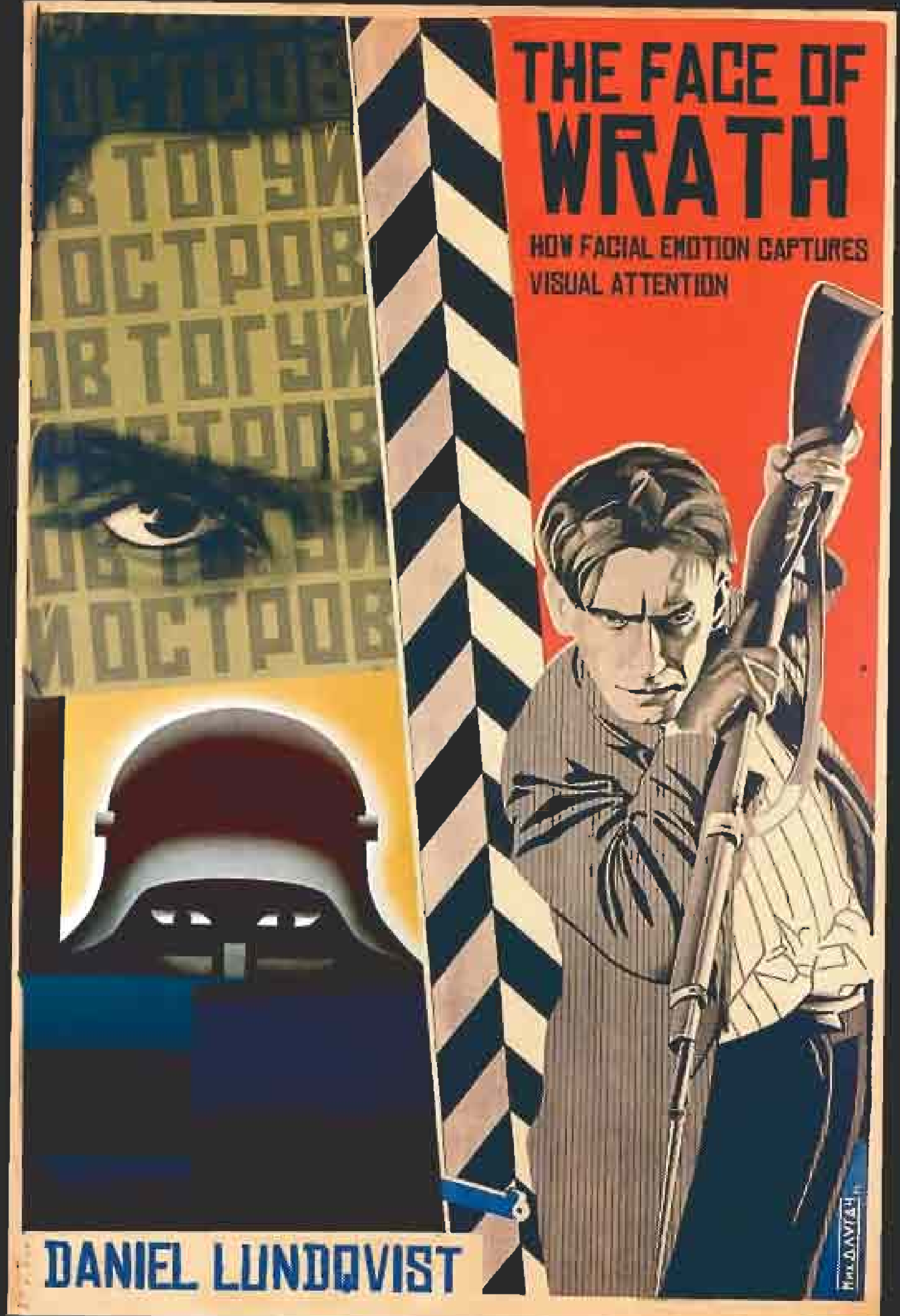
Daniel Lundqvist

The Face of Wrath: How Facial Emotion Captures Visual Attention

Department of Clinical Neuroscience, Psychology Section, Karolinska Institutet
Stockholm, Sweden, 2003



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ABSTRACT

The aim of this thesis was to examine the relation between facially conveyed emotion and visual attention.

