant stimuli (Dayan), resulting in the release of norepinephrine (also known as noradrenaline) through widespread cortical projections (Aston-Jones et al., 1984). This diffuse response generally increases the responsiveness of efferent target neurons (Berridge & Waterhouse, 2003). The phasic release of NE within the LC is quickly followed by a transient refractory period during which the LC–NE is silent (Usher et al., 1999), a time course resembling the natural course of the AB effect. Nieuwenhuis, Gilzenrat, et al. (2005) thus hypothesised that the boost of activation due to the release of NE supports the consolidation of targets in WM, and that the ensuing attentional blink is the result of the transient refractory period following LC activity. One strong prediction that can be made from this hypothesis is that any stimulus presented before this refractory period should not have much of an impact on the AB. Nieuwenhuis, Gilzenrat, et al. confirmed this hypothesis in two experiments, showing that varying the type of masks immediately following T1 has an impact on the report of T1 but does not affect the report on T2. The authors replicated these results using a computational model of the LC activity (Gilzenrat et al., 2002), suggesting that NE activity plays a critical role in the dynamics of the AB. More weight is offered in support of this hypothesis in a series of double-blind experiments by De Martino, Strange, & Dolan (2008) in which different types of β–adrenoceptor agonists (propanolol hydrochloride, reboxetine methansulphonate, or nadolol) not only generally rendered the AB worse compared to placebo, but emotional/arousing words, hypothesised as eliciting an increase in NE release, were still detected more frequently than neutral words. One study however failed to show such pharmacologically-elicited deterioration of the AB with an $\alpha 2$–adrenoreceptor agonist (clonidine), emphasising the complexity of the LC–NE system and its involvement in higher-level tasks like the orienting of attention (Nieuwenhuis et al., 2007).

Compared to other psychological phenomena the attentional blink has aroused the appetite of many computational modellers (Taylor, 2003; Fragopanagos et al., 2005; Dehaene et al., 2003; Nieuwenhuis, Gilzenrat, et al., 2005; M. Lundqvist et al., 2006; Shih, 2007; Bowman & Wyble, 2007). The reason for this sustained attention may simply lay in the relative ease of building a model that reproduces a U-shaped curve resembling the AB. This ease may however lead to the mistaken conclusion that a model producing a U-shaped curve therefore fully accounts for the mechanisms underlying the AB. Nonetheless, provided that there is a sensible benchmark, much can be learnt about the feasibility (i.e., implementability) of the proposed theories. The description of this benchmark exceeding the framework of this thesis, we refer the reader to an earlier publication (Roesch et al., 2007).

Temporal perspectives on attention describe the unfolding competition between incoming stimuli. This competition biases each stage of the processing in favour of one stimulus, which is then used to perform a particular task (e.g., identification, report, fight, flight). Addressing the unfolding stages of this processing has been the main topic of interest of emotion and attention researchers. However it is only recently that they have used experimental paradigms that explicitly allow to tap into the evolving processing of stimuli[8]. The AB paradigm in particular sets an explicit emphasis on the sequence of processes yielding a correct response, providing researchers with ways to rephrase classical questions about emotion and attention, and formulate new ones.

2.3 Emotional attentional blink

The AB paradigm taps into the sequence of processes occurring immediately after the perception of target stimuli appearing in close temporal adjacency. Said differently, this particular effect spreads out the competition between the processes evaluating incoming target stimuli: Each point of the AB curve (Figure 2.1, panel b) thus reflects the result of the competition between the processes evaluating both the first and second targets. By setting the emphasis on the temporal dimension of the processing, this paradigm renders it possible to address the sequence of events responsible for the report of targets. It is especially interesting for emotion research, as it allows once to probe the processing priority that seem to benefit emotion-laden stimuli throughout the various stages of processing (Vuilleumier, 2005).

Emotion researchers using this paradigm typically compare an AB response obtained with emotional material to a control condition reflecting a “normal” AB response with neutral material. Varying the onset time of the second target relative to the first target allows to probe 1) the general availability of the processing system to perform both tasks, 2) the processing priority of the first target (i.e., the likelihood of preventing the second target to be reported), and 3) the processing priority of the second target (i.e., the likelihood for the second target to be reported, as well as the likelihood of disturbing the processing of the first target). Researchers will thus seek to control one of such aspects to manipulate and investigate the others.

Not surprisingly, a number of neuroimaging studies in human and non-human primates have demonstrated activation of emotion-laden brain areas, like the amygdala and parahippocampic areas (Marois et al., 2004; Kranczioch et al., 2005; Johnston et al., 2007), the locus coeruleus (Nieuwenhuis, Gilzenrat, et al., 2005; Nieuwenhuis, Aston-Jones, & Cohen, 2005), or cingulate cortices (Marois et al., 2004; Gross et al., 2004; Feinstein et al., 2004; Kranczioch et al., 2005; Johnston et al., 2007). These particular brain areas may produce biasing signals that may support the processing of emotional signals, and explain why unreported targets (missed T2) still seem to be processed to an extended level, supporting some priming effect on a subsequent task (e.g. Luck et al., 1996; Marois et al., 2004).

What is the effect of an emotional T2? By far, the most common situation is to present participants with a neutral stimulus as T1 and an emotional stimulus as T2, addressing the extent to which emotional stimuli can defeat the "blink" mechanism triggered by the perception of T1 (see Table 2.2). In this context, researchers hypothesise that emotional material is less dependent on attentional resources to achieve awareness, and is thus more likely to reach the stages of processing required for conscious awareness and report (Anderson & Phelps, 2001; E. Fox et al., 2005). Using this variation of the paradigm, the AB has been shown to be alleviated by personal names (i.e. compared to names of other people; Shapiro, Caldwell, & Sorensen, 1997), primed words (Maki et al., 1997; Nieuwenstein et al., 2005; Nieuwenstein, 2006), negative words (Anderson & Phelps, 2001; Kihara & Osaka, 2008), and otherwise neutral pictures conditioned to white noise (S. D. Smith et al., 2006). Similarly, the AB is alleviated by happy schematic faces (Mack et al., 2002), distinctive (Ryu & Chaudhuri, 2007) or familiar faces (Jackson & Raymond, 2006; Gomez-Cuerva et al., 2008). Several studies however tend to show that the arousal elicited by emotional words has stronger of an effect on the AB than their valence (Anderson, 2005; Keil & Ihssen, 2004; Keil et al., 2006). As one could expect, the magnitude of the blink has been shown to correlate negatively with trait anxiety for fearful (E. Fox et al., 2005) and angry faces (Jong & Martens, 2007), and the same pattern of results is demonstrated for spider phobics presented with spider-related stimuli (Reinecke et al., 2007) – the more pronounced the disorder the less AB.

Publication	Type of T1 (Task)	Type of T2 (Task)	Dur. (ISI) in ms	Part.	Results	Lag-1	Lags
Shapiro et al. (1997)							
– Experiment 1	Nouns (ID)	Own name, other name, noun (DE)	60 (15)	N=3x9	Own name > Other name >> Noun	yes	1–8
– Experiment 2	Nouns (ID)	Own name, other name, noun (DE)	60 (15)	N=3x9	Own name >> Other name = Noun	yes	1–8
– Experiment 3	Nouns (ID)	Own name, other name (DE)	60 (15)	N=9	Small AB ; Own name = Other name	yes	1–7
– Experiment 4	Nouns (ID)	Own name, noun (DE)	60 (15)	N=9	Small AB ; Own name = Other name	no	1–7
Maki et al. (1997) – manipulated semantic relations between T1, T2 and distractors							
Experiments 1–5	Nouns (ID)	Nouns (ID)	≈85 (≈15)	N=≈64	Less AB when T1 and T2 related	n/a	1–4
Anderson et al. (2001)	Nouns (ID)	Nouns (ID): Neg vs Neu	130 (0)	Bi Amyg + RTL/LTL	Neg >> Neu (except Bi Amyg + LTL)	n/a	E/L
Mack et al. (2003)	Misc objects (ID)	HFI, HFI inverse, trees (DE)	75 (0)	N=42	HFI >> HFI > Tree	yes	1–7
Keil et al. (2004)							
– Experiment 1	Verbs (ID)	HA verbs (ID): Pos vs Neg vs Neu	116 (19)	N=19	Neg > Pos >> Neu	no	1–6
– Experiment 2	Verbs (ID)	LA verbs (ID): Pos vs Neg vs Neu	116 (19)	N=19	Neg = Pos >> Neu	no	1–6
– Experiment 3	Verbs (ID)	HA verbs (ID): Pos vs Neg vs Neu	116 (19)	N=19	Neg > Pos >> Neu	no	1–6
Anderson (2005)							
– Experiment 1	Nouns (ID)	Nouns (ID): Neg vs Taboo vs Neu	100 (0)	N=2x20	Taboo >> Neg > Neu	no	1–7
– Experiment 2	Nouns (ID)	Pos nouns (ID): HA vs LA vs Neu	100 (0)	N=2x16	HA > LA > Neu	no	1–7
– Experiment 3a	Nouns (ID)	Nouns (ID); HA vs Neu vs Neu ∼HA	100 (0)	N=2x22	HA >> Neu = Neu ∼ spelling HA	yes	1–7
– Experiment 3b	Numerical (ID)	Nouns (ID): HA vs Unusual Neu	100 (0)	N=17	HA >> unusual Neu	yes	1–7
– Experiment 3c	Numerical (ID)	Nouns (ID): HA vs Unusual Neu	100 (0)	N=20	Unusual Neu >> HA	no	1–7
– Experiment 4a	Nouns (ID)	Nouns (ID): HA vs Neu	100 (0)	N=20	HA >> Neu	no	1–7
– Experiment 4b	X or O (IDs)	Nouns (ID): HA vs Neu	100 (0)	N=20	HA >> Neu ; HA less affect in RT	no	1–7
Fox et al. (2005)	Mushrooms vs Flowers (ID)	Faces: Fearful vs Happy	110 (0)	AD N= 14H + 14L	HAnx: Fearful >> Happy ; LAnx: Fearful = Happy	n/a	1–6
Nieuwenstein et al. (2005)							
– Experiment 1	Digits (ID), cue	Digits (ID)	33 (50)	N=18	T2-2 >> T2-1 = T2 = uncued	n/a	E/L
– Experiment 2	Digits (ID), cue	Digits (ID), T2-2: Same or Different	33 (50)	N=18	Same >> Different > uncued	n/a	E/L
– Experiment 3	Digits (ID), cue	Digits (ID), T2-2: Same or Different	33 (50)	N=20	Single task >> Dual task	n/a	E/L
Jackson et al. (2006)							
– Experiment 1	Circles vs Squares (ID)	Unfamiliar faces (DE)	85 (0)	N=26	AB (with ditractors: unfamiliar faces)	no	1–5

Continued on next page

Publication	Type of T1 (Task)	Type of T2 (Task)	Dur. (ISI) in ms	Part.	Results	Lag-1	Lags
– Experiment 2	Circles vs Squares (ID)	Famous faces (DE)	85 (0)	GB N=16 vs OE N=12	GB > OE (1 lag)	no	1–5
– Experiment 3	Circles vs Squares (ID)	Unfamiliar faces (DE)	85 (0)	GB N=43	AB (with distractors: famous faces)	yes	1–5
Keil et al. (2006)	Verbs (ID)	HA Verbs ; Pos vs Neg vs Neu	116 (0)	N=13	Neg > Pos > Neu	n/a	2, 4, 6
Reinecke et al. (2007)							
– Experiment 1	Household items (ID)	Neu (mushrooms) vs Pos (blossom) vs Neg (Spiders) (ID)	80 (80)	N=60	Neg >> Pos > Neu	yes	1–6
– Experiment 2	Household items (ID)	Neu (mushrooms) vs Pos (blossom) vs Neg (Spiders+Snakes) (ID)	80 (80)	SPh N=31H + 36L	Neg > Pos > Neu ; no group difference	yes	1–6
Ryu et al. (2007) – #2	Houses (ID)	Neu face (average vs distinctive) (DE)	100 (0)	N=37	Distinctive > Average	no	1–8
Einhäuser et al. (2007)	Neutral faces, Watches (ID)	Neutral misc pictures	6-40Hz	N=6	Faces > Watches ; Duration of AB is category-dependent	yes (faces)	25, 167 ms
De Martino et al. (2008) – Pharmacological study investigating adrenergic system							
– Experiment 1	Nouns (ID)	Nouns (ID): Aro vs Neu	130 (0)	N=2x36	Emo >> Neu, and	no	2–7
– Experiment 2	Nouns (ID)	Nouns (ID): Aro vs Neu	110 (0)	N=3x10	β-blockade reduces performance, and	no	E/L
– Experiment 3	Nouns (ID)	Nouns (ID): Aro vs Neu	110 (0)	N=3x10	especially for emotion-laden stimuli	no	E/L
De Jong et al. (2007)	Happy, Angry faces (ID)	Happy, Angry faces (ID)	120 (0)	SAD N= 16H + 17L	T1 Angry: no change AB ; T2 Angry alleviates AB ; no group diff.	n/a	2, 3, 8
Thompson et al. (2007)	Digits (ID)	Vowels (ID)	100 (0)	N=60	Non-primed > Primed (300 ms)	no	1–5
Trippe et al. (2007)	IAPS Neu	IAPS Neg vs Neu (Distractors: Spiders, etc)	144 (0)	SPh N=14 vs N=16	Controls = Patients (Emo >> Neu) ; Patients (Spiders >> Others)	n/a	1 (288 ms)
Kihara et al. (2008)							
– Experiment 1	Kanji: Neu (ID)	Kanji: Pos vs Neu; Neg vs Neu (ID)	100 (0)	N=2x18	Neg >> Neu ; Pos = Neu	no	1, 3, 7
– Experiment 2	Kanji: Neu, High Neg, Low Neg (ID)	Kanji: Neu (ID)	100 (0)	N=14	Neg T1 creates AB	no	1, 3, 7
– Experiment 3	Kanji: Neu, Neg (ID)	Kanji: Neg vs Neu (ID)	100 (0)	N=16	Lag 1: Neu > Neg ; Lag 3: Neg > Neu ; Lag 7: Neu = Neg	yes	1, 3, 7
DeMartino et al. (2008)	Misc landscape (ID)	Faces: Fea vs Neu	70 (0)	N=15	Fea >> Neu	n/a	5 (350 ms)
Maratos et al. (2008)	Schematic faces: Neu (ID)	Schematic faces: Hap vs Ang vs Neu	128.5 (0)	N=23	Angry > Happy > Neutral	no	2–9

Continued on next page

Publication	Type of T1 (Task)	Type of T2 (Task)	Dur. (ISI) in ms	Part.	Results	Lag-1	Lags
Gomez-Cuerva et al. (2008)	Circles vs Squares (ID)	Faces: Fea vs Hap vs Ang	85 (0)	undisclosed	AB for all emotion ; Long SOA: Happy >> Angry/Fearful	n/a	n/a
Giesbrecht et al. (2008)							(in ms)
– Experiment 1	R/L Arrows, flanked (ID)	Own name, Other name (GD)	53.3 (53.3)	N=24	AB to own name is load-dependent	no	200–800
– Experiment 2	1 digit vs 2 digits (PA)	Own name, Other name (GD)	53.3 (53.3)	N=16	AB to own name is load-dependent	no	200–800
– Experiment 3	1 digit vs 2 digits (PA)	Own name, Other name (GD)	53.3 (53.3)	N=15	No effect of load; Own > Other	no	320, 400, 920
Roesch et al. (2009)							
– Experiment 1	Faces: Neu (GD)	Faces: Mode x Emotion (DE)	80 (0)	N=37	Mode: Dyn >> Stat; Emotion: shorter lag-1 sparing	yes	1–5, 7
– Experiment 2	Faces: Neu (GD)	Faces: Static Fea vs Dyn Fea vs Dyn scrambled	60 (0)	N=14	Statif Fear = Dyn Fea >> Dyn Scrambled	n/a	240, 480 ms
Raymond et al. (2009)	Circles vs Squares (ID)	Faces Neu ($)	85 (80)	N=24	Rewarded faces decreased AB	n/a	200, 800 ms

Table 2.2: Emotion and the AB in the literature – Studies that have investigated the impact of emotional T2. Ang: Angry; Bi Amyg: bilateral amygdala lesion; DE: Detect; E/L: Early vs Late; GB/OE: British/Other European; GD: Gender decision; Fea: Fearful; H/L: High/Low; HA: High arousal; Hap: Happy; HFI: Happy Face Icon; ID/IDs: Identify/speeded; n/a: not applicable; Neg: Negative; Neu: Neutral; PA: Parity decision; Pos: Positive; RTL/LTL: Right/Left Temporal lobe lesion; RT: Reaction time; SPh: Spider phobics. (Original work elaborated in the course of this thesis.)

What is the effect of an emotional T1? A second situation involves presenting an emotional stimulus as T1, and a neutral stimulus as T2 to address the extent to which the processing of emotional material prevents subsequent stimuli from entering the stages required for report (see Table 2.3). In other words, researchers hypothesise that, compared to neutral targets, the processing of emotional targets will occupy and hold attention for a longer period of time, causing a stronger AB on subsequent targets. Fewer studies have addressed this phenomena but, in general, results confirm this hypothesis: showing such an effect when participants are asked to identify negative words (compared to positive and neutral words; Vaquero et al., 2006), emotional faces (Jong & Martens, 2007), and arousing/taboo words (Arnell et al., 2007; Mathewson et al., 2008; Kihara & Osaka, 2008) or arousing pictures (Most et al., 2007), or even when they do not need to perform any task and the emotional material is seen as a simple distractor (Barnard et al., 2004; Huang et al., 2008; Giesbrecht et al., 2008).

Publication	Type of T1 (Task)	Type of T2 (Task)	Dur. (ISI) in ms	Part.	Results	Lag-1	Lags
Barnard et al. (2004)	Nouns (ID): human-, household-, nature-related	Job (DE)	110 (0)	N=30	Semantically related T1 creates AB	yes	1–7
Vaquero et al. (2006)	Nouns (ID): Pos vs Neg vs Neu	"AGUA" (DE)	41 (0)	N=36	Neg T1 creates AB	yes	
Smith et al. (2006)	Birds vs Cars (No task) conditioned vs landscapes	Rotated landscapes vs buildings	100 (16)	N=16	Conditioned T1 increases AB	n/a	E/L
De Jong et al. (2007)	Happy, Angry faces (ID)	Happy, Angry faces (ID)	120 (0)	SAD N= 16H + 17L	T1 Angry: no change AB ; T2 Angry alleviates AB ; no group diff.	n/a	2, 3, 8
Arnell et al. (2007) – no task on T1							
– Experiment 1	Nouns: Neu vs Pos vs Neg vs HA	Colour name (ID)	110 (0)	N=18	HA creates AB	yes	1, 2, 4, 5, 8
– Experiment 2	Nouns: Neu vs Pos vs Neg (Sad) vs HA	Colour name (ID)	110 (0)	N=24	Lag 3: HA creates AB	n/a	3, 8
– Experiment 3	Nouns: music vs sexual taboo	Colour name (ID)	110 (0)	N=43	Lag 3: Sexual taboo creates AB	n/a	3, 8
Most et al. (2007) – no task on T1							
– Experiment 1	♀nude vs ♀/♂clothed	Rotated landscapes, buildings (ID)	106 (0)	♂N=20	Lag 2: nude creates AB	n/a	2, 8
– Experiment 2	Erotic couples vs ♀nude vs Neu	Rotated landscapes, buildings (ID)	111 (0)	♀N=16 ($)	Lag 2: nude creates AB despite reward	n/a	2, 8
– Experiment 3	Erotic couples vs gore vs Neu	Rotated landscapes, buildings (ID)	106 (0)	♂N=15 vs ♀N=8	Gore + nude create AB; priming of T2 alleviates AB	n/a	2, 8
Mathewson et al. (2008)							
– Experiment 1	Nouns (ID): Neu vs Neg vs Pos vs Taboo	Nouns (ID)	117 (0)	N=24	Taboo creates AB even in single-task condition	yes	1–5, 8
– Experiment 2	Nouns (ID): Neu vs Neg vs Pos vs Taboo	Nouns (ID)	117 (0)	N=78	Taboo creates AB even in single-task condition	yes	1–5, 8
Kihara et al. (2008)							
– Experiment 1	Kanji: Neu (ID)	Kanji: Pos vs Neu; Neg vs Neu (ID)	100 (0)	N=2x18	Neg >> Neu ; Pos = Neu	no	1, 3, 7
– Experiment 2	Kanji: Neu, High Neg, Low Neg (ID)	Kanji: Neu (ID)	100 (0)	N=14	Neg T1 creates AB	no	1, 3, 7
– Experiment 3	Kanji: Neu, Neg (ID)	Kanji: Neg vs Neu (ID)	100 (0)	N=16	Lag 1: Neu > Neg ; Lag 3: Neg > Neu ; Lag 7: Neu = Neg	yes	1, 3, 7

Continued on next page

Publication	Type of T1 (Task)	Type of T2 (Task)	Dur. (ISI) in ms	Part.	Results	Lag-1	Lags
Huang et al. (2008) – no task on T1							
– Experiment 1	Nouns: Neg vs Neu	Fruit names (ID)	75 (0)	N=16	Neg creates more AB than Neu	yes	1, 2, 3, 6
– Experiment 2	Nouns: Neg vs Neu	Fruit names (ID) in capital letters	75 (0)	N=16	Neg = Neu	yes	1, 2, 3, 6
– Experiment 3	Nouns: Neg vs Neu	Rhyming words (ID)	75 (0)	N=16	Neg = Neu	yes	1, 2, 3, 6
– Experiment 4	(not an AB experiment)						
– Experiment 5	Nouns: Neg vs Neu	Fruit names or capital words (ID)	75 (0)	N=32	Effect of emotion only for lag 3 in semantic task	yes	1, 2, 3, 6

Table 2.3: Emotion and the AB in the literature – Studies that have investigated the impact of emotional T1. See table 2.2 for legend. (Original work elaborated in the course of this thesis.)

2.4 Conclusion

In this chapter, we quickly reviewed some fundamental aspects covering the link between emotion and attention. In particular, an impressive variety of data suggests that emotion influences attention in several ways: emotion-laden material modulates spatial attention, enhances perception and takes precedence over concurrent information. However, the various paradigms from which this coherent picture emerges seem to be very sensitive, and under certain conditions provide radically different results. New apertures are being developed in the form of experimental paradigms that specifically target the unfolding of the processing. In the AB for instance, a second target is used to probe the general availability of the processing system as it is currently processing a first target. A typical response shows that after a short period of time during which both targets can be processed together ("Lag-1 sparing"), the performance drops dramatically (for a peak at about 300 msec after T1) before recovering slowly.

Emotion researchers have used this paradigm to assess the extent to which the processing system is tuned in favour of emotion-laden material. Results generally demonstrate that emotional stimuli benefit from biases throughout the many stages of processing, and that upon ignition of this processing, the cognitive system becomes less susceptible to interference and supports emotion-laden information. However, even though the AB could, in theory, provide valuable information about the stream of processing, the coarse picture depicted so far by these studies does not allow for the precise description of the sequence of cognitive processes underlying the orienting of attention to emotional material.

One reason for this may be the heterogeneity with which researchers implement this experimental paradigm. In this paradigm, which focuses on the temporal aspect of the processing, it is to be expected that different temporal parameters (e.g., durations, ISI) will affect the results. For instance, one trial, containing about 20 stimuli rapidly flickering on the screen (distractors and two targets), may yield different perception depending on the rate of stimulation. The dispute between Hommel & Akyurek (2005) and Dehaene et al. (2003), for instance, each side claiming that conscious recognition of targets is signed by the cortical activity within a particular frequency band, may be resolved by considering differences in temporal parameters yielding different stimulation rate (see Einhauser et al., 2007; Vul, Hanus, & Kanwisher, 2008, for experiments with different presentation rate).

Another reason may be the lack of an efficient methodology to assess the results obtained with this paradigm. If the AB makes it "easy" to probe the state of the processing system, and its readiness to emotional interference at a given moment of the processing, there is no straightforward way to measure and characterise the stages of processing being probed. A possible way to answer to this critic may be through the use of tailored statistical analyses (Cousineau et al., 2006), as we used in this work and will present in the next chapters.

Chapter 3

Statement of objectives

What drives the orienting of attention to emotion-laden stimuli and how?

With a view to addressing these questions, we used current emotion theories to guide an investigation of the sequence of cognitive processes yielding the orienting of attention to emotional objects in the environment. In Chapter 1, we introduced three of the main theoretical traditions of emotion: dimensional theories, basic emotion theories and appraisal theories of emotions. In Chapter 2, we reviewed some of the methodologies used to investigate emotional attention, and identified temporal attention as an ideal framework to shape our efforts. In this chapter, we will contrast the predictions from the three theoretical traditions, and formulate the working hypotheses that served as foundation to our work.

3.1 Background summary

Dimensional theorists characterise affective experience in a low-dimensional space, whose dimensions represent the fundamental domains of affective life. In this theoretical framework, Russell (1980, 2003) proposed the concept of core affect, a compound-state of affect that allows the organism to attend and react to changes in its environment through homeostatic mechanisms. According to this hypothesis, the affective system would spread along two fundamental dimensions, valence and arousal. We made the following prediction: attention will preferentially be drawn by stimuli that activate the systems that respond to these dimensions.

Basic emotion theorists take a radically different stand by proposing that emotion-specific networks of brain areas supervise the evaluation of perceived stimuli, and motivate the behavioural responses that have been successful in dealing with key survival issues in the phylogenesis of our species (Ekman, 1992, 2004; Izard, 2007). In particular, Öhman & Mineka (2001) describe a module dedicated to the evaluation of stimuli that have been experienced in contingency with physical harm (e.g., snakes, spiders, social situations of aggression). This module is proposed to lay at the very beginning of the stream of cognitive processes and yield reflex-like behavioural responses (automatic, fast, pre-attentive and preconscious) promoting the survival of the individual. One of the main outcome of this module would thus be the orienting of attention to threatening stimuli. We made the general prediction that attention will preferentially be drawn by threatening stimuli.

Appraisal theories of emotion focus on the commonalities between emotions rather than the differences. Theorists aim at circumscribing the functional domains of the cognitive processes evaluating occurring events. The component process model (Scherer, 2001), in particular, describes the sequence of processes antecedents to the genesis of emotions. Central to this theory is the evaluation of the relevance of the occurring event to the individual and her well-being. The evaluation of relevance is proposed to support the unfolding of the appraisal process by allocating the attentional and processing resource required for an appropriate response. This proposal differs from the fear module hypothesis in that any stimulus that can potentially influence the well-being of the individual and her goals and concerns, regardless of it valence, is considered relevant. We made the prediction that attention will preferentially be drawn by relevant stimuli, regardless of their valence.

As can be understood from the above, the proposed mechanisms of interaction between emotion and attention differ quite significantly. With a view to engaging in the empirical testing of these proposals, characterising how theories relate to each other can help reduce the problematic to a tractable level of investigation. Of particular interest to our work is the relationship between dimensional and appraisal theories of emotion, as represented by the core affect hypothesis (Russell, 1980, 2003) and the component process model (Scherer, 2001), respectively. Even though these two models originate from very different theoretical assumptions, and make radically different claims about the implementation in the brain of the link between emotion and attention, they both suggest that occurring events are evaluated against a finite number of general criteria, from which ensues the orienting of attention *prior* in-depth processing. In that respect, appraisal theories of emotions appear as more specific versions of dimensional theories (P. Ellsworth, personal communication, February 1st, 2007). One of the main differences between these two models resides in the status attached to the concepts of valence and arousal. Whereas the core affect hypothesis describes these two concepts as generative of emotion, the CPM sees general arousal and valence as *resulting* from the early appraisals of the occurring event. In this light, the predictive value of the CPM seems inclusive of the predictions made in the context of the core affect hypothesis, which allows us to reduce this equation to predictions formulated through the CPM. We thus propose to reduce the study of the link between emotion and attention to the comparison of predictions made by basic emotion theories and appraisal theories of emotion. More precisely, we oppose the fear module hypothesis (Öhman & Mineka, 2001) to the component process model (Scherer, 2001).

3.2 Methodology and general hypotheses

In this work, we aimed at studying the sequence of processes yielding the orienting of attention to emotionally salient stimuli. To that end, we reviewed the methodologies commonly used to investigate the link between emotion and attention (Chapter 2), from which we selected two complementary experimental paradigms: the modulation of the AB effect by emotional targets (neutral T1 and emotional T2), to examine the extent to which emotional stimuli benefit from a processing bias allowing them to interfere in the ongoing processing, and the manipulation of the conscious awareness of emotional stimuli through backward masking, to investigate the mechanisms underlying these processing biases.

We chose to use emotional facial expressions because they have been heavily used in the research investigating the link between emotion and attention. Opposing predictions from the fear module against predictions from the CPM, we make the following general hypothesis: *If attention is driven by a process resembling a fear module, then fearful facial expressions will attract attention more than both happy and neutral facial expressions. In contrary, if attention is driven by the relevance* *of perceived stimuli as predicted by the CPM, both fearful and happy facial expressions will attract attention more than neutral facial expressions.*

Subsequently, if attention is driven by a process resembling a fear module, then the modulation of attention by fearful facial expressions will be stronger for participants scoring high on anxiety scales (Spielberger et al., 1983), compared to both extraverts (Costa & McCrae, 1991; McCrae & Costa, 1997) and control participants. Similarly, the modulation of attention by happy facial expressions may be stronger for participants scoring high on scales of extraversion. In addition to the valence of presented stimuli, we thus manipulated their relevance by selecting participants on the basis of their scores on personality questionnaires: We have shown in Chapter 2 that trait anxiety may influence the processing of emotional information and the orienting of attention in several ways, and there is a growing body of evidence showing that other personality traits may have as strong of an influence on early attentional processes. Extraversion, in particular, has recently been shown to modulate responses to positively connotated stimuli. We therefore hypothesise that this particular personality trait may influence the orienting of attention as much as trait anxiety, as shown in both behavioural and neuroimaging studies: On the one hand, in a dot-probe task, Derryberry & Reed (1994) showed that extravert participants were slow to shift attention away from cues that were assigned to positive incentive values (i.e. gain of points), whereas introvert participants were slow to shift attention away from negative incentive (i.e. loss of points). On the other hand Canli et al. (2001, 2002) reported that amygdala activations due to the perception of happy facial expressions correlate with levels of extraversion. They emphasise that all participants exhibited amygdala activation to the perception of fearful facial expressions, and that this correlation was only found for the perception of happy facial expressions. They further propose to reinterpret the conclusions of studies that showed the amygdala was only activated by fearful facial expressions (Morris, Friston, et al., 1998; Whalen et al., 1998), arguing that investigators did not control for the personality traits of the participants. The reinterpretation of this data seems sound in the context of results showing that amygdala activation correlates in similar ways with trait anxiety (Etkin et al., 2004; Bishop et al., 2004).

3.3 Conclusion: Common thread and structure

The common thread to our work resides in the investigation of emotional attention (Vuilleumier, 2005). We propose to use different and complementary experimental paradigms to address this phenomenon. The remain of this thesis describes in details the steps taken in this endeavour.

All aspects of this work have been presented at several international conferences, and are either submitted or in press in the form of journal articles.

Chapter 4 (on page 51) introduces FACSGen, a novel software we wrote to allow the creation of realistic, static and dynamic, emotional facial expressions. When we were investigating the experimental material available to setup our experiments, we soon realised the flaws and drawbacks of the experimental material commonly used in the research community. Because the tools and the funding were available, we seized the opportunity to design and produce an original piece of software that would allow the manipulation and control of the information cues portrayed in facial expressions. By allowing the creation and manipulation of synthesised facial expressions, FACSGen represents a significant departure from conventional methods in the investigation of emotional perception. This novel tool is now being used by several research groups. Chapter 4 is a reproduction of the journal article presenting our software in details, which we is now in revision for Journal of Nonverbal Behavior.

Chapter 5 (on page 69) describes two experiments investigating the modulation of the AB effect by static and dynamic facial expressions of emotion. We used curve fitting techniques to analyse particular aspects of the AB curve (Cousineau et al., 2006). To our knowledge, this is the first attempt to use these methods to investigate the sequence of cognitive processes yielding the unfolding of attention to emotional stimuli.

Chapter 6 (on page 95) describes a psychophysical experiment investigating the minimum display duration necessary to make a correct gender decision, a situation very similar to the one setup in both of our AB experiments. Not only did this experiment allow us to test both of our general hypotheses, it also allowed us to pinpoint some of the mechanisms underlying the orienting of attention to emotional stimuli. In particular, we investigated the proposal that emotion-laden information may interfere in either or both voluntary and involuntary attention. Our experimental paradigm allowed to disentangle these two aspects.

Chapter 7 (on page 107) concludes this work. After quickly describing the context within which this work evolved, we review our contributions to the field, and propose tracks for future research.

Chapter 4

FACSGen: A tool to synthesize FACS-based facial expressions

Reproduced from: Roesch, E.B., Tamarit, L., Reveret, L., Grandjean, D., Sander, D. and Scherer, K.R. (in revision). FACSGen: A tool to synthesize realistic, static and dynamic emotional facial expressions based on facial action units. *Journal of Nonverbal Behavior*.

Abstract: To investigate the perception of emotional facial expressions, researchers rely on shared sets of photos or videos, most often generated by actors' performance. The drawback of this kind of readily available material is a lack of flexibility and controllability, as it does not allow the systematic parametric manipulation of specific features of facial expressions on the one hand, and of more general properties of the facial identity (age, ethnicity, gender) on the other. To remedy this problem, we developed FACSGen: a novel tool that allows the creation of unique, realistic, static or dynamic, synthetic 3D facial stimuli based on the Facial Action Coding System. FACSGen provides researchers with total control over facial action units, and corresponding informational cues in 3D synthetic faces. We present four studies validating both the software and the general methodology of systematically generating controlled facial expression patterns for stimulus presentation.

4.1 Introduction

Much of the research addressing the communication of emotion concerns the perception and interpretation of facial expressions. Typically, participants are shown still pictures or videos of facial expressions, and researchers analyze recognition rates and confusion matrices (e.g., Hess et al., 1997). Alternatively, some researchers, in the field of neuroscience for instance, may be interested in the measurement of the influence of the perception of a given facial expression on a second task, like in experiments involving priming (e.g., Ruys & Stapel, 2008) or backward masking (e.g., Szczepanowski & Pessoa, 2007) of facial expressions.

A growing number of databases are available, containing a vast number of facial expressions (D. Lundqvist et al., 1998; Goeleven et al., 2008; Hirsh et al., 2009). This material can of course be used as is, but researchers often manipulate it to suit their needs. Specific types of facial expressions can be investigated by applying various methods to create specific experimental stimuli. Image morphing techniques, for instance, allow the creation of dynamic facial expressions by extrapolating a configuration of facial features from a source picture and transfer it to a target picture. Using this technique, a typical stimulus would show a neutral face evolving into one of the basic emotions (e.g., Joorman & Gotlib, 2006). However, manipulation of the kind has some limitations related, for example, to the assumption that a linear function from neutral to emotional expression reflects the actual dynamics of unfolding of emotional expressions – a situation which is unlikely to happen (e.g., Scherer & Ellgring, 2007). Researchers can further manipulate this tailored material in a limited number of ways, by specifying the speed of the unfolding, or creating ambiguous stimuli midway between two emotions.

Whereas shared and standardized stimulus sets facilitate the comparison of results across studies, often researchers have to expect major limitations in their ability to manipulate stimulus features, and to ascertain appropriate experimental control. For instance, only very few databases of actor-posed facial expressions contain facial configurations that have been controlled in terms of precise muscle movements, specifying the informational cues available in the face. Generally, actors are only provided with verbal labels of emotions – often only basic emotions – and instructed to pose the respective expressions corresponding to their personal interpretation of those emotions. A researcher seeking to manipulate particular facial features (e.g., the amount of eye opening for example), or interested in studying less orthodox facial expressions (e.g., the expression of pain), is thus left with the difficult task of creating her own database.

In this article, we describe FACSGen, a novel tool to create experimentally controlled facial expression patterns. FACSGen takes advantage of the flexibility of the Facial Action Coding System (FACS; Ekman & Friesen, 1976; Ekman et al., 2002) to represent facial expressions while fulfilling the requirements for reproducibility and comparison of material across studies. FACSGen allows the creation of realistic facial expressions by parametrically manipulating action units (AUs) portrayed on an infinite number of synthesized 3D faces, created with FaceGen Modeller 3.3 (Singular Inversions Inc., 2009) – see for instance Cristinzio, N'Diaye, Seeck, Vuilleumier, & Sander (in press), N'Diaye, Sander & Vuilleumier (in press), Roesch, Sander & Scherer (2009), Roesch, Sander, Mumenthaler, Kerzel & Scherer (in revision), and Roesch, Sander & Scherer (in preparation). The FACS defines the common AUs that facial muscles can produce, thus allowing the formal description of the constituents of any facial expression. It contains 58 AUs, out of which 20 are commonly used to describe most facial expressions of emotions. FACSGen dynamically combines individual AUs to generate a virtually infinite variety of dynamic facial expressions and allow the creation of an unlimited number of facial expressions, static or dynamic, that can be modeled on a potentially infinite number of facial identities. Thus, FACSGen promises to become a key tool in the investigation of the perception of facial expressions in general, and the inferences from emotional facial expressions in particular.

We begin by introducing FaceGen Modeller 3.3, a commercial tool we use to create and handle realistic 3D facial stimuli. We then describe FACSGen, the tool we developed, which allows the parametric manipulation of facial AUs, as an add-on to FaceGen Modeller 3.3. Next, we present four studies that we conducted to validate the software as well as the methodology of using the synthetic stimuli created with this tool. We conclude by discussing the potential of FACSGen as compared to other software currently available.

4.2 FACSGen: the parameterization of facial expressions

FACSGen is a software we developed to manipulate the expression of synthesized 3D faces on the basis of the FACS. It is used in conjunction with FaceGen Modeller 3.3 (Singular Inversions Inc., 2009), a commercial software that allows the creation and manipulation of an infinite number of realistic synthesized faces (Shimojo et al., 2003; Moradi et al., 2005; Corneille et al., 2007; Oosterhof & Todorov, 2008; Todorov et al., 2008; J. B. Freeman & Ambady, 2009). A representation of the information flow in FACSGen is shown in Figure 4.1. As can be seen, FACSGen integrates components of FaceGen Modeller 3.3, allowing the precise and coherent control of the same 3D objects, and providing FACSGen with many of the features available in FaceGen Modeller 3.3.

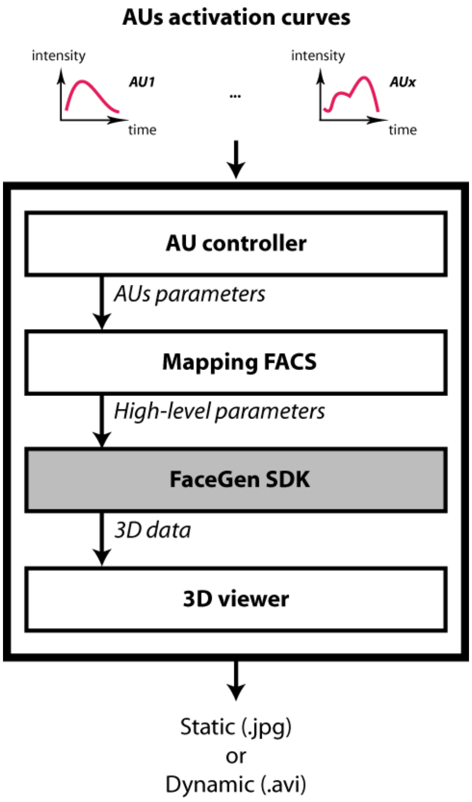

Figure 4.1: Architecture and information flow in FACSGen. A graphical user interface allows the user to describe the dynamics of activation over time for each AU (curves at the top of the figure). Different layers process this information, mapping it to action units, before applying the corresponding facial expression on 3D faces created with FaceGen Modeller 3.3. FACSGen manipulates FaceGen faces through the FaceGen software development kit released by Singular Inversion Inc.

Basically, the user provides FACSGen with a representation of the dynamics of activation over time for each AU (the curves in the figure), and FACSGen produces the corresponding facial expression unfolding over time, either in the form of a series of still pictures (jpeg files) or a movie (avi files). This facial expression can be mapped onto any face created using FaceGen Modeller 3.3.