In Study I and II, we (Lundqvist, Esteves, & Öhman, 1999; 2004) examined how different facial features are involved in conveying facial emotion, specifically in conveying a threatening or friendly emotional impression. In the two studies, a total of 201 participants rated their emotional impression of different schematic facial stimuli, using semantic differential scales (Activity, Negative Valence and Potency). The results showed that the shape of the eyebrows has a dominating effect on the emotional impression of a face, but also that the shape of the mouth and the eyes modulate the effect of eyebrows and thus clearly contribute to the emotional impression of a face. Thus, to specifically convey a threatening impression, v-shaped eyebrows are the best means, especially in combination with ∩-shaped mouth.

The data from Study I and II were interpreted in an evolutionary perspective on human facial expressions and emotions, and discussed in relation to face processing and signal evolution theory.

In Study III and IV, we (Öhman, Lundqvist, & Esteves, 2001; Lundqvist, & Öhman, submitted) investigated the relation between emotion and attention. By using different facial emotional stimuli in a visual search task, we collected data on how a total of 212 participants searched for discrepant faces in arrays of otherwise identical faces. By comparing how different schematic threatening and friendly faces affected attention, we tested the hypothesis that humans preferentially orient attention towards threatening information. In Study IV, participants also rated their emotional impression of the different facial stimuli. The results showed that, in terms of shorter response latencies and higher response accuracy, threatening faces were detected more efficiently than friendly faces. The threat-advantage was maintained across a range of experimental conditions, and was even demonstrated for facial stimuli in which only one facial feature (eyebrows, mouth or eyes) conveyed the facial emotion. A closer analysis of the covariation of emotion and attention measures in Study IV showed that visual attention to faces was closely related to the emotional properties of the stimuli, and thus suggested that the emotional impression of a facial stimulus regulates how that face affects attention.

The data from Study III and IV were viewed against a background of visual perception and visual attention theories, and were interpreted in relation to face processing and emotion theory.

LIST OF PUBLICATIONS

The thesis is based on the following original articles, which will be referred to in the text by their Roman numerals:

I. Lundqvist, D., Esteves, F., & Öhman, A. (1999). The face of wrath: Critical features for conveying facial threat. Cognition and Emotion, 13, 691-711.

II. Lundqvist, D., Esteves, F., & Öhman, A. (2004). The face of wrath: The role of features and configurations in conveying social threat. Cognition and Emotion, 18, (in press).

III. 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, 381-396.

IV. Lundqvist, D. & Öhman, A. (Submitted). Emotion regulates attention: The relation between facial configurations, facial emotion and visual attention.

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LIST OF ABBREVIATIONS

ACC	Anterior Cingulate Cortex
A.k.a.	Also known as
Cf.	*Confer*, compare
EB	Eyebrows
E.g.	*Exempli gratia*, for example
EPA-structure	The semantic dimensions of Evaluation, Potency, and Activity
Et al.	*Et alii*, and others
EY	Eye
FFA	The Facial Fusiform Area; the fusiform gyrus in the temporal lobe
I.e.	*Id est*, that is
IOC	Inferior Occipital Cortex
IT	Inferior Temporal
K	Koniocellular
LGN	Lateral Geniculate Nucleus
M	Magnocellular
MO	Mouth
MT	Medial Temporal
MST	Medial Superior Temporal
OTC	Occipito-Temporal Cortex
P	Parvocellular
PC	Parietal Cortex
PPC	Posterior Parietal Cortex
RT	Response Time
SC	Superior Colliculus
STS	Superior Temporal Sulcus
V1, V2, V3, etc	Visual cortical area 1, 2, 3 etc.
VIP	Ventral Intra-Parietal cortex

Success is nothing more than going from failure to failure with undiminished enthusiasm.