4.2.1 FaceGen Modeller 3.3

FaceGen Modeller 3.3 is a commercial tool that was originally designed for the creation of realistic 3D faces in video games (Singular Inversions Inc., 2009).). It is based on a database of thousands of human faces whose shape and texture have been digitized into 3D objects. Representing these faces into factorial space allows the extrapolation of new, unique, faces on the basis of a number of continua. Faces created with FaceGen Modeller 3.3 vary in gender, age, and ethnicity, and can be manipulated in ways very similar to a sculptor to create very realistic faces. All faces from all constitutions (e.g., chubby, skinny) and all shapes (e.g., sharp-edged, oval) could, in theory, be reproduced. The user interacts with the software through an intuitive graphical user interface, without requiring special training. FaceGen Modeller 3.3 also provides the user with the ability to create her own 3D mesh (i.e., 3D topology and detailed texture) from close-up photographs of a person. Digitized faces can be altered and imported into FACSGen just like any other 3D faces created using FaceGen Modeller 3.3 (Figure 6.3). By default, heads created with FaceGen Modeller 3.3 are bald, but additional 3D objects (e.g., hair, facial hair or miscellaneous accessories) can be added if needed. FaceGen Modeller 3.3 is primarily dedicated to the creation of 3D facial morphology. Given a specific morphology, FaceGen Modeller 3.3 allows limited control over the manipulation of some basic features of facial expression (e.g., gaze, head direction, or phonological codebook) and offers a small number of full-blown, non FACS-based emotional expressions. In our first study, because researchers already using FaceGen Modeller 3.3 may want to use these built-in expressions, we asked FACS coders to code these expressions (denoted ”FG expressions” in the article) as well as expressions produced using FACSGen.

4.2.2 FACSGen

FACSGen is a software that can import any face exported from FaceGen Modeller 3.3 (i.e., created from scratch or from close-up photographs; see Figure 2). It interfaces with FaceGen Modeller 3.3 through a C++ SDK library released by Singular Inversions Inc. that allows the manipulation of the same 3D objects. The SDK provides access to 150 high-level, morphological parameters manipulating different aspects of the topology of the face (see Figure 1). In some cases, FACS coders are required to base their judgment on both the movements performed by the muscles of the face and the co-occurrence of particular features, like the folding of the skin and changes in its pigmentation. In the presence of AU 12 “smile”, for instance, FACS coders will code the activation of AU 6 “cheek raise” if so-called crow’s feet wrinkles appear in the outer corner of the eyes. Situations of this type not only involve changes in the morphology of the face but also in the visual aspect of the skin. As FaceGen Modeller 3.3 itself does not support the manipulation of such features, we complemented FaceGen parameters with our own set of dedicated parameters.

A graphical user interface allows the linear manipulation of AUs (Figure 4.3), and the non-linear manipulation of activation curves (Figure 4), which allow the representation of detailed dynamics over time. The output consists of a series of frames depicting the unfolding facial expression mapping the intensity for each AU, for each point in time. These frames can then be used as static displays of an evolving facial expression, or converted into movie clips. The values of the

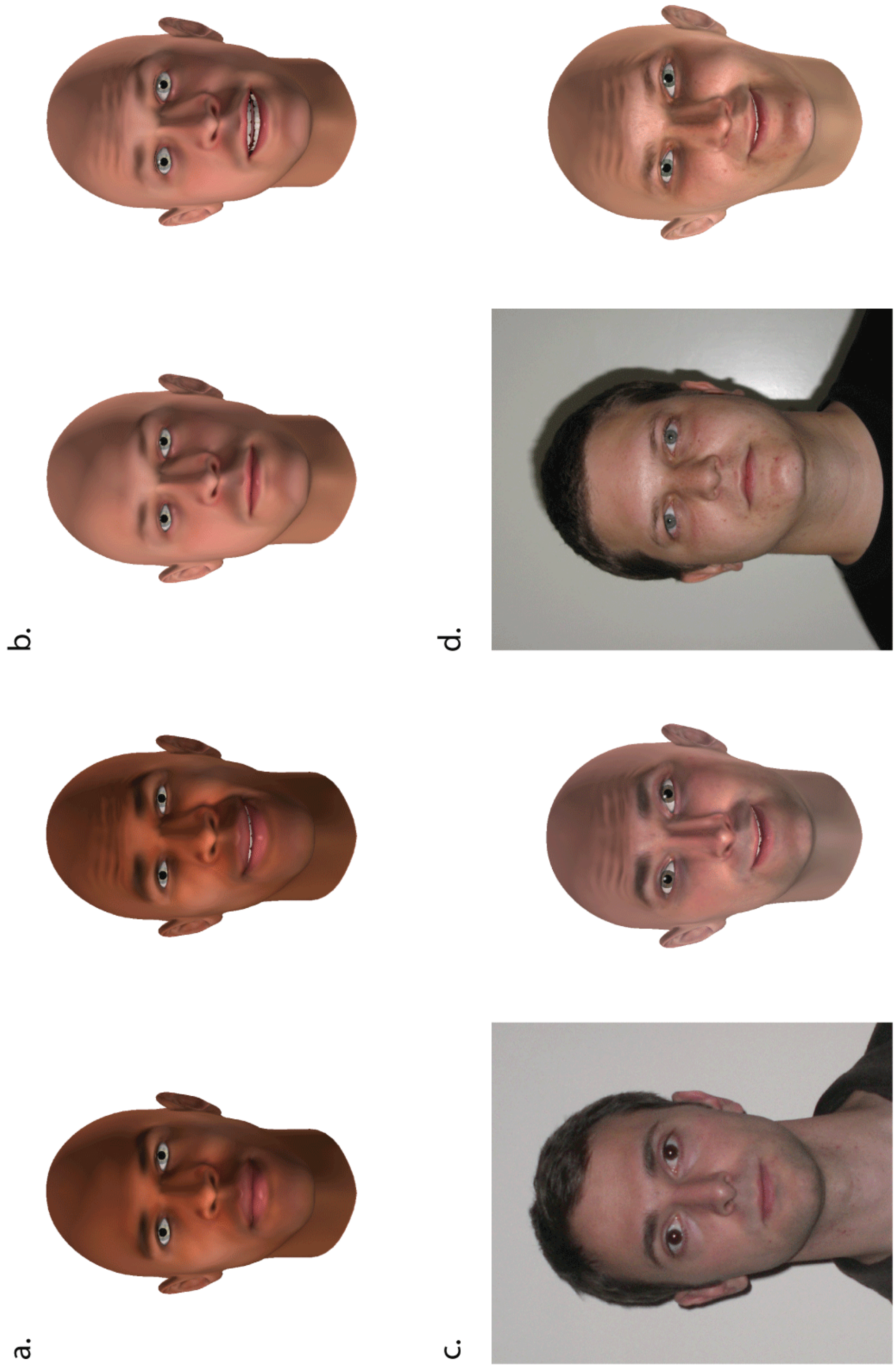

Figure 4.2: Examples of faces manipulated with FACSGen. Panel a. Random African face: neutral expression and portraying AU 1+2+6+12+25. Panel b. Random Caucasian face: AU 1+2+5+25+26. Panel c and d. Synthesized faces digitized from close-up pictures: neutral photograph and portraying the exact same facial expression (AU 1+2+6+12+25).

activation curves can be exported in text files for offline analyses, and imported back again in FACSGen to generate the same facial expressions on different faces. This feature responds to the need for the reproducibility of experimental setups across studies.

4.3 Validation studies

The general methodology consists in creating a number of faces using FaceGen Modeller 3.3 to define the base morphology, importing and manipulating them in FACSGen to create controlled facial expressions to be used as experimental material for the systematic study of inferences made from AU static and/or dynamic configurations. The creation of ecologically valid stimuli requires that a) the AUs manipulated in FACSGen correspond to what is described in the FACS, b) synthesized 3D identities produced in FaceGen Modeller 3.3 are reliably perceived by lay participants (e.g., in terms of gender, believability, and intrinsic emotionality, related for example to attractiveness or trust), and c) that the manipulation of AUs on these identities produce facial expressions that are reliably recognized by lay participants. Here, we consider these as the central criteria for a validation of the tool.

The validation procedure we conducted consisted of three parts. In study 1, we verified that our operational definitions of the AUs, and their implementation on a 3D model, correspond to current convergence among FACS coders. For this study, we created a number of video clips depicting combinations of AUs that were submitted to certified FACS coders for coding. In study 2, and studies 3a and 3b, we verified the applicability of the procedure to frequently encountered experimental settings using static pictures. First, we investigated how lay participants perceived synthesized 3D faces produced with FaceGen Modeller 3.3, portraying no particular expression to examine the quality of the facial identities (Study 2). Second, we manipulated a selection of these faces using FACSGen, applying a selection of the controlled emotional facial expressions validated in the first study and asked participants to rate the underlying emotion. In this part of the research, we used two different versions of these emotional faces: color stimuli and processed grayscale stimuli in two separate studies. This comparison was made because a growing number of researchers, especially in psychophysics and neuroscience, seek to control for the low-level features of visual material, including facial expression, by manipulating it in a number of ways. For instance, often color pictures of facial expressions are converted into grayscale, and the gray level intensity of all pixels is normalized to ensure the recognition of emotions is not unevenly affected by the general luminance and contrast of a particular experimental condition(e.g., Pourtois et

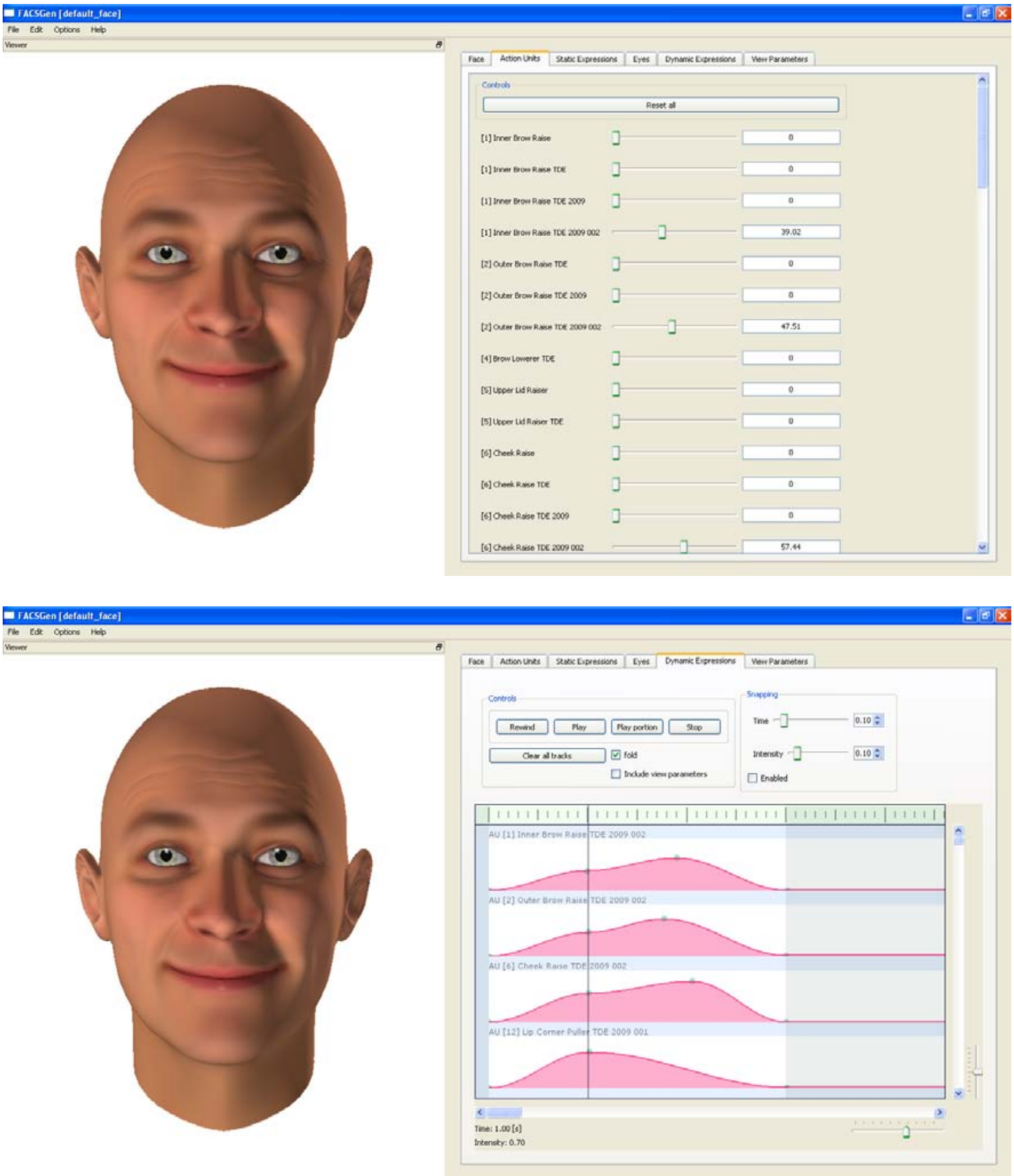

Figure 4.3: Screenshots of the interface of FACSGen. The user can control action units in a linear (top) and non-linear (bottom) fashion to produce any facial expression. The resulting expression can be exported as a movie clip, and each step of the unfolding can be exported as a still picture.

al., 2004, , see also Delplanque, N'Diaye, Scherer, Grandjean, 2007, for related issues on spatial frequencies). Because such widely used techniques may alter the general perception of facial expressions – which might be a particularly serious problem for synthesized 3D faces – we had both color (Study 3a) and processed grayscale pictures (Study 3b) evaluated by lay judges.

4.3.1 Study 1. Validation of the Action Units manipulated by FACSGen

The facial action coding system (FACS; Ekman & Friesen, 1976; Ekman et al., 2002) is the most popular facial coding scheme to date. It defines common action units that facial muscles can operate, and thus allows the formal and exhaustive description of the constituents of any facial expression, static or dynamic. Comparing the results produced with FACSGen to what is defined in the FACS manual is therefore a critical step in the evaluation of our software.

Procedure

Four certified FACS coders were provided with two second clips (50 frames) depicting the unfolding of either a single AU or a combination of several AUs, evolving from no activation to 100% of activation to produce realistic full-blown expressions. Clips were numbered, and each FACS coder was assigned to a randomized presentation order. For each clip, FACS coders were instructed to mark if the AUs were present (noted 1) or absent (noted 0), yielding an activation profile of AUs. FACS coders were not asked to rate the intensity of activation for each AU, as this is known to give poor inter-rater agreement (Sayette et al., 2004).

Each AU was portrayed on 6 different Caucasian identities (3 females). Portrayals unfolded from a neutral expression to one out of 16 single AU, or one out of 17 combinations of AUs as described by the Emotional FACS (EMFACS; Ekman et al., 1994). In addition, because emotional facial expressions created with FaceGen Modeller 3.3 have already been used in research, and are likely to be integrated in setups involving FACSGen, we created and evaluated clips portraying FaceGen built-in facial expressions (denoted "FG"). All clips portrayed one face in full color against a black background, frontal view, and facing the observer.

Results and discussion.

Table 4.2 shows that both the clips portraying a single AU, and the clips portraying a combination of AUs were reliably recognized and coded by FACS coders. Cronbach alphas were computed for

FACSGen manipulation	Name	Cronbach α	AUs coded
AU 1	Inner brow raiser	.990	AU 1
AU 2	Outer brow raiser	.989	AU 2
AU 4	Brow lowerer	.998	AU 4
AU 6	Cheek raiser	.975	AU 6
AU 7	Lids tight	.982	AU 7
AU 12	Lip corner puller	.987	AU 12 (+6)
AU 17	Chin raiser	.977	AU 17 (+5+24)
AU 19 (+25+26)	Tongue show	.988	AU 25+26 (+10)
AU 20	Lip stretch	.903	AU 20 (+12+24)
AU 22	Lip funneler	.992	AU 22+25
AU 23	Lip tightener	.933	AU 23 (+5+24)
AU 25+26	Jaw drop	.998	AU 25+26
AU 61	Eyes left	.989	AU 61
AU 62	Eyes right	.991	AU 62
AU 63	Eyes up	1.	AU 63
AU 64	Eyes down	.998	AU 64
AU 1+2		.994	AU 1+2 (+5)
AU 1+2+5	Surprise	.982	AU 1+2+5
AU 1+2+5+25+26	Fear	.994	AU 1+2+5+25+26
AU 4+7	Anger	.993	AU 4+7
AU 4+7+23	Anger	.990	AU 4+7+23
AU 4+17+23	Anger	.978	AU 4+17+23
AU 5+25+26	Surprise	.997	AU 5+25+26
AU 12+25	Happiness	.987	AU 12+25 (+6)
AU 22+25+25	Neutral (mouth open)	.970	AU 22+25+25
FG: Anger		.971	AU 9+16+25
FG: Anger + AU 25	Anger	.968	AU 9+25+26 (+16)
FG: Disgust		.988	AU 9+15 (+4+10)
FG: Fear		.978	AU 1+25+26 (+4+7+10)
FG: Sadness		.986	AU 4+7 (+24)
FG: Fear + AU 1+2+5+25+26	Fear	.994	AU 1+2+5+25+26
FG: Hap + AU 1+2+6+12+25	Happiness	.992	AU 1+2+6+12+25

Table 4.2: Inter-rater agreement, and results of coding by FACS coders. Parentheses show AUs that were proposed by some but not all FACS coders. Combinations of AUs were taken from the Emotional FACS (Ekman, Irwin, & Rosenberg, 1994), or produced by FaceGen. "FG" expressions refer to the built-in emotional facial expressions in FaceGen Modeller 3.3.

each FACSGen manipulation, using coded AUs as items, and the 24 profiles (4 coders × 6 identities) of AUs as variables. We did not manipulate and evaluate AUs that describe head movements. Consequently, all faces were facing the observer, which may have hindered the recognition of certain AUs. For instance, FACS coders did not code AU 19 ”tongue show”, but only coded AU 25+26 describing the opening of the mouth, even though the tongue was visible. We conclude that certified FACS coders reliably recognize the synthetically produced AUs and AU configurations.

4.3.2 Study 2. Validation of the faces produced using FaceGen Modeller 3.3

FaceGen Modeller 3.3 can create an infinite number of synthesized 3D identities, either from scratch or from digitized close-up photographs (see Figure 4.2). To use this computer-generated material to systematically study the interaction between facial expression and facial identity, we need to ensure that lay participants reliably perceive the synthesized identities. In an optimal situation, faces produced with FaceGen Modeller 3.3 should be unambiguously recognized as male or female (note that some researchers may need androgynous faces, in which case the procedure would have to be adapted accordingly). They should also be most believable (i.e., looking as natural as possible given the limitations of 3D synthesis) and as emotionally neutral as possible. Study 2 addressed this issue, and provided us with a pool of rated identities from which we selected the faces used in studies 3a and 3b.

Procedure

We created 180 faces using FaceGen Modeller 3.3: Faces were Caucasian male or female, of an estimated age between 20 and 45 years old. The faces were created with the aim of being as believable as possible, and as emotionally neutral as possible. Color pictures of the faces were then presented in random orders to 44 students (35 females, mean age 23.7 years) from the University of Geneva. Participants were gathered in classrooms, and used a web-based interface to report their judgments. Participants were instructed to rate the 180 faces on three continuous dimensions:

- Gender – ”Is this the face of a male, an androgynous person, a female?” (anchored ”Male”, and ”Female”)

- Believability – "Is this face natural? Could you encounter it in the street?" (anchored "Synthetic", and "Believable/Realistic/Natural")
- Intrinsic emotionality – "Does this face seem to show a positive, neutral, or negative emotion?" (anchored "Positive", "Neutral", "Negative")

Results and discussion

Cronbach α were computed for each of the three dimensions, using participants' ratings as items and the 180 pictures as variables. Results showed that the faces were reliability rated on the three dimensions: α for gender = 0.996 ; α for believability = 0.939 ; α for intrinsic emotionality = 0.962. To determine whether participants managed to discriminate the faces on the three dimensions, a t-test was performed on the ratings obtained for each of the three dimensions, comparing the first and last quartiles of the respective ordered sample. Results showed that the faces could be discriminated on each of the dimensions. Male faces yielded ratings significantly closer to the "Male" anchor (M = 2.79, SD = 4.11) than did female faces (M = 81.99, SD = 17.76), $t(2141)$ = -191 ; $p < .001$. Results also showed that the first quartile of the sample was significantly less believable (M = 29.67, SD = 27.94) than the last quartile of the sample (M = 68.63, SD = 28.87), $t(3820)$ = -42.3 ; $p <.001$. Finally, results showed that the first quartile of the sample was perceived more negatively (M = 35.72, SD = 16.11) than the last quartile of the sample (M = 62.51, SD = 15.08), $t(3790)$ = -53.0 ; $p <.001$.

Overall these results show that lay participants reliably perceive the gender of FaceGen faces, and can reliably attribute ratings of believability, and intrinsic emotionality to such faces. Because FaceGen allows the creation of very different kinds of faces (from very realistic to more caricatural), it is very important to be able to assess and control these dimensions.

4.3.3 Study 3a. Validation of FACSGen facial expressions (color version)

Procedure

Out of the 180 faces created for Study 2, we selected 77 faces (40 females), for being the most unambiguously gender-typed, the most believable, and the most emotionally neutral faces. We then manipulated the faces using FACSGen, to depict the combinations "Anger: AU 9+16+25", "Fear: AU 1+2+5+25+26", "Happiness: AU 1+2+6+12+25", and "Neutral: AU 22+25+26" (as described in Study 1, and validated by FACS coders). These AU combinations do not fully concur with some of the complete prototypical facial expressions described in the literature (although there is much discrepancy in these descriptions and complete prototypical configurations are very rarely found, see Scherer & Ellgring, 2007). However, these combinations are very likely to occur in real life situations and frequently occur in actor portrayals of emotions (see, Scherer & Ellgring, 2007). In consequence, we assumed that they can be recognized by lay participants with reasonable agreement.

The procedure used was similar to Study 2. Twenty students (14 females, mean age 22.1 years) rated colorful pictures of the 77 faces, each of which portrayed the four facial expressions. Participants were instructed to rate the extent to which the following emotions could be perceived in the facial expressions: anger, disgust, fear, happiness, sadness, and surprise. Blank fields allowed them to propose other emotions. A scale from 0 ("not at all") to 100 ("enormously") was provided. They also had to rate the overall intensity of the facial expression. A scale from 0 ("not intense") to 100 ("very intense") was provided.

Results and discussion

Cronbach α were computed, using participants' ratings as items, and pictures as variables. Results showed that the faces were reliably rated on the 7 scales (6 emotions, and intensity): α for anger = 0.977 ; α for disgust = 0.916 ; α for happiness = 0.969 ; α for fear = 0.977 ; α for surprise = 0.824 ; α for sadness = 0.865 ; α for intensity = 0.941. To determine whether participants can discriminate the emotions portrayed by FACSGen faces portrayed on color pictures, repeated measures analysis of variance (ANOVAs) was performed for each of the three portrayed emotions Anger, Fear, Happiness and the Neutral facial expression. The dependent variables were participants' ratings on the 7 scales. In all four cases, there was a significant main effect of Emotion (Anger: $F(5,380) = 1337.0$; $p < .001$; Fear: $F(5,380) = 784.7$; $p < .001$; Happy: $F(5,380) = 1010.0$; $p < .001$; Neutral: $F(5,380) = 276.9$; $p < .001$). Contrast analyses were performed by assigning the target emotion as the reference category. There was a significant effect for targets' emotions (ps<.001), indicating that participants reliably recognized the target emotion portrayed by the faces (see Figure 4.3.3). The mean intensity ratings for Anger, Fear, Happy and Neutral were 60 (SD = 5.52), 55.6 (SD = 5.82), 37.9 (SD = 4.78) and 20.8 (SD = 5.52) respectively.

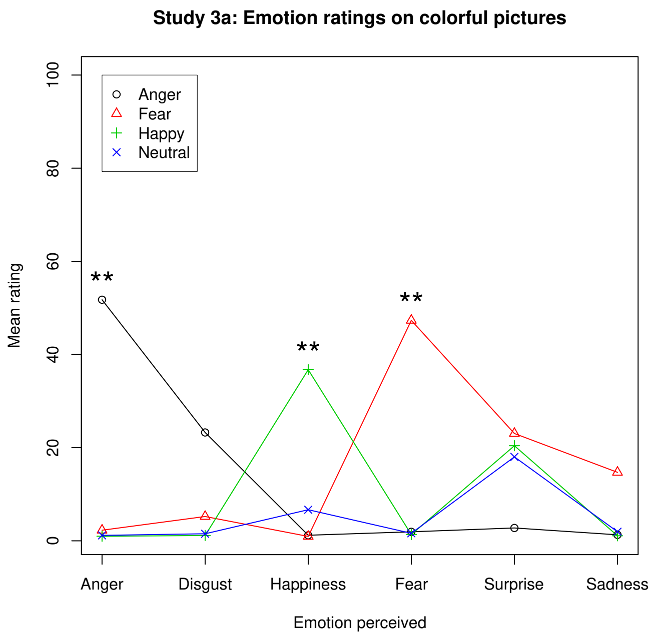

Figure 4.4: Results of study 3a. Emotion ratings on colorful pictures. Faces were depicting the FACSGen combinations: "Anger: AU 9+16+25", "Fear: AU 1+2+5+25+26", "Happiness: AU 1+2+6+12+25", and "AU 22+25+26" (as described in Study 1, and validated by FACS coders).

We conclude that, from FACSGen produced stimuli, lay participants can recognize the emotions represented by specific AU configurations, according to agreement in the literature and some empirical findings, with satisfactory accuracy and with a very high degree of agreement.

4.3.4 Study 3b. Validation of FACSGen facial expressions (grayscale version)

Whereas most psychologists investigating the perception and interpretation of facial expressions do not need to alter the stimulus sets available to the research community, a growing number of researchers in adjacent disciplines – especially in the neuroscience and in psychophysics – seek to disentangle the higher-level effects of the facial expressions from the lower-level effects of several dimensions intrinsic to the visual material depicting the facial expressions; e.g, the saliency and contrast (e.g., Pourtois et al., 2004) or the spatial frequencies (e.g., Delplanque et al., 2007). To do so, they process this material in ways that may hinder its recognition (Fiser et al., 2003). Because this situation may be even worse for synthesized material, like faces produced with FaceGen Modeller 3.3, we replicated the evaluation of Study 3a to a sub-selection of the 77 emotional facial expressions that were being used in a separate experiment, and which we processed in the same way as Pourtois et al. (2004).

Procedure

Out of the 77 faces created for Study 3a, we selected 10 faces (5 females), depicting the combinations Fear, Happiness, and Neutral, as described in the previous section. These pictures were used in separate experiments, studying the modulation of attention by emotion (Roesch et al., 2009, and Roesch et al., in preparation – see also Roesch et al., in revision). Incidentally, because anger was not part of the facial expressions of interest for this series of experiments, it was not rated by participants. Upon completion of the experiment, participants were asked to rate the faces they had seen during the experiment in an identical way as in Study 3a. 37 students (29 females, mean age 22.9 years) rated the grayscale pictures of the 10 faces (5 females), each of which portrayed the three facial expressions. Participants were instructed to rate the extent to which the following emotions could be perceived in the facial expressions: anger, disgust, fear, happiness, sadness, and surprise. Blank fields allowed them to propose other emotions. A scale from 0 (”not at all”) to 100 (”enormously”) was provided. They also had to rate the overall intensity of the facial expression. A scale from 0 (”not intense”) to 100 (”very intense”) was provided.Out of the 77 faces created for Study 3a, we selected 10 faces (5 females), depicting the combinations Fear, Happiness, and Neutral, as described in the previous section. These pictures were used in a separate experiment, studying the modulation of attention by emotion. Upon completion of the experiment, participants were asked to rate the faces they had seen during the experiment in an identical way as in Study 3a. 37 students (29 females, mean age 22.9 years) rated the grayscale pictures of the 10 faces (5 females), each of which portrayed the three facial expressions. Participants were instructed to rate the extent to which the following emotions could be perceived in the facial expressions: anger, disgust, fear, happiness, sadness, and surprise. Blank fields allowed them to propose other emotions. A scale from 0 (”not at all”) to 100 (”enormously”) was provided. They also had to rate the overall intensity of the facial expression. A scale from 0 (”not intense”) to 100 (”very intense”) was provided.

Results and discussion

Cronbach alphas were computed, using participants’ ratings as items, and pictures as variables. Results showed that the faces were reliably rated on the 7 dimensions: alpαha for anger = 0.807 ; α for disgust = 0.912 ; α for happiness = .991 ; α for fear = 0.990 ; α for surprise = 0.818 ; α for sadness = 0.926 ; α for intensity = 0.973. Means on the ratings showed that participants perceived the intended emotions in the facial expressions produced (Figure 6). To determine whether participants can discriminate the emotions portrayed in the grayscale version of the FACSGen faces,

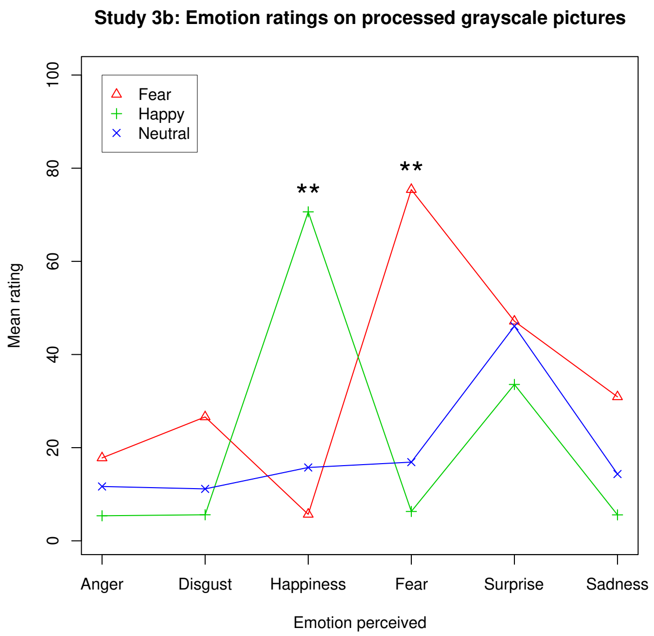

Figure 4.5: Results of study 3b. Emotion ratings on processed grayscale pictures. Faces were depicting the FACSGen combinations: "Fear: AU 1+2+5+25+26", "Happiness: AU 1+2+6+12+25", and "AU 22+25+26" (as described in Study 1, and validated by FACS coders).

repeated measures analysis of variance (ANOVAs) was performed for each of the three portrayed emotions Fear, Happiness and Neutral. The dependent variables were participants' ratings on the 7 scales. In all four cases, there was a significant main effect of Emotion (Fear: $F(5{,}1845) = 399.3$; $p < .001$; Happy: $F(5{,}1845) = 1048$; $p < .001$; Neutral: $F(5{,}1845) = 157$; $p < .001$). Contrast analyses were performed by assigning the target emotion as the reference category. There was a significant effect for targets' emotions ($ps < .001$), indicating that participants reliably recognized the target emotion portrayed by the faces. The mean intensity ratings for Fear, Happy and Neutral were 76.99 (SD = 16.78), 60.01 (SD = 20.40) and 36.66 (SD = 23.15) respectively.

We conclude that, from processed greyscale FACSGen stimuli, lay participants can recognize the emotions represented by specific AU configurations with satisfactory accuracy and with a very high degree of agreement.

4.4 Summary and discussion

Researchers interested in facial expressions of emotions often rely on shared sets of stimuli. This material contains static pictures, or videos of facial expressions portrayed by actors or recorded from live occurrence. Although using this shared material has proven useful to compare results across studies, its lack of flexibility often does not allow the necessary degree of experimental control. To avoid creating their own dedicated stimulus sets, researchers have attempted to use techniques such as morphing existing photographs. , Only fairly recently researchers in psychology and neuroscience discovered the potential of synthetic stimuli (e.g., Ellison & Massaro, 1997; Wehrle et al., 2000; Pelphrey et al., 2004; Sander et al., 2007; Moser et al., 2007; Gaag et al., 2007; Parr et al., 2008; Hirsh et al., 2009; N'Diaye et al., in press; Cristinzio et al., in press; Roesch et al., 2009, in revision; J. B. Freeman & Ambady, 2009). In response to the manifest need to develop means of systematically manipulating facial expressions to allow a optimal degree of experimental stimulus control, we developed the tool described in this article, FACSGen.

To validate FACSGen, we investigated the perception of single AUs, combinations of AUs, and complex full-blown facial expressions of emotion that used 16 AUs in total. In four studies, we submitted this material to both certified FACS coders, and lay participants. Our results showed that a) the AUs manipulated in FACSGen correspond to the FACS specifications and are reliably recognized by certified FACS coders, b) the synthesized identities produced by FaceGen Modeller 3.3 are perceived by lay participants as reasonably believable, and thus can be used in place of naturalistic portrayals, and c) the manipulation of FaceGen faces in FACSGen produces facial expressions of emotions that are reliably recognized by lay participants.

FACSGen can be compared to other software like Poser 7 (e frontier, 2007), Greta (Pasquariello & Pelachaud, 2001; Malatesta et al., 2006), realEmotion (Grammer et al., to appear), or the Virtual Actor Project (Hezle et al., 2004). These solutions differ widely with respect to user friendliness: Researchers often have at their disposal tools that are either too difficult to use in a research context (but produce hollywood-class material), or very easy to use but produce relatively low quality, often caricature-like material. In contrast, FACSGen has been designed for researchers with the aim to strike a balance between usability and believable realism: on the one hand, FACSGen does not require users to acquire new technical knowledge, compared to the other solutions; on the other, it produces high quality, ecologically valid research material.

Contrasting with other current methods for producing synthetic tailored facial expressions to FACSGen, we identify a number of additional benefits associated with our approach. Firstly, FaceGen Modeller 3.3 allows the creation of a virtually infinite number of realistic identities, of any gender, age, or ethnicity. For example, the software makes it possible to create androgynous faces, and/or mixtures of ethnic backgrounds. Secondly, FaceGen Modeller 3.3 also provides the ability to create 3D meshes from close-up photographs of any person. Digitized faces can then be altered, and used in FACSGen just like any other 3D faces created using FaceGen. Thirdly, the output of FACSGen consists of a series of frames, depicting the unfolding facial expression mapping the activation of AUs on the geometry of the face. The frames can then be used either as still portrayals, or converted into movie clips, overcoming the limitations of morphing techniques. Finally, the activation curves describing the unfolding intensity of each AU in FACSGen can be exported in separate files. These files can be imported back into FACSGen, and applied to a different set of faces or facial expressions, thus allowing comparable material to be used in experimental studies. These options are not available in any of the other software currently available.

Whereas FACSGen provides researchers with new avenues for creating ad hoc material, any synthesized material admittedly poses limitations. First, the information conveyed by facial expressions cannot be reduced to a combination of topological changes in the face. Other channels of information include, for instance, changes in the color, the texture, and the elasticity of the skin; all of which is also subject to great inter-individual differences. These are problematic issues for any synthesis system. FACSGen does, however, take some of these aspects into account in the form of dedicated parameters to create realistic wrinkles, and we are developing more parameters to achieve the best results. Second, through FaceGen Modeller 3.3, users of FACSGen can animate 3D models digitized from close-up photographs of a person (see Figure 4.2).

To conclude, we presented FACSGen, a novel tool that allows researchers on facial expressions in general, and on facial expressions of emotions, in particular to manipulate informational cues portrayed in facial expressions. It outputs synthetic, yet realistic, 3D faces used to produce either static or dynamic material. It also offers a very handy way of representing the unfolding dynamics of the constituents of facial expressions, which allows (1) the portrayal of complex dynamic facial expressions, and (2) the comparison of the material produced between studies. We argue that solutions of this kind constitute new methods for research, allowing researchers to come back to influential theories, to then tailor specific material to be used in the testing of precise predictions.

Chapter 5

Emotion and motion in facial expressions modulate the AB

Abstract: How does the mind prioritise information over time? To answer this question, we used the modulation of the attentional blink (AB) to compare predictions from two of the most dominant emotion models today: the fear module hypothesis, and the component process model. The AB refers to a transient period of time during which the processing of a first target (T1) hinders the perception and processing of a second target (T2), if it appears within 200-400 milliseconds after T1. The competition between the two targets offers a window into the first few hundreds of milliseconds upon perception. In line with the predictions of the component process model, we show that (1) both fearful and happy facial expressions alleviate the AB more than neutral facial expressions, and that (2) dynamic facial expressions alleviate the AB more than static facial expressions. (3) Additionally, our results point to three different periods of time after T1 during which relevant stimuli elicit selective processing. We conclude by discussing our results in light of current emotion models, and emphasize the sensitivity of our perceptual system.

See also: Roesch, E. B., Sander, D., Scherer, K. R. (2009). Emotion and motion in facial expressions modulate the attentional blink [abstract]. *Perception. 38.* pp. 466.

5.1 Introduction

Perception counts more than just height, length, and width. The human organism needs to make sense of the *constant flow of information* it perceives, and research often neglects the temporal dimension of perception. Attentional systems are believed to play a major role in perception by filtering information, and selecting only that information which is most relevant (Desimone & Duncan, 1995). Spatial attention refers to the ability to select a particular piece of information in the static 3D space. This line of research has witnessed an increase in literature over the past 20 years, and recent results show that the emotional salience of the information plays a critical part in how the mind selects information (Vuilleumier, 2005). In contrast, very little effort has been devoted to what can be called ”temporal attention”. Temporal attention refers to the ability to allocate processing resources over time. It asks the question: How do we prioritise the processing of certain information over time? Two theoretical traditions of emotion research are concerned with this question. They both emphasise the role of pre-attentive emotional evaluation in easing the processing of selected stimuli.

The most dominant view today stresses that the emotion system was shaped by evolution to favour stimuli that are most significant for the organism's survival (Seligman, 1970, 1971). The fear module hypothesis (Öhman & Mineka, 2001; Mineka & Öhman, 2002), in particular, suggests that a dedicated module, centred in the amygdala, subserves selective attention to evolutionary prepared threat stimuli. Many behavioural and neuroimaging results indeed showed an early modulation of spatial attention to fear-relevant stimuli, especially in high anxious participants (for a review see Compton, 2003). This view, however, has recently been challenged by studies showing that spatial attention was also drawn by threat-related stimuli that are not evolutionary justified (Brosch & Sharma, 2005; Blanchette, 2006; Flykt et al., 2007; E. Fox et al., 2007), or by stimuli with positive connotations (Tipples et al., 2002; Lipp et al., 2004; Brosch et al., 2007, in press). In the light of these results, it is thus proposed to refine the functional domain of the amygdala to include any stimulus showing some degree of relevance to the organism (Sander et al., 2003; Vuilleumier, 2005; Fitzgerald et al., 2006; Cunningham et al., 2008).

Relevance detection is at the core of the appraisal theories of emotion. In the component process model (CPM; Scherer, 2001) in particular, it is located at the beginning of a series of processes appraising the occurring event, yielding to the genesis of the appropriate emotion. This first appraisal is believed to attribute some degree of priority to the further processing of the perceived stimulus. Importantly, it includes evaluative processes concerned with low-level features of the occurring event in regards to the present state of the organism (e.g., the suddenness of its onset, its intrinsic pleasantness and goal relevance). This mechanism is evolutionary justified in that it provides the organism with the ability for economy of limited resources, favouring the processing of important stimuli. Unlike the fear module, it is believed to enhance the processing of *any* stimulus that would show some degree of relevance for the organism's well-being, and the satisfaction of its goals. Additionally, this process is believed to contribute not only to the genesis of fear-related emotions, but also to the processing and elicitation of any other emotion.

Temporal attention is addressed by means of paradigms tapping the sharing of processing resources between several targets (usually two) closely related in time. In such paradigms, the second of two targets (T2) in a visual stream of events cannot be reported accurately if it appears between 200 and 400 msec after the correct identification of the first target (T1), yielding to what has been rhetorically called an attentional blink (AB; Raymond et al., 1992). In a review of behavioural and neuroimaging results, Hommel et al. (2006) proposed that the AB occurs in response to the perception of T1 in a ballistic fashion. This mechanism would act as the "closure of an attentional gate", which would prevent subsequent stimuli from interfering with the ongoing processing of the first target.

Only few studies addressed the extent to which emotions modulate this phenomenon. In a seminal study, Anderson & Phelps (2001) showed that, not only did negative T2 (words) alleviate the typical AB response compared to neutral targets, but also that the amygdala is critical to benefit from the emotional significance of the targets. Comparing the arousal and valence of words, other authors have shown that arousal seemed a prerequisite for enhanced awareness, enabling emotion significance to shape perceptual experience (Keil & Ihssen, 2004; Anderson, 2005). In line with the results addressing spatial attention, E. Fox et al. (2005) reported that high anxious participants show an alleviated AB for fearful faces compared to low anxious participants. Similarly, T2 targets depicting disorder-related animals have been shown to diminish the AB in phobic participants (Reinecke et al., 2007). In the same study, however, both positive and negative targets alleviated the AB more than neutral targets, casting some doubts on the specificity of the underlying processes. Additionally, Jong & Martens (2007) showed that the AB for angry faces was attenuated for both high and low anxious participants. Recent results in the healthy population go in the same direction, showing that threat-related material (faces, and words) benefits from a processing bias enhancing its reportability (Maratos et al., 2008; Kihara & Osaka, 2008; De Martino, Kalisch, et al., 2008).

Interestingly, it has also been shown that the AB was modulated by the significance of targets.

First, Shapiro, Caldwell, & Sorensen (1997) showed that participants did not experience an AB for their own names, but did for either other names or nouns. Equivalent results have been reported when targets were familiar faces compared to unfamiliar faces, the former alleviating the AB (Jackson & Raymond, 2006). Second, in other studies, researchers experimentally manipulated the relevance of the targets. Cousineau et al. (2006), for instance, showed differential responses depending on whether the instructions emphasised the task on T1 or on T2. And, S. D. Smith et al. (2006) showed that otherwise neutral stimuli could modulate the response on a subsequent target, if conditioned to an aversive white noise.

In our work, we were interested in the modulation of temporal attention by emotional facial expressions in the healthy population. We assumed that pre-attentive processes, similar to the ones observed in the research addressing spatial attention, would underlie the modulation of the AB by emotional faces presented as T2 targets. In this context, we contrasted predictions made from the fear module hypothesis with predictions from the CPM. We made the following hypotheses, which we addressed in two experiments.

H1 – Modulation of the AB by emotion. Should these pre-attentive processes subserve the fear module hypothesis, we hypothesised that the AB would be modulated only by fearful faces, compared to happy and neutral faces. Alternatively, we hypothesised that the AB would be modulated by both fearful and happy faces, compared to neutral faces, if this process resembles a relevance detector, as described in the CPM.

H2 – Modulation of the AB by the type of stimulus. A strong prediction from the CPM lies in the proposal that *any* stimulus showing some degree of relevance for the organism will be granted priority in the subsequent stages of its processing, compared to a less relevant stimulus. In the domain of facial expressions, it has been shown that the intrinsic dynamics of the unfolding of the expression convey pieces of information that are crucial for the perception, and a correct recognition (Edwards, 1998; Kamachi et al., 2001; LaBar et al., 2003; Krumhuber, Manstead, Cosker, et al., 2007; Krumhuber, Manstead, & Kappas, 2007). Therefore we hypothesised that dynamic facial expressions would be more relevant than static facial expressions, and thus modulate the AB to a greater extent, as predicted by the CPM. In contrary, there should be no difference in the modulation of the AB between dynamic and static facial expressions if results are in accordance with the fear module hypothesis.

The next sections describe two experiments we conducted to address these hypotheses. Both experiments were standard dual-task AB experiments, in which we assessed the modulation of the AB response by T2 targets. We conclude by discussing our results in light of current emotion models.

5.2 Experiment 1. Emotion × Type of Stimulus

5.2.1 Method

Participants

37 students (29 females, mean age 24.0 years) from the University of Geneva participated in this experiment for course credit. All participants were right-handed, had normal or corrected-to-normal vision, and no history of psychiatric or neurological diseases.

The participants were selected from a pool of students in such a way that they represented groups on a controlled continuum spanning from anxious to extraverts (Table 5.1), for two reasons: first, research on the perception of emotion often relates findings to trait personality differences (see also Derryberry & Reed, 1994; Mogg & Bradley, 1998; E. Fox et al., 2001), and we wanted to be able to control for it; second, results in the neuroscience showed that the activation of certain brain areas upon perception of emotional stimuli was correlated to personality traits (Canli et al., 2001, 2004; Hamann & Canli, 2004; Mobbs et al., 2005), especially the amygdala, which was shown to correlate with extraversion scores (Canli et al., 2002; Canli, 2004; Most et al., 2006). Prior to the experiment, participants filled in the following questionnaires: NEO Five-Factor Inventory (NEO-FFI; Costa & McCrae, 1991), State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983), and the dual scale Fear of Negative Evaluation - Social Avoidance Disorder (FNE-SAD; D. Watson & Friend, 1969). One-way analyses of variance (ANOVA) yielded main effects of the *Group* (Anxious, Controls, Extraverts) for each of these scales (two-sided tests), indicating that the groups differed significantly for all measures.

Apparatus

Stimuli were presented on a wide CRT screen, with a refresh rate of 100 Hz, and a resolution of 1024 × 768. Participants were comfortably seated in an armchair presenting head and arm rests. The screen was placed 60 cm away from the head of the participant. The experiment

	Anxious (N = 13)		Controls (N = 13)		Extraverts (N = 11)	
	M.	SD.	M.	SD.	M.	SD.
STAI-Trait **	55.31	7.46	44.08	12.93	30.27	3.37
Fear of Negative Evaluation **	23.08	5.39	18.15	7.74	12.27	6.05
Social Avoidance and Distress **	15.69	6.00	9.46	6.76	3.64	3.17
Neuroticism *	36.62	3.25	33.15	7.29	29.82	3.40
Extraversion **	35.38	2.29	40.46	4.27	45.55	1.63

Table 5.1: Experiment 1. Participants' trait personality scores. *: $p < .01$; **: $p < .001$

was administered using Matlab, and the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997).

Stimuli

T1 and T2 stimuli were faces, subtending 18° × 15° visual angle. Each T1 stimulus consisted of one out of 10 faces (five females), showing no emotional expression. Each T2 stimulus consisted of one out of 10 faces (five females), showing controlled combinations of facial Action Units, depicting expressions recognised as happy, fearful, or neutral (Figure 5.1, panel a).

The faces were produced using our software FACSGen (Roesch et al., in revision ; see Chapter 4, on page 51). FACSGen is a novel tool that allows the creation of unique, realistic, static or dynamic, synthetic 3D facial stimuli based on the Facial Action Coding System (Ekman et al., 2002). It provides control over the intensity, and temporal dynamics, of the facial Action Units, and allows researchers to apply the same facial expression to any face produced using FaceGen Modeller 3.3 (Singular Inversions Inc., 2009; Shimojo et al., 2003; Moradi et al., 2005; Corneille et al., 2007). After they took part in the experiment, all 37 participants rated the extent to which the following emotions could be perceived in the facial expressions used during the experiment: anger, disgust, fear, happiness, sadness, and surprise. A scale was provided, anchored in 0 ("not at all") and 100 ("enormously"). To determine whether participants could discriminate the emotions portrayed in the faces, repeated measures analysis of variance (ANOVA) were performed on the ratings for each target emotion. There was a significant effect for targets' emotions (ps $< .001$), indicating that participants reliably recognised the target emotion portrayed by the faces.

To be able to contrast static with dynamic facial expressions using the same facial expressions, all emotional facial expressions were depicting faces with the mouth open. Dynamic T2 stimuli consisted of eight frames, morphing from a mouth-closed neutral expression (0% expression) to

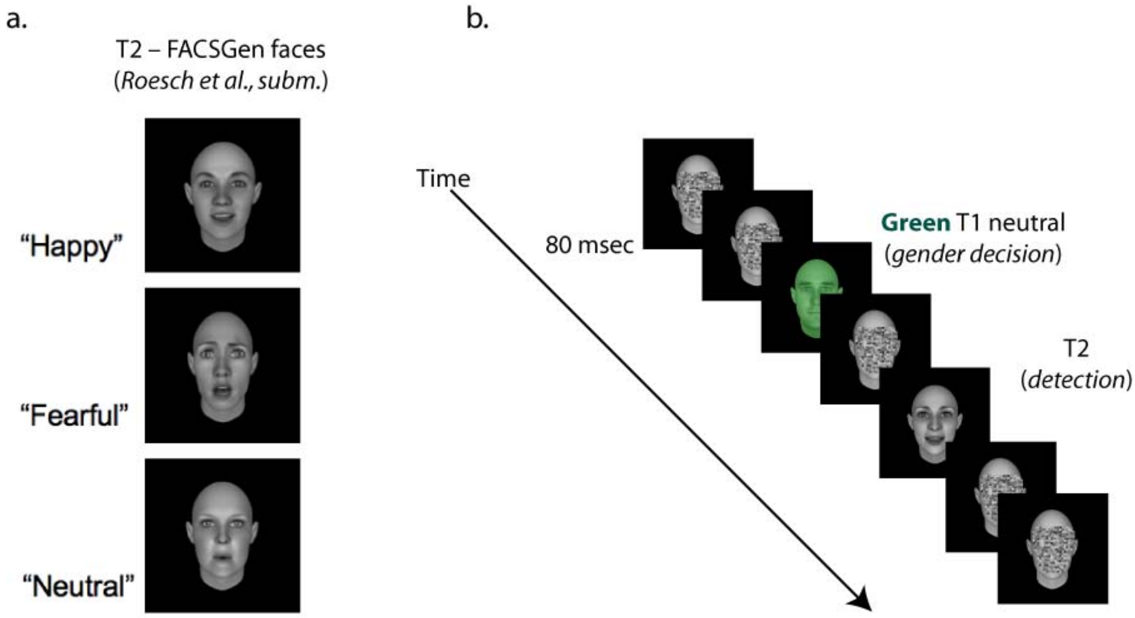

Figure 5.1: Experiment 1. Emotion × Type of stimulus. Panel a. Examples of T2 targets. Panel b. Example of a trial. Static stimuli (i.e., T1, static T2, and distractors) were presented for 80 msec (eight refresh periods of the screen), whereas each frame of the dynamic T2 was presented for 10 msec (one refresh period of the screen).

one of the three facial expressions (100% expression), mouth open. Static T2 stimuli were showing 100% expression, mouth open.

Distractors consisted of neutral faces, for which the inside of the face was divided in 10 × 10 pixel squares, and scrambled randomly. All faces were presented in grayscale, but the T1 faces which were tinted in green to ease their detection (Milders et al., 2006). Statistical analyses confirmed that the three emotional conditions for T2 stimuli did not differ for luminance, and contrast.

Procedure

The experiment consisted of one block of 10 practice trials, followed by 10 blocks of 60 trials. Between blocks, participants were forced to a resting period of at least three minutes. Participants were instructed to perform a gender decision task on T1 (green face), and to indicate if they had perceived a non-scrambled face immediately following the first target. Response was given at the end of each trial.

Each trial began with a fixation cross, displayed for 800 msec. Participants were instructed to focus on the fixation cross, and to sustain this gaze throughout the trials, as this was the optimal way to perceive each face as a whole, and gather a maximum amount of information for the tasks.

A trial consisted of 15 stimuli, presented for 80 msec each, without any inter-stimulus interval (Figure 5.1, panel b). Each of the eight frames of the dynamic T2 stimuli was presented for exactly 10 msec (one refresh period of the screen), whereas static stimuli (i.e., T1, static T2, and distractors) were presented for 80 msec (eight refresh periods). T1 stimuli appeared equally often in serial positions 2–5. On T2–present trials, emotional faces appeared equally often in serial positions 3–7, and 9, yielding to T1–T2 intervals of 80, 160, 240, 320, 400, and 560 msec. T2 stimuli were present in 75% of the trials, and absent in the remaining 25%. This allowed us to maximize the number of T2–present trials without making the experiment too long. It also gave some validity to the experiment, as the nature of the experiment often leads to the impression that T2–present trials are very infrequent (E. Fox et al., 2005).

5.2.2 Data analysis

Out of the methods available to address the AB effect, the Condition × Lags analysis of variance (ANOVA) is the solution preferred by most researchers to compare T2 conditions in dual–task experiments. Unfortunately, Cousineau et al. (2006) showed that this procedure neglects important aspects of the data and, more importantly, that the necessary assumptions for such tests (i.e., sphericity of the variance-covariance matrix, identity of the variance-covariance matrix across conditions, and normality of the distributions) are often not met. The authors addressed this latter issue in a series of simple experiments, and through Monte Carlo simulations of large datasets. Results showed that both the intrinsic setting of AB experiments (e.g., performance at lag n and lag n+1 being strongly correlated), as well as the between- and within-subject variability, often yield the rejection of most assumptions. Consequently, significance tests can be misinterpreted in many ways.

To overcome these shortcomings, Cousineau et al. (2006) proposed a parametric solution to focus the analysis on particular aspects of the AB curve, which are likely to be of theoretical importance. The method they propose uses curve-fitting techniques to quantify four aspects of the data: the duration of the effect, the amplitude between the minimum and the asymptotic performance, the minimum performance, and the amount of Lag-1 sparing. This approach is a-theoretical in essence, as it does not rely on a particular interpretative theory of the AB, but provides an objective way to characterize the resulting curve. To validate their method, the authors applied this technique to data gathered in experimental settings, and to simulated datasets. Results showed that, in addition to easing the comparison of results between experiments, this method is valid, and allows the testing of particular aspects of the data to be tested at a time. More importantly, results showed that this method yields to more powerful statistical tests than conventional methods.

Simply put, Cousineau et al. (2006) defined an equation with four parameters, which scale different parts of an AB curve (figure 5.2). They then performed a constrained fit of the equation over the data, and used the value of the four fitted parameters to test specific hypothesis. Fitting can be achieved through the minimization of the root mean square deviation, the sum of squared error, or the chi-square index of fit (Van Zandt, 2000; Cousineau et al., 2004; Heathcote, 2004; Cousineau et al., 2006).

The particularity of this method resides in the informational value of the four parameters. Researchers are provided with objective measures of particular aspects of the AB curve, which they can then use to render hypotheses as to the cognitive processes underlying the AB effect. Of interest for cognitive theorists is the fact that these parameters refer to different periods of the unfolding of the AB (Figure 5.2, panel a), which we will discuss later. Let us now provide a description of each parameter.

Beta (β) – Duration of the AB phenomenon

Beta measures the width of the curve, reflecting the duration of the effect (Figure 5.2, panel b). It corresponds to the amount of time needed for P(T2|T1) (i.e., the probability of success to the task on T2 given a correct response to the task on T1) to come back to baseline, after the blink has occurred. The bigger the β, the longer the duration of the blink. It is interesting to note that β refers to a period of time starting at about 200 msec to 500 msec after the onset of T1, a rather late stage of the processing of T1. We can refine our hypotheses: A modulation of the AB will yield smaller β (**H1**β, and **H2**β).

Delta (δ) – Relative blink

Delta measures the amplitude between the minimum and the asymptotic performance described by the curve (Figure 5.2, panel c). It refers to what researchers commonly call the "blink", describing the temporary dysfunction in the processing of T2, compared to baseline, which occurs after the perception, and correct identification of T1. The smaller the δ, the less AB effect (i.e., the flatter the curve) ; refining our hypotheses: A modulation of the AB will yield smaller δ (**H1**δ, and **H2**δ).

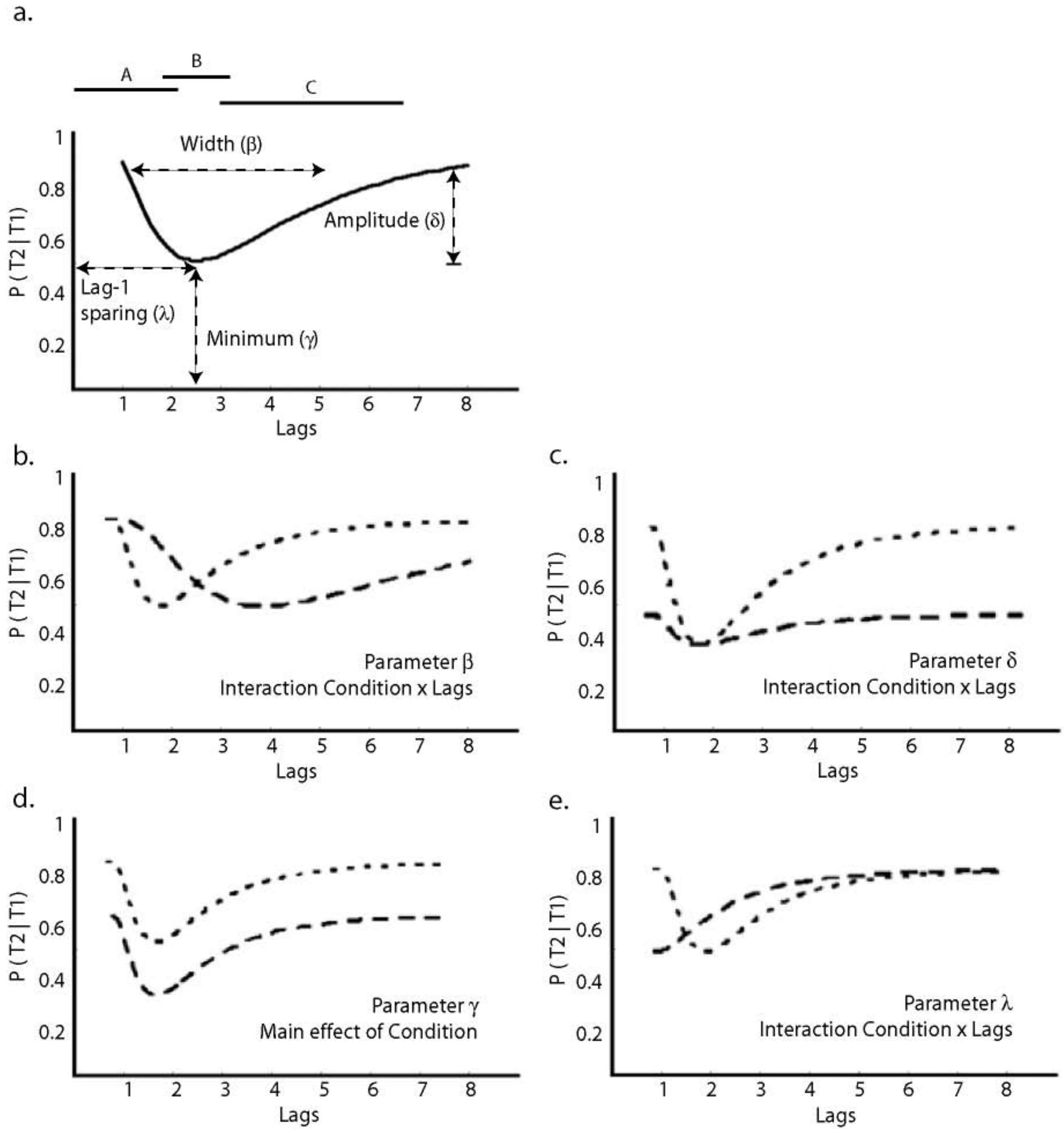

Figure 5.2: Panel a. Typical AB curve displaying the four parameters manipulated by Cousineau et al. (2006). In our work, we distinguish three main periods of the processing, noted A, B, and C. Periods A and C refer to the unfolding of the processing stream, whereas period B refers to the apex of the interference mechanism occurring in response to the perception of T1. Panel b, c, d, e. Possible results of an AB experiment manipulating a factor of interest Condition (dotted and dashed lines) and Lags (1 through 8). Manipulation of parameters β, δ and λ generate a Condition $\times$ Lags interaction in an ANOVA. Only the manipulation of γ generates a main effect of Condition in an ANOVA. Copyright, Canadian Psychology Association, 2008.

Gamma (γ) – Performance level of the minimum

Gamma represents the vertical aspect of the curve. It measures the objective minimum of the blink, regardless of the shape of the curve (Figure 5.2, panel d). The bigger the γ, the better the minimum performance. We can refine our hypotheses: A modulation of the AB will yield greater γ (**H1**γ, and **H2**γ).

Lambda (λ) – Amount of Lag-1 sparing

Lambda measures what is commonly called the Lag-1 sparing, that is the amount of time after the perception of T1 until the peak of the interference over T2. During this short period of time, P(T2|T1) decreases to reach a minimum at about 300 msec after the onset of T1. The bigger the λ, the less Lag-1 sparing (i.e., the earlier the "closure of the attentional gate"). It is interesting to note that, during this short period of time, performance on T2 stimuli can be very high, showing that both T1 and T2 *can* be processed somehow simultaneously (Visser et al., 1999; Kessler et al., 2006). However, the processing of T2 seems to interfere with the performance on T1 stimuli, as the performance on T1 stimuli often starts low, increasing across later lags (Shapiro, Raymond, & Arnell, 1997; Cousineau et al., 2006; Nieuwenhuis, Gilzenrat, et al., 2005; Nieuwenhuis et al., 2007). This latter phenomena confirms the hypothesis that the goal of the blink may be to prevent T2 stimuli from interfering with the processing of T1 stimuli (Raymond et al., 1992; Sergent et al., 2005; Hommel & Akyurek, 2005). The stronger the interference of T2 stimuli, the greater the λ (**H1**λ, and **H2**λ).

5.2.3 Results

We did not find any effect of the Group (anxioux, controls, extraverts), therefore we excluded the groups from the analyses, and combined the participants in one big sample (N = 37).

We used two methodologies to analyze the data. Where suitable, we used the method proposed by Cousineau et al. (2006) to extract parameters from the data, and tested each aspect at a time, comparing conditions using a 2 × 3 ANOVA, treating Type of Stimulus (dynamic, static), and Emotion (fearful, happy, and neutral) as within-subject variables with fixed effects (one-tailed tests). One-way ANOVAs on subsets of the data were performed to decompose significant main effects. Where this methodology was unsuitable, we used nonparametric Pearson's χ^2 tests to

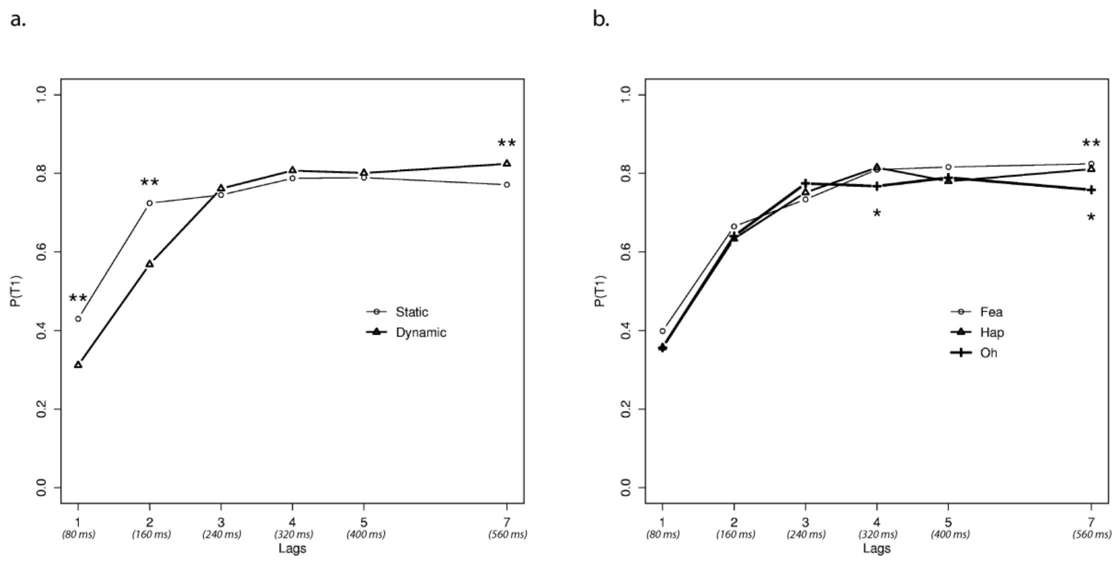

Figure 5.3: Proportion correct on task on T1, comparing Type of Stimulus (Panel a), and Emotion (Panel b).

address the null hypothesis that the proportions (probabilities of success) between conditions were the same.

We will first describe the performance on T1 targets. As described in the previous section, the performance on T2 targets can interfere with the performance on T1 targets. We will use these results to complement the interpretations of the data showing the modulation of the AB by T2 targets. We will then address each hypothesis separately and confront it to the data.

Response on T1

As shown on figure 5.3, participants were very accurate in the gender decision task on T1 stimuli (mean accuracy across conditions equals 70%). As expected, performance was low on earlier lags, to then reach an asymptote in lag 2 and 3.

A Pearson's χ^2 test was performed to examine the relation between the Type of Stimulus (dynamic, static) and P(T2|T1) across lags. Results showed that the performance in the two conditions was not equally distributed over the lags, χ^2 $(5,\ N\ =\ 222)\ =\ 40.27,\ p\ <\ .001$. Targetted χ^2 tests showed that the performance was significantly lower in the dynamic condition for lags 1, 2, and 7 (ps $< .01$).

Similarly, comparing emotional conditions, results showed no significant difference in the overall performance over the lags ($p = .848$). Targetted χ^2 tests, however, showed that the performance in

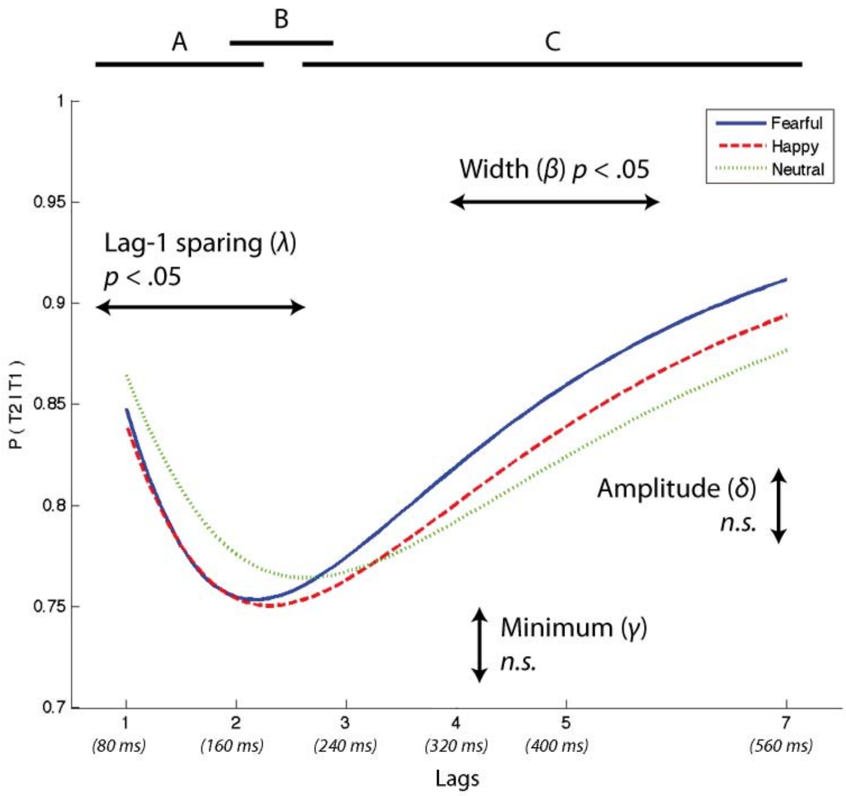

Figure 5.4: Experiment 1. Mean plot of the fitted data contrasting levels of the Emotion condition. Above the graphic, we distinguish three periods of time which may see the unfolding of different processing, see text for details.

T1 task was significantly better when T2 was depicting either a fearful or a happy facial expression, compared to a neutral facial expression, in lags 4 (happy > neutral, $p < .05$), and 7 (happy > neutral, $p < .05$; fearful > neutral, $p < .01$).

H1 – Modulation of the AB by emotion

H1 β– Duration of the AB phenomenon Beta parameters were subjected to a 2×3 ANOVA. The main effect of Emotion yielded an F ratio of $F(2{,}210) = 2.39$; $p < .05$. Pairwise comparisons showed no significant difference between fearful and happy T2 ($F(1{,}144) < .0001$; $p = .9$). Comparisons between fearful and neutral T2 yielded an F ratio of $F(1{,}144) = 4.25$; $p < .05$, and the comparison between happy and neutral T2 yielded an F ratio of $F(1{,}144) = 3.03$; $p < .05$, indicating that β was significantly smaller for both fearful and happy T2, compared to neutral T2.

H1δ – Relative blink Delta parameters were subjected to the same 2×3 ANOVA, but the main effect of Emotion was not significant ($F(2{,}210) = .52$; $p = .3$).

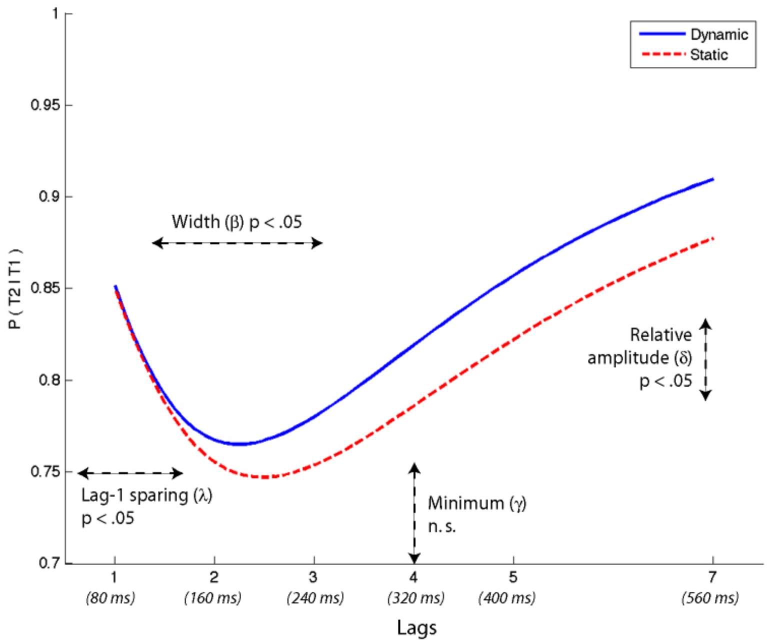

Figure 5.5: Experiment 1. Mean plot of the fitted data contrasting levels of Type of stimulus.

H1γ – Overall performance across lags Gamma parameters were subjected to the same 2 × 3 ANOVA, and the main effect of Emotion was not significant (F(2,210) = .37 ; p = .3).

H1λ – Amount of Lag-1 sparing Lambda parameters were subjected to the same 2 × 3 ANOVA. The main effect of Emotion yielded an F ratio of F(2,210) = 2.54 ; p < .5. Pairwise comparisons showed no significant difference between fearful and happy T2 (F(1,144) = .41 ; p = .26). Comparisons between fearful and neutral T2 yielded an F ratio of F(1,144) = 4.67 ; p = .054, and the comparison between happy and neutral T2 yielded an F ratio of F(1,144) = 2.49 ; p < .05, indicating that λ was marginally greater for fearful T2, and significantly greater for happy T2, compared to neutral T2.

H2 – Modulation of the AB by the type of stimulus

H2β– Duration of the AB phenomenon Beta parameters were subjected to a 2 × 3 ANOVA. The main effect of Type of Stimulus yielded an F ratio of F(1,210) = 2.74 ; p < .05, indicating that β was greater for static than for dynamic T2.

H2δ – Relative blink Delta parameters were subjected to the same ANOVA. The Type of Stimulus was statistically significant, yielding to a F ratio of F(1,210) = 3,25 ; p <.05, indicating that δ was greater for dynamic T2 than for static T2.

H2γ – Overall performance across lags Gamma parameters were subjected to the same ANOVA, but the main effect of Type of Stimulus was not significant ($F(1{,}210) = 2.02$; $p = .075$).

H2λ – Amount of Lag-1 sparing Finally, λ parameters were subjected to the same ANOVA. The main effect of Type of Stimulus yielded an F ratio of $F(1{,}210) = 5.05$; $p < .05$, indicating that λ was greater for dynamic than for static T2.

5.2.4 Conclusion

The best way to address the AB phenomenon is to take a grand perspective of its unfolding over time. AB theorists have hinted at that in many ways, most often discussing versions of a two-stage processing stream (for review, Shapiro, Raymond, & Arnell, 1997; Shapiro, 2001). Most experimental researchers, on the other hand, have mainly been focusing on the modulation of the AB by different types of stimuli, measuring the modulation of the response as a whole, without explicitly addressing the underlying stages of their processing (e.g., Keil & Ihssen, 2004; Anderson, 2005; E. Fox et al., 2005; Jong & Martens, 2007).

In our work, we assume the AB response curve to be the result of the competition between many cognitive processes. This competition can happen during several of many stages of the processing. In this framework, a modulation of the AB (i.e., observed by comparing two experimental conditions) signals a differiential activity within the system "in favor" of one of the experimental condition. Recent emotion theorists account for the early processes that will attribute higher priority levels to the further processing of emotional stimuli. We thus assume that the AB paradigm taps into these very processes, providing emotion researchers with the ability to compare theoretical predictions.

In a traditional AB experiment, we manipulated both the emotion, and the type of T2 targets. We hypothesised that both fearful and happy facial expressions would benefit from a selective response, compared to neutral targets (**H1**). We made similar predictions for dynamic facial expressions, compared to static facial expressions (**H2**). This behavior, we argue, would reflect a process close to a relevance detector prioritizing the processing of stimuli important for the organism's well-being (Scherer, 2001; Sander et al., 2003), rather than a fear module selectively prioritizing threat-related stimuli (Öhman & Mineka, 2001; Mineka & Öhman, 2002).

We used a curve-fitting technique introduced by Cousineau et al. (2006) to analyze our data. This methodology disentangles several aspects of the data, which can be analyzed separately. In particular, we addressed the modulation of the performance to the task on T2 (after correct response on T1) over three periods of time (Figure 5.2, panel a):

- Period A. The period starting upon the onset of T1 to the peak of the interference over T2, the so-called Lag-1 sparing (λ), covering about 200 msec after T1.
- Period B. The peak of the interference at about 200 msec after T1. This period corresponds to the moment during which the "attentional gate" is completely closed (Hommel et al., 2006; Shapiro et al., 1994). It is addressed through two measures: distinguishing the minimum performance level regardless of the shape of the curve (γ), from the modulation of the relative blink (δ) suffered by T2 targets.
- Period C. The period during which the processing of T2 is hindered until the moment it goes back to baseline (β), starting at about 200 msec to about 500 msec after T1. Of interest is the moment when the interference over T2 is weakening, leaving some room for the competition between the processes involved in the processing of T1 and T2 targets.

H1 – Modulation of the AB by emotion

Our results showed a modulation of the AB by the emotion of T2 targets, regardless of their valence, for periods A and C, but not for the period B of the processing stream (Figure 5.4). First, the analysis of λ showed that the amount of Lag-1 sparing was significantly smaller for both fearful and happy T2 targets, compared to neutral targets. Second, the duration of the interference (β) was significantly smaller for both fearful and happy T2 targets, compared to neutral targets. No difference was observed between fearful and happy facial expresions for either of these measures. Finally, contrary to our expectations, the analysis of δ and γ did not yield significant main effects of *Emotion*, indicating that the performance of the participants did not differ across emotional conditions, during period B of the processing. Taken together, these results seem to support the relevance hypothesis, casting some doubts on the necessity of emotion-specific modules, like the fear module.

During several stages of the processing, we showed that the emotion of T2 targets yielded to selective responses, compared to neutral targets. Of particular interest, we showed that the mechanism interfering with the processing of T2 (i.e., the "closure of the attentional gate") occured earlier when T2 was either a fearful or a happy face, compared to a neutral face. This could either indicate that neutral targets held it back for a short period of time, or that an early process appraised emotional targets, and triggered the early occurrence of this interfering mechanism. The results we obtained for β support the latter hypothesis, as the performance for both fearful and happy targets was significantly better than for neutral targets during period C (i.e., shortening the period after T1 during which the processing of upcoming stimuli is prevented); a result similar to what has been observed in previous studies for a corresponding period of time (e.g., E. Fox et al., 2005; Jong & Martens, 2007). We can thus hypothesize that emotional targets may have had a greater chance to disturb the ongoing processing of T1 targets, which triggered a cascade of events leading to the early closure of the attentional gate.

Contrary to our expectations, only the processes involved in the unfolding of the AB (periods A and C) seem to have granted some priority to emotional stimuli, as we did not observe a smaller interference for either emotional targets in period B. An increase in performance (i.e., a smaller interference) during this period would have been an indication of a stronger involvement of higher-level processes (e.g., related to working memory, the recognition, or the identification of the emotional targets), which would have had a bigger impact in the competition, and alleviated the blink.

Therefore we can propose the following scenario: Emotional targets may have been appraised by the perceptual system as having the potential to interfere with the processing of T1, which yielded to an early "closure of the attentional gate". This early closure defeated the bottom-up activation of the emotional targets in the early stages of the processing. In later stages however, because most of the processing for T1 is complete, the bottom-up activation of the emotional targets benefited their processing, and higher-level processes granted them priority.

Overall, these results go in line with the increasing electrophysiological literature showing that even unreported T2 targets are processed at a semantic level (Luck et al., 1996; Shapiro, Raymond, & Arnell, 1997; Vogel et al., 1998; Marois et al., 2004; Sergent et al., 2005; Dehaene et al., 2006; Hommel et al., 2006), and support the existence of a relevance detector early in the processing stream, as described in the component process model. Yet, our results pinpoint two different endeavours: an "obstructive" endeavour that precluded emotional targets from entering further processing (up to 200 msec after T1), and a "conducive" endeavour that supported their processing (after 200 msec after T1). This could indicate the implication of two different appraising processes, aiming at keeping some order in the incoming flow of information, while at the same time prioritizing important information: a first process appraising dimensions of novelty, suddenness, and the degree to which upcoming stimuli can interfere with the ongoing processing; then a second process supporting the processing of relevant stimuli, regardless of their valence.

H2 – Modulation of the AB by dynamic facial expressions

Our second set of hypotheses referred to the modulation of the AB by the motion contained in dynamic facial expressions of emotions. Because the intrinsic dynamic of facial expressions convey pieces of information that are crucial to the perception and recognition of emotions, we hypothesised that dynamic facial expressions would be more relevant than static facial expressions, and would therefore modulate the AB more than static facial expressions. Our results confirm this hypothesis (Figure 5.5).

Similarly to the results addressing our first hypothesis, we show a modulation of the AB by dynamic facial expressions, compared to static facial expressions, for periods A and C of the processing. First, the analysis of *lambda* showed that the amount of Lag-1 sparing was significantly smaller for dynamic targets than for static targets. Second, the duration of the AB (β) was significantly shorter for dynamic targets compared to static targets. Finally, contrary to our hypotheses, the response curve for dynamic stimuli was shown to be more ample than the one for static stimuli (δ). We did not show significant difference in the minimum performance level (γ).

Taken together, these results go in line with the results to our first set of hypotheses, showing that early preattentive processes prioritized dynamic stimuli over static stimuli, a behavior better explained in terms of a relevance detector than a fear module. In addition, we showed that the bottom-up activation of dynamic stimuli was strong enough to fully interfere with the blink even in period B of the processing, compared to static stimuli. Interestingly, the analysis of the responses on T1 showed that the performance for early lags was significantly lower when T1 was followed by a dynamic target, than when it was followed by a static target. We can thus hypothesize that the early "closure of the attentional gate" (as shown by the analysis of *lambda*) may have interfered with the ongoing processing of T1, reducing the probability for a correct identification.

However, this experiment does not allow to rule out the alternative explanation that the modulation of the AB we observed might have been due to the motion contained in the stimuli we presented, and not to the facial motion portrayed by the targets. We addressed this question in a second experiment.

	Participants (N = 14)	
	M.	SD.
STAI-Trait	40.20	5.86
Fear of Negative Evaluation	15.62	7.24
Social Avoidance and Distress	8.85	6.90
Neuroticism	30.77	6.95
Extraversion	38.35	4.18

Table 5.2: Experiment 2. Participants' trait personality scores.

5.3 Experiment 2. Motion of facial expressions

The second experiment we conducted addressed the particular case of the motion contained in dynamic facial expressions. In this second experiment, we disentangled the effect due to the *motion* contained in the stimuli we used, from the effect due to the *facial motion* portrayed by the targets.

5.3.1 Method

Participants

14 students (14 females, mean age 25.2 years) from the University of Geneva, who had not participated in Experiment 1, participated in this experiment for course credit. All participants were right-handed, had normal or corrected-to-normal vision, and no history of psychiatric or neurological diseases. Before the experiment, the participants completed the following personality questionnaires: NEO Five-Factor Inventory (NEO-FFI; Costa & McCrae, 1991), State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983), and the dual scale Fear of Negative Evaluation - Social Avoidance Disorder (FNE-SAD; D. Watson & Friend, 1969).

Apparatus

The apparatus was similar to Experiment 1.

Stimuli

Each T1 stimuli consisted of one out of 20 faces (10 females), showing no expression, tinted in green to ease their detection. Each T2 stimuli consisted of one out of 20 faces (10 females) manipulated to correspond to the following three conditions (Figure 5.6, panel a):

1. In the ”no dynamic–emotion” condition, T2 stimuli were similar to the static fearful faces used in Experiment 1.

2. In the ”dynamic–emotion” condition, T2 stimuli were similar to the dynamic fearful faces used in Experiment 1, except that they were made of six frames instead of eight.

3. In the ”dynamic–no emotion” condition, T2 stimuli were created from the stimuli in the ”dynamic-emotion” condition, scrambling both configural and featural information of the face to avoid recognition of the facial expression (Ellison & Massaro, 1997; Cabeza & Kato, 2000; Calder et al., 2000; Rakover, 2002; Calder & Young, 2005), while making sure stimuli still contained the same amount of intrinsic motion.

Procedure

The experiment consisted of one block of 10 practice trials, followed by five blocks of 160 trials. In addition to explanations of the tasks, the instructions contained examples of the different types of T2 targets that could occur during the experiment, expressing no emotion. The facial identities were different from the ones used in the experimental blocks. Between blocks, participants were forced to a resting period of at least 3 minutes. Participants were instructed to perform a gender decision task on T1 (green face), and to indicate if they had perceived either of the T2 targets immediately following the first target. Response was given at the end of each trial.

Each trial began with a fixation cross, displayed for 700 msec. Participants were instructed to focus on the fixation cross, and to sustain this gaze throughout the trials, as this was the optimal way to perceive each face as a whole, and gather a maximum of information for the tasks.

A trial consisted of 22 stimuli, presented for 60 msec each, without any inter-stimulus interval (Figure 5.6, panel b). Each of the six frames of the dynamic T2 was presented for exactly 10 msec (one refresh period of the screen), whereas static stimuli (i.e., T1, static T2, and distractors) were presented for 60 msec (six refresh periods). T1 stimuli appeared equally often in serial positions 2–5. On the basis of the results obtained in our first experiment, and to maximize the power of our design, T2 targets appeared equally often in either of two serial positions corresponding to 240 msec after T1 (early lag), and 480 msec after T1 (late lag). Similarly to our first experiment, T2 stimuli were present in 75% of the trials, and absent in the remaining 25%, to maximize the number of T2–present trials without making the experiment too long.

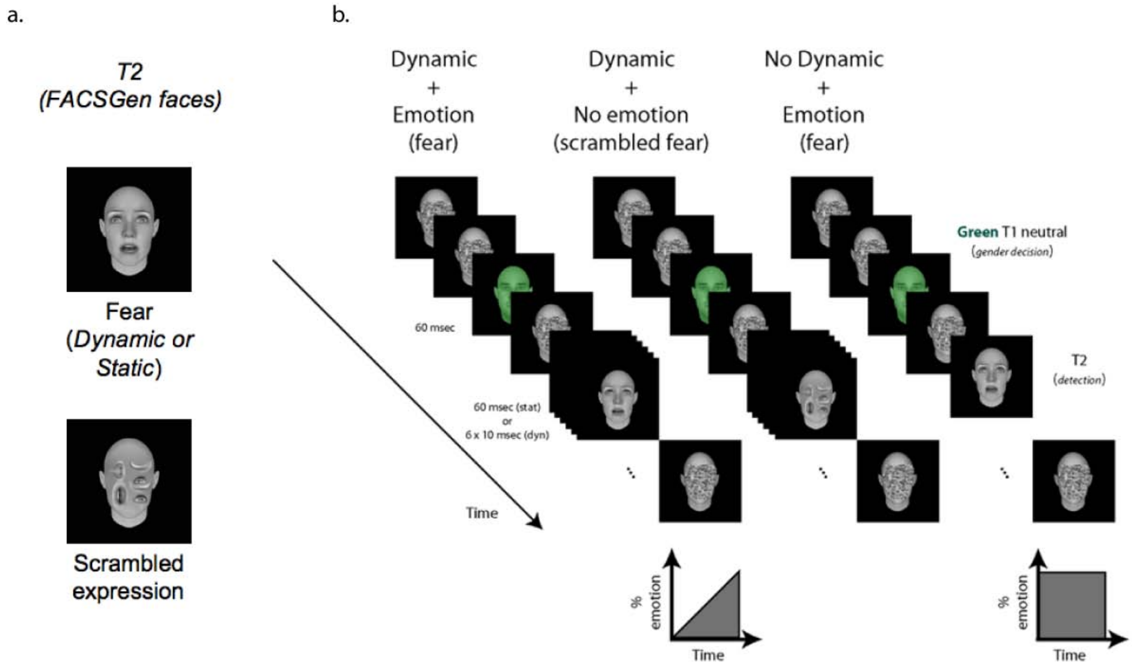

Figure 5.6: Experiment 2. Type of stimulus. Panel a. Examples of T2 targets. Panel b. Examples of trials. Static stimuli (i.e., T1, static T2, and distractors) were presented for 60 msec (six refresh periods of the screen), whereas each frame of the dynamic T2 was presented for 10 msec (one refresh period of the screen).

5.3.2 Results

First, pairwise Pearson's χ^2 tests (one-sided) were computed to compare the performance at early and late lags, within each condition. Results showed that the performance at early lags did not differ significantly from the performance at the late lags (ps $> .2$), even though the trend was in the predicted direction (Figure 5.7). These results show that our procedure failed to show a clear AB within each condition.

Second, pairwise Pearson's χ^2 tests were performed to compare conditions within each lag. Results showed that, for both early and late lags, emotional conditions did not differ significantly from each other (ps $> .1$). However, importantly, performance for both emotional conditions were significantly higher than the "dynamic-no emotion" condition in both early and late lags (ps $<$ .01), indicating that targets containing emotion were easier to detect than targets with no emotion.

5.3.3 Conclusion

In this experiment, we addressed the extent to which the intrinsic motion contained in dynamic fearful facial expressions can modulate temporal attention. In a traditional AB experiment, T2

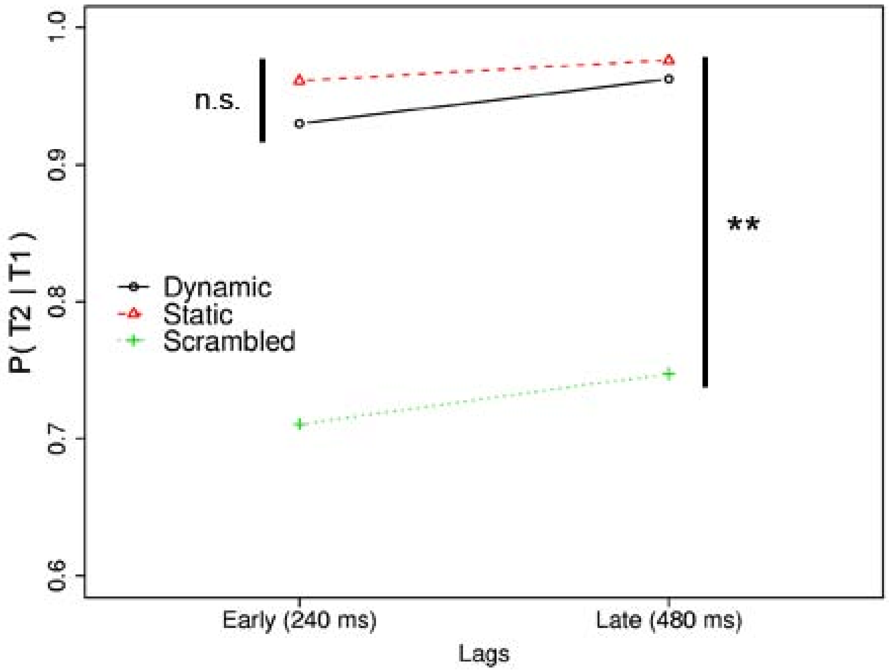

Figure 5.7: Experiment 2. Motion of facial expresions. Proportion correct on T2 given T1 as a function of lags.

targets could be of three types: a static fearful expression ("no dynamic–emotion" condition), a dynamic fearful expression ("dynamic–emotion"), or a stimulus tailored to display the same amount of motion as the "dynamic-emotion" condition, whilst at the same time scrambling the featural and configurational information of the facial expression to prevent the recognition of the facial expression ("dynamic–no emotion"). We hypothesised that only conditions portraying emotion would benefit the processing and reportability of T2 targets. Consequently, we hypothesised that targets in the "dynamic-no emotion" condition would not be reported, and exhibit a traditional blink response. Results confirmed our hypotheses.

5.4 General discussion

In two traditional attentional blink (AB) experiments, we addressed the extent to which emotionally relevant stimuli modulate temporal attention in the healthy population. We hypothesised that both fearful and happy facial expressions, as T2 targets, would modulate the AB more than neutral facial expressions (**H1**). We also hypothesised that dynamic facial expressions would modulate the AB more than static facial expressions (**H2**). Results to our first experiment confirmed both of these hypotheses. In a second experiment, we ruled out the alternative explanation that the strong modulation of the AB for dynamic stimuli we observed might have been due to the sole motion contained in the stimuli we presented, and not to the facial motion portrayed by the face targets.

The AB phenomenon reflects the competition of several processes early in the processing stream. The resulting behavioural curve expresses a very particular view of this competition: the evolution over time of the performance on T2 task upon correct response on T1 task. This curve, studied as a whole, does not allow to perceive the underlying competing processes. If properly described, however, some understanding of the underlying processes can be gathered by focusing on "aspects of interest". The novel methodology we used (Cousineau et al., 2006) allowed to disentangle four of such aspects, which we interpreted as reflecting the activation and competition of a number of processes during three periods of time (Figure 5.2, panel a).

Of particular interest, we showed that each of these three periods may reflect the effects of distinct processes involved in the competition between T1 and T2. We propose the following scenario: From onset up to 200 msec after the onset of T1, a process appraises low-level features of the occurring event, and the degree to which upcoming stimuli can interfere with the ongoing processing. We predict that the perceptual system will attempt to prevent this new stimulus from disturbing the ongoing processing by activating *a* particular mechanism (i.e. the "closure of an attentional gate", Kessler et al., 2005; Sergent et al., 2005; Hommel et al., 2006). The "stronger" this second stimulus, the earlier in time will occur this interfering mechanism. In later stages of the competition, however, a stimulus eliciting a strong bottom-up activation (e.g., an emotional stimulus) will benefit from the support of higher-level processes, which will alleviate the weakening interfering mechanism, and support its reportability.

Interestingly, a similar distinction between "early" and "late" pre-attentive evaluative processes has emerged in an attempt to explain discrepant results in studies addressing emotional modulation of spatial attention. In dot-probe paradigms in particular, researchers are concerned with the stimuli onset asynchrony (SOA) between the cue and the target: short and long SOAs yielding to very different results. According to the hypervigilance-avoidance hypothesis, patients suffering from social anxiety would be more prone to attend to threatening information during the early stages (SOA up to 300 msec) of the processing stream, and would shift their attention away from such information in later stages (SOA over 400 msec) of the processing (see Amir et al., 1998; Santesso et al., 2008).

Our results also go in line with the increasing electrophysiological literature showing that even unreported T2 targets in AB experiments are processed at a semantic level (Luck et al., 1996;

Shapiro, Raymond, & Arnell, 1997; Vogel et al., 1998; Marois et al., 2004; Sergent et al., 2005; Dehaene et al., 2006; Hommel et al., 2006). In particular, we showed that emotional stimuli, regardless of their valence, are being appraised very early in the processing stream. Results of this appraisal influenced the unfolding of the AB curve by either interfering or supporting their further processing, depending on the current stage of processing of T1 targets.

Taken together, our results add to the literature questioning the usefulness for the concept of a dedicated fear module. According to the proponents of this hypothesis (Öhman & Mineka, 2001; Mineka & Öhman, 2002; Wiens et al., 2004), evolutionary pressure would have shaped our perceptual system with a dedicated module to quickly detect, and attend to threat-related material in the environment. Our results, and others (Tipples et al., 2002; Lipp et al., 2004; Brosch & Sharma, 2005; Flykt et al., 2007; E. Fox et al., 2007; Brosch et al., 2007, in press), show that the perceptual system generally favors important information, and is not tuned to process one particular emotion. These results support appraisal theories of emotion in general, and the component process model in particular, by pointing at common evaluative mechanisms to all emotions. The fear module hypothesis, like basic emotion models in general, does not account for the details of the processing of emotional stimuli. In contrast, the component process model allows researchers to build more precise hypotheses concerning the mechanisms involved in emotional processing.

Our results naturally invite new challenges.

Computations. We proposed detailed descriptions of the early processes appraising upcoming stimuli. AB-like experiments can only provide indirect evidence for such claims, and our results need to be investigated further to grasp the content of the computations performed.

Automaticity. We did not address the extent to which these early appraisals are automatic (i.e. immune from top-down influences), and future work could manipulate motivational or task contexts.

Inter-individual differences. An increasing literature addresses inter-individual differences of perceptual systems. Two tracks are of particular interest. First, one study showed that temporal attention varies along at least three dissociable dimensions: efficacy, latency, and precision (Vul, Nieuwenstein, & Kanwisher, 2008). From one moment to the next, attention selection can for instance be more or less diffuse, and precision more or less spred out over time. Second, a few studies address inter-individual differences in attentional sensitivity (Pessoa et al., 2005; Szczepanowski & Pessoa, 2007; Roesch et al., in revision, , see also next chapter), separating subjective awareness (i.e. what the participants report having perceived) from objective awareness (i.e. their actual performance). These two tracks are complementary (as the former can be used to explain the latter), and future research should take these points into consideration.

Chapter 6

Psychophysics of emotion: the QUEST for emotional perception

Reproduced from: Roesch, E.B., Sander, D., Mumenthaler, C., Kerzel, D., Scherer, K.R. (in revision). Psychophysics of emotion: the QUEST for emotional perception. *Journal of Vision.*

Abstract: To investigate the mechanisms involved in automatic processing of facial expressions, we used the QUEST procedure to measure the display durations needed to make a gender decision on emotional faces portraying fearful, happy, or neutral facial expressions. In line with predictions of appraisal theories of emotion, our results showed greater processing priority of emotional stimuli regardless of their valence. Whereas all experimental conditions led to an averaged threshold of about 50 msec, fearful and happy facial expressions led to significantly less variability in the responses than neutral faces. Results suggest that attention may have been automatically drawn by the emotion portrayed by face targets, yielding more informative perceptions and less variable responses. The temporal resolution of the perceptual system (expressed by the thresholds) and the processing priority of the stimuli (expressed by the variability in the responses) may influence subjective and objective awareness, respectively.

6.1 Introduction

For a few decades, researchers have been investigating the processing of neutral and emotional stimuli. While an impressive sum of studies suggests that emotion-laden information benefits from enhanced processing (Vuilleumier, 2005), not all evidence is in favour of this hypothesis. For instance, in a visual search paradigm with schematic emotional facial expressions, Horstmann & Becker (2009) showed that emotion-laden information only produced shorter reaction times when it was task-relevant. These results, and others, illustrate that attention to emotional stimuli is biased by both top-down (i.e., task-driven) and bottom-up (stimulus-driven) mechanisms that eventually yield perception (Beck & Kastner, 2009). Therefore, any successful attempt at characterizing the role of perceived emotion in visual processing necessarily involves innovative methods to disentangle voluntary from involuntary attention.

The processes leading to awareness of emotion-laden stimuli may be investigated in experimental settings employing backward masking (Breitmeyer & Ogmen, 2000; Wiens, 2006), which rules out conscious recognition as a factor in emotional processing. In this paradigm, a brief presentation of an emotional stimulus (target) is immediately followed by a visual mask that limits the processing of the target, and often prevents its recognition. If the interval between the onsets of the two stimuli is sufficiently short, participants may not perceive the target, and report only seeing the mask. In this context, a threshold refers to the minimum display duration necessary for the conscious perception and report of the target.

Characterizing the involvement of attention in emotion perception is, however, made difficult by the fact that an observer may perceive a significant amount of information about the target even in the absence of conscious awareness (e.g., Szczepanowski & Pessoa, 2007). Threshold measurement thus distinguishes subjective measures of threshold (i.e., based on the observer's reported perception) from objective measures of threshold (i.e., her actual performance). Arguably, attention may have a strong impact in both cases, and may involve different processes, thus influencing conscious experience in very different ways.

In the present study, we used psychophysical methods to evaluate the extent to which perceptual and attentional systems are sensitive to emotional stimuli. We measured the minimum display duration needed by participants to perform a gender decision task on emotional faces, portraying fearful, happy and neutral facial expressions. In this two-alternative forced choice paradigm, we considered the display duration that yields 75% correct gender decisions as the threshold (A. B. Watson & Pelli, 1983; Klein, 2001). The curve representing the probability of a correct discrimination response over the increasing stimulus strength (i.e., display duration) is called a psychometric function (PF). In addition to the threshold, which is equivalent to the location of the PF, we also consider the slope of the curve. The slope is a measure of the variability of observers' judgments. Shallow slopes result from high variability and indicate that the transition between chance and 100% correct is spread out. Steep curves indicate that there is a neat transition between chance and 100% correct. The distinction between threshold and variability is important, as attention has been shown to affect both variables. There is ample evidence that accuracy (i.e., percent correct responses) improves when participants voluntarily attend a stimulus (e.g., Bashinski & Bacharach, 1980; Cheal & Lyon, 1991; Dosher & Lu, 2000), indicating that perceptual thresholds decreased. The situation is less clear for involuntary shifts of attention. Typically, involuntary shifts of attention are triggered by a peripheral flash that does not predict the target location. Recently, Prinzmetal et al. (2005) demonstrated that involuntary attention does not affect perceptual accuracy. However, involuntary attention made judgments less variable (Prinzmetal & Wilson, 1997). Thus, improvements of variability without changes in accuracy may be considered a signature of involuntary (or automatic) attention.

We hypothesized that the emotion portrayed by the faces will facilitate their processing and yield better performance in a gender decision task. Facilitation may reduce thresholds, variability, or both. Most likely, facilitation is mediated by the larger capacity of emotional stimuli to attract attention.

6.2 Method

6.2.1 Participants

31 participants (15 females, mean age 29.4 year old) took part in this experiment, in exchange for 10 SFr. All participants were right-handed, had normal or corrected-to-normal vision, and had no history of psychiatric or neurological diseases.

6.2.2 Apparatus

Stimuli were presented on a wide CRT screen, with a refresh rate of 100 Hz, and a resolution of 1024 × 768 (Wiens et al., 2004; Wiens, 2006). The screen was placed 60 cm away from the head of the participant. Participants were comfortably seated in an armchair, with their head in a chin rest to ensure the distance to the screen was held constant throughout the experiment. The experiment was administered using MatLab, and the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997).

6.2.3 Stimuli

Targets consisted of 10 faces (five females), subtending $18^\circ \times 15^\circ$ visual angle. The faces portrayed 4 controlled combinations of facial action units, depicting expressions recognized as happy, fearful, and two types of neutral expressions. To control for perceptual effects, emotional facial expressions along with the faces from one of the neutral conditions showed an open mouth. The faces for the other neutral condition showed a closed mouth.

The faces were produced using our software FACSGen (Roesch et al., submitted ; see Chapter 4, on page 51). FACSGen is a tool that allows for the creation of unique, realistic, static or dynamic, synthetic 3D facial stimuli based on the Facial Action Coding System (Ekman et al., 2002). It provides control over the intensity of the facial action units and allows researchers to apply the same facial expression to any face produced with FaceGen Modeler 3.2 (`http://www.facegen.com/`; Shimojo et al., 2003; Moradi et al., 2005; Corneille et al., 2007). As part of a separate judgment study, 37 participants rated the extent to which the following emotions could be perceived in the facial expressions used in this experiment: anger, disgust, fear, happiness, sadness, and surprise. A scale was provided, anchored in 0 (”not at all”) and 100 (”enormously”). To determine whether participants could discriminate the emotions portrayed in the faces, repeated measures analyses of variance (ANOVAs) were performed on the ratings for each target emotion. There was a significant effect for target emotions (ps $< .001$), indicating that participants reliably recognized the target emotion portrayed by the faces.

Masks consisted of neutral FACSGen faces, for which the inside of the face was divided in 10×10 pixel squares, and scrambled randomly.All faces were presented in gray scale. Statistical analyses confirmed that stimuli did not differ in luminance and contrast.

6.2.4 Procedure

Trials and blocks

The experiment consisted of three blocks of 240 trials each. Participants were asked to determine the gender of the targets. Instructions contained practice trials presenting targets (different from

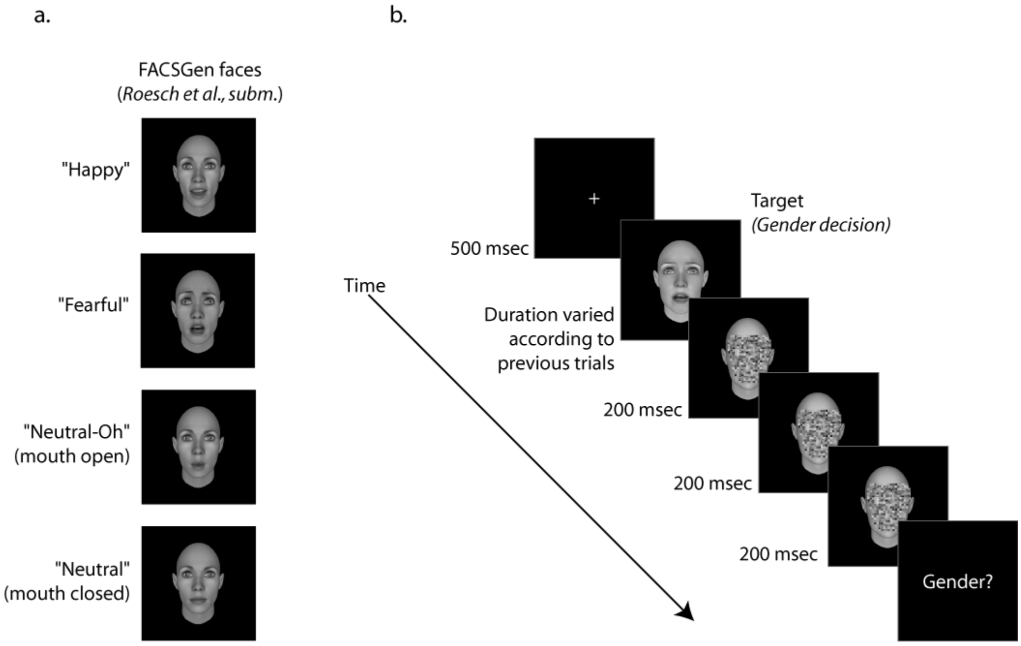

Figure 6.1: Example of a trial. Panel a. Stimuli were FACSGen faces expressing AU combinations recognized as happy, fearful and neutral. Panel b. Sequence of stimuli for one trial.

the ones in the experimental blocks) with decreasing durations. Between blocks, participants were forced to a resting period of at least three minutes.

Each trial began with a fixation cross, displayed for 500 msec (Figure 6.2.4). Participants were instructed to focus on the fixation cross, and to maintain fixation throughout the trials, as this was the optimal way to perceive each face as a whole, and gather a maximum amount of information for the task.

A trial consisted of 4 stimuli, presented without any inter-stimulus interval. The target appeared immediately after the fixation cross. The display duration of the target varied from trial to trial on the basis of the staircase QUEST procedure (A. B. Watson & Pelli, 1983; Pelli & Farell, 2001), described later in this section. Three masks, randomly chosen from a pool of 17 followed the target. Each mask was presented for 200 msec. At the end of the trial, participants were asked to determine the gender of the face in a 2-alternative forced choice procedure.

QUEST: A bayesian adaptive psychometric method

The estimation of thresholds is the core of psychophysics, and several methods are available. These methods can be separated into two broad strategies (Macmillan, 2001). The first (and earlier) strategy presupposes a priori knowledge of the psychometric function studied, in which performance increases from 0, or chance level, to perfect performance. Researchers typically sample this function at several points (usually more than five), and determine what point constitutes the threshold for each observer (method of constant stimuli), The second strategy is said to be an adaptive procedure, in which stimulus values are chosen on the basis of the observer's performance in previous trials. Results of behavioural experiments, and simulations, showed that adaptive methods are more accurate, and more efficient, than the method of constant stimuli (A. B. Watson & Fitzhugh, 1990, see also the special issue on threshold estimation in Perception and Psychophysics, 2001—An alternative strategy consists of letting the observer control the level of stimulus until it becomes barely detectable (method of adjustment), but it only provides very little information about the shape of the PF).

QUEST (A. B. Watson & Pelli, 1983; Pelli & Farell, 2001) is an adaptive staircase procedure. It has been used in studies investigating both low-level perceptual filters, like spatiotemporal integration of visual information (Melcher & Morrone, 2003) or contrast sensitivity (Burr et al., 1994), and higher-level object recognition, like letters (e.g., Solomon & Pelli, 1994) or faces (C. J. Fox et al., 2008). One study used it to investigate the effect of attention and emotion on contrast sensitivity (Phelps et al., 2006). In QUEST, the algorithm assumes the observer's PF follows a Weibull distribution (see mathematical details on page 105). The estimated parameters of this distribution are updated after each trial on the basis of the observer's performance and a new stimulus value is chosen for the next trial. In the original algorithm, stimulus values are chosen at the best quantile of this updated function. The final estimate of the threshold is at the mean of the function. The Psychophysics Toolbox includes MatLab code that implements this procedure.

In our experiment, we used QUEST to estimate the minimum display duration required by participants to make a gender decision on faces portraying four facial expressions. In each block, four QUESTs ran concurrently, and were randomly interleaved. After each block, we recorded the mean and the standard deviation of the participant's PF for each condition. The mean of the PF corresponds to the threshold of the observer, which is the minimum display duration required for the observer to make a 75% correct decision on the gender of the face targets. The standard deviation of the PF represents the dispersion of the Weibull distribution of the trials at the end of the block. Because the total number of trials was held constant (60 trials per QUEST), more trials around the threshold resulted in smaller standard deviations. It thus indirectly corresponds to the number of trials needed by QUEST to estimate the threshold of the observer. More generally, the standard deviation of the Weibull distribution corresponds to the variability of participants' responses in a block of trials.

6.3 Results

One participant systematically gave incorrect answers in the first block. We therefore discarded his data from the analyses involving this block. We conducted exploratory analyses to assess inter-individual differences. We then performed targeted analyses to address a learning effect over the blocks, and the extent to which the emotion of the targets influenced performance.

6.3.1 Exploratory analysis

Exploratory analysis of the data showed great inter-individual differences. Frequency analysis of the thresholds obtained after each block showed a skewed distribution (see Figure 6.3, Panel a, for an example), indicating that, on average and across emotions, participants required the targets to be displayed for at least 50 msec to be able to make a correct decision about the gender of the targets.

We also computed the mean psychometric functions for each emotion, graphically representing the unfolding of the probability for a correct response as the duration of the target increases. As shown on Figure 6.3, Panel b, the estimated cumulative Weibull distributions vary as a function of emotion. Of importance are the slopes, and the points where the probability to make a correct decision becomes greater than .75, corresponding to the threshold.

6.3.2 Targeted analyses

Analyses of variance (ANOVAs) were performed, treating Blocks (1, 2, and 3) and Emotion (happy, fearful, neutral with mouth open, and neutral with mouth closed) as fixed factors, and Participants as a random variable (two-sided tests). The ANOVA on thresholds (Figure 2, Panel c) yielded a main effect of Blocks, $F(2,58) = 3.275$, $p < .001$, $\eta^2 = .242$. Contrast analyses confirmed that performance improved significantly over blocks (ps $< .05$). The analysis also yielded a main effect of Emotion, $F(3,87) = 3.677$, $p = .015$, $\eta^2 = .113$, but posthoc Tuckey analyses only showed a significant difference between the two neutral conditions ($p = .033$).

The ANOVA on standard deviations (Figure 2, Panel d) did not yield a main effect of Blocks, $F(2,58) = .471$, $p = .627$, but it did yield a main effect of Emotion, $F(3,87) = 4.31$, $p = .007$, $\eta^2 = .129$. Posthoc Tuckey analyses confirmed that the number of trials needed by QUEST to estimate the threshold was significantly smaller for emotional targets than for neutral targets (ps $< .05$). No difference was found between fearful and happy targets ($p = .991$).

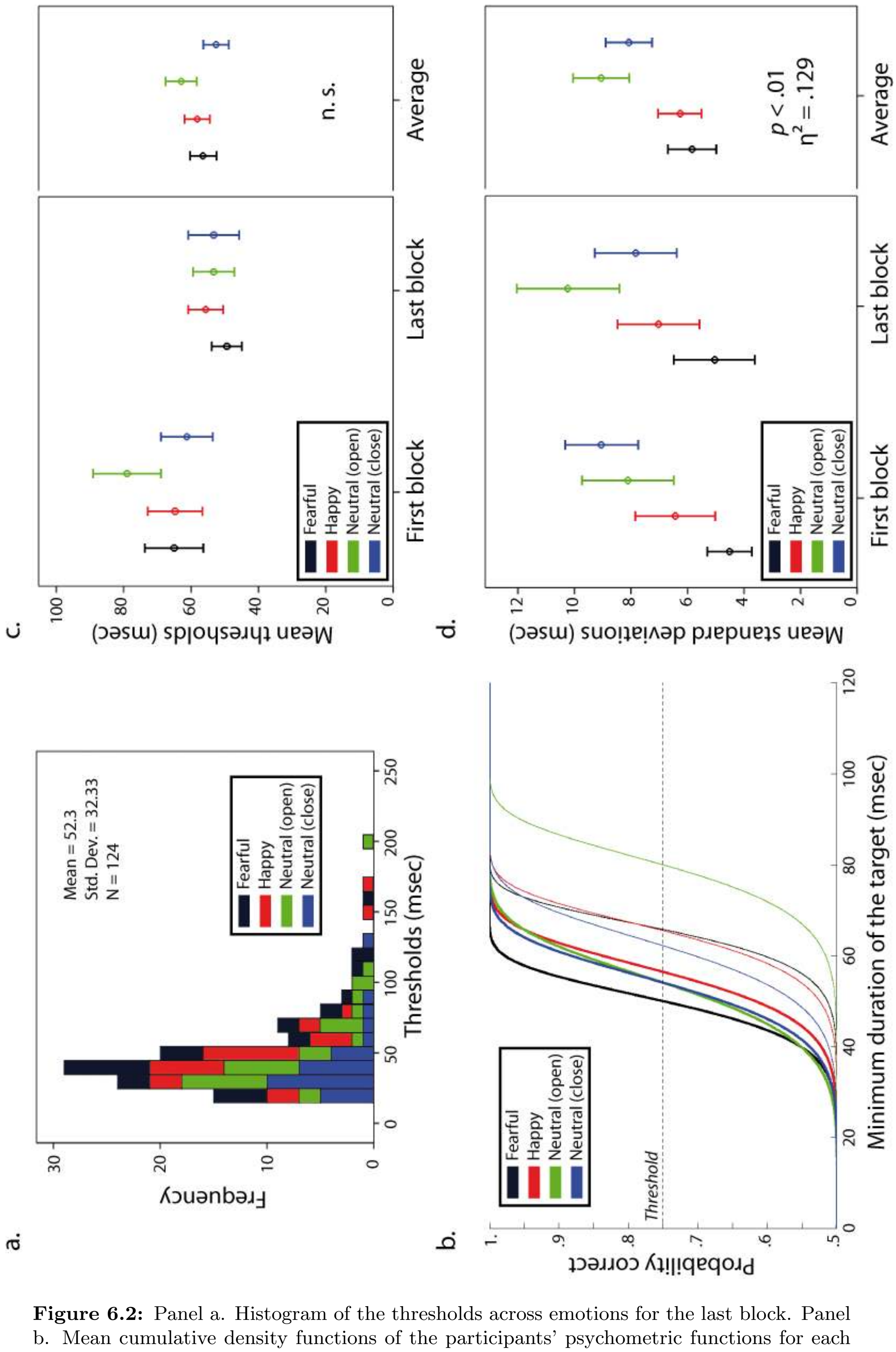

Figure 6.2: Panel a. Histogram of the thresholds across emotions for the last block. Panel b. Mean cumulative density functions of the participants' psychometric functions for each experimental condition, estimated from the thresholds and the standard deviations for the first and last blocks. Thin lines represent results to the first block. Thick lines represent results to the last block. Panel c. Mean thresholds for each emotion after the first and the last blocks, along with the average over all the blocks. Panel d. Mean standard deviations of the participants' psychometric functions for each emotion, after the first and last blocks, along with the average over all the blocks. All error bars correspond to 1 SEM.

6.4 Discussion

The present work examined the minimum display duration needed by participants to make a correct gender decision on emotional faces. We compared the perception of fearful, happy and neutral facial expressions. We used a staircase procedure, QUEST (A. B. Watson & Pelli, 1983; Pelli & Farell, 2001), to estimate the minimum display durations (the thresholds) needed for this task, and a measure of the variability of the participants' responses (the standard deviation of the resulting distribution of trials).

Thresholds for all emotions were subject to great inter-individual differences. Across blocks, the average threshold was 50 msec, which corresponds to the perceptual limit often reported and used in backward masking studies(Esteves & Öhman, 1993; Morris, Öhman, & Dolan, 1998; Whalen et al., 1998; Öhman, 2002; Stapel et al., 2002; Ruys & Stapel, 2008, 2009). However, quite a few thresholds were below the mean of 50 msec, indicating that, if 50 msec was an average, some participants could perform the task under this threshold. This finding is consistent with studies addressing the objective and subjective awareness of fear perception (Pessoa et al., 2005; Szczepanowski & Pessoa, 2007), in which participants can sometimes detect fearful faces displayed at a duration as short as 17 msec. We extended these results by showing that this was also the case for happy and neutral faces.

Our hypothesis concerned the extent to which the emotion portrayed by the faces facilitate their processing. Analysis of the variability of responses throughout the blocks revealed a significant main effect of emotion. Posthoc analyses indicated that responses were less variable for emotional targets compared to the neutral targets.

Our procedure allowed us to separate two aspects of the processing involved in a gender decision task with emotional facial expressions. Each of these aspects can influence and limit the processing of perceived stimuli. We propose the following distinction:

1. The measure of thresholds may relate to the subjective awareness reported by the participants (Szczepanowski & Pessoa, 2007). It refers to the limit of the conscious perceptual experience. The absence of reliable differences between emotional and neutral targets is consistent with the view that conscious visual experience (which has been shown to resemble an all-or-nothing phenomenon, Sergent et al., 2005) is subject to the same temporal resolution regardless of whether it is emotionally salient or not.

2. The variability of the participants' responses (expressed by the standard deviation of the resulting distribution of trials at the end of each block) may relate to the objective awareness of the participants, which often yields smaller thresholds than subjectively reported. The fact that the QUEST algorithm needed less trials to estimate the observers' thresholds (i.e. resulting in smaller standard deviations) for emotional targets shows that emotional targets benefited from a heightened processing priority, compared to neutral targets, which could in turn benefit an orthogonal task (gender decision). This view is coherent with results showing that emotional material can influence higher levels of processing even if presented subliminally, without conscious awareness of the participants (Stapel et al., 2002; Ruys & Stapel, 2008, 2009).

This interpretation is supported by studies addressing the effect of attention on perceptual processing. In a series of experiments, Prinzmetal et al. (1997) showed that attention did not render the percept of achromatic targets more intense, but it significantly reduced the variability of the responses. They replicated this effect in several modalities, spanning from lower-level features like colour and spatial frequencies to higher-level features like the length or the orientation of the target (Prinzmetal & Wilson, 1997; Prinzmetal et al., 1998). They concluded that "attention reduces the variability of responses but it does not cause biases in perception. The searchlight of attention illuminates in terms of providing more information, but it does not illuminate in terms of changing contrast" (Prinzmetal et al., 1997, p. 408).

The phenomenology of this effect can be described as the observer being more certain of the identity of the perceived targets. In other words, attention would reduce the range of possible answers, by increasing the number of information samples taken by the perceptual system, for instance. In a connectionist framework, this could be achieved by either more perceptual neurons firing, or perceptual neurons firing at a higher rate. This would explain why attention has often been shown to increase the activation of perceptual brain regions (e.g., Vuilleumier, 2005; Kastner & Ungerleider, 2000; Zelano et al., 2005; Esterman et al., 2008). In contrast, thresholds for emotional stimuli did not differ from thresholds for neutral stimuli. In light of previous research on the distinction between involuntary and voluntary attention, the pattern of results suggests that emotional stimuli elicit involuntary shifts of attention. If voluntary attention had been involved, thresholds would also be expected to decrease. This was not the case, making it unlikely that participants voluntarily chose to attend more to emotional than to neutral stimuli.

To conclude, emotional targets led to less variability in the responses given by participants, compared to two types of neutral targets. We thus suggest that attention may have been automatically drawn by the emotion portrayed by the face targets, leading to more informative perceptions and less variable responses by the participants on an orthogonal task. This proposal is supported by Phelps et al. (2006) who showed that a perception of emotion led to a heightened perception of a lower-level feature like a contrast gradient in a subsequent stimulus. Importantly, in our study the emotional effect was observed for both negative (fearful faces) and positive (happy faces) emotional stimuli, as predicted by the component process model of emotion (Scherer, 2001).

Appendix – Mathematical details of the Weibull distribution in QUEST

The QUEST algorithm is a psychometric staircase procedure to estimate thresholds (A. B. Watson & Pelli, 1983). It makes use of responses to previous trials to guide the testing. More precisely, it places each (next) trial at the current most probable Bayesian estimate of threshold, assuming the observer's psychometric function (PF) follows a Weibull distribution. The corresponding cumulative Weibull distribution is defined by the following equation:

$$P(x) = \delta \times \gamma + (1 - \delta)(1 - (1 - \gamma) \times \exp(-10^{\beta(x - T + error)})$$

where x represents log10 contrast relative to threshold, with specified upper asymptote to take into account the observer's occasional errors when the intensity of the stimulus is well above threshold (A. B. Watson & Pelli, 1983). β, δ and γ are not free parameters, and should be specified before the start of the experiment. The values used in our experiment were chosen after Watson and Pelli's original recommendations for a two-alternative forced choice procedure. They are indicated inside parentheses. β controls the steepness of the PF (3.5). δ is the fraction of trials on which the observer presses at random (.05). γ specifies the probability of a success at zero intensity (.5). T is a prior estimate of the threshold. In a two-alternative forced choice procedure, the aim of the procedure is to find the threshold that yields 75% correct decision. The $error$ term is introduced so that T will be the ideal testing point. We ran our analyses on the thresholds recorded at the end of each block and the standard deviations of the resulting distributions of responses.

Chapter 7

Conclusions

Abstract: The work presented in this thesis investigated the temporal dimension of emotional attention, with a view to studying the sequence of processes leading to conscious awareness of facial expressions and its modulation by emotion. We used two experimental paradigms – the attentional blink, and a psychophysical setup – to compare predictions from two of the major emotion theories. In this chapter, we review the contributions of our work, in the methodological, experimental and theoretical domains. We conclude by highlighting some of the limitations of this work, and give possible tracks for future work.

7.1 Research overview

In this work, we used emotion theories to guide the investigation of emotional attention (Vuilleumier, 2005). In particular, we studied the cognitive processes responsible for the fast orienting of attention to emotional stimuli. The relationship between emotion and attention is thoroughly described by most emotion theories. It is generally perceived through the lens of evolutionary pressure as one of the main mechanisms that promoted the survival of the species, providing individuals with ways of developing and rapidly setting up coping strategies to a growing range of situations.

We reviewed three of the most influential theoretical traditions of emotion (Chapter 1 on page 1), and selected two models that propose precise accounts for the orienting of attention: Studies that have addressed emotional attention generally showed that attention was drawn by threat-related stimuli. Öhman & Mineka (2001) thus proposed that a phylogenetically inherited system, dubbed the fear module, would be promoting the detection and rapid orienting of attention to threat-related stimuli in the environment. A growing body of data, however, suggests that attention may be more generally attracted by relevant stimuli, and several authors call for a redefinition of the fear module into a relevance detector (Scherer, 2001; Sander et al., 2003). Both models suggest that the centre for this system is placed in the amygdala, as this brain structure is well-placed to both receive very early perceptual input and influence early processing through top-down connections.

In contrast to traditional methods of investigation to emotional attention, which focus on a finite moment of the processing of information, we used methods tapping into temporal attention that investigate the unfolding sequence of processes yielding conscious awareness. In particular, we investigated the moments of the information processing most sensitive to emotional content. In two AB experiments and one experiment investigating the psychophysics of emotional perception, we studied the extent to which emotional facial expressions attract attention.

With a view to contrasting predictions from the fear module hypothesis (Öhman & Mineka, 2001) with predictions from the relevance hypothesis (Scherer, 2001; Sander et al., 2003), we made the following general hypothesis (Chapter 3 on page 45):

If attention ensues from a cognitive process resembling a fear module, it should preferentially be drawn by fearful faces, compared to happy and neutral faces. If attention ensues from a cognitive process resembling a relevance detector, it should equally be drawn by fearful and happy faces, compared to neutral faces.

Subsequently, if attention ensues from a cognitive process resembling a fear module, anxious participants should exhibit a bias to fearful faces, while extraverts and control participants should not exhibit any bias. If attention ensues from a cognitive process resembling a relevance detector, anxious participants should exhibit a bias to fearful faces and extraverts should exhibit a similar bias to happy faces, compared to control participants.

The contributions of our work to the study of emotional attention take three directions: methodological, experimental and theoretical, which we review in details in this chapter. The methodological contributions of our work comprise the development of a novel tool that allow the creation and manipulation of experimental material (Section 7.2.1), and the application of analysis methods to address the cognitive processes responsible for the AB (Section 7.2.4). The experimental contribution of our work include data relative to the modulation of the AB blink by emotional material. In particular, we investigated the effect of the emotion portrayed by faces on temporal attention (Section 7.2.2) as well as the effect of the intrinsic motion of emotional facial expressions over attention (Section 7.2.3), and attempted the description of the mechanisms that may be underlying some of the aspects of the attentional biases to emotional faces (Section 7.2.5). Finally, by guiding the investigation of emotional attention through the lens of selected models from current emotion theories, our results can be used to perfect the theoretical understanding of the processes underlying the orienting of attention (Section 7.2.6).

7.2 Contributions of our work

7.2.1 FACSGen: a novel tool to create synthetic facial expressions

Reviewing the experimental material available for studies on facial expressions of emotion, we realised the need for new solutions. This material gathers static photographs or movie clips of actors portraying a given emotion, or live occurrences of emotions captured from media content. The common use of this material eases the comparison of results across studies. Its lack of flexibility however prevents the manipulation and control of different aspects of facial expressions that have been shown to play a great role in both expression and perception of emotion. This includes high level features like race, gender or age, but it also relates to the different informational cues that compose a facial expression, and their dynamic unfolding to form a coherent modal expression of emotion (e.g. Scherer & Ellgring, 2007). These drawbacks often motivate researchers to produce their own database of facial expressions, or to alter this material with crude methodologies (e.g. morphing techniques).

In response to the combined need for reproducibility and flexibility, we developed FACSGen. This novel tool allows the creation of synthetic, realistic, both static and dynamic facial expressions based on the facial action coding system (Ekman et al., 2002). This innovative solution provides researchers with the ability to parametrically control for, and manipulate each of the constituents of facial expressions. Action units can be manipulated separately to create an infinite number of facial expressions, which can then be animated following non-linear dynamics. The exact same expression can then be portrayed on an infinite number of identities produced using FaceGen

Modeller 3.1 (Singular Inversions Inc., 2009). Our work included the development of the software, the validation of both the material produced using this software and the general methodology of using such tailored material in experimental work. As a result, we produced and validated a database of 180 different FaceGen identities, and a database of 77 FACSGen emotional facial expressions, which we used as experimental material throughout this work and is being used in several collaborative projects. This part of our work under consideration for publication in the Journal of Nonverbal Behavior (Chapter 4 on page 51).

We strongly believe that initiatives of the kind will promote new avenues for research, as the material available to researchers can often be an important limiting factor for the testing of out-of-the-box hypotheses. In the case of emotional facial expressions for instance, basic emotion theories oppose appraisal theories in proposing different mechanisms supporting the unfolding of full-blown emotions. At the moment, this debate can only be addressed indirectly (Scherer & Ellgring, 2007), as the investigation of precise unfolding patterns cannot be produced by using current research material. Tools like FACSGen however provide researchers with ways of modelling the dynamics of unfolding hypothesised in this debate and directly address the issues raised by theorists.

7.2.2 Emotion modulates temporal attention: early vs late

The main goal of our AB experiments was to study the extent to which the processing of emotion-laden stimuli is prioritised. We hypothesised that emotional targets would elicit a boost of activation, rendering them less dependent on attentional resources to achieve awareness, and thus more likely to reach the stages of processing required for conscious awareness and report. In a traditional AB experiment, participants were asked to perform a gender decision task on a neutral face (T1) and to report seeing a second face (T2). The second target could either be portraying a fearful, happy or neutral expression.

The few studies that have addressed this issue generally showed that the course of the AB could be modulated by threat-related targets (e.g. Anderson & Phelps, 2001; E. Fox et al., 2005; Jong & Martens, 2007; Reinecke et al., 2007), but also by happy schematic faces (Mack et al., 2002), distinctive (Ryu & Chaudhuri, 2007) or familiar faces (Jackson & Raymond, 2006; Gomez-Cuerva et al., 2008). However the natural course of the AB spans 500 msec after the first target, a long time during which a sequence of several processes is likely to occur. By addressing the modulation of the AB as a whole, these authors failed to investigate the particular moments of the processing during which emotional material modulates temporal attention.

In contrast, our data shows that the natural course of the blink is modulated differently depending on the moment the second target occurs and interferes with the first target: First, compared to neutral stimuli, we found evidence for an attentional control mechanism preventing emotion-laden stimuli from reaching conscious awareness in the the period commonly referred to as the lag-1 sparing (0–150 msec after the first target). Second, we found that the AB is shorter for emotional targets than for neutral targets. These results emphasise the distinction between early and late processes, in line with reviews of results from other paradigms, like the dot-probe for instance for which different results are found depending on the SOAs between emotional cues and probes (Cooper & Langton, 2006).

We show that attention is generally drawn by emotion-laden stimuli, regardless of their valence. These results generally go in line with appraisal theories of emotion and against a dedicated module for the processing of threat stimuli. We did not find any evidence for the modulation of these results by personality traits (anxiety, or extraversion), therefore we cannot make conclusions about our second hypothesis.

This part of our work was presented at several international conferences, and yielded an abstract in Perception. A full article presenting our results is in preparation (Chapter 5 on page 69).

7.2.3 Dynamic facial expressions of emotion modulate the AB

Similarly, we investigated the extent to which dynamic facial expressions of emotion modulate the AB more than static facial expressions. In two traditional AB experiments, participants were asked to perform a gender decision task on a neutral face (T1) and to report seeing a second face (T2). The second face could either be static or dynamic - the expression unfolded from 0 to 100%.

Experiment 1 showed that dynamic facial expressions globally alleviate the AB more than static facial expressions. Experiment 2 allowed us to disentangle the effect due to the motion contained in the stimuli we used, from the effect due to the facial motion portrayed by the targets. T1 was a neutral face. T2 was a fearful static, dynamic or scrambled-dynamic face – tailored to show scrambled configural and featural information, avoiding emotion recognition while displaying the same intrinsic motion as dynamic facial expressions. Results confirmed the AB was modulated by emotion and not simply by dynamic targets.

These findings suggest that facial movement provides at least as much information as the end configuration of muscles composing modal facial expressions of emotions[9], even though display durations were as short at 60 msec (six frames, 0 to 100% of emotional expression). Similar results have recently been demonstrated using the visual search paradigm (Horstmann & Ansorge, 2009).

7.2.4 A process-based approach to the attentional blink

With a view to studying the sequence of cognitive processes underlying the attentional blink and its modulation by emotion, we examined the AB curve through a novel methodology allowing the discretization of specific aspects of the data (Cousineau et al., 2006). In particular, this approach disentangles moments of interest, and provides non-biased measurements of its modulation by targets. In other words, it locates moments during the natural course of the AB that may reveal the occurrence of particular cognitive processes. To our knowledge, this is the first time that such an approach is being used to investigate the sequence of cognitive processes underlying the modulation of attentional blink (Chapter 5 on page 69), after the approach has been originally demonstrated.

Current models accounting for the attentional blink generally describe a two-stage process. Authors propose different interpretations of the underlying processing, often in relation to other hypothesised psychological phenomena (e.g. WM consolidation, “token” individuation), based on their subjective understanding of what may be happening and the results of their empirical work. Cousineau et al. (2006) took a radically different direction by objectively describing the AB curve, capturing “aspects of the data that are most likely to be of theoretical importance” (p. 176) while remaining a-theoretical in nature, that is unbiased by a particular theory or model of the AB. Each of these aspects may relate to particular aspects of the processing that may be sensitive in their own way to the material being presented. In particular, this approach distinguishes Lag-1 sparing differences, amplitude differences, width differences, and minimum accuracy differences.

Guiding the interpretation of our results by means of emotion theories allowed us to formulate new hypotheses as to the function and the nature of the processes illustrated by the AB effect. We observed three different periods of time (Figure 7.1), which are differently sensitive to emotional information (Section 7.2.2 and 7.2.3). These periods of time may see the unfolding of several processes implementing different functions.

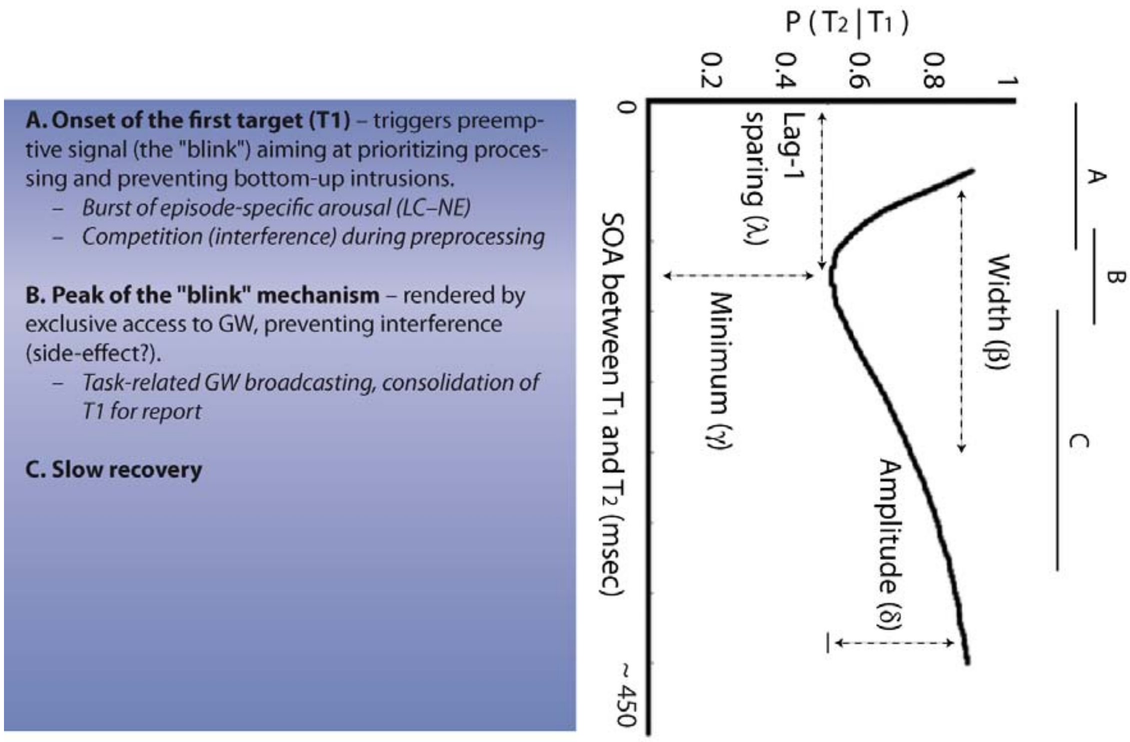

Figure 7.1: Proposed scenario accounting for the AB effect. Following the onset of the first target (T1), we identify three periods differently sensitive to emotional information. Each period may see the computation of a number of processes implementing particular functions. We hypothesise that the overall aim of this sequence is a) to prioritise the processing of the first target, b) to prevent intrusions, and c) to keep some order in the processing flow. (Original work elaborated in the course of this thesis.)

We propose the following scenario, generally hypothesising the implications of two features of the cognitive system: preemptive signalling and information integration. Both have already been addressed in the context of the attentional blink separately (Section 2.2 on page 26, for a review). We propose that they are both involved at some level with what is being observed through the AB curve, through different timing, and attempt to phrase the unfolding of the processing as follows.

Preemptive signalling. This part of the scenario is inspired by a theoretical paradigm in computer science called preemptive multi-tasking (Tanenbaum & Woodhull, 2006), which aims at ordering the tasks performed by computers, ensuring that all processes get some amount of central processing time at any given time. Nowadays, it is implemented by most operating systems as a way of emulating parallel processing on otherwise serial processors (CPU). It generally involves the use of an interrupt mechanism that both invokes a scheduler to determine which process should be next executed, and suspends any other executing process by emitting a preemptive signal.

We propose that similar mechanisms may account for the ignition of the attentional blink. The first period of time we observed (Figure 7.1, Period A) starts on the onset of the first target, and finishes during the onset of the "blink" mechanism. We hypothesise that this mechanism is a ballistic reaction to the perception of the first target, aiming at supporting its processing while preventing intrusion, in a similar way as preemptive signals emitted in today's operating systems. We hypothesise that this mechanism is implemented in the locus coeruleus–norepinephrine system (LC–NE), which has been implicated in the ignition and maintenance of arousal states and already hypothesised as a factor in the attentional blink (see Section 2.2.4 on page 32).

This first period of time is often referred to as the "lag-1 sparing" because, under certain conditions, both targets seem to be able to access subsequent levels of processing. However, activated representations are not immune to interference. As we have shown in our experiments and reported by others (e.g., Dehaene et al., 2003; Hommel & Akyurek, 2005), the report of the first target can be prevented by the second target. During that period of time, the "blink" mechanism slowly unfolds, preventing the processing of the second target altogether. The second period of time (Figure 7.1, Period B) constitutes the peak of this interference. We did not find that the amount of "blink" was modulated by emotion, thus we hypothesise that this ballistic process occurs in an all-or-nothing manner.

Information integration. We generally hypothesise that the peak of the AB (Figure 7.1, Period B) would signal the peak of information integration yielding conscious awareness and correct identification. As reviewed earlier (Section 2.2 on page 26), several authors hypothesised that the core of this stage of processing involves the invocation of some kind of a global workspace (GW) that would integrate all information available about the task and the target[10]. Evidence indeed suggests that no later than 300 msec after the onset of the first target, a distributed, target-dedicated and task-related network of temporo-parietal-frontal network shows coupling behaviour through phase synchrony (e.g., Gross et al., 2004; Sergent et al., 2005; Hommel et al., 2006).

The concept of GW refers to the notion that the different high-level, specialised, brain areas involved in the processing of (visual) stimuli interconnect to each other (Baars, 1988, 2002; Baars & Franklin, 2003), to form a global workspace processing the stimuli into a unitary assembly supporting conscious reportability. Perceived stimuli would thus compete to recruit this global workspace that, once activated, only affords exclusive access, yielding to the inability to process subsequent stimuli for a transient period of time (Figure 7.1, Period B).

In particular, Hommel et al. (2006) hypothesise that after nonselective processing in specialised perceptual cortices, targets are fed to object-specific temporal areas, where they are matched against long-term knowledge and, consequently, identified. Identified objects are then maintained in frontal working memory, and receive support by means of the synchronisation of the relevant structures in frontal and parietal cortices. Seemingly closing a perceptual window, this synchronisation stabilises the representation maintained in working memory, increasing the likelihood that the target be reported, and preventing other stimuli from entering further processing. The general availability of the cognitive system is then slowly restored (Figure 7.1, Period C).

In our scenario, both preemptive signalling and information integration are only hypothesised *features* of the information processing system, which can only be "perceived" through appropriate methods, tools and experimental paradigms. The reader should therefore avoid visualising yet another couple of dedicated modules grounding the implementation of these features in the brain. They are most likely separable although interacting, and most likely involve many more complex processing steps than foreseen by this naive scenario.

Guiding our investigation through the lenses of emotion theories provides nonetheless some light on potential implementations in the brain, and might partly explain why emotion-laden stimuli seem to benefit from a heightened processing priority. The amygdala for instance, is in the highlight of most emotion theories. It is known to be crucial in fear processing and fear learning (Vuilleumier, 2005), and a growing body of data also seems to suggest that the scope of its functional domain generally spans information that is *relevant* for the individual's general well-being (Sander et al., 2003). Its position in the processing stream of perceptual information makes it a perfect candidate to potentially influence many cortical and subcortical regions. If there is still some debate about the precise circuitry involving the amygdala in humans, researchers agree nonetheless to attribute an initial appraisal of emotional significance to this brain structure, based on coarse and limited information, early in the processing stream. This influence could take the form of direct feedback to sensory cortices (Vuilleumier, 2005), but also as indirect modulation of parietal and frontal regions (e.g., PFC) through the LC–NE system. These top-down influences would then produce a cascade of events which would signal emotional significance, which could be modulating both preemptive signalling and information integration.

7.2.5 Psychophysics of emotion

With a view to investigating the mechanisms yielding automatic processing of emotional facial expressions, we employed methods of psychophysics to examine the influence of emotion over perceptual thresholds. We used the QUEST procedure (A. B. Watson & Pelli, 1983; A. B. Watson & Fitzhugh, 1990) to measure the minimum display duration required to make a correct gender decision on fearful, happy and neutral faces. In particular, we recorded both minimum perceptual thresholds and the variability of the participants' responses at the end of each block, disentangling the temporal resolution of the perceptual system from the processing biases that can benefit emotional stimuli yielding better recognition respectively (Chapter 6 on page 95).

Our results showed that, compared to two neutral facial expressions, the emotion portrayed by the faces did not affect perceptual thresholds. All experimental conditions led to an averaged threshold of about 50 msec, as reported and used in most studies investigating perception bordering conscious awareness. However, compared to neutral facial expressions, the emotion portrayed by the faces significantly reduced the variability of the participants' responses. In other words, whereas emotion did not affect perceptual thresholds, it affected perception in such a way as to render perception more accurate. These results are in line with other results showing that involuntary shift of attention reduces the variability of perception while not affecting perceptual thresholds. We thus hypothesise that the emotion portrayed by the faces led to an involuntary boost of attention, which in turn rendered perception more accurate.

The phenomenology of this phenomenon can be described as the observer being more certain about her perception, resulting from the increasing of information sampling of the perceptual space for instance. In a connectionist framework, such an effect can be obtained by more perceptual neurons firing, or by neurons firing at a high rate, as shown by studies demonstrating increased activations of perceptual brain areas due to attention. We believe these results are of major importance. Not only do they confirm that both fearful and happy facial expressions attract involuntary attention, compared to two neutral facial expressions, but *they also suggest a possible mechanism for the interaction between emotion and attention (i.e., reduction of uncertainty).*

7.2.6 Implications for emotion theories

Emotion theories are concerned about the description of the processing steps involved in the genesis of emotions in general, and the interactions of the many processes required in this endeavour with both the individual's inner and outer environment. Circumscribing the study of emotions through the investigation of emotional influences over attention provides some context to this problematic. In doing this, we reviewed competing models, and our results generally support appraisal theories of emotions. In a series of experiments, we show that attention is generally drawn by emotion-laden stimuli regardless of their valence. However, we failed to show a modulation of this effect by personality traits and thus cannot make conclusions about our second hypothesis.

In line with the two models we sought to compare, we hypothesise that the effects we show in three experiments are, for a big part, due to the early processing of the amygdala. The functional domain of the amygdala may not be restricted to the detection and fast reaction of threat-related stimuli, including the rapid orienting of attention and processing resources (Öhman & Mineka, 2001). It may instead be regarded as a relevance detector (Sander et al., 2003) that will orient attention and prepare the individual to any stimulus in the environment showing some degree of importance to her current goals and well-being. However, if the amygdala plays a central role in relevance detection, it can only be regarded as a node of a more complex functional network including structures like the PFC or the LC–NE system, as hypothesised in some of the studies we reviewed in this work.

In addition, in light of our results, the concept of relevance as it was initially proposed (Scherer, 2001) lacks flexibility, in that it fails to account for the opposite results we describe: an attentional control mechanism precluding emotional stimuli from entering conscious awareness immediately after the onset of a first target (up to 100 msec), while supporting these same emotional stimuli in the competition against the first target after 300 msec. It therefore seems likely that if the early processing of relevance occurs, different outcomes may be expected depending on the current state of the cognitive system.

7.3 Limitations

By virtue of the scientific method (Popper, 1962), this work is limited in many ways. Let us review some aspects of our work that raise questions, and possible solutions to these issues.

General hypothesis. If we repeatedly found that both happy and fearful facial expressions modulate attention equally, and more than neutral facial expression, we failed to show a link to personality traits. Throughout our work, we used two methodologies to operationalize this second hypothesis. On the one hand, for the AB experiments, we selected groups of participants on the basis of their answer to personality questionnaires. We managed to create three homogeneous groups: an "anxious" group, an "extravert" group and a "control" group in-between the two first groups. On the other hand, for the psychophysical experiment, we simply asked our participants to fill in personality questionnaires and correlated their scores to these questionnaires to their results to the experiment. None of these methodologies provided us with usable material to test the influence of personality traits. We see two plausible explanations to this.

Firstly, we relied on a classical view of personality based on the five-factor model of personality (Costa & McCrae, 1991; McCrae & Costa, 1997). This model sees personality traits as durable dispositions of the individual and define invariants centrered around extraversion, agreeableness, conscientiousness, neuroticism and openness. Specifically, we hypothesised a continuum between extraversion and anxiety based on the perception of emotional facial expressions, on the basis of particular empirical results (Chapter 3 on page 45). This hypothesis – daring but valid given our knowledge at the time – may not rely on tangible ground after all. If the five-factor model is heavily used in psychology, other views emphasise the situational context during which personality dispositions emerge. Mischel & Shoda (1998, p. 233) for instance remark that "personality theory needs to analyse dispositions in a way that allows [us] to understand how individuals interact with situations and, most importantly, to identify and assess the dynamic intra-individual processes that underlie these interactions", pointing at what is known as the "personality paradox" (p. 246). Described in this paradox is the mismatch between the stability of personality traits hypothesised by the theory and the natural inclination of individuals to respond in particular ways depending on the situation. It may thus have been illusory to expect participants – selected to represent population at large – to behave in a predicted way within our experiment setup.

Secondly, we may have faced an issue in the sampling of our participants. Most studies investigating the link between emotion perception and personality traits rely on close-to-extreme groups, if not clinically diagnosed. At the same time, studies involving sub-clinical populations often report mix results. Therefore, it may be that the student population from which we drew our participant pools is not the best representative of either extravert or anxious populations. At the very least, we could have expected to find correlational links between personality as measured by questionnaires and measures of attention processing, which we did not find. This casts some doubt on the sensitivity of our measures to personality as measured by questionnaires.

The attentional blink effect to study attention. The AB is a very particular phenomenon. It has been brought to the attention of the research community only recently (Raymond et al., 1992), compared to other attentional phenomena like the Stroop effect (Stroop, 1935), for instance, and as such it is relatively unexplored and misunderstood. Because it explicitly brings a new dimension (i.e., time) in the general picture of how the cognitive system proceeds, explanations necessarily increase in complexity. The interpretation of our results are thus limited in many ways, and the scenario we proposed earlier has to be taken with a grain of salt.

In particular, the experimental paradigm yielding the AB effect enforces *serial processing* by definition. By instructing participants to perform several tasks, one after the other, researchers "set up" the cognitive system to perform in a serial way. It is consequently difficult to conclude unequivocally that there may be a dedicated system managing the serial processing of incoming targets (e.g. preemptive signalling), even though it may make sense given the intrinsic serial nature of events. Other models of perception for instance emphasise the reconstruction of perceived scenes based on a massively parallel processing system within which all possible states could be represented (e.g. Edelman, 2003; Tononi, 2004). These models hypothesise a processing very similar to the GW theory, but assume that the ordering of perception is due to the internal dynamics of the system. Edelman (2003) for instance proposes that a selective process, dubbed reentry, aggregates neural events in a coherent percept over time. However, if these theories account for the parallel processing power of the brain, until now they offered only few testable predictions.

On a different level, the RSVP paradigm rendering the AB effect offers a lot of room for researchers to manipulate a wide variety of parameters. In this work, we only tested a particular situation, namely the extent to which emotion-laden second targets benefit from a processing bias in a context of limited resources, most resources being engaged in the processing of the first target. This particular experimental situation only accounts for part of what may be going on, and future work could address the corollary situation with emotion-laden stimuli as first targets.

7.4 Future work

Emotional attention is the result of many interacting processes, and future work could address the causal relationships in the network of processes underlying this function. We believe this ambitious long-term program of research would depart from current efforts by explicitly investigating the temporal aspects of the processing, and would gain by including the perspectives generated from adjacent disciplines. This program of research is, of course, grounded on the work of cognitive scientists like Gardner (1985), and Kosslyn & Koenig (1995) who tentatively define general efforts of the kind in the framework of cognitive neuroscience as "a logical exercise aimed at determining what processing subsystems are necessary to produce a specific behaviour, given specific input" (Kosslyn & Koenig, 1995, page 41). It is interesting to note that these authors also attempted to bridge the gaps between relevant scientific disciplines and promoted interdisciplinary dialogue (see also Sander & Koenig, 2002).

Much in the same light, we thus propose to involve three different perspectives: theoretical modelling, computational neuroscience and empirical testing. From this standpoint, we believe that approaches that ground computational neuroscience in empirical work are capable of generating novel and innovative hypotheses about the brain. However, in addition to being constrained by empirical results, computational models should also be evaluated within similar experimental paradigms if their predictions are to be truly insightful (Figure 7.2).

In Chapter 2 (page 26), we defined temporal attention as the result of the competition over time between many neural mechanisms, to manage computing resources and prevent interference. Methods to address this phenomenon are mainly concerned with the probing of the very processes at play over time, aiming at describing the flow of information in the brain from the onset of the stimulus event to the ignition of the appropriate reaction by the organism. These methods generally embrace a number of assumptions, which form the foundations of modern (cognitive) psychology and (cognitive) neuroscience (Dolan, 2008), and can be defined as follows (Posner & DiGirolamo, 2000, quoting Miller & Lenneberg, 1978):

1. "Complex brain functions can be decomposed into simpler, more general processes.
2. These components can be localised anatomically and studied in relative isolation.
3. The simpler brain processes can be correlated directly with their simpler behaviour processes".

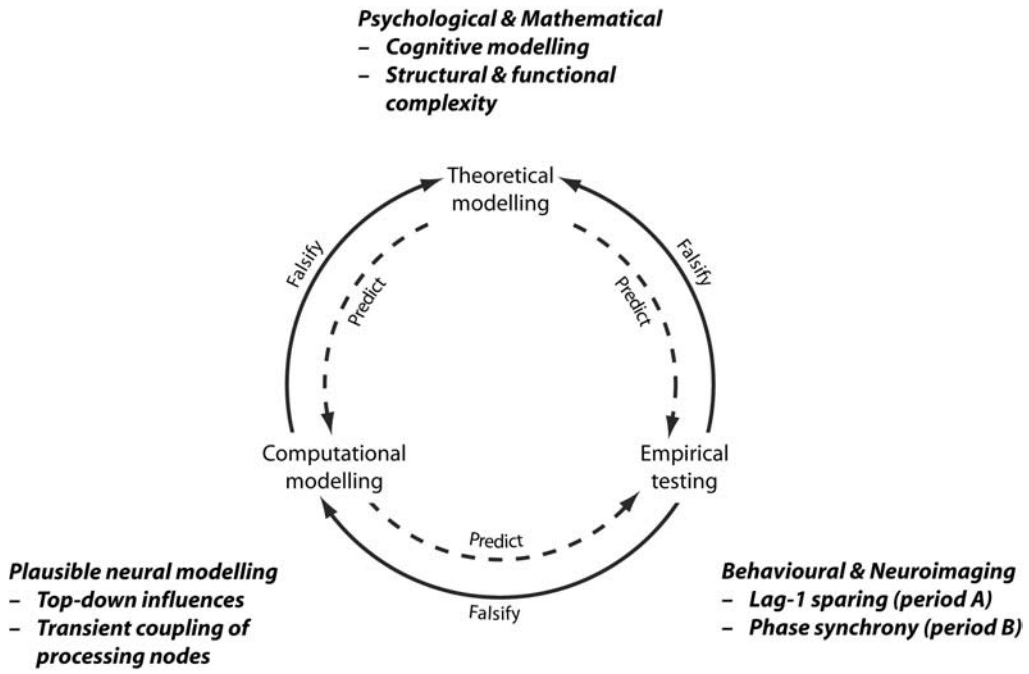

Figure 7.2: Three pillars of interdisciplinary dialogue applied to the investigation of emotional attention. Following work by Gardner (1985), and Kosslyn & Koenig (1995) we derived a representation of the iterative dialogue we believe is required to investigate the unfolding of attention to the processing of emotion-laden stimuli. A first version of this approach is described in Roesch et al. (2007), see Appendix B, on page 157. Possible tracks to extend the investigation of the AB are presented eccentrically. (Original work elaborated in the course of this thesis.)

Even though these assumptions constitute the foundation of modern (mainstream) research in psychology and neuroscience, and explicitly stating them here may seem redundant, we feel it is important to acknowledge that it is *one* particular way of addressing the broad topic of "cognition", for other approaches are proposed that should be reconciled as well (Sun, 2008, reviews several of such approaches). Efforts to form concepts of cognition based on mathematical theory of dynamical systems for instance are suitable candidates to address the topics of attention/consciousness (e.g., Tononi, 2004; Shanahan, 2007; Seth, 2008) and emotion (e.g., Scherer, 2000; Sander et al., 2005; Seth, 2009). In its most extreme form, this theoretical framework differs from mainstream conceptions in that theorists have been reluctant to assign any functional domain to the nodes of processing networks in the brain leading to conscious awareness and report. "What the brain does" is perceived through a complex interplay of activated nodes in a network of processing units, and described as a set of properties expressed through mathematical equations (W. J. Freeman, 1975).

In an agenda extending the work we presented in this manuscript, we would generally aim at investigating the rise of conscious awareness and its modulation by emotion. This ambitious long-term project leverages in part in the reconciliation of the approaches introduced above, through the design of experimental paradigms that allow the testing of predictions issued from these theories, and efforts to address these results through a strategy of analysis by synthesis (e.g., see Seth, 2009; Fleischer & Krichmar, 2007).

7.4.1 Experimental work

We identified a number of aspects in the AB literature in general and in our AB data in particular, which we believe offer points of entry to studying the antecedents to conscious awareness of emotional stimuli. Applying statistical methods tailored for this particular paradigm, we showed that the time course of the attentional blink can be decomposed into several periods, each of which may be differentially sensitive to emotion-laden information. We would thus propose to investigate what makes this periods of the processing particular, and the extent to which they are sensitive to emotion-laden information.

We would complement carefully designed experimental paradigms with the investigation of some of the markers of cognitive processing described in the neuroscience literature. The amount of synchrony between brain processes, for instance, has been repeatedly suggested as one of the mechanisms underlying conscious awareness and report of targets (see Section 2.2, on page 26, for review). One potential line of research would thus investigate the amount of cortical synchrony, during each of these three periods of processing.

In addition, the field of neuroimaging sees the development of exciting analysis techniques that focus on the causal relationships during the activation of the brain networks engaged in particular tasks (e.g., Friston et al., 2003; Seth & Edelman, 2007). Not only does this work offer a rounded view of causality that goes beyond the mere observation of correlations, but it also offers some insight into the assumptions we are making when describing a "cognitive process".

7.4.2 Computational modelling

Computational modelling provides researchers with the opportunity to put to the test the theories accounting for a particular psychological phenomenon. Simply put, "writing a piece of software forces theoreticians to be honest" (D. Evans, personal communication, August 21st, 2009). Computational neuroscience is that part of computational modelling that builds upon data from psychology and neuroscience, and attempts to understand the brain through modelling. We believe that efforts of the kind provide complementary perspectives to theoretical and experimental work.

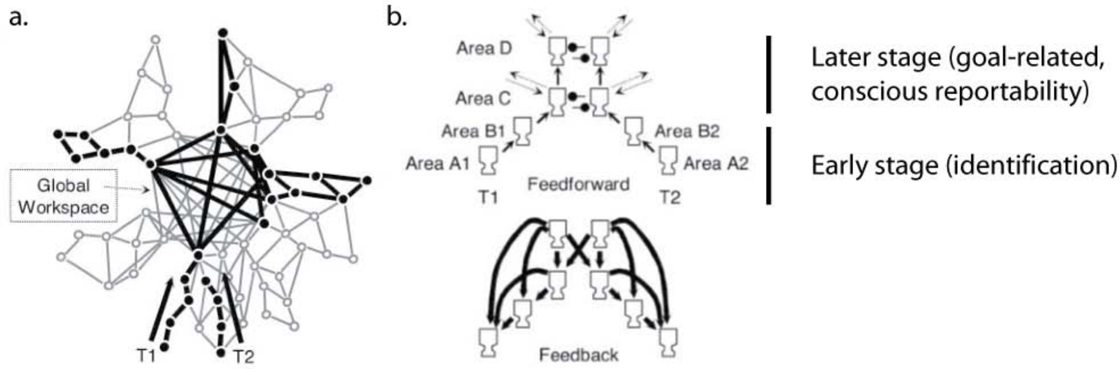

Figure 7.3: Panel a. Theoretical representation of the "global workspace" used by Dehaene et al. (2003) to investigate the competition between T1 and T2 targets in the attentional blink. Panel b. Representation of the neural modelling performed by Dehaene et al. (2003). Results showed that once the global workspace (areas C and D) is recruited by the first target, it gradually becomes inaccessible to the second target. Areas A and B represents occipito-temporal pathways through which targets are progressively identified. Areas C and D are involved in the conscious awareness of perceived targets, are goal-related (e.g., report).

Aims to this side of the project could thus be twofold: 1) To build and evaluate a biologically plausible neural network whose structure and dynamics are constrained by recent results in psychology (e.g.„ the functional description of the cognitive processes involved in emotional processing) and neuroscience (e.g.„ cortical and sub-cortical interactions, coherence within specialised networks of structures). 2) To engage in an interdisciplinary dialogue by formulating and testing new hypotheses in close collaboration with psychologists and neuroscientists.

More specifically, this effort extends the work on global workspace theory and proposes a framework for cognition (Baars, 1988; Dehaene et al., 2003). This framework permits the study of attention in the form of the cortical broadcast of information and the competition for resources between parallel specialist processing units (see Figure 7.3).

Combining data from functional magnetic resonance imaging and magnetoencephalography, several authors situated the processing bottleneck underlying the AB in a "global neuronal workspace", rendered by the transient synchronisation of several specialised networks of brain structures (Sergent et al., 2005; Hommel et al., 2006). This synchronisation would aim at stabilising the representation maintained in working memory, thereby increasing the likelihood of the target reaching awareness and being reported, whilst preventing other stimuli from perturbing the current processing. We hypothesise that emotional stimuli would benefit from the sustained activation produced in subcortical systems, centred in the amygdala, influencing cortical areas by means of top-down activations supporting their further processing. This activation would then be strong enough to interfere with the ongoing processing and enter the global workspace. The proposed research extends the work on the global workspace theory byShanahan & Baars (2005) and Shanahan (2006, 2007). Results from past simulations showed the feasibility of the approach, and act as a proof-of-concept to extend the model further. More specifically, we will develop large-scale, real-time artificial neural networks using the accelerated computing power of reconfigurable hardware. The model will be structured on the basis of current data from psychology and neuroscience, and thus allow us to investigate the dynamics of the underlying processing network. We will submit the model to experimental paradigms like the attentional blink to test current theories, formulate new hypotheses, which will then be used to perfect experimental efforts in psychology and neuroscience.

Bibliography

Allport, D. A. (1992). Attention and control. Have we been asking the wrong questions? A critical review of twenty-five years. In D. E. Meyer & S. Kornblum (Eds.), *Attention and performance XIV* (p. 183-218). Cambridge, MA: MIT Press.

Amir, N., Foa, E. B., & Coles, M. E. (1998). Automatic activation and strategic avoidance of threat-relevant information in social phobia. *Journal of Abnormal Psychology*, *107*(2), 285-290.

Anderson, A. K. (2005). Affective influences on the attentional dynamics supporting awareness. *Journal of Experimental Psychology: General*, *134*(2), 258–281.

Anderson, A. K., & Phelps, E. A. (2001). Lesions of the human amygdala impair enhanced perception of emotionally salient events. *Nature*, *411*(6835), 305–309.

Arnell, K. M., Killman, K. V., & Fijavz, D. (2007). Blinded by emotion: target misses follow attention capture by arousing distractors in rsvp. *Emotion*, *7*(3), 465–477.

Arnold, M. B. (1960). *Emotion and personality.* New York: Columbia University Press.

Aston-Jones, G., & Cohen, J. D. (2005). An integrative theory of locus coeruleus-norepinephrine function: adaptive gain and optimal performance. *Annual Reviews of Neuroscience*, *28*, 403–450.

Aston-Jones, G., Foote, S. L., & Bloom, F. E. (1984). Anatomy and physiology of locus coeruleus neurons: functional implications. In M. Ziegler & C. R. Lake (Eds.), *Norepinephrine: Frontiers of clinical neuroscience* (Vol. 2, p. 92-116). Baltimore: Williams and Wilkins.

Aston-Jones, G., Rajkowski, J., & Cohen, J. (1999). Role of locus coeruleus in attention and behavioral flexibility. *Biol Psychiatry*, *46*(9), 1309–1320.

Aston-Jones, G., Rajkowski, J., Ivanova, S., Usher, M., & Cohen, J. (1998). Neuromodulation and cognitive performance: recent studies of noradrenergic locus ceruleus neurons in behaving monkeys. *Advances in Pharmacology*, *42*, 755–759.

Baars, B. J. (1988). *A cognitive theory of consciousness.* Cambridge: Cambridge University Press.

Baars, B. J. (2002). The conscious access hypothesis: origins and recent evidence. *Trends in Cognitive Sciences*, *6*(1), 47–52.

Baars, B. J., & Franklin, S. (2003). How conscious experience and working memory interact. *Trends in Cognitive Science*, *7*(4), 166–172.

Barnard, P. J., Scott, S., Taylor, J., May, J., & Knightley, W. (2004). Paying attention to meaning. *Psychological Science*, *15*(3), 179–186.

Bashinski, H. S., & Bacharach, V. R. (1980). Enhancement of perceptual sensitivity as the result of selectively attending to spatial locations. *Perception and Psychophysics*, *28*(3), 241-248.

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

Berridge, C. W., & Waterhouse, B. D. (2003). The locus coeruleus-noradrenergic system: modulation of behavioral state and state-dependent cognitive processes. *Brain Research Reviews*, *42*, 33-84.

Bishop, S. J. (2007). Neurocognitive mechanisms of anxiety: an integrative account. *Trends in Cognitive Sciences*, *11*(7), 307-316.

Bishop, S. J., Duncan, J., & Lawrence, A. D. (2004). State anxiety modulation of the amygdala response to unattended threat-related stimuli. *Journal of Neuroscience*, *24*(46), 10364–10368.

Blanchette, I. (2006). Snakes, spiders, guns, and syringes: how specific are evolutionary constraints on the detection of threatening stimuli? *Quaterly Journal of Experimental Psychology*, *59*(8), 1484-1504.

Borod, J. C., & Madigan, N. K. (2000). Neuropsychology of emotion and emotional disorders: an overview and research directions. In J. C. Borod (Ed.), *The neuropsychology of emotion* (p. 3-28). Oxford University Press.

Boucher, J. D., & Brant, M. E. (1981). Judgment of emotion: American and malay antecedents. *Journal of Cross-Cultural Psychology*, *12*, 272-283.

Bowman, H., & Wyble, B. (2007). The simultaneous type, serial token model of temporal attention and working memory. *Psychological Review*, *114*(1), 38–70.

Bradley, B. P., Mogg, K., Falla, S. J., & Hamilton, L. R. (1998). Attentional bias for threatening facial expressions in anxiety: effect of stimulus duration. *Cognition and Emotion*, *12*(6), 737-753.

Bradley, B. P., Mogg, K., White, J., Groom, C., & Bono, J. de. (1999). Attentional bias for emotional faces in generalized anxiety disorder. *British Journal of Clinical Psychology*, *38*, 267-278.

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision*, *10*, 433-436.

Breitmeyer, B. G., & Ogmen, H. (2000). Recent models and findings in visual backward masking: a comparison, review and update. *Perception and Psychophysics*, *62*(8), 1572-1595.

Broadbent, D., & Broadbent, M. (1987). From detection to identification: response to multiple targets in rapid serial visual presentation. *Perception and Psychophysics*, *42*(2), 105-113.

Brosch, T., Sander, D., Pourtois, G., & Scherer, K. R. (in press). Beyond fear: Rapid spatial orienting towards positive emotional stimuli. *Psychological Science*.

Brosch, T., Sander, D., & Scherer, K. R. (2007). That baby caught my eye... attention capture by infant faces. *Emotion*, *7*(3), 685–689.

Brosch, T., & Sharma, D. (2005). The role of fear-relevant stimuli in visual search: a comparison of phylogenetic and ontogenetic stimuli. *Emotion*, *5*(3), 360–364.

Burr, D., Morrone, M., & Ross, J. (1994). Selective suppression of the magnocellular visual pathway during saccadic eye movements. *Nature*, *371*(6497), 511–513.

Cabeza, R., & Kato, T. (2000). Features are also important: contributions of featural and configural processing to face recognition. *Psychological Science*, *11*(5), 429-433.

Cacioppo, J. T., Bernston, G. G., & Crites, S. L. (1996). Social neuroscience: Principles of psychophysiological arousal and response. In E. T. Higgins & A. W. Kruglanski (Eds.), *Social psychology: Handbook of basic principles.* New York: Guilford Press.

Cacioppo, J. T., & Gardner, W. L. (1999). Emotion. *Annual Reviews in Psychology*, *50*, 191-214.

Calder, A. J., & Young, A. W. (2005). Understanding the recognition of facial identity and facial expression. *Nature Reviews: Neuroscience*, *6*, 641-651.

Calder, A. J., Young, A. W., Keane, J., & Dean, M. (2000). Configural information in facial expression perception. *Journal of Experimental Psychology: Human Perception and Performance*, *26*(2), 527–551.

Canli, T. (2004). Functional brain mapping of extraversion and neuroticism: learning from individual differences in emotion processing. *Journal of Personality*, *72*(6), 1105–1132.

Canli, T., Amin, Z., Haas, B., Omura, K., & Constable, R. T. (2004). A double dissociation between mood states and personality traits in the anterior cingulate. *Behavioral Neuroscience*, *118*(5), 897-904.

Canli, T., Sivers, H., Whitfield, S. L., Gotlib, I. H., & Gabrieli, J. D. (2002). Amygdala response to happy faces as a function of extraversion. *Science*, *296*(5576), 2191.

Canli, T., Zhao, Z., Desmond, J. E., Kang, E., Gross, J. J., & Gabrieli, J. D. (2001). An fmri study of personality influences on brain reactivity to emotional stimuli. *Behavioral Neuroscience*, *115*(1), 33-42.

Cheal, M., & Lyon, D. R. (1991). Central and peripheral precuing of forced-choice discrimination. *Quarterly Journal of Experimental Psychology*, *43A*(4), 859-880.

Chun, M. M. (1997). Types and tokens in visual processing: a double dissociation between the attentional blink and repetition blindness. *Journal of Experimental Psychology: Human Perception and Performance*, *23*(3), 738–755.

Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance*, *21*(1), 109–127.

Colombetti, G. (2005). Appraising valence. *Journal of Consciousness Studies*, *12*(8-10), 103-126.

Compton, R. J. (2003). The interface between emotion and attention: A review of evidence from psychology and neuroscience. *Behavioral and Cognitive Neuroscience Reviews*, *2*(2), 115-129.

Cooper, R. M., & Langton, S. R. H. (2006). Attentional bias to angry faces using the dot-probe task? it depends when you look for it. *Behaviour Research and Therapy*, *44*(9), 1321–1329.

Corneille, O., Hugenberg, K., & Timothy, P. (2007). Applying the attractor field model to social cognition: perceptual discrimination is facilitated, but memory is impaired for faces displaying evaluatively congruent expressions. *Journal of Personality and Social Psychology*, *93*(3), 335-352.

Costa, P., & McCrae, R. (1991). *Neo five-factor inventory (neo-ffi) professional manual.* Odessa, FL: Psychological Assessment Resources.

Cousineau, D., Brown, S., & Heathcote, A. (2004). Fitting distributions using maximum likelihood: methods and packages. *Behavioral Research Methods, Instruments and Computers*, *36*(4), 742–756.

Cousineau, D., Charbonneau, D., & Jolicoeur, P. (2006). Parameterizing the attentional blink effect. *Canadian Journal of Experimental Psychology*, *60*(3), 175–189.

Cristinzio, C., N'Diaye, K., Seeck, M., Vuilleumier, P., & Sander, D. (in press). Integration of gaze direction and facial expression in patients with unilateral amygdala damage. *Brain*.

Cunningham, W. A., Van Bavel, J. J., & Johnsen, I. R. (2008). Affective flexibility: Evaluative processing goals shape amygdala activity. *Psychological Science*, *19*(2), 152-160.

Darwin, C. (1872). *The expression of the emotions in man and animals* (3rd ed, 1999 ed.; P. Ekman, Ed.). London: HarperCollins.

Davidson, R. J. (1992). Emotion and affective style: hemispheric substrates. *Psychological Science*, *3*, 39-43.

Davidson, R. J. (1998). Affective style and affective disorders: perspectives from affective neuroscience. *Cognition and Emotion*, *12*(3), 307-330.

Davidson, R. J. (2000). The functional neuroanatomy of emotion and affective style. In R. D. Lane (Ed.), *Cognitive neuroscience of emotion* (p. 371-388). Oxford University Press.

Davidson, R. J. (2001). Toward a biology of personality and emotion. *Ann N Y Acad Sci*, *935*, 191–207.

Davidson, R. J., & Irwin, W. (1999). The functional neuroanatomy of emotion and affective style. *Trends in the Cognitive Sciences*, *3*(1), 11-21.

Davidson, R. J., Lewis, D. A., Alloy, L. B., Amaral, D. G., Bush, G., Cohen, J. D., et al. (2002). Neural and behavioral substrates of mood and mood regulation. *Biological Psychiatry*, *52*(6), 478-502.

Davidson, R. J., Pizzagalli, D., Nitschke, J. B., & Putnam, K. (2002). Depression: perspectives from affective neuroscience. *Annual Reviews in Psychology*, *53*, 545–574.

Dayan, P., & Yu, A. J. (2006). Phasic norepinephrine: a neural interrupt signal for unexpected events. *Network*, *17*(4), 335–350.

Dehaene, S., Changeux, J.-P., Naccache, L., Sackur, J., & Sergent, C. (2006). Conscious, preconscious, and subliminal processing: a testable taxonomy. *Trends in Cognitive Sciences*, *10*(5), 204–211.

Dehaene, S., Sergent, C., & Changeux, J.-P. (2003). A neuronal network model linking subjective reports and objective physiological data during conscious perception. *Proceedings of the National Academy of Sciences of the United States of America*, *100*(14), 8520–8525.

Delplanque, S., N'Diaye, K., Scherer, K. R., & Grandjean, D. (2007). Spatial frequencies or emotional effects?: A systematic measure of spatial frequencies for IAPS pictures by a discrete wavelet analysis. *Journal of Neuroscience Methods*, *165*, 144-150.

De Martino, B., Kalisch, R., Rees, G., & Dolan, R. (2008). Enhanced processing of threat stimuli under limited attentional resources. *Cerebral Cortex*.

De Martino, B., Strange, B. A., & Dolan, R. J. (2008). Noradrenergic neuromodulation of human attention for emotional and neutral stimuli. *Psychopharmacology*, *197*, 127-136.

Derryberry, D., & Reed, M. (1994). Temperament and attention: orienting toward and away from positive and negative signals. *Journal of Personality and Social Psychology*, *66*(6), 1128-1139.

Derryberry, D., & Reed, M. A. (2002). Anxiety-related attentional biases and their regulation by attentional control. *Journal of Abnormal Psychology*, *111*(2), 225–236.

Desimone, R. (1998). Visual attention mediated by biased competition in extrastriate visual cortex. *Philosophical Transactions of the Royal Society of London. Series B.*, *353*, 1245-1255.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Reviews of Neuroscience*, *18*, 193-222.

Dolan, R. J. (2008). Neuroimaging of cognition: past, present, and future. *Neuron*, *60*(6), 496-502.

Dosher, B. A., & Lu, Z. L. (2000). Noise exclusion in spatial attention. *Psychological Science*, *11*(2), 139-146.

Driver, J. (2001). A selective review of selective attention research from the past century. *British Journal of Psychology*, *92*(1), 53-78.

Duffy, E. (1934). Emotion: an example of the need for reorientation in psychology. *Psychological Review*, *41*(2), 184-198.

Duffy, E. (1957). The psychological significance of the concept of arousal or activation. *Psychological Review*, *64*(5), 265-275.

Duncan, J. (1996). Cooperating brain systems in selective perception and action. In T. Inui & J. L. McClelland (Eds.), *Attention and performance XVI.* Cambridge, MA: MIT Press.

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review*, *96*(3), 433-458.

Duncan, J., Ward, R., & Shapiro, K. L. (1994). Direct measurement of attentional dwell time in human vision. *Nature*, *369*(6478), 313-315.

Dux, P. E., & Coltheart, V. (2005). The meaning of the mask matters: evidence of conceptual interference in the attentional blink. *Psychological Science*, *16*(10), 775–779.

Dux, P. E., & Harris, I. M. (2007). On the failure of distractor inhibition in the attentional blink. *Psychonomic Bulletin and Review*, *14*(4), 723–728. (- cognitive penetrability / permeability)

e frontier. (2007). *Poser 7.* (http://www.e-frontier.com/go/products/poser)

Edelman, G. M. (2003). Naturalizing consciousness: a theoretical framework. *Proceedings of the National Academy of Sciences of the United States of America*, *100*(9), 5520-5524.

Edwards, K. (1998). The face of time: Temporal cues in facial expressions of emotion. *Psychological Science*, *9*(4), 270-276.

Einhauser, W., Koch, C., & Makeig, S. (2007). The duration of the attentional blink in natural scenes depends on stimulus category. *Vision Research*, *47*(5), 597–607.

Ekman, P. (1992). Are there basic emotions? *Psychological Review*, *99*, 550-553.

Ekman, P. (1999). Basic emotions. In T. Dalgleish & M. J. Power (Eds.), *Handbook of cognition and emotion.* Chichester, England ; New York: Wiley.

Ekman, P. (2003). *Emotions revealed: recognizing faces and feelings to improve communication and emotional life* (1st ed.). London, UK: Weidenfeld & Nicolson.

Ekman, P. (2004). What we become emotional about. In A. S. R. Manstead, N. H. Frijda, & A. Fischer (Eds.), *Feelings and emotions : the amsterdam symposium* (p. 119-135). Cambridge, UK ; New-York: Cambridge University Press.

Ekman, P., & Friesen, W. V. (1976). Measuring facial movement. *Environmental Psychology and Non-verbal Behavior*, *1*(1), 56-75.

Ekman, P., Friesen, W. V., & Hager, J. (2002). The facial action coding system (2nd ed. ed.) [Computer software manual]. London, UK.

Ekman, P., Irwin, W., & Rosenberg, E. L. (1994). The emotional facial action coding system (emfacs) (2nd ed. ed.) [Computer software manual]. London, UK.

Ellison, J. W., & Massaro, D. W. (1997). Featural evaluation, integration, and judgment of facial affect. *Journal of Experimental Psychology: Human Perception and Performance*, *23*(1), 213-226.

Ellsworth, P. C., & Scherer, K. R. (2003). Appraisal processes in emotion. In R. J. Davidson, K. R. Scherer, & H. H. Goldsmith (Eds.), *Handbook of affective sciences.* Oxford University Press.

Enns, J., & Di Lollo, V. (2000). What's new in visual masking? *Trends in Cognitive Sciences*, *4*(9), 345–352.

Epstein, S. (1972). The nature of anxiety with emphasis upon its relationship to expectancy. In C. D. Spielberger (Ed.), *Anxiety: Current trends in theory and research* (Vol. 2, p. 292-338). New York: Academic Press.

Esterman, M., Prinzmetal, W., DeGutis, J., Landau, A., Hazeltine, E., Verstynen, T., et al. (2008). Voluntary and involuntary attention affect face discrimination differently. *Neuropsychologia*, *46*(4), 1032-1040.

Esteves, F., & Öhman, A. (1993). Masking the face: recognition of emotional facial expressions as a function of the parameters of backward masking. *Scandinavian Journal of Psychology*, *34*(1), 1-18.

Etkin, A., Klemenhagen, K. C., Dudman, J. T., Rogan, M. T., Hen, R., Kandel, E. R., et al. (2004). Individual differences in trait anxiety predict the response of the basolateral amygdala to unconsciously processed fearful faces. *Neuron*, *44*, 1043-1055.

Eysenck, M. W. (1992). *Anxiety: the cognitive perspective.* Hove, UK ; Hillsdale, USA: Erlbaum Associates.

Feinstein, J. S., Stein, M. B., Castillo, G. N., & Paulus, M. P. (2004). From sensory processes to conscious perception. *Consciousness and Cognition*, *13*(2), 323–335.

Feldman Barett, L. (2006). Valence is a basic building block of emotional life. *Journal of Research in Personality*, *40*, 35-55.

Fenske, M. J., & Eastwood, J. D. (2003). Modulation of focused attention by faces expressing emotion: evidence from flanker tasks. *Emotion*, *3*(4), 327-343.

Fiser, J., Bex, P. J., & Makous, W. (2003). Contrast conservation in human vision. *Vision Research*, *43*, 2637-2648.

Fitzgerald, D. A., Angstadt, M., Jelsone, L. M., Nathan, P. J., & Phan, K. L. (2006). Beyond threat: amygdala reactivity across multiple expressions of facial affect. *Neuroimage*, *30*(4), 1441–1448.

Fleischer, J. G., & Krichmar, J. L. (2007). Sensory integration and remapping in a model of the medial temporal lobe during maze navigation by a brain-based device. *Journal of Integrative Neuroscience*, *6*(3), 403-431.

Flykt, A., Esteves, F., & Ohman, A. (2007). Skin conductance responses to masked conditioned stimuli: phylogenetic/ontogenetic factors versus direction of threat? *Biological Psychology*, *74*(3), 328–336.

Fodor, J. A. (1983). *The modularity of mind : an essay on faculty psychology.* Cambridge, Mass: MIT Press.

Fontaine, J. R., Scherer, K. R., Roesch, E. B., & Ellsworth, P. C. (2007). The world of emotions is not two-dimensional. *Psychological Science*, *18*(12), 1050-1057.

Fox, C. J., Oruc, I., & Barton, J. J. S. (2008). It doesn't matter how you feel. the facial identity aftereffect is invariant to changes in facial expression. *Journal of Vision*, *8*(3), 1-13.

Fox, E. (1996). Selective processing of threatening words in anxiety: the role of awareness. *Cognition and Emotion*, *10*(5), 449-480.

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

Fox, E., Mathews, A., Calder, A. J., & Yiend, J. (2007). Anxiety and sensitivity to gaze direction in emotionally expressive faces. *Emotion*, *7*(3), 478-486.

Fox, E., Russo, R., Bowles, R., & Dutton, K. (2001). Do threatening stimuli draw or hold visual attention in subclinical anxiety? *Journal of Experimental Psychology: General*, *130*(4), 681-700.

Fox, E., Russo, R., & Georgiou, G. (2005). Anxiety modulates the degree of attentive resources required to process emotional faces. *Cognitive, Affective, & Behavioral Neuroscience*, *5*(4), 396-404.

Fragopanagos, N., Kockelkoren, S., & Taylor, J. G. (2005). A neurodynamic model of the attentional blink. *Brain research. Cognitive Brain Research*, *24*(3), 568–586.

Freeman, J. B., & Ambady, N. (2009). Motions of the hand expose the partial and parallel activation of stereotypes. *Psychological Science*, *xx*(xx), xx-xx.

Freeman, W. J. (1975). *Mass action in the nervous system: examination of the neurophysiological basis of adaptive behavior through the eeg.* New York: Academic Press.

Frewen, P. A., Dozois, D. J. A., Joanisse, M. F., & Neufeld, R. W. J. (2008). Selective attention to threat versus reward: meta-analysis and neural network modeling of the dot-probe task. *Clinical Psychological Review*, *28*(2), 307-337.

Frijda, N. H. (2005). Emotion experience. *Cognition and Emotion*, *19*(4), 473-497.

Frijda, N. H., & Tcherkassof, A. (1997). Facial expressions as modes of action readiness. In J. A. Russell (Ed.), *The psychology of facial expression* (p. 78-102). New-York, NY: Cambridge University Press.

Friston, K. J., Harrison, L., & Penny, W. (2003). Dynamic causal modelling. *Neuroimage*, *19*, 1273-1302.

Gaag, C. van der, Minderaa, R. B., & Keysers, C. (2007). The bold signal in the amygdala does not differentiate between dynamic facial expressions. *Social Cognitive and Affective Neuroscience*, *2*, 93-103.

Gardner, H. (1985). *The mind's new science: a history of the cognitive revolution.* New York: Basic Books.

Giesbrecht, B., & Kingstone, A. (2004). Right hemisphere involvement in the attentional blink: evidence from a split-brain patient. *Brain Cogn*, *55*(2), 303–306.

Giesbrecht, B., Sy, J., & Lewis, M. (2008). Personal names do not always survive the attentional blink: Behavioral evidence for a flexible locus of selection. *Vision Research.*

Gilzenrat, M. S., Holmes, B. D., Rajkowski, J., Aston-Jones, G., & Cohen, J. D. (2002). Simplified dynamics in a model of noradrenergic modulation of cognitive performance. *Neural Networks*, *15*(4), 647-663.

Goeleven, E., De Raedt, R., Leyman, L., & Verschuere, B. (2008). The karolinska directed emotional faces: a validation studies. *Cognition and Emotion*, *22*(6), 1094-1118.

Gomez-Cuerva, J., Jackson, M. C., & Raymond, J. E. (2008). Identification of expressive faces in the attentional blink [abstract]. *Journal of Vision*, *8*(6), 702-702.

Gotlib, I. H., & McCann, D. C. (1984). Construct accessibility and depression: an examination of cognitive and affective factors. *Journal of Personality and Social Psychology*, *47*(2), 427-439.

Grammer, K., Tessarek, A., & Hofer, G. (to appear). From emoticons to avatars: the simulation of facial expression. In A. Kappas (Ed.), *Emotional communication on the internet.* xxx: xxx.

Grandison, T. D., Ghirardelli, T. G., & Egeth, H. E. (1997). Beyond similarity: masking of the target is sufficient to cause the attentional blink. *Perception and Psychophysics*, *59*(2), 266–274.

Grandjean, D., & Scherer, K. R. (2008). Unpacking the cognitive architecture of emotion processes. *Emotion*, *8*(3), 341-351.

Gross, J., Schmitz, F., Schnitzler, I., Kessler, K., Shapiro, K. L., Hommel, B., et al. (2004). Modulation of long-range neural synchrony reflects temporal limitations of visual attention in humans. *Proceedings of the National Academy of Sciences of the United States of America*, *101*(35), 13050–13055.

Hamann, S., & Canli, T. (2004). Individual differences in emotion processing. *Current Opinion in Neurobiology*, *14*(2), 233-8.

Hamm, A. O., Schupp, H. T., & Weike, A. I. (2003). Motivational organization of emotion: autonomic changes, cortical responses, and reflex modulation. In R. J. Davidson, K. R. Scherer, & H. H. Goldsmith (Eds.), *Handbook of affective sciences* (p. 187-211). Oxford ; New York: Oxford University Press.

Heathcote, A. (2004). Fitting wald and ex-wald distributions to response time data: an example using functions for the s-plus package. *Behavioral Research Methods, Instruments and Computers*, *36*(4), 678–694.

Hebb, D. O. (1955). Drives and the CNS (conceptual nervous system). *Psychological Review*, *62*(4), 243-254.

Hein, G., Alink, A., Kleinschmidt, A., & Muller, N. (2008). The attentional blink modulates activity in the early visual cortex. *Journal of Cognitive Neuroscience*.

Heinrichs, N., & Hofmann, S. G. (2001). Information processing in social phobia: A critical review. *Clinical Psychological Review*, *21*(5), 751-770.

Hess, U., Blairy, S., & Kleck, R. E. (1997). The intensity of emotional facial expressions and decoding accuracy. *Journal of Nonverbal Behavior*, *21*(4), 241-257.

Hezle, V., Biehn, C., Schlömer, T., & Linner, F. (2004). Adaptable setup for performance driven facial animation. In *Proceedings of SIGGRAPH'04 - Sketches.* Los Angeles, U.S.A.: Springer.

Hirsh, J., Alqudah, A. F., Stutts, L. A., & Robinson, M. E. (2009). Virtual human technology: capturing sex, race, and age influences in individual pain decision policies. *Pain*, *140*, 231-238.

Hommel, B., & Akyurek, E. G. (2005). Lag-1 sparing in the attentional blink: benefits and costs of integrating two events into a single episode. *Quaterly Journal of Experimental Psychology*, *58A*(8), 1415–1433.

Hommel, B., Kessler, K., Schmitz, F., Gross, J., Akyurek, E., Shapiro, K. L., et al. (2006). How the brain blinks: towards a neurocognitive model of the attentional blink. *Psychol Res*, *70*(6), 425–435.

Horenstein, M., & Segui, J. (1997). Chronometrics of attentional processes in anxiety disorders. *Psychopathology*, *30*, 25-35.

Horstmann, G., & Ansorge, U. (2009). Visual search for facial expressions of emotions: A comparison of dynamic and static faces. *Emotion*, *9*(1), 29-38.

Horstmann, G., & Becker, S. I. (2009). Attentional effects of negative faces: top-down contingent or involuntary? *Perception and Psychophysics*, *70*, 1416-1434.

Horstmann, G., Borgstedt, K., & Heumann, M. (2006). Flanker effects with faces may depend on perceptual as well as emotional differences. *Emotion*, *6*(1), 28-39.

Huang, Y.-M., Baddeley, A., & Young, A. W. (2008). Attentional capture by emotional stimuli is modulated by semantic processing. *Journal of Experimental Psychology-Human Perception and Performance*, *34*, 328-339.

Izard, C. E. (1979). Emotions as motivations: an evolutionary-developmental perspective. In H. E. Howe & R. A. Dienstbier (Eds.), *Nebraska symposium on motivation* (p. 163-200). University of Nebraska Press.

Izard, C. E. (1992). Basic emotions, relations among emotions, and emotion-cognition relations. *Psychological Review*, *99*(3), 561-565.

Izard, C. E. (2007). Basic emotions, natural kinds, emotion schemas, and a new paradigm. *Perspectives on psychological science*, *2*, 260-280.

Jackson, M. C., & Raymond, J. E. (2006). The role of attention and familiarity in face identification. *Perception and Psychophysics*, *68*(4), 543–557.

Johnston, S. J., Shapiro, K. L., Vogels, W., & Roberts, N. J. (2007). Imaging the attentional blink: perceptual versus attentional limitations. *Neuroreport*, *18*(14), 1475–1478.

Jolicoeur, P. (1998). Modulation of the attentional blink by on-line response selection: evidence from speeded and unspeeded task1 decisions. *Memory and Cognition*, *26*(5), 1014–1032.

Jolicoeur, P. (1999). Dual-task interference and visual encoding. *Journal of Experimental Psychology: Human Perception and Performance*, *25*(3), 596-616.

Jong, P. J. de, & Martens, S. (2007). Detection of emotional expressions in rapidly changing facial displays in high- and low-socially anxious women. *Behaviour Research and Therapy*, *45*(6), 1285–1294.

Joorman, J., & Gotlib, I. H. (2006). Is this happiness I see? biases in the identification of emotional facial expressions in depression and social phobia. *Journal of Abnormal Psychology*, *115*(4), 705-714.

Juth, P., Lundqvist, D., Karlsson, A., & Öhman, A. (2005). Looking for foes and friends: perceptual and emotional factors when finding a face in the crowd. *Emotion*, *5*(4), 379-95.

Kamachi, M., Bruce, V., Mukaida, S., Gyoba, J., Yoshikawa, S., & Akamatsu, S. (2001). Dynamic properties influence the perception of facial expressions. *Perception*, *30*(7), 875-887.

Kanwisher, N. (1987). Repetition blindness: type recognition without token individuation. *Cognition*, *27*, 117-143.

Kanwisher, N., & Wojciulik, E. (2000). Visual attention: insights from brain imaging. *Nature Reviews: Neuroscience*, *1*(2), 91-100.

Kastner, S., & Ungerleider, L. (2000). Mechanisms of visual attention in the human cortex. *Annual Reviews of Neuroscience*, *23*, 315-341.

Keil, A., & Ihssen, N. (2004). Identification facilitation for emotionally arousing verbs during the attentional blink. *Emotion*, *4*(1), 23-35.

Keil, A., Ihssen, N., & Heim, S. (2006). Early cortical facilitation for emotionally arousing targets during the attentional blink. *BMC Biology*, *4*, 23.

Kessler, K., Gross, J., Schmitz, F., & Schnitzler, A. (2006). Cortical dynamics and synchronization related to multiple target consolidation under rapid-serial-visual-presentation conditions. *J Physiol Paris*, *99*(1), 21–28.

Kessler, K., Schmitz, F., Gross, J., Hommel, B., Shapiro, K. L., & Schnitzler, A. (2005). Target consolidation under high temporal processing demands as revealed by meg. *Neuroimage*, *26*(4), 1030–1041.

Kihara, K., Hirose, N., Mima, T., Abe, M., Fukuyama, H., & Osaka, N. (2007). The role of left and right intraparietal sulcus in the attentional blink: a transcranial magnetic stimulation study. *Experimental Brain Research*, *178*(1), 135–140.

Kihara, K., & Osaka, N. (2008). Early mechanism of negativity bias: An attentional blink study. *Japanese Psychological Research*, *50*, 1-11.

Klein, S. A. (2001). Measuring, estimating, and understanding the psychometric function: a commentary. *Perception and Psychophysics*, *63*(8), 1421–1455.

Kleinginna, P. R., & Kleinginna, A. M. (1981). A categorized list of emotion definitions, with suggestions for a consensual definition. *Motivation and Emotion*, *5*(4), 345-359.

Kosslyn, S. M., & Koenig, O. (1995). *Wet mind: the new cognitive neuroscience* (1st ed.). New York: Free Press.

Kranczioch, C., Debener, S., & Engel, A. K. (2003). Event-related potential correlates of the attentional blink phenomenon. *Brain research. Cognitive Brain Research*, *17*(1), 177–187.

Kranczioch, C., Debener, S., Schwarzbach, J., Goebel, R., & Engel, A. K. (2005). Neural correlates of conscious perception in the attentional blink. *Neuroimage*, *24*(3), 704–714.

Kroeze, S., & van den Hout, M. A. (2000). Selective attention for cardiac information in panic patients. *Behaviour Research and Therapy*, *38*, 63-72.

Krumhuber, E., Manstead, S. R. A., Cosker, D., Marshall, D., Rosin, P. L., & Kappas, A. (2007). Facial dynamics as indicators of trustworthiness and cooperative behavior. *Emotion*, *7*(4), 730-735.

Krumhuber, E., Manstead, S. R. A., & Kappas, A. (2007). Temporal aspects of facial displays in person and expression perception: the effects of smile dynamics, head-tilt, and gender. *Journal of Nonverbal Behavior*, *31*, 39-56.

LaBar, K. S., Crupain, M. J., Voyvodic, J. T., & McCarthy, G. (2003). Dynamic perception of facial affect and identity in the human brain. *Cerebral Cortex*, *13*(10), 1023–1033.

Lane, R. D., Chua, P. M., & Dolan, R. J. (1999). Common effects of emotional valence, arousal and attention on neural activation during visual processing of pictures. *Neuropsychologia*, *37*(9), 989–997.

Lang, P. J., Bradley, B. P., & Cuthbert, B. N. (1997). Motivated attention: affect, activation, and action. In P. J. Lang, R. F. Simons, & M. Balaban (Eds.), *Attention and orienting: sensory and motivational processes.* Mahwah, N.J.: Erlbaum.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1990). Emotion, attention, and the startle reflex. *Psychological Review*, *97*(3), 377-395.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1998). Emotion and motivation: measuring affective perception. *Journal of Clinical Neurophysiology*, *15*(5), 397-408.

Lang, P. J., Davis, M., & Öhman, A. (2000). Fear and anxiety: animal models and human cognitive psychophysiology. *Journal of Affective Disorders*, *61*(3), 137-159.

Lang, P. J., Greenwald, M. K., Bradley, M. M., & Hamm, A. O. (1993). Looking at pictures: affective, facial, visceral, and behavioral reactions. *Psychophysiology*, *30*(3), 261-273.

Lazarus, R. S. (1966). *Psychological stress and the coping process.* New York: McGraw-Hill.

Lazarus, R. S. (1991). *Emotion and adaptation.* New York, NY: Oxford University Press.

LeDoux, J. E. (1996). *The emotional brain: the mysterious underpinnings of emotional life.* New York, NY: Simon & Schuster.

Levenson, R. W. (1999). The intrapersonal functions of emotion. *Cognition and Emotion*, *13*(5), 481-504.

Levenson, R. W. (2003). Blood, sweat and fears. *Annals of the New York Academy of Sciences*, *1000*, 348-366.

Lewontin, R. C. (2000). *The triple helix: gene, organism, and environment.* Cambridge, Mass.: Harvard University Press.

Lipp, O. V., & Derakshan, N. (2005). Attentional bias to pictures of fear-relevant animals in a dot probe task. *Emotion*, *5*, 365-369.

Lipp, O. V., Derakshan, N., Waters, A. M., & Logies, S. (2004). Snakes and cats in the flower bed: Fast detection is not specific to pictures of fear-relevant animals. *Emotion*, *4*(3), 233–250.

Luck, S. J., Vogel, E. K., & Shapiro, K. L. (1996). Word meanings can be accessed but not reported during the attentional blink. *Nature*, *383*(6601), 616–618.

Lundqvist, D., Esteves, F., & Öhman, A. (1998). The Karolinska Directed Emotional Faces - KDEF, CD ROM from Dept. Clinical Neuroscience, Psychology section, Karolinska Institutet, ISBN 91-630-7164-9.

Lundqvist, M., Rehn, M., Djurfeldt, M., & Lansner, A. (2006). Attractor dynamics in a modular network model of neocortex. *Network*, *17*(3), 253–276.

Mack, A., Pappas, Z., Silverman, M. E., & Gay, R. (2002). What we see: inattention and the capture of attention by meaning. *Consciousness and Cognition*, *11*, 488-506.

MacLeod, C. (1991). Half a century of research on the stroop effect. *Psychological Bulletin*, *109*(2), 163-203.

MacLeod, C., Mathews, A., & Tata, P. (1986). Attentional bias in emotional disorders. *Journal of Abnormal Psychology*, *95*, 15-20.

Macmillan, N. A. (2001). Threshold estimation: the state of the art. *Perception and Psychophysics*, *63*(8), 1277–1278.

Maki, W. S., Frigen, K., & Paulson, K. (1997). Associative priming by targets and distractors during rapid serial visual presentation: does word meaning survive the attentional blink? *Journal of Experimental Psychology: Human Perception and Performance*, *23*(4), 1014-1034.

Maki, W. S., & Mebane, M. W. (2006). Attentional capture triggers an attentional blink. *Psychonomic Bulletin and Review*, *13*(1), 125–131.

Malatesta, L., Raouzaiou, A., Karpouzis, K., & Kollias, S. (2006). Mpeg-4 facial expression synthesis based on appraisal theory. In *3rd ifip conference in artificial intelligence applications and innovations, aiai 2006.* Athens, Greece: rd IFIP conference in Artificial Intelligence Applications and Innovations, AIAI 2006.

Mansell, W., Clark, D. M., & Ehlers, A. (2003). Internal versus external attention in social anxiety: an investigation using a novel paradigm. *Behavioral Research and Therapy*, *41*, 555-572.

Mansell, W., Clark, D. M., Ehlers, A., & Chen, Y. P. (1999). Social anxiety and attention away from emotional faces. *Cognition and Emotion*, *13*, 673-690.

Maratos, F. A., Mogg, K., & Bradley, B. P. (2008). Identification of angry faces in the attentional blink. *Cognition and Emotion*, *22*(1), 1-13.

Marcantoni, W. S., Lepage, M., Beaudoin, G., Bourgouin, P., & Richer, F. (2003). Neural correlates of dual task interference in rapid visual streams: an fmri study. *Brain and Cognition*, *53*(2), 318–321.

Marois, R. (2005). Two-timing attention. *Nature Neuroscience*, *8*(10), 1285-1286.

Marois, R., Chun, M. M., & Gore, J. C. (2000). Neural correlates of the attentional blink. *Neuron*, *28*(1), 299–308.

Marois, R., Yi, D.-J., & Chun, M. M. (2004). The neural fate of consciously perceived and missed events in the attentional blink. *Neuron*, *41*(3), 465–472.

Mathewson, K. J., Arnell, K. M., & Mansfield, C. A. (2008). Capturing and holding attention: the impact of emotional words in rapid serial visual presentation. *Memory and Cognition*, *36*(1), 182–200.

Matsumoto, D., Kudoh, T., Scherer, K. R., & Wallbott, H. (1988). Antecedents of and reactions to emotions in the united states and japan. *Journal of Cross-Cultural Psychology*, *19*(3), 267-286.

McCrae, R. R., & Costa, P. T. J. (1997). Personality trait structure as a human universal. *American psychologist*, *52*(5), 509-516.

McKenna, F. P., & Sharma, D. (2004). Reversing the emotional stroop effect reveals that it is not what it seems: the role of fast and slow components. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *30*(2), 382-392.

McNally, R. J. (1995). Automaticity and the anxiety disorders. *Behavioral Research and Therapy*, *33*(7), 747-754.

Melcher, D., & Morrone, M. C. (2003). Spatiotopic temporal integration of visual motion across saccadic eye movements. *Nature Neuroscience*, *6*(8), 877-881.

Milders, M., Sahraie, A., Logan, S., & Donnellon, N. (2006). Awareness of faces is modulated by their emotional meaning. *Emotion*, *6*(1), 10-17.

Miller, G. A., & Lenneberg, E. (Eds.). (1978). *Psychology and biology of language and thought: essays in honor of eric lenneberg.* New York, NY: Academic Press.

Mineka, S., & Öhman, A. (2002). Phobias and preparedness: the selective, automatic, and encapsulated nature of fear. *Biological Psychiatry*, *52*(10), 927-937.

Mischel, W., & Shoda, Y. (1998). Reconciling processing dynamics and personality dispositions. *Annual Reviews of Psychology*, *49*, 229-258.

Mobbs, D., Hagan, C. C., Azim, E., Menon, V., & Reiss, A. L. (2005). Personality predicts activity in reward and emotional regions associated with humor. *Proceedings of the National Academy of Sciences of the United States of America*, *102*(45), 16502–16506.

Mogg, K., & Bradley, B. P. (1998). A cognitive-motivational analysis of anxiety. *Behaviour Research and Therapy*, *36*, 809-848.

Mogg, K., & Bradley, B. P. (1999). Orienting of attention to threatening facial expressions presented under conditions of restricted awareness. *Cognition and Emotion*, *13*(6), 713-740.

Mogg, K., Bradley, B. P., Dixon, C., Fisher, S., Twerlfree, H., & McWilliams, A. (2000). Trait anxiety, defensiveness and selective processing of threat: An investigation using two measures of attentional bias. *Personality and Individual Differences*, *28*, 1063-1077.

Mogg, K., & Marden, B. (1990). Processing of emotional information in anxious subjects. *Br J Clin Psychol*, *29 (Pt 2)*, 227–229.

Mogg, K., Mathews, A., & Eysenck, M. W. (1992). Attentional bias to threat in clinical anxiety states. *Cognition and Emotion*, *6*, 149-159.

Mogg, K., Philippot, P., & Bradley, B. P. (2004). Selective attention to angry faces in clinical social phobia. *Journal of Abnormal Psychology*, *113*(1), 160-165.

Moore, C. M., Egeth, H. E., Berglan, L. R., & Luck, S. J. (1996). Are attentional dwell times inconsistent with serial visual search. *Psychonomic Bulletin and Review*, *3*(3), 360-365.

Moors, A., & De Houwer, J. (2006). Automaticity: a theoretical and conceptual analysis. *Psychological Bulletin*, *132*(2), 297-326.

Moradi, F., Koch, C., Shimojo, S., Sarma, G., & Gutierrez, J. (2005, May). Adaptation to face identity and emotional expression depends on attention. In *Proceedings of vision sciences society 5th.* Sarasota, FL: Journal of Vision.

Morris, J. S., Friston, K. J., Büchel, C., Frith, C. D., Young, A. W., Calder, A. J., et al. (1998). A neuromodulatory role for the human amygdala in processing emotional facial expressions. *Brain*, *121*(Pt 1), 47-57.

Morris, J. S., Öhman, A., Arne, & Dolan, R. J. (1998). Conscious and unconscious emotional learning in the human amygdala. *Nature*, *393*(6684), 467-470.

Moser, E., Derntl, B., Robinson, S., Fink, B., Gur, R. C., & Grammer, K. (2007). Amygdala activation at 3t in response to human and avatar facial expressions of emotions. *Journal of Neuroscience Methods*, *161*(1), 126–133.

Most, S. B., Chun, M. M., Johnson, M. R., & Kiehl, K. A. (2006). Attentional modulation of the amygdala varies with personality. *Neuroimage*, *31*(2), 934–944.

Most, S. B., Smith, S. D., Cooter, A. B., Levy, B. N., & Zald, D. H. (2007). The naked truth: Positive, arousing distractors impair rapid target perception. *Cognition and Emotion*, *21*(5), 964-981.

N'Diaye, K., Sander, D., & Vuilleumier, P. (in press). Self-relevance processing in the amygdala: gaze direction, facial expression, and emotion intensity. *Emotion*.

Nieuwenhuis, S., Aston-Jones, G., & Cohen, J. D. (2005). Decision making, the P3, and the locus coeruleus-norepinephrine system. *Psychol Bull*, *131*(4), 510–532.

Nieuwenhuis, S., Gilzenrat, M. S., Holmes, B. D., & Cohen, J. D. (2005). The role of the locus coeruleus in mediating the attentional blink: a neurocomputational theory. *J Exp Psychol Gen*, *134*(3), 291–307.

Nieuwenhuis, S., Nieuwpoort, I. C. van, Veltman, D. J., & Drent, M. L. (2007). Effects of the noradrenergic agonist clonidine on temporal and spatial attention. *Psychopharmacology*, *193*(2), 261–269.

Nieuwenstein, M. R. (2006). Top-down controlled, delayed selection in the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance*, *32*(4), 973–985.

Nieuwenstein, M. R., Chun, M. M., Lubbe, R. H. J. van der, & Hooge, I. T. C. (2005). Delayed attentional engagement in the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance*, *31*(6), 1463–1475.

Öhman, A. (2002). Automaticity and the amygdala: nonconscious responses to emotional faces. *Current Directions in Psychological Science*, *11*(2), 62-66.

Öhman, A., Eriksson, A., & Olfsson, C. (1975). One trial learning and superior resistance to extinction of autonomic responses conditioned to potentially phobic stimuli. *Journal of Comparative and Physiological Psychology*, *88*, 619-627.

Öhman, A., Frederickson, M., Hugdahl, K., & Rimmö, P. A. (1976). The premise of quipotentiality in human conditioning: Conditioned electrodermal responses to potentially phobic stimuli. *Journal of Experimental Psychology: General*, *103*, 313-337.

Öhman, A., Lundqvist, D., & Esteves, F. (2001). The face in the crowd revisited: a threat advantage with schematic stimuli. *Journal of Personality and Social Psychology*, *80*(3), 381-396.

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

Öhman, A., & Wiens, S. (2004). The concept of an evolved fear module and cognitive theories of anxiety. In A. S. R. Manstead, N. H. Frijda, & A. Fischer (Eds.), *Feelings and emotions : the amsterdam symposium* (p. 58-80). Cambridge, UK ; New-York: Cambridge University Press.

Oosterhof, N. N., & Todorov, A. (2008). The functional basis of face evaluation. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(32), 11087-11092.

Osgood, C. E. (1957). *The nature and measurement of meaning*. University of Illinois Press.

Osgood, C. E., May, W. H., & Miron, M. S. (1975). *Cross-cultural universals of affective meaning*. Urbana: University of Illinois Press.

Parr, L. A., Waller, B. M., & Heintz, M. (2008). Facial expression categorization by chimpanzees using standardized stimuli. *Emotion*, *8*(2), 216-231.

Pashler, H. (1984). Processing stages in overlapping tasks: evidence for a central bottleneck. *Journal of Experimental Psychology: Human Perception and Performance*, *10*(3), 358-377.

Pasquariello, S., & Pelachaud, C. (2001, September). Greta: A simple facial animation engine. In R. Rajkumar, M. Köppen, S. Ovaska, T. Furuhashi, & F. Hoffmann (Eds.), *6th online world conference on soft computing in industrial applications, session on soft computing for intelligent 3d agents.* Germany: Springer.

Pelli, D. G. (1997). The videotoolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision*, *10*, 437-442.

Pelli, D. G., & Farell, B. (2001). Psychophysical methods, or how to measure threashold, and why. In M. Bass (Ed.), *Handbook of optics* (2nd ed. ed., chap. Psychophysical methods). New York: McGraw-Hil.

Pelphrey, K., Viola, R., & McCarthy, G. (2004). When strangers pass: processing of mutual and averted social gaze in the superior temporal sulcus. *Psychological Science*, *15*(9), 598-603.

Pessoa, L. (2008). On the relationship between emotion and cognition. *Nature Reviews: Neuroscience*, *9*(2), 148–158.

Pessoa, L., Japee, S., & Ungerleider, L. G. (2005). Visual awareness and the detection of fearful faces. *Emotion*, *5*(2), 243-7.

Pessoa, L., Kastner, S., & Ungerleider, L. (2002). Attentional control of the processing of neural and emotional stimuli. *Brain Research; Cognitive Brain Research*, *15*(1), 31-45.

Phaf, R. H., & Kan, K.-J. (2007). The automaticity of emotional stroop: a meta-analysis. *Journal of Behavior Therapy and Experimental Psychiatry*, *38*(2), 184–199.

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

Picard, R. W. (1997). *Affective computing.* Cambridge, Mass.: MIT Press.

Plutchik, R. (1962). *The emotions: facts, theories, and a new model.* New-York, NY: Random House.

Plutchik, R. (1980). *Emotion, a psychoevolutionary synthesis.* New York: Harper & Row.

Popper, K. R. (1962). *Conjectures and refutations: the growth of scientific knowledge.* New York: Basic Books.

Posner, M. I., & DiGirolamo, G. J. (2000). Cognitive neuroscience: origins and promise. *Psychological Bulletin*, *126*(6), 873-889.

Pourtois, G., Grandjean, D., Sander, D., & Vuilleumier, P. (2004). Electrophysiological correlates of rapid spatial orienting towards fearful faces. *Cerebral Cortex*, *14*(6), 619-633.

Prinzmetal, W., Amiri, H., Allen, K., & Edwards, T. (1998). Phenomenology of attention: 1. color, location, orientation, and spatial frequency. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(1), 261-282.

Prinzmetal, W., McCool, C., & Park, S. (2005). Attention: reaction time and accuracy reveal different mechanisms. *Journal of Experimental Psychology: General*, *134*(1), 73-92.

Prinzmetal, W., Nwachuku, I., Bodanski, L., Blumenfeld, L., & Shimizu, N. (1997). The phenomenology of attention: 2. brightness and contrast. *Consciousness and Cognition*, *6*, 372-412.

Prinzmetal, W., & Wilson, A. (1997). The effect of attention on phenomenal length. *Perception*, *26*, 193-205.

Rakover, S. S. (2002). Featural vs. configurational information in faces: A conceptual and empirical analysis. *British Journal of Psychology*, *93*, 1-30.

Raymond, J. E. (2003). New objects, not new features, trigger the attentional blink. *Psychological Science*, *14*(1), 54–59.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an rsvp task: an attentional blink? . *Journal of Experimental Psychology: Human Perception and Performance*, *18*(3), 849-860.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1995). Similarity determines the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance*, *21*(3), 653–662.

Raz, A., & Buhle, J. (2006). Typologies of attentional networks. *Nature Reviews: Neuroscience*, *7*, 367-379.

Reinecke, A., Rinck, M., & Becker, E. (2007). How preferential is the preferential encoding of threatening stimuli? working memory biases in specific anxiety and the attentional blink. *Journal of Anxiety Disorders*.

Rensink, R. A., O'Regan, K. J., & Clark, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science*, *8*(5), 368-373.

Robbins, T. W. (1997). Arousal systems and attentional processes. *Biological Psychology*, *45*, 57-71.

Roesch, E. B., Sander, D., Mumenthaler, C., Kerzel, D., & Scherer, K. R. (in revision). Psychophysics of emotion: the quest for emotional perception. *Journal of Vision*.

Roesch, E. B., Sander, D., & Scherer, K. R. (2007). The link between temporal attention and emotion: A playground for psychology, neuroscience, and plausible artificial neural networks. In M. d. S. Joaquim (Ed.), *International conference on artificial neural networks* (Vol. 2, p. 859-868). Springer-Verlag.

Roesch, E. B., Sander, D., & Scherer, K. R. (2009). Emotion and motion in facial expressions modulate the attentional blink. *Perception*, *38*, 466.

Roesch, E. B., Sander, D., & Scherer, K. R. (in preparation). The 4th dimension(s) of emotion perception: Emotion and motion in facial expressions modulate the attentional blink.

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

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology*, *39*(6), 1161-1178.

Russell, J. A. (1983). Pancultural aspects of the human conceptual organization of emotions. *Journal of Personality and Social Psychology*, *45*(6), 1281-1288.

Russell, J. A. (2003). Core affect and the psychologcial construction of emotion. *Psychological Review*, *110*(1), 145-172.

Russell, J. A., & Feldman Barett, L. (1999). Core affect, prototypical emotional episodes, and other things called emotion: dissecting the elephant. *Journal of Personality and Social Psychology*, *76*(5), 805-819.

Russell, J. A., Lewicka, M., & Niit, T. (1989). A cross-cultural study of a circumplex model of affect. *Journal of Personality and Social Psychology*, *57*(5), 848-856.

Russell, J. A., & Mehrabian, A. (1977). Evidence for a three-factor theory of emotions. *Journal of Research in Personality*, *11*(3), 273–294.

Ruys, K. I., & Stapel, D. A. (2008). Emotion elicitor or emotion messenger. subliminal priming reveals two faces of facial expressions. *Psychological Science*, *19*(6), 593-600.

Ruys, K. I., & Stapel, D. A. (2009). The secret life of emotions. *Psychological Science*, *19*(4), 385-391.

Ryu, J.-J., & Chaudhuri, A. (2007). Differences in attentional involvement underlying the perception of distinctive and typical faces. *Perception*, *36*(7), 1057–1065.

Salemink, E., van den Hout, M. A., & Kindt, M. (2007). Selective attention and threat: quick orienting versus slow disengagement and two versions of the dot probe task. *Behaviour Research and Therapy*, *45*(3), 607–615.

Sander, D., Grafman, J., & Zalla, T. (2003). The human amygdala: An evolved system for relevance detection. *Reviews in the Neurosciences*, *14*, 303-316.

Sander, D., Grandjean, D., Kaiser, S., Wehrle, T., & Scherer, K. R. (2007). Interaction effect of perceived gaze direction and dynamic facial expression: evidence for appraisal theories of emotion. *European Journal of Cognitive Psychology*, *19*(3), 470-480.

Sander, D., Grandjean, D., & Scherer, K. R. (2005). A systems approach to appraisal mechanisms in emotion. *Neural Networks*, *18*(4), 317-352.

Sander, D., & Koenig, O. (2002). No inferiority complex in the study of emotion complexity: a cognitive neuroscience computational architecture of emotion. *Cognitive Science Quaterly*, *2*, 249-272.

Sander, D., & Scherer, K. R. (2005). Amalgams and the power of analytical chemistry: Affective science needs to decompose the appraisal-emotion interaction. (commentary on lewis "bridging emotion theory and neurobiology through dynamic systems modeling"). *Behavioral and Brain Sciences*, *28*, 216-217.

Santesso, D., Meuret, A., Hofmann, S., Mueller, E., Ratner, K., Roesch, E., et al. (2008). Electrophysiological correlates of spatial orienting towards angry faces: A source localization study. *Neuropsychologia*.

Sayette, M. A., Cohn, J. F., Wertz, J. M., Perrott, M. A., & Parrott, D. J. (2004). A psychometric evaluation of the facial action coding system for assessing spontaneous expression. *Journal of Nonverbal Behavior*, *25*(3), 167-186.

Scherer, K. R. (1984). On the nature and function of emotion: A component process approach. In K. R. Scherer & P. Ekman (Eds.), *Approaches to emotion* (p. 293-317). Hillsdale, NJ: Erlbaum.

Scherer, K. R. (1992). What does facial expression express? In K. Strongman (Ed.), *International review of studies on emotion* (Vol. 2, p. 139-165). Chichester, England: Wiley.

Scherer, K. R. (2000). Emotions as episodes of subsystem synchronization driven by nonlinear appraisal processes. In M. D. Lewis & I. Granic (Eds.), *Emotion, development, and self-organization: dynamical systems approaches to emotional development* (p. 70-99). Cambridge: Cambridge University Press.

Scherer, K. R. (2001). Appraisal considered as a process of multilevel sequential checking. In K. R. Scherer, A. Schorr, & T. Johnstone (Eds.), *Appraisal processes in emotion: Theory, methods, research* (p. 92-120). New York: Oxford University Press.

Scherer, K. R. (2004). Feelings integrate the appraisal-driven response organization in emotion. In A. S. R. Manstead, N. H. Frijda, & A. Fischer (Eds.), *Feelings and emotions : the amsterdam symposium* (p. 136-157). Cambridge, UK ; New-York: Cambridge University Press.

Scherer, K. R., & Ellgring, H. (2007). Are facial expressions of emotion produced by categorical affect programs or dynamically driven by appraisal? *Emotion*, *7*(1), 113-130.

Scherer, K. R., Summerfield, A. B., & Wallbott, H. (1983). Cross-national research on antecedents and components of emotion: a progress report. *Social Science Information*, *22*(3), 335-386.

Schlosberg, H. (1952). The description of facial expression in terms of two dimensions. *Journal of Experimental Psychology*, *44*, 229-237.

Schmukle, S. C. (2005). Unreliability of the dot probe task. *European Journal of Personality*, *19*, 595-605.

Schweizer, T. A., Alexander, M. P., Cusimano, M., & Stuss, D. T. (2007). Fast and efficient visuotemporal attention requires the cerebellum. *Neuropsychologia*, *45*(13), 3068–3074.

Seiffert, A. E., & Di Lollo, V. (1997). Low-level masking in the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance*, *23*(4), 1061-1073.

Seligman, M. (1970). On the generality of the laws of learning. *Psychological Review*, *77*(5), 406-418.

Seligman, M. (1971). Phobias and preparedness. *Behavior Therapy*, *2*, 307-321.

Sergent, C., Baillet, S., & Dehaene, S. (2005). Timing of the brain events underlying access to consciousness during the attentional blink. *Nature Neuroscience*, *8*(10), 1391–1400.

Sergent, C., & Dehaene, S. (2004). Is consciousness a gradual phenomenon? evidence for an all-or-none bifurcation during the attentional blink. *Psychological Science*, *15*(11), 720–728.

Seth, A. K. (2008). Theories and measures of consciousness develop together. *Conscious Cogn*, *17*(3), 986–988.

Seth, A. K. (2009). Explanatory correlates of consciousness: theoretical and computational challenges. *Cognitive Computation*, *1*, 50-63.

Seth, A. K., & Edelman, G. M. (2007). Distinguishing causal interactions in neural populations. *Neural Computation*, *19*(4), 910–933.

Shanahan, M. (2006). A cognitive architecture that combines internal simulation with a global workspace. *Consciousness and Cognition*, *15*(2), 433–449.

Shanahan, M. (2007). A spiking neuron model of cortical broadcast and competition. *Consciousness and Cognition*.

Shanahan, M., & Baars, B. J. (2005). Applying global workspace theory to the frame problem. *Cognition*, *98*(2), 157–176.

Shapiro, K. L. (Ed.). (2001). *The limits of attention : temporal constraints in human information processing.* Oxford ; New York: Oxford University Press.

Shapiro, K. L., Caldwell, J., & Sorensen, R. (1997). Personal names and the attentional blink: a visual "cocktail party" effect. *Journal of Experimental Psychology: Human Perception and Performance*, *23*(2), 504-514.

Shapiro, K. L., Hillstrom, A. P., & Husain, M. (2002). Control of visuotemporal attention by inferior parietal and superior temporal cortex. *Current Biology*, *12*, 1320-1325.

Shapiro, K. L., Raymond, J. E., & Arnell, K. M. (1994). Attention to visual pattern information produces the attentional blink in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance*, *20*(2), 357-371.

Shapiro, K. L., Raymond, J. E., & Arnell, K. M. (1997). The attentional blink. *Trends in the Cognitive Sciences*, *1*(8), 291-296.

Shih, S.-I. (2007). The attention cascade model and attentional blink. *Cognitive Psychology*.

Shih, S.-I., & Reeves, A. (2007). Attentional capture in rapid serial visual presentation. *Spatial Vision*, *20*(4), 301–315.

Shimojo, S., Simion, C., Shimojo, E., & Scheier, C. (2003). Gaze bias both reflects and influences preference. *Nature Neuroscience*, *6*(12), 1317-22.

Singular Inversions Inc. (2009). *Facegen modeler 3.3.* (http://www.facegen.com/)

Smith, C. A., & Scott, H. S. (1997). A componential approach to the meaning of facial expressions. In J. A. Russell & J.-M. Fernández-Dols (Eds.), *The psychology of facial expression* (p. 229-254). New-York, NY: Cambridge University Press.

Smith, S. D., Most, S. B., Newsome, L. A., & Zald, D. H. (2006). An emotion-induced attentional blink elicited by aversively conditioned stimuli. *Emotion*, *6*(3), 523–527.

Solomon, J. A., & Pelli, D. G. (1994). The visual filter mediating letter identification. *Nature*, *369*(2), 395-397.

Spielberger, C. D., Gorsuch, R. L., Lushene, R., Vagg, P. R., & Jacobs, G. A. (1983). *Manual for the State-Trait anxiety inventory (Form Y).* Consulting Psychologists Press.

Stapel, D. A., Koomen, W., & Ruys, K. I. (2002). The effects of diffuse and distinct affect. *Journal of Personality and Social Psychology*, *83*(1), 60-74.

Stein, T., Vallines, I., & Schneider, W. X. (2008). Primary visual cortex reflects behavioral performance in the attentional blink. *Neuroreport*, *19*(13), 1277–1281.

Stroop, J. R. (1935). Studies of interference in serial verbal reaction. *Experimental Psychology*, *18*, 643-662.

Sun, R. (2008). *The cambridge handbook of computational psychology.* Cambridge: Cambridge University Press.

Susskind, J. M., Lee, D. H., Cusi, A., Feiman, R., Grabski, W., & Anderson, A. K. (2008). Expressing fear enhances sensory acquisition. *Nature Neuroscience*, *11*(7), 843–850.

Szczepanowski, R., & Pessoa, L. (2007). Fear perception: can objective and subjective awareness measures be dissociated? *Journal of Vision*, *7*(4), 10-17.

Tanenbaum, A. S., & Woodhull, A. S. (2006). *Operating systems: design and implementation* (3rd ed.). Upper Saddle River, N.J.: Pearson/Prentice Hall.

Taylor, J. G. (2003). Paying attention to consciousness. *Prog Neurobiol*, *71*(4), 305–335.

Tipples, J., Young, A. W., Quinlan, P., Broks, P., & Ellis, A. W. (2002). Searching for threat. *Quaterly Journal of Experimental Psychology*, *55A*(3), 1007–1026.

Todorov, A., Baron, S. G., & Oosterhof, N. N. (2008). Evaluating face trustworthiness: a model based approach. *Social Cognitive Affective Neuroscience*, *3*, 119-127.

Tomkins, S. S. (1962). *Affect, imagery, consciousness.* New York: Springer Pub. Co.

Tononi, G. (2004). An information integration theory of consciousness. *BMC Neuroscience*, *5*(42), 1-22.

Tooby, J., & Cosmides, L. (1990). The past explains the present: Emotional adaptations and the structure of ancestral environment. *Ethology and Sociobiology*, *11*, 375-424.

Usher, M., Cohen, J. D., Servan-Schreiber, D., Rajkowski, J., & Aston-Jones, G. (1999). The role of locus coeruleus in the regulation of cognitive performance. *Science*, *283*(5401), 549–554.

Van Zandt, T. (2000). How to fit a response time distribution. *Psychonomic Bulletin and Review*, *7*(3), 424–465.

Vaquero, J. M. M., Frese, B., Lupianez, J., Megias, J. L., & Acosta, A. (2006). The attentional blink effect: influence of negative words in an affective valence categorization task. *Psicothema*, *18*(3), 525–530.

Visser, T. A. W., Bischof, W. F., & Di Lollo, V. (1999). Attentional switching in spatial and nonspatial domains: evidence from the attentional blink. *Psychological Bulletin*, *125*(4), 458-469.

Vogel, E. K., Luck, S. J., & Shapiro, K. L. (1998). Electrophysiological evidence for a postperceptual locus of suppression during the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(6), 1656-1674.

von der Malsburg, C. (1999). The what and why of binding: the modeler's perspective. *Neuron*, *24*(1), 95–104.

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

Vul, E., Hanus, D., & Kanwisher, N. (2008). Delay of selective attention during the attentional blink. *Vision Research*, *48*(18), 1902–1909.

Vul, E., Nieuwenstein, M. R., & Kanwisher, N. (2008). Temporal selection is suppressed, delayed, and diffused during the attentional blink. *Psychological Science*, *19*(1), 55-61.

Watson, A. B., & Fitzhugh, A. (1990). The method of constant stimuli is inefficient. *Perception and Psychophysics*, *47*(1), 87-91.

Watson, A. B., & Pelli, D. G. (1983). Quest: A bayesian adaptive psychometric method. *Perception and Psychophysics*, *33*(2), 113-120.

Watson, D., & Friend, R. (1969). Measurement of social-evaluative anxiety. *Journal of consulting and clinical psychology*, *33*(4), 448-457.

Wehrle, T., Kaiser, S., Schmidt, S., & Scherer, K. R. (2000). Studying the dynamics of emotional expression using synthesized facial muscle movements. *Journal of Personality and Social Psychology*, *78*(1), 105-19.

Weichselgartner, E., & Sperling, G. (1987). Dynamics of automatic and controlled visual attention. *Science*, *238*(4828), 778-780.

Wells, A., & Matthews, G. (1994). *Attention and emotion: clinical perspectives.* East Sussex, UK: Erlbaum.

Whalen, P. J., Rauch, S. L., Etcoff, N. L., McInerney, S. C., Lee, M. B., & Jenike, M. A. (1998). Masked presentations of emotional facial expressions modulate amygdala activity without explicit knowledge. *Journal of Neuroscience*, *18*(1), 411–418.

Wiens, S. (2006). Current concerns in visual masking. *Emotion*, *6*(4), 675-680.

Wiens, S., Fransson, P., Dietrich, T., Lohmann, P., Ingvar, M., & Ohman, A. (2004). Keeping it short: a comparison of methods for brief picture presentation. *Psychological Science*, *15*(4), 282-285.

Wiens, S., Peira, N., Golkar, A., & Öhman, A. (2008). Recognizing masked threat: fear betrays, but disgust you can trust. *Emotion*, *8*(6), 810-819.

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

Wundt, W. M. (1896). *Grundriss der Psychologie.* Leipzig: W. Engelmann.

Zelano, C., Bensafi, M., Porter, J., Mainland, J., Johnson, B., Bremner, E., et al. (2005). Attentional modulation in human primary olfactory cortex. *Nat Neurosci*, *8*(1), 114–120.

Notes

[1]Ancient folk tale relating the encounter of a group of blind men and an elephant. Each blind fellow studies a different part of the elephant, such as the tail or the tusks. They then compare their conclusions, and realise they are in complete disagreement.

[2]To be distinguished from emotions: “Where, on the other hand, a series of feelings succeeding one another in time unite to an interconnected process which is distinguished from preceding and following processes as an individual whole, and has in general a more intense effect on the subject than a single feeling, we call the unitary succession of feelings an *emotion*” (Wundt, 1896; p. 169).

[3]Because this work did not specifically address the link between emotion and attention, we will not describe it in details here. It is described in Fontaine et al. (2007), which the interested reader will find reproduced in Appendix A on page 147.

[4]This argument is further developed by Feldman Barett (2006) who suggests this is an “error of arbitrary aggregation”, where a feature is mistaken for a function (Lewontin, 2000).

[5]At this point, it is useful to distinguish an emotion from its subjective feeling. Based on the distinction introduced by Scherer (2004), we refer to the latter as the reportable part of the emotion. An emotion is characterised by a transient synchronisation of all emotional components (cognitive, neurophysiological, motivational, expressive components, and the subjective feeling).

[6]Here, we define automaticity as referring to a number of distinctive features about the nature of the occurring process. In general, a process is considered automatic if, to some extent, it is uncontrolled, goal-independent, autonomous, efficient (costless), unconscious, and fast (McNally, 1995; Moors & De Houwer, 2006). The features of efficiency, speed and awareness of the processing are particularly relevant for emotional stimuli.

[7]A recent study by Stein et al. (2008) however showed that the activation of retinotopically specific primary visual cortex (V1) might reflect the conscious perception of T2 during the AB.

[8]Table.. presents a recapitulation of the 34 studies (65 experiments) investigating the modulation of the AB by salient material.

[9]A modal facial expression of emotion refers to an expressive pattern of facial muscles that can reliably be attached to an emotional label by most people (Frijda & Tcherkassof, 1997; Wehrle et al., 2000; Scherer, 1992; Scherer & Ellgring, 2007; C. A. Smith & Scott, 1997).

[10]It is interesting to realise that this proposal has been made earlier in other contexts as well. von der Malsburg (1999, page 100) for instance remarked that “it seems plausible that temporal binding on the one hand and attentional mechanisms on the other are just two points on an uninterrupted continuum.”

Appendix A
The world of emotion is not two-dimensional (2007)

Appeared as Fontaine, J.R.J., Scherer, K.R., Roesch, E.B., Ellsworth, P. (2007). The world of emotion is not two-dimensional. *Psychological Science. 18*(12). pp. 1050-1057.

Research Report

The World of Emotions Is Not Two-Dimensional

Johnny R.J. Fontaine,[1] Klaus R. Scherer,[2] Etienne B. Roesch,[2] and Phoebe C. Ellsworth[3]

[1]*Ghent University, Ghent, Belgium;* [2]*University of Geneva, Geneva, Switzerland; and* [3]*University of Michigan*

ABSTRACT—*For more than half a century, emotion researchers have attempted to establish the dimensional space that most economically accounts for similarities and differences in emotional experience. Today, many researchers focus exclusively on two-dimensional models involving valence and arousal. Adopting a theoretically based approach, we show for three languages that four dimensions are needed to satisfactorily represent similarities and differences in the meaning of emotion words. In order of importance, these dimensions are evaluation-pleasantness, potency-control, activation-arousal, and unpredictability. They were identified on the basis of the applicability of 144 features representing the six components of emotions: (a) appraisals of events, (b) psychophysiological changes, (c) motor expressions, (d) action tendencies, (e) subjective experiences, and (f) emotion regulation.*

Reduction of complex data sets involving a large number of measures to a few meaningful underlying dimensions is common in many branches of science. For example, the perception of color is described by the dimensions of brightness, hue, and saturation. For more than half a century, emotion researchers have attempted to establish the underlying dimensional space that most economically accounts for the similarities and differences in emotional experience, and there has been considerable disagreement about the number and nature of the dimensions that provide an optimal framework for studying emotions. Most early research suggested at least three dimensions, commonly evaluation-pleasantness, potency-control, and activation-arousal (e.g., Osgood, May, & Miron, 1975). Although many recent researchers have focused exclusively on two-dimensional models, such as the valence-arousal model (e.g., Yik, Russell, & Feldman-Barrett, 1999), the search for the optimal low-dimensional representation of the emotion domain remains open.

Past work has primarily derived dimensions of emotion from the perceived similarity of emotion labels or facial expressions (e.g., Fontaine, Poortinga, Setiadi, & Suprapti, 2002; Schlosberg, 1952; Shaver, Schwartz, Kirson, & O'Conner, 1987), or from individual differences in verbal descriptions of emotional experiences (e.g., Yik et al., 1999), and the dimensions have often been derived in an atheoretical manner. In contrast, the work reported here started from the widely shared theoretical conceptualization of emotions as consisting of variably interrelated changes in activity across a set of six components: (a) appraisals of events, (b) psychophysiological changes (bodily sensations), (c) motor expressions (face, voice, gestures), (d) action tendencies, (e) subjective experiences (feelings), and (f) emotion regulation (Ellsworth & Scherer, 2003; Niedenthal, Krauth-Gruber, & Ric, 2006; Scherer, 2005). No previous studies have included all six of these components, and most have included only one or two. To obtain definitive evidence concerning the optimal low-dimensional space, we used a semantic-profile approach (Scherer, 2005), asking participants from three different Indo-European language groups (English, French, and Dutch) to evaluate 24 prototypical emotion terms on scales representing 144 features that represent activity in all six of the major components of emotion (Ellsworth & Scherer, 2003).

METHOD

Instrument

For this study, we used a new instrument originally constructed in English, the GRID instrument (Scherer, 2005). The GRID consists of a Web-based questionnaire composed of 24 emotion terms and 144 emotion features. The 24 terms are prototypical emotion terms commonly used in both emotion research and

Address correspondence to Johnny R.J. Fontaine, Faculty of Psychology and Educational Sciences, Ghent University, Henri-Dunantlaan 2, 9000 Ghent, Belgium, e-mail: johnny.fontaine@ugent.be, or to Klaus Scherer, Swiss Centre for Affective Sciences, University of Geneva, 7 rue des Battoirs, 1205 Geneva, Switzerland, e-mail: klaus.scherer@pse.unige.ch.

daily language. This representative set was chosen on the basis of frequent use in the emotion literature, consistent appearance in cross-cultural free-listing and prototypicality-rating tasks, and frequent mention in the self-reports from a large-scale Swiss household study of people's descriptions of an emotional situation they experienced the previous day (Scherer, Wranik, Sangsue, Tran, & Scherer, 2004). The 144 emotion features operationalize activity in each of the six emotion components (see Table 1). Thirty-one features refer to appraisals, 18 to bodily experiences, 9 to facial expression, 12 to vocal expression, 5 to gestural expression, 40 to action tendencies, 22 to subjective feelings, and 4 to regulation. An additional 3 features represent other qualities, such as frequency and social acceptance. The features were derived from a broad range of very diverse emotion theories and literature, such as the appraisal theory of Scherer (2001), the psychophysiological emotion literature (Stemmler, 2003), the action-tendency theory of Frijda (Frijda, Kuipers, & Terschure, 1989), the current-affect theory of Russell (Yik et al., 1999), and the expression-regulation theory of Ekman and Friesen (1969). The English GRID instrument was translated into French and Dutch by means of the translation/back-translation procedure.

Procedure

The GRID was administered in a controlled Web study (Reips, 2002) in which each participant was given 4 emotions randomly chosen from the set of 24 and asked to rate each in terms of the 144 emotion features. Using a 9-point scale ranging from *extremely unlikely* (1) to *extremely likely* (9), they rated the likelihood that each of the 144 emotion features can be inferred when a person from their cultural group uses the emotion term to describe an emotional experience. Each of the 144 emotion features was presented on a separate screen, and participants rated all 4 emotion terms for that feature before proceeding to the next feature.

Participants

In total, 198 Dutch-speaking students in Belgium (102 males, 96 females; average age = 20.88 years), 188 English-speaking students in the United Kingdom (74 males, 114 females; average age = 21.23 years), and 145 French-speaking students in Switzerland (37 males, 108 females; average age = 23.26) completed the GRID instrument in their own language.

RESULTS

To reduce the dimensionality of the emotion domain, we used principal component analysis (PCA), which finds the dimensions of greatest variance in the data set and represents each observation by its coordinates along each of these dimensions. PCAs were computed within and across the three languages, treating the 24 emotion terms as observations and the average scores on the 144 emotion features as variables.[1] A four-dimensional solution was selected on the basis of both the scree plots and the replicability of the configurations across the three languages (van de Vijver & Leung, 1997).[2] This solution accounted for 75.4% of the total variance. After varimax rotation, the first dimension (evaluation-pleasantness) accounted for 35.3% of the variance, the second dimension (potency-control) for 22.8%, the third dimension (activation-arousal) for 11.4%, and the last dimension (unpredictability) for 6.0%. This overall structure was replicated within each of the three language-culture samples.

The interpretation of the four dimensions is based on their relationships with the 144 emotion features and on the coordinates of the 24 emotion terms. Table 1 lists all 144 emotion features and their relationships to the four emotion dimensions (component loadings). Figure 1 represents the coordinates of the 24 emotion terms on these dimensions.[3] The first dimension can be interpreted as an evaluation-pleasantness dimension. Appraisals of intrinsic pleasantness and goal conduciveness, as well as action tendencies of approach versus avoidance or moving against, characterize this dimension. Pleasant emotions are opposed to unpleasant emotions on this dimension (see Fig. 1a). The second dimension is characterized by appraisals of control, leading to feelings of power or weakness; interpersonal dominance or submission, including impulses to act or refrain from action; changes in the rate and volume of speech; and parasympathetic symptoms. On this dimension, emotions such as pride, anger, and contempt are opposed to sadness, shame, and despair (see Fig. 1a). This dimension can therefore be interpreted in terms of potency-control. The third dimension is an activation-arousal dimension. It is mainly characterized by sympathetic arousal, such as rapid heartbeat and readiness for action. It opposes emotions such as stress, anger, and anxiety to disappointment, contentment, and compassion (see Fig. 1b). The last dimension is characterized by appraisals of novelty and unpredictability (and behaviors such as jaw dropping, eyebrow raising, and spontaneous exclamations), as compared with appraisals of expectedness or familiarity. Obviously, surprise is

[1]Because there are only 24 emotion terms in the analysis, the variation in the 144 emotion features could be perfectly represented by a solution with 24 components. Thus, the matrix is not positive definite (the rank is only 24, not 144). Factor analyses (exploratory or confirmatory) that assume underlying factors cannot be used with these data, as these techniques require a positive definite matrix. PCA, however, is adequate, as it is a pure reduction technique. It makes sense to see whether a matrix of rank 24 can be further reduced to an even smaller number of components without losing much information. Analyzing a matrix with more variables than observations is not uncommon in lexical personality research. In that area of research, as here, the replicability and the reliability of the components are considered most important. A more extensive account of the analytic procedures is available from the first author.

[2]First, a structure was identified across the three languages. Then, a language-specific structure was computed and orthogonally Procrustes-rotated toward the overall structure. For each of the three language groups and for each of the four dimensions, the Tucker's phi congruence coefficient exceeded .90.

[3]The profiles of the emotion words on the four emotion dimensions can be requested from the first author.

TABLE 1

The 144 Emotion Features, the Components of Emotion They Represent, and Their Correlations With the Four Dimensions After Varimax Rotation

		Correlation			
Emotion feature	Emotion component[a]	D1	D2	D3	D4
Incongruent with own standards and ideals	Appraisal	**.926**	.201	.113	.180
Pressed lips together	Face	**.919**	.038	.245	−.086
Wanted to destroy whatever was close	Action	**.914**	.024	.206	−.022
Frowned	Face	**.914**	−.010	.172	.091
In itself unpleasant for the person	Appraisal	**.911**	.321	.103	.103
Wanted to do damage, hit, or say something that hurts	Action	**.908**	−.090	.183	−.011
Wanted to oppose	Action	**.907**	−.131	.195	.053
Consequences negative for person	Appraisal	**.905**	.325	.113	.103
Treated unjustly	Appraisal	**.901**	.172	.091	.212
Felt negative	Feelings	**.886**	.425	.078	−.005
Wanted to break contact with others	Action	**.871**	.354	.105	−.047
Violated laws or socially accepted norms	Appraisal	**.858**	.157	.133	.169
Felt the urge to stop what he or she was doing	Action	**.844**	.457	.109	.142
Wanted to undo what was happening	Action	**.843**	.491	.075	.041
Wanted to prevent or stop sensory contact	Action	**.843**	.454	.074	.064
Felt bad	Feelings	**.835**	.515	.084	.013
Felt inhibited or blocked	Action	**.805**	.491	.186	.094
Wanted to keep or push things away	Action	**.801**	.516	.110	.088
In itself unpleasant for somebody else	Appraisal	**.799**	.294	.026	.149
Consequences negative for somebody else	Appraisal	**.781**	.292	.020	.030
Withdrew from people or things	Gesture	**.760**	.546	.037	.009
Irrevocable loss	Appraisal	**.748**	.450	.117	.137
Moved against people or things	Gesture	**.745**	−.263	.287	.016
Wanted to run away in whatever direction	Action	**.709**	.602	.213	.120
Felt out of control	Feelings	**.702**	.241	.513	.136
Felt powerless	Feelings	**.695**	.619	.079	.162
Wanted to be in control of the situation	Action	**.677**	−.166	.348	−.105
In danger	Appraisal	**.675**	.333	.331	.332
Muscles tensing (whole body)	Body	**.674**	−.052	.636	.177
Tried to control the intensity of the emotional feeling	Regulation	**.669**	.415	.170	−.091
Felt exhausted	Feelings	**.653**	.644	.068	−.029
Consequences avoidable or modifiable	Appraisal	**.641**	−.006	.070	−.338
Hid the emotion from others by smiling	Regulation	**.617**	.581	.123	−.111
Wanted to be in command of others	Action	**.593**	−.497	.229	−.172
Inconsistent with expectations	Appraisal	**.527**	.219	.198	.486
Frequency of experience in the cultural group	Other	**−.321**	−.213	.257	−.245
Caused by a supernatural power	Appraisal	**−.364**	.023	.101	.285
Felt an urge to be attentive to what was going on	Action	**−.475**	−.419	.216	.104
Confirmed expectations	Appraisal	**−.539**	−.405	−.130	−.443
Familiar event	Appraisal	**−.587**	−.349	−.061	−.516
Felt in control	Feelings	**−.684**	−.615	−.127	−.254
Event with consequences the person was able to live with	Appraisal	**−.701**	−.324	−.076	−.187
Important and relevant for goals of somebody else	Appraisal	**−.702**	−.316	−.044	−.100
Important and relevant for the person's goals	Appraisal	**−.724**	−.278	−.001	−.126
In itself pleasant for somebody else	Appraisal	**−.727**	−.451	−.015	−.014
Person was at the center of attention	Appraisal	**−.730**	−.053	.370	−.038
Wanted to take care of another person or cause	Action	**−.739**	−.040	−.091	−.205
Consequences positive for somebody else	Appraisal	**−.757**	−.443	−.058	−.067
Wanted to go on with what he or she was doing	Action	**−.767**	−.536	−.026	−.147
Felt calm	Feelings	**−.771**	−.172	−.529	−.172
Wanted to comply with someone else's wishes	Action	**−.812**	.037	−.084	−.135
Wanted to get totally absorbed in the situation	Action	**−.815**	−.493	.032	−.049
Social acceptability of the emotion	Other	**−.819**	−.193	−.058	.111
Muscles relaxing	Body	**−.827**	−.128	−.368	−.108

Table 1. (Contd.)

Emotion feature	Emotion component[a]	Correlation D1	D2	D3	D4
Felt at ease	Feelings	**−.882**	−.414	−.121	−.082
Wanted to be near or close to people or things	Action	**−.883**	−.145	−.072	−.032
Felt positive	Feelings	**−.887**	−.436	−.034	−.021
Wanted the ongoing situation to last or be repeated	Action	**−.901**	−.392	−.060	−.025
Felt good	Feelings	**−.905**	−.394	−.048	−.011
Consequences positive for person	Appraisal	**−.906**	−.345	−.078	−.070
Smiled	Face	**−.916**	−.341	−.014	−.029
Wanted to be tender, sweet, and kind	Action	**−.916**	−.056	−.198	−.128
Wanted to sing and dance	Action	**−.918**	−.329	.011	.003
In itself pleasant for the person	Appraisal	**−.925**	−.334	−.049	−.017
Wanted to submit to the situation as it was	Action	**−.930**	−.097	−.126	−.020
Decreased the volume of voice	Voice	.076	**.855**	−.360	−.145
Wanted to hand over the initiative to someone else	Action	.024	**.832**	.095	.079
Felt weak limbs	Body	.105	**.832**	.298	.209
Fell silent	Voice	.368	**.831**	−.102	.004
Felt submissive	Feelings	.426	**.825**	.049	−.036
Felt weak	Feelings	.542	**.803**	.012	.076
Wanted to make up for what he or she had done	Action	.220	**.766**	−.083	−.205
Wanted to withdraw into him- or herself	Action	.596	**.765**	.006	−.042
Lacked the motivation to do anything	Action	.535	**.740**	−.218	−.029
Wanted to do nothing	Action	.315	**.737**	−.321	−.071
Wanted to disappear or hide from others	Action	.655	**.713**	.057	−.031
Wanted someone to be there to provide help or support	Action	.498	**.700**	.065	.134
Closed his or her eyes	Face	.092	**.696**	−.164	.040
Spoke slower	Voice	.068	**.683**	−.572	−.132
Wanted to flee	Action	.672	**.679**	.160	.091
Got pale	Body	.589	**.675**	.158	.307
Had a feeling of a lump in the throat	Body	.422	**.671**	.228	.052
Wanted to be hurt as little as possible	Action	.533	**.663**	.123	−.081
Felt cold	Body	.562	**.650**	−.166	.207
Felt tired	Feelings	.598	**.633**	−.052	−.158
Had a trembling voice	Voice	.564	**.632**	.364	.068
Showed tears	Face	.067	**.628**	.112	.020
Had stomach troubles	Body	.600	**.610**	.391	.046
Showed the emotion to others less than he or she felt it	Regulation	.321	**.600**	.103	−.144
Lacked the motivation to pay attention to what was going on	Action	.436	**.591**	−.219	−.095
Will be changed in a lasting way	Other	−.107	**.557**	−.087	−.360
Wanted to act, whatever action it might be	Action	.376	**−.529**	.487	.009
Wanted to move	Action	−.085	**−.581**	.535	−.013
Produced a long utterance	Voice	−.310	**−.599**	.121	−.072
Moved toward people or things	Gesture	−.583	**−.599**	.123	.078
Showed the emotion to others more than he or she felt it	Regulation	−.248	**−.601**	−.069	.330
Caused intentionally	Appraisal	−.205	**−.649**	−.089	−.169
Wanted to show off	Action	−.606	**−.650**	.109	−.107
Felt alert	Feelings	−.100	**−.664**	.473	.166
Felt an urge to be active, to do something, anything	Action	−.184	**−.699**	.407	−.109
Felt powerful	Feelings	−.574	**−.702**	.093	−.182
Felt energetic	Feelings	−.624	**−.707**	.269	.019
Wanted to be seen, to be in the center of attention	Action	−.571	**−.711**	.114	−.112
Felt strong	Feelings	−.589	**−.733**	.111	−.142
Increased the volume of voice	Voice	.079	**−.777**	.460	.218
Wanted to tackle the situation	Action	.034	**−.786**	.242	−.064
Wanted to take initiative him- or herself	Action	−.093	**−.796**	.191	−.126
Felt dominant	Feelings	−.374	**−.822**	.127	−.183
Had an assertive voice	Voice	−.060	**−.908**	.072	−.105
Felt heartbeat getting faster	Body	−.019	−.210	**.927**	.100

Table 1. (Contd.)

Emotion feature	Emotion component[a]	Correlation			
		D1	D2	D3	D4
Felt breathing getting faster	Body	.260	−.099	**.893**	.161
Felt hot	Body	.189	−.077	**.850**	−.088
Sweated	Body	.339	.231	**.843**	.017
Perspired, or had moist hands	Body	.372	.272	**.799**	.005
Spoke faster	Voice	−.055	−.576	**.717**	.107
Produced abrupt body movements	Gesture	.217	−.356	**.688**	.419
Felt restless	Feelings	.397	−.115	**.688**	.066
Was in an intense emotional state	Feelings	.164	.151	**.647**	−.043
Felt shivers	Body	−.048	.157	**.647**	.403
Blushed	Body	−.402	−.049	**.602**	−.212
Felt nervous	Feelings	.541	.381	**.593**	.013
Felt warm	Body	−.413	−.420	**.558**	−.264
Produced speech disturbances	Voice	.520	.461	**.557**	.182
Opened her or his eyes widely	Face	−.254	−.464	**.537**	.496
Required an immediate response	Appraisal	.187	−.005	**.528**	.486
Wanted to overcome an obstacle	Action	.226	−.355	**.509**	−.161
Changed the melody of his or her speech	Voice	−.190	−.287	**.388**	.192
Did not show any changes in face	Face	.008	.085	**−.519**	−.358
Did not show any changes in vocal expression	Voice	−.252	.053	**−.578**	−.357
Did not show any changes in gestures	Gesture	−.017	.288	**−.585**	−.361
Felt breathing slowing down	Body	−.496	.102	**−.701**	−.096
Felt heartbeat slowing down	Body	−.208	.369	**−.715**	.006
Had no bodily symptoms at all	Body	−.154	−.072	**−.779**	.006
Had the jaw drop	Face	−.014	.105	−.129	**.798**
Had eyebrows go up	Face	−.018	−.291	.136	**.723**
Unpredictable event	Appraisal	.120	.153	.348	**.680**
Produced a short utterance	Voice	.399	−.057	.151	**.608**
Event occurred suddenly	Appraisal	−.058	.083	.400	**.589**
Caused by chance	Appraisal	−.516	−.150	.136	**.521**
Caused by somebody else's behavior	Appraisal	.396	−.335	.106	**.416**
Caused by the person's own behavior	Appraisal	−.532	−.126	.069	**−.599**
Consequences predictable	Appraisal	−.320	−.385	−.210	**−.621**
Person had enough resources to avoid or modify consequences of the event	Appraisal	−.027	−.199	.043	**−.632**
Experienced the emotional state for a long time	Feelings	−.089	.224	−.061	**−.755**

Note. For each feature, the highest loading is in boldface. D1 = evaluation-pleasantness dimension, D2 = potency-control dimension, D3 = activation-arousal dimension, D4 = unpredictability dimension.
[a]Action = action tendency, Body = bodily experience, Face = facial expression, Feelings = subjective experience, Gesture = gestural expression, Voice = vocal expression.

distinguished from all other emotions on this dimension. However, meaningful differentiations emerge among these other emotions as well; for example, fear is distinguished from stress and disgust from contempt (see Fig. 1c).

DISCUSSION

The results of this cross-cultural study provide robust evidence that more than two dimensions are needed for a low-dimensional representation of the semantic space of emotion. It is important to note that there were no major differences among the three language-culture groups. As suggested half a century ago, the three most important dimensions are evaluation-pleasantness, potency-control, and activation-arousal, in that order of importance. A fourth dimension, unpredictability, seems necessary to allow a satisfactory differentiation of emotions reflecting an urgent reaction to a novel stimulus or an unfamiliar situation. Although unpredictability has not emerged in most previous general studies of the dimensions of emotion, uncertainty is an important dimension in many appraisal theories (cf. Ellsworth & Scherer, 2003), and unexpectedness in the form of interruption was central to Mandler's (1975) model. In fact, the emergence of this factor in our comprehensive approach may explain the ambivalent status surprise has always had in the emotion pantheon, as it often co-occurs with and is confused with other emotions. Our results suggest that the term *surprise* may in fact refer to a particular quality or dimension of emotional experience based on appraisal of novelty and unexpectedness.

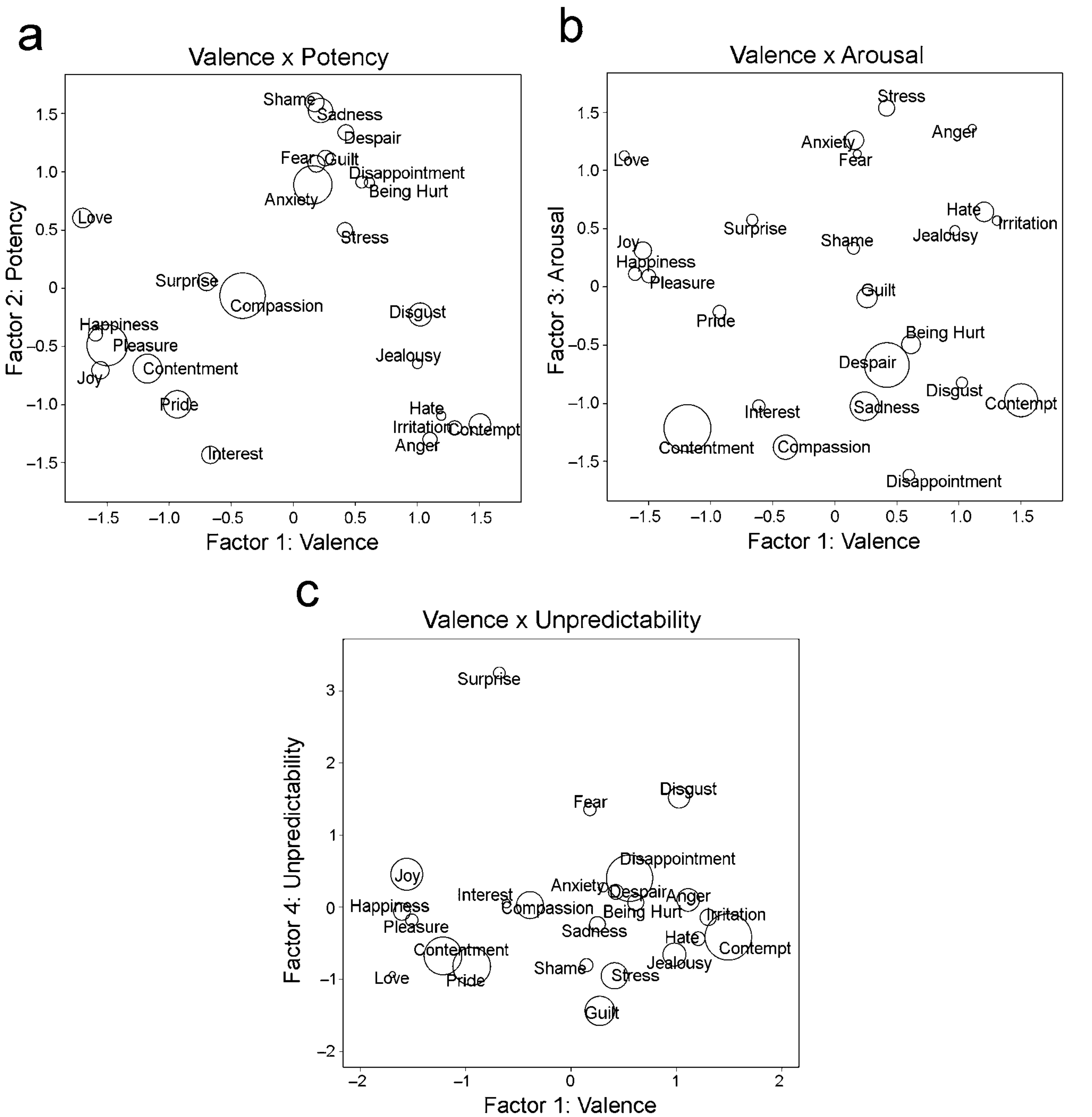

Fig. 1. The four-dimensional solution representing the 24 emotion terms. Midpoints of the circles represent the mean coordinates across the three languages. The diameter of each circle represents the mean euclidean distance among the coordinates for the three languages; the smaller the circle, the more similar the respective terms across the languages. The three panels show plots of coordinates for (a) Evaluation-Pleasantness × Potency-Control, (b) Evaluation-Pleasantness × Activation-Arousal, and (c) Evaluation-Pleasantness × Unpredictability.

The four-dimensional structure of emotion derived in the present research can be considered important because it is based not only on a representative sample of prototypical emotion labels, but also on a representative sample of features of emotional experience. This is the first study that has included all six of the major components of emotion identified by emotion researchers. The explanations as to why the same two or three emotion dimensions emerged in previous research were speculative. A major contribution of the present study is that it recovered the same three dimensions from a very precise analysis of the meaning of emotion terms, as rated on 144 specific criteria that most current emotion theorists explicitly assume are centrally relevant to the domain of emotions. Moreover, basing a dimensional analysis on comprehensive feature profiles for different emotion terms allowed us to infer, for the first time, the features on which similarity judgments for emotion words and experiences are based and the subsets of those features that underlie specific dimensions (see Table 1). The complete profiles for the terms, with respect to both the 144 individual features and the four dimensions (not reported in this article), allow us to determine which features are essential for the meaning of a term and to compare terms across languages.

A limitation of the current study is that it included only student samples. Although the same overall emotion structure can be expected with representative adult samples—the students were asked not about their own experiences, but about the meaning of the emotion words in their culture—it is possible that slight differences exist between different age groups. For instance, in our student samples, *love* was scored high on arousal features. It is quite possible that the meaning of *love* is associated with less arousal in older age groups.

Moreover, because our research involved perceptions of the meanings of emotion words, it is obviously relevant to the meaning structure of the emotion domain in three *languages*. We cannot be sure that our findings represent the dimensions of emotional *experience*. Robinson and Clore (2002) have highlighted the distinction between current emotion, which is episodic, experiential, and contextual, and beliefs about emotion, which are semantic, conceptual, and decontextualized. Clearly, by design, our data on semantic profiles belong to the latter category. However, the fact that the same four dimensions emerged for all three language-culture groups suggests that the findings represent more than mere linguistic or cultural conventions. We are currently conducting research in a much larger sample of linguistic and cultural groups, including non-Western languages and cultures, and preliminary data confirm the patterns reported here. Although language is abstracted from human experience, it must correspond to human experience and represent important human concerns. Consequently, as the emotion words and features used in the present research are highly similar to those commonly used in procedures for assessing emotion, one would expect to find a similar four-factor structure in assessments of emotional experience. But this is for future research to show. Of course, a representative selection of emotion words and emotion features is a precondition for an emotion-experience instrument to uncover the same structure.

Given that the comprehensive approach reported here confirms the existence and the importance of the classic factors of valence and arousal, working with these two factors is not an issue of right or wrong choices. The optimal number of dimensions to be included in a study depends on the question the researcher is asking. For a researcher interested in the effects of sympathetic activation, one dimension (arousal) may be sufficient. For a researcher interested in the subtle distinctions among related emotions such as shame, guilt, embarrassment, and self-anger, four dimensions might not be enough. But for researchers interested in providing a fairly comprehensive general account of the emotional experiences of the people they study, we strongly advocate using at least four dimensions.

Because models drive research design, restricting the number of emotion dimensions studied may severely bias the choice of methods and the interpretation of results. The current results imply that simple two-dimensional models, such as the valence-arousal model, miss major sources of variation in the emotion domain. Such models fail to differentiate important emotions like fear and anger (see Fig. 1b), which are clearly separated on the potency-control dimension (Fig. 1a) and on the unpredictability dimension (Fig. 1c). The potency-control dimension is of particular interest for emotion research. Its meaning is not limited to social and interpersonal experiences of dominance and submissiveness, as has been suggested in the past (e.g., Russell, 1991). It is also characterized by specific vocal response characteristics and action tendencies, such as wanting to take initiative versus being apathetic. Low potency-control is particularly relevant for emotion researchers who are interested in the biological underpinnings of emotions, as this dimension also captures parasympathetic forms of activation, such as weak limbs and gastrointestinal symptoms. The currently dominant two-dimensional models, such as the valence-arousal model, represent only sympathetic forms of activation (see Fig. 1b).

The findings of the present study have implications for very diverse forms of emotion research. For instance, experimental neuropsychological research designed to identify the brain processes underlying subjective emotional experiences requires a representative mapping of these subjective experiences. For many clinical and applied studies, it is crucial to distinguish whether a person is experiencing fear or anger, and two-dimensional models do not capture this distinction, which can be more adequately studied with the four-dimensional emotion model. Even for those researchers who are interested only in evaluation and activation, the four-dimensional model allows for better control of unintended variation on the two other emotion dimensions. Whereas two-dimensional models may be appropriate for studying some questions, researchers should seriously consider whether such models are sufficient for their particular questions.

Acknowledgments—This work was supported in part by an institutional grant from the Swiss National Science Foundation to the Swiss Center for Affective Sciences and by a grant from the European Network of Excellence HUMAINE–6th Framework Programme IST Multimodal Interfaces. The authors gratefully acknowledge the help of Roddy Cowie and Rainer Banse in obtaining the English-language sample.

REFERENCES

Ekman, P., & Friesen, W.V. (1969). The repertoire of nonverbal behavior: Categories, origins, usage, and coding. *Semiotica*, *1*, 49–98.

Ellsworth, P.C., & Scherer, K.R. (2003). Appraisal processes in emotion. In R.J. Davidson, K.R. Scherer, & H. Goldsmith (Eds.), *Handbook of affective sciences* (pp. 572–595). New York: Oxford University Press.

Fontaine, J.R.J., Poortinga, Y.H., Setiadi, B., & Suprapti, S.M. (2002). Cognitive structure of emotion in terms of Indonesia and The Netherlands. *Cognition and Emotion*, *16*, 61–86.

Frijda, N.H., Kuipers, P., & Terschure, E. (1989). Relations among emotion, appraisal, and emotion action readiness. *Journal of Personality and Social Psychology*, *57*, 212–228.

Mandler, G. (1975). *Mind and emotion*. New York: John Wiley & Sons.

Niedenthal, P., Krauth-Gruber, S., & Ric, R. (2006). *Psychology of emotion*. New York: Psychology Press.

Osgood, C.E., May, W.H., & Miron, M.S. (1975). *Cross-cultural universals in affective meaning*. Urbana: University of Illinois Press.

Reips, U.-D. (2002). Standards for Internet-based experimenting. *Experimental Psychology*, *49*, 243–256.

Robinson, M.D., & Clore, G.L. (2002). Belief and feeling: Evidence for an accessibility model of emotional self-report. *Psychological Bulletin*, *128*, 934–960.

Russell, J.A. (1991). Culture and the categorization of emotions. *Psychological Bulletin*, *110*, 426–450.

Scherer, K.R. (2001). Appraisal considered as a process of multilevel sequential checking. In K.R. Scherer, A. Schorr, & T. Johnstone (Eds.), *Appraisal processes in emotion: Theory, methods, research* (pp. 92–120). New York: Oxford University Press.

Scherer, K.R. (2005). What are emotions? And how can they be measured? *Social Science Information*, *44*, 693–727.

Scherer, K.R., Wranik, T., Sangsue, J., Tran, V., & Scherer, U. (2004). Emotions in everyday life: Probability of occurrence, risk factors, appraisal and reaction pattern. *Social Science Information*, *43*, 499–570.

Schlosberg, H. (1952). The description of facial expressions in terms of two dimensions. *Journal of Experimental Psychology*, *44*, 229–237.

Shaver, P., Schwartz, J., Kirson, D., & O'Conner, C. (1987). Emotion knowledge: Further exploration of a prototype approach. *Journal of Personality and Social Psychology*, *52*, 1061–1086.

Stemmler, G. (2003). Methodological considerations in the psychophysiological study of emotion. In R.J. Davidson, K.R. Scherer, & H. Goldsmith (Eds.), *Handbook of affective sciences* (pp. 225–255). New York: Oxford University Press.

van de Vijver, F.J.R., & Leung, K. (1997). *Methods and data analysis for cross-cultural research*. London: Sage.

Yik, M.S.M., Russell, J.A., & Feldman-Barrett, L. (1999). Structure of self-reported current affect: Integration and beyond. *Journal of Personality and Social Psychology*, *77*, 600–619.

(Received 2/27/07; Revision accepted 6/6/07; Final materials received 7/6/07)

Appendix B
The link between temporal attention and emotion: a playground for psychology, neuroscience and plausible artificial neural networks (2007)

Appeared as Roesch, E.B., Sander, D. & Scherer, K.R. (2007). The link between temporal attention and emotion: A playground for psychology, neuroscience and plausible artificial neural network. In *Proc. of the Intl. Conf. on Art. Neural. Networks*. Springer Lecture Notes in Computer Science, Vol. 2. p. 859–868

The Link Between Temporal Attention and Emotion: A Playground for Psychology, Neuroscience, and Plausible Artificial Neural Networks

Etienne B. Roesch[1], David Sander[1,2], and Klaus R. Scherer[1,2]

[1] Geneva Emotion Research Group, University of Geneva, Switzerland
Etienne.Roesch@pse.unige.ch
[2] Swiss Center for Affective Sciences, Geneva, Switzerland

Abstract. In this paper, we will address the endeavors of three disciplines, Psychology, Neuroscience, and Artificial Neural Network (ANN) modeling, in explaining how the mind perceives and attends information. More precisely, we will shed some light on the efforts to understand the allocation of attentional resources to the processing of emotional stimuli. This review aims at informing the three disciplines about converging points of their research and to provide a starting point for discussion.

Keywords: Attention, Emotion, Cognitive Science.

1 Introduction

In this paper, we address the endeavors of three disciplines, Psychology, Neuroscience, and Artificial Neural Network (ANN) modeling, in explaining how the mind perceives and attends information. More precisely, we address the efforts to understand the allocation of attentional resources to the processing of emotional stimuli. By bringing the three disciplines together, we aim at informing researchers about some of the recent advances in the other disciplines: whereas temporal attention and emotion are often studied separately, and with very disciplinary approaches, we argue that advances in one domain can help to refine the others. We further argue that the interplay between Psychology, Neuroscience, and ANN modeling lies in the constraints that each discipline can impose on the others, offering converging evidence towards one common goal. To focus our enterprise, we will address results from studies investigating the modulation of *temporal attention* by emotional stimuli. Temporal attention contrasts with other types of attention, like spatial attention, by setting the focus on the unfolding allocation of attentional resources to the processing of stimuli over time, and the underlying processing dynamics. Studies addressing temporal attention use experimental paradigms like Rapid Serial Visual Presentations (RSVP), for which it has been shown that emotional stimuli elicit particular patterns of response. Our paper is structured as follows. In the next section, we present the recent theoretical advances in emotion psychology with regards to

J. Marques de Sá et al. (Eds.): ICANN, Part II, LNCS 4669, pp. 859–868, 2007.

the modulation of temporal attention by emotion. The third section describes the brain mechanisms highlighted by neuroscience, pointing out the key areas of the brain involved in the cognitive functions of attention and emotion, and the brain mechanisms underlying their interaction. In the fourth section, we will briefly present some of the ANN modeling proposed to account for the modulation of temporal attention. We will conclude by highlighting some of the issues an interaction between Psychology, Neuroscience, and ANN modeling can help to resolve.

2 Psychological Perspectives on Pre-attentive Processes and Emotion

Psychology plays a major role in preparing the stage for the interplay between the disciplines. In this section, we will first describe the modulation of temporal attention by emotion, along with some of the behavioral results issued from experimental psychology. We will then introduce two sets of theories that have a special interest in describing the unfolding dynamics underlying the allocation of attentional resources to the processing of emotional stimuli.

2.1 The Modulation of Temporal Attention by Emotion

In a typical RSVP experiment, participants are presented with rapidly flowing images (presented at a frequency ± 10 Hz), one replacing the other at the same spatial location on the screen. Participants are asked to spot and perform tasks on one or more targets embedded within distracting images. Varying the time interval between two targets renders it possible to indirectly measure the amount of resources that is allocated to the processing of targets: results in a typical dual task experiment indeed show that the perception and processing of a first target (T1) hinders the perception and processing of a second target (T2) if it appears within 200-400 milliseconds after T1 (Figure 1). This phenomena has been rhetorically named an "Attentional Blink" (AB) [13]. Interestingly, emotional targets seem to benefit from a processing bias, alleviating the blink. If extensive research has been done on temporal attention, surprisingly little has been devoted to the modulation of temporal attention by emotion.

In an early study, Anderson and Phelps [1] showed that, not only did negative words alleviate the typical blink response compared to neutral words, but also that the amygdala was critical to benefit from the emotional significance of the words. These authors concluded that a critical function of the human amygdala is to enhance the perception of stimuli that have emotional significance. As we will discuss in the next section of the paper, the amygdala seems to play an important role in the interaction between attention and emotion. The modulation of the blink by the intrinsic significance of the targets has also been reported in a study showing that participants did not experience an AB for their own names but did for either other names or nouns [18]. Equivalent results have been reported when T2 targets were familiar faces compared to unfamiliar faces, the former

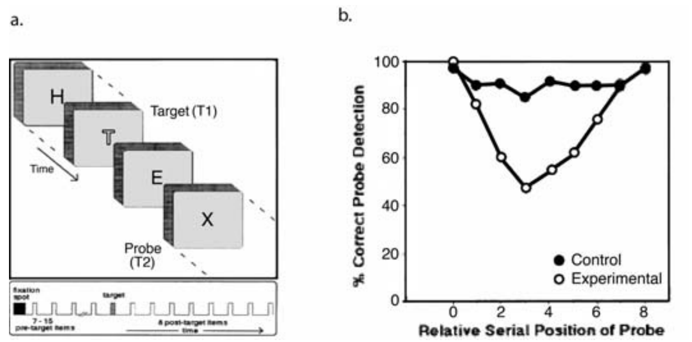

Fig. 1. *Panel a.* Ilustration of the RSVP, T1 was a white letter, T2 was the black letter "X". *Panel b.* Group mean % of trials in which T2 was correctly detected, after correct identification of T1, plotted as a function of the relative serial position after T1 [13], with permission, copyright American Psychology Association 2007.

alleviating the blink [8]. The latter results have been shown to be sensitive to trait personality differences, like trait anxiety.

In the remain of this section, we will provide the reader with accounts from current theoretical frameworks of emotion psychology. In the landscape of emotion theories, two sets of theories have a particular interest in describing the unfolding dynamics underlying the genesis of emotions, and the allocation of attentional and cognitive resources to the processing of emotional stimuli.

2.2 Accounts by "Basic Emotions" Theories

The concept of basic emotions refers to the postulate that there is a small number of emotions, fundamentally distinct from one another [5, e.g.]. As a result of this perspective, some emotions have been studied more thoroughly than others, as in the case of fear for which several models are proposed. In this theoretical thread, Öhman and colleagues [12] proposed an evolved module of fear and fear learning. Shaped by evolutionary pressure, this so-called *fear module* would have become specialized in the solving of potentially harmful situations for the species, like snakes, spiders or particular social encounters. The authors further argue that a dysfunction of this module would explain the selective anxiety disorders that are commonly described, like snake phobias, spider phobias, or social phobias, respectively [11]. The authors describe this module as being selective, automatic, encapsulated, and implemented in a dedicated cerebral circuit centered on the amygdala. This module is related to the research on fear conditioning in rats by LeDoux [10], who showed evidence for two routes involved in the processing of fearful stimuli, emphasizing the role of the amygdala in early stages of the processing. Interestingly, this last model has been computationally modeled using plausible ANN [2], offering converging evidence that responses to fear conditioning could occur even without the impulse from primary auditory cortices.

2.3 Accounts by Appraisal Theories of Emotions

The theoretical framework offered by the appraisal theories of emotions posits that emotions result from cognitive appraisals that individuals make about occurring events. Unlike the theories previously described, these theories suggest common mechanisms to the genesis of all emotions. These mechanisms can take the form of rapid, automatic, unconscious, cognitive appraisals evaluating stimuli against particular criteria. In other words, the process causally linking a stimulus to an emotional response is divided into multiple cognitive processes, which are common to every emotions, and that, in turn, evaluate the stimulus against a finite number of criteria. The result of this appraisal process yields to the genesis of a particular emotion. Several appraisal theories are available [16, for a review], out of which we selected Scherer's Component Process Model [15] for being sufficiently detailed to allow precise predictions, and sufficiently general to encompass a fair number of phenomena.

The Component Process Model defines an emotion as an episode of interrelated, synchronized changes in the states of all or most of the five subsystems classically described in the emotion literature, in response to the evaluation of an external or internal stimulus event as relevant to major concerns of the organism. More precisely, Scherer defines the nature and the functions of the cognitive evaluations yielding to the genesis of an emotion. These evaluations are described in terms of cognitive appraisals, named Stimulus Evaluation Checks, allowing the genesis of differentiate emotions. One can see checks as devoted processes evaluating the stimulus in regards to a specific criteria. The concept of *relevance* is at the core of the theory, being the first step in the sequence of appraisals [15]. It is also of particular importance in our endeavor as this first appraisal process is believed to determine the amount of cognitive resources to be allocated to the further processing of the perceived stimulus. This mechanism is evolutionarily justified in that it provides the organism with the economy of available resources, only allocating processing resources to important stimuli.

In general, any stimulus that could potentially influence the goals, or maintain the individual, in a sustained level of well-being is considered relevant. From this first appraisal unfold the orienting of the attention towards the stimulus event, the allocation of cognitive resources to its further processing, and the preparation of the organism to a behavioral response. A facial expression of fear or anger, for instance, will both represent a relevant information for the individual, signaling the occurrence of a negative event, obstructing the goals of the individual, or a potential danger. The degree to which the individual will process this information, allocating more or less attentional resources to its processing, attributing to it a particular emotional value, and adequately choose a line of reaction will depend on his goals, his needs, or the context in which the stimulus appeared. As will be discussed in the next section, the amygdala may be a potential candidate for implementing some kind of relevance detector [14].

To summarize, both sets of theories emphasize the role of pre-attentive processing mechanisms in the unfolding of temporal attention and allocation of resources to cognitive processing. Whereas the predictions from the "basic emotions" theories are mainly focused on threat-related stimuli, the predictions from the appraisal theories of emotion extend to any stimulus which is relevant to the organism, for any of many different reasons. Finally, both sets of theories emphasize the role of subcortical brain areas, like the amygdala, in subserving these mechanisms. Therefore, we suggest that the influence of emotion over temporal attention can occur in a pre-attentive scenario, as soon as the perceived, relevant stimuli enters the thalamo-amygdala circuitry.

3 Pre-attentive Processes and Emotion in the Light of Neuroscience

The knowledge gained from Neuroscience is of two kinds. Using very different technologies, researchers either describe the topography of the brain networks involved in specific tasks, or the temporal dynamics at play in these networks of structures. In this section, we will set a particular emphasis on the description of the dynamics involved in the modulation of both attention, and temporal attention, by emotion.

3.1 Brain Mechanisms Underlying the Modulation of Attention by Emotion

Endogenous modulation of attention (e.g., spatial attention) by emotion, is often described in terms of top-down bias effects from one region of the brain in favor of other, lower level, regions of the brain [20]. Many neuroscience studies have indeed shown enhanced responses to emotional stimuli relative to neutral stimuli, and researchers suggest that direct top-down signals might be emitted not only from fronto-parietal regions (e.g., Pre-Frontal Cortices, PFC), but also from subcortical regions like the amygdala. As discussed in the previous section, the amygdala, in particular, is known to be crucial in fear processing and fear learning [10]. Its position in the processing stream of perceptual information makes it a perfect candidate to potentially influence many cortical and subcortical regions. However, if two routes have reliably been identified in rats, there is still some debate about the precise circuitry involving the amygdala in humans. Regardless of the hypothesis advanced, researchers agree nonetheless to attribute an initial appraisal of emotional significance to this structure, based on limited information, early in the processing stream. This influence could take the form of direct feedback to sensory cortices, but also as indirect modulation of parietal and frontal regions (e.g., PFC). This latter signals would then produce a cascade of events which would signal emotional significance.

3.2 Brain Mechanisms Underlying the Modulation of Temporal Attention by Emotion

Dehaene and colleagues used recordings of event-related potentials (ERP) to compare the temporal dynamics of seen and unseen (blinked) words in a typical AB experiment [4,17]. Describing the cortical activations of unseen words, the authors report a drop in the waveform of components peaking around 300 milliseconds, which correlated with behavioral visibility ratings. Whereas ERP methodology cannot be used to make unambiguous inferences about brain localizations, estimations techniques allow to roughly determine the sources of cortical electrical activity. Using this approach, the authors report that seen words, compared to unseen words, initiated an intense spread of activation within left temporal and inferior frontal regions (about 300 milliseconds after stimulus onset), which would then spread to lateral prefrontal and anterior cingulate cortices (about 440 milliseconds), before extending in more posterior regions (about 580 milliseconds). In their interpretation, the authors introduce the concept of a *global workspace*, which refers to the notion that the different high-level, specialized, brain areas involved in the processing of visual stimuli interconnect to each other, to form a global workspace processing the stimuli into a unitary assembly supporting conscious reportability. Perceived stimuli would thus compete to recruit this global workspace that, once activated, only affords exclusive access, yielding to the inability to process subsequent stimuli for a transient period of time. Areas in the global workspace theoretically map onto the description of the processing streams involved in visual perception, from perceptual areas to higher associative areas of temporal, parietal, frontal, and cingulate cortex [4]. Which is to say that the bottleneck described in AB studies would therefore lay in such top-down influence of higher-level areas, like the PFC or more parietal areas, over the lower-level areas involved in the visual streams.

A second scenario has been proposed by Hommel and colleagues in an article reviewing evidence from numerous imaging techniques [7]. In this article, the authors present a neurocognitive model of the AB, which situates the processing bottleneck reported in behavioral results in the rendering of an intrinsically parallel system into effectively serial dynamics: after nonselective processing in specialized perceptual cortices, stimuli are fed to object-specific temporal areas, where they are matched against long-term knowledge and, consequently, identified. Identified objects are then maintained in frontal working memory, and receive support by means of the synchronization of the relevant structures in frontal and parietal cortices. By closing a perceptual window, this synchronization stabilizes the representation maintained in working memory, increasing the likelihood that the target be reported, and preventing other stimuli from entering further processing.

If these two scenarios have received considerable interest from the research community and, being somehow complementary, do provide consistent explanations about the dynamics underlying temporal attention, and its modulation by top-down processes, none explicitly takes into account the modulation of temporal attention by emotion, and no better account is being offered as of today. To summarize, both representative scenarios start from the assumption that the processing of perceived stimuli is initiated in perceptual cortices, which then feed into fronto-parietal systems processed and aggregated feature-representations. These systems then complete the processing of the stimuli, whilst preventing other stimuli to interfere with the processing by one means or another. We therefore suggest that emotion may modulate temporal attention by means of top-down enhancing signals emitted very early in the processing stream, mediated by the amygdala, for instance.

4 ANN Modeling of Temporal Attention and Emotion

Because attention in general, and the AB in particular, represent fairly constrained and well described phenomena, a reasonable number of ANN models are available, compared to other phenomena, each emphasizing a different aspect of the findings. Out of the few models that exist, we selected three models for representing the range of focus ANN models can entail. This range of focus is best appreciated at the light of the abstraction level emphasized by each ANN model. In that sense, the first model we describe focuses on the high-level interpretation of the findings of behavioral experiments, whereas the second and third models set a special emphasis on the low-level neurobiological plausibility of the network and the dynamics involved. We discuss the appropriate balance between these levels in the conclusion of this manuscript.

In a recent effort to converge the different findings of the literature into a unifying theory of the AB, Bowman & Wyble [3] presented a model of temporal attention and working memory encapsulating 5 principles that represent the main effects described in psychology literature. This model, called the Simultaneous Type, Serial Token (ST^2) model, is modeled using several layers and explicit mechanisms closely mapping the effects that are described in the literature. Whereas results obtained with this model provide a good fit with the results reported in the literature, the authors acknowledge that their ambition was to provide a "cognitive-level explanation of the AB, and temporal attention in general", rather than a plausible implementation of the mechanisms described in Neuroscience studies. Therefore, we argue that it is unclear to what extent this data-driven implementation can fully explain the dynamics underlying the interaction between temporal attention and emotion, even though some of the principles this model rely on do refer to emotional significance, at least semantically.

A competing ANN model is provided by Dehaene and colleagues [4]. Unlike the previous ANN model, the authors based their model on the neurobiology of neural pathways from early sensory regions (Areas A and B) to higher association areas (Areas C and D). The global workspace, as described in the previous section, lays in the interconnections of the nodes in higher areas C and D (Figure 2, panel a). In addition, the basic brick from which they built the model closely models a thalamo-cortical column, reproducing the laminar distribution of projections between excitatory and inhibitory spiking neurons. In doing so, they reproduced the basic computational unit that can be found in neural pathways, and managed to explicitly compare results from their model with actual neuroimaging data, providing converging evidence for a global workspace hypothesis. However, if their implementation closely models some aspects of neurobiology, it neglects other aspects that have been highlighted in Neuroscience research, and described in the previous section: one of which being the close interaction between subcortical and cortical structures in the processing of visual stimuli. Furthermore, their model does not provide any mechanism from which a modulation of temporal attention by emotion could arise.

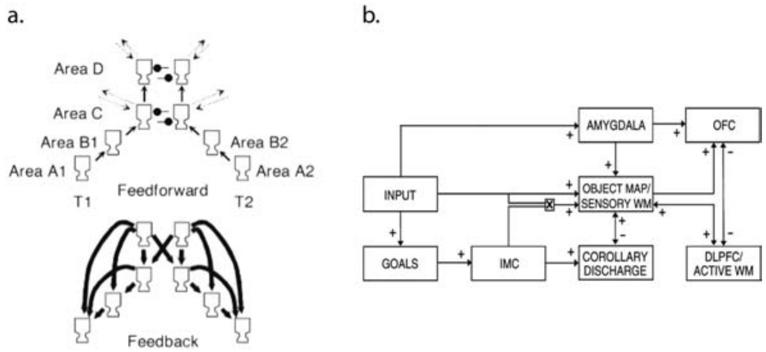

Fig. 2. *Panel a.* Schematic architecture of the global workspace model. Areas A and B represent the perceptual pathways leading to the global workspace, areas C and D implement the global workspace including fronto-parietal regions [4]. Adapted with permission, copyright National Academy of Science of U. S. A. 2007. *Panel b.* CODAM architecture extended by Amygdala and Orbito-Frontal Cortex to address emotional influences on attention [9]. Adapted with permission, copyright Elsevier 2007.

A third attempt at modeling temporal attention has been made by Taylor and colleagues [20,6] in the COrollary Discharge of Attention Movement (CODAM) model. This model was developed by analogy to models of motor controls applied to attention [20,19,9] in which the creation of the attention modulation signal is emitted from a controller structure onto separate modules where activations are to be modulated (Figure 2, panel b). The CODAM model is based on the descriptions provided by Neuroscience, both in terms of the structure of the network and of the dynamics implemented. As such, it contains input pathways leading to a working memory that can be influenced by the conjunction of several signals, both exogenous and endogenous. Critical to this approach is the Inverse Model Controller (IMC), which boosts the representation of perceived stimuli. This attentional boost is required for stimuli to reach working memory, and thus be reported. In conjunction with a conflict monitor, the IMC interferes with subsequent stimuli if the first stimuli has not yet reached the working memory. As a result, the monitor will suppress the second stimulus in the IMC, and thus withhold its attentional boost, hindering its successful encoding in working memory (i.e., yielding to an AB). This model also contains modules representing subcortical structures, like the amygdala. Input to the amygdala comes from crude, early signals directly from the input module, representing posterior sites in the brain. It also interacts with the OFC module, which encodes the value of stimuli and can influence attention via top-down activations.

5 Conclusion

In this paper, we addressed the perspectives of three disciplines in explaining temporal attention, and its modulation by emotion. We highlighted concepts issued from Psychology that are now being rediscovered by Neuroscience. The concept of *relevance*, for instance, central in the appraisal theories of emotion [15] seems to play a major role in the definition of the functional domain of the amygdala [14]. We then introduced several scenarios proposed by neuroscientists to account for the unfolding of temporal attention. Finally, we described examples of ANN models accounting for the AB, and some of the mechanisms implemented to underlie a modulation by emotional stimuli. However, ANN approaches are very different, depending on the abstraction level that modelers choose to pursue. The ST^2 model, for instance, only semantically represents the computations that could be implemented in the brain and, even though it provides a good fit with behavioral results, it does not, however, offer plausible converging evidence as to how emotional stimuli modulate temporal attention in the brain. The CODAM model, on the other hand, is structured on the basis of what has been described in the Neuroscience literature. By doing so, the authors had to fill in the blanks by making a number of assumptions. For instance, they introduced the notion of corollary discharge mediated by an Inverse Model Controller for which there is only indirect evidence. This offers new tracks to explore to both psychologists and neuroscientists.

In the introduction of this paper, we proposed that advances in one discipline could help to refine the other disciplines. We further argued that the interplay between the disciplines lied in the *constraints* that each discipline can impose on the others. These constraints can be expressed in the form of the *goodness-of-fit* between the models proposed by each discipline. In other words, by providing the three disciplines with a common goal, i.e. the modulation of temporal attention by emotion, we argue that the findings in one discipline should be able to address the findings in the others. Taking this interdisciplinary view, we raise a number of questions:

- Most of what is known about the modulation of temporal attention by emotion has been investigated using threat-material. What is the effect of positive *relevant* stimuli over the unfolding process of attention?
- If relevance is subjectively determined by the appraised propensity of stimuli to affect the goals, the needs of the individual, how do inter-individual or personality factors modulate the unfolding process of attention? How could this be accounted for in Neuroscience, and in plausible ANN models?
- If mechanisms like the corollary discharge have proven useful in modeling the modulation of temporal attention by emotion [6], how do these mechanisms relate to recent findings in Neuroscience? In what way can we model the perceptual window described by Hommel et al. [7]?

References

1. Anderson, A.K., Phelps, E.A.: Lesions of the human amygdala impair enhanced perception of emotionally salient events. Nature 411(6835), 305–309 (2001)
2. Armony, J.L., Servan-Schreiber, D., Cohen, J.D., LeDoux, J.: Computational modeling of emotion: explorations through the anatomy and physiology of fear conditioning. Trends in the Cognitive Sciences 1(1), 28–34 (1997)
3. Bowman, H., Wyble, B.: The simultaneous type, serial token model of temporal attention and working memory. Psychol Rev 114(1), 38–70 (2007)
4. Dehaene, S., Sergent, C., Changeux, J.-P.: A neuronal network model linking subjective reports and objective physiological data during conscious perception. Proc Natl Acad Sci U S A 100(14), 8520–8525 (2003)
5. Ekman, P.: Are there basic emotions? Psychological Review 99, 550–553 (1992)
6. Fragopanagos, N., Kockelkoren, S., Taylor, J.G.: A neurodynamic model of the attentional blink. Cognitive Brain Research 24, 568–586 (2005)
7. Hommel, B., Kessler, K., Schmitz, F.: How the brain blinks: towards a neurocognitive model of the attentional blink. Psychological Research 70(6) (2005)
8. Jackson, M.C., Raymond, J.E.: The role of attention and familiarity in face identification. Percept Psychophys 68(4), 543–557 (2006)
9. Korsten, N.J.H., Fragopanagos, N.F., Hartley, M., Taylor, N., Taylor, J.G.: Attention as a controller. Neural Netw 19(9), 1408–1421 (2006)
10. LeDoux, J.: The emotional brain: the mysterious underpinnings of emotional life. Simon & Schuster, New York, NY (1996)
11. Öhman, A.: Psychology. conditioned fear of a face: a prelude to ethnic enmity? Science 309(5735), 711–713 (2005)
12. Öhman, A., Mineka, S.: Fears, phobias, and preparedness: toward an evolved module of fear and fear learning. Psychological Review 108(3), 483–522 (2001)
13. Raymond, J.E., Shapiro, K.L., Arnell, K.M.: Temporary suppression of visual processing in an rsvp task: an attentional blink? J Exp Psychol Hum Percept Perform 18(3), 849–860 (1992)
14. Sander, D., Grafman, J., Zalla, T.: The human amygdala: An evolved system for relevance detection. Reviews in the Neurosciences 14, 303–316 (2003)
15. Scherer, K.R.: Appraisal considered as a process of multilevel sequential checking. In: Scherer, K.R., Schorr, A., stone, T.J. (eds.) Appraisal processes in emotion: Theory, methods, research, pp. 92–120. Oxford University Press, New York (2001)
16. Scherer, K.R., Schorr, A., Johnstone, T.: Appraisal processes in emotion: theory, methods, research, volume Series in affective science. Oxford University Press, Oxford, New York (2001)
17. Sergent, C., Baillet, S., Dehaene, S.: Timing of the brain events underlying access to consciousness during the attentional blink. Nat Neurosci 8(10), 1391–1400 (2005)
18. Shapiro, K.L., Caldwell, J., Sorensen, R.E.: Personal names and the attentional blink: a visual "cocktail party" effect. J Exp Psychol Hum Percept Perform 23(2), 504–514 (1997)
19. Taylor, J.G., Fragopanagos, N.F.: The interaction of attention and emotion. Neural Netw 18(4), 353–369 (2005)
20. Taylor, J.G., Rogers, M.: A control model of the movement of attention. Neural Networks 115, 309–326 (2002)