Winston Churchill

1 LOOKING FOR TROUBLE

1.1 BACKGROUND

1.1.1 Pay attention

We look at the things that matter to us. We may rest our eyes on things that attract us, stare at something horrifying, or glare at someone we dislike: things that affect us emotionally are also things that capture our visual attention.

A central and important role of emotion is to emphasize things in the environment that are significant to us, and thus direct attention and actions (see e.g. Oatley & Jenkins, 1996). The aim of this thesis was to examine the relation between emotion and visual attention.

When performing research on emotion, a strategic and crucial decision is the choice of stimuli. In the studies presented in this thesis, *faces* were used as emotional stimuli. Faces are good for that purpose, because they can convey different types of emotion, and can also be manipulated experimentally. Although faces are good emotional stimuli, the use of faces in experimental research is far from uncomplicated. It is, for instance, difficult to separate the emotional effects of a face from its perceptual properties. It is also problematic to define how different types of facial information contribute to the emotional impression and what the core in the communicated emotion is.

In Study I and II, we (Lundqvist, Esteves, & Öhman, 1999; 2004) examined how different facial features are involved in recognition of facial emotion, specifically in recognition of threatening and friendly faces.

When examining a relation between emotion and attention, another strategic decision is how one should measure attention. In this thesis, a *visual search* task was used for that purpose. Visual search has proved to be an effective tool for investigating how attention is directed to different types of visual information (see Neisser, 1964; or Wolfe, 1998, for an overview). The visual search task is highly sensitive for perceptual stimulus dimensions, and this has been known to make it difficult to separate emotional effects on attention from perceptual effects (see e.g. Hansen, & Hansen, 1988; Purcell, Stewart, & Skov, 1996).

In Study III and IV, we (Öhman, Lundqvist, & Esteves, 2001; Lundqvist, & Öhman, submitted) used perceptually controlled facial stimuli to investigate the effect of facial emotion on visual attention. In Study IV, the issue of how facial emotion affects visual attention was directly examined by using the visual search task in parallel with measurement of the involved stimuli’s emotional properties.

The thesis starts with a general background, and then presents the two sets of studies in turn.

1.1.2 No idea

Early on, philosophers identified an important human shortcoming: the truth is out there in the world around us, but there is no *real truth* inside our minds. Plato (ca 428 to 347 BC) stated that humans are unable to perceive the *ideas* - the true world outside our senses. Similarly, Immanuel Kant (1724-1804) argued that the incapability to perceive the real world beyond our senses, the *things-in-themselves*, is a borderline for human phenomenological knowledge (Russell, 1945).

The way the human mind handles information from the world around us is much a result of our evolutionary history, and the mind is not shaped to copy the outer world into an internal duplicate. Rather, processes such as perception, attention and emotion jointly transform and interpret the outer world into useful and meaningful representations, and enhance it according to personal relevance.

Much of today's research within the field of psychology is directly or indirectly occupied with understanding how evolution has shaped the human mind, and how different properties of psychological processes affect the way we perceive and recognize the world around us.

1.1.3 Human origin

The human mind has evolved with the human species over millions of years. Much of human properties were most likely shaped long before the species of Homo and Homo sapiens branched from the phylogenic tree, and many aspects of human biology and psychology are accordingly very similar to those of our primate relatives. But much of our design is also uniquely human, shaped and evolved during conditions that have separated us markedly from our primate relatives.

The history of the modern human, Homo sapiens, has been dated to a common ancestral origin in Africa at about 200 000 years ago (see Johanson & Edgar, 1996). It is believed that humans then lived in semi-nomadic hunter-gatherer groups of about 10 to 30 people, under environmental demands that required and rewarded cooperation around common group goals. Along with the increased importance of cooperation, the social demands are believed to have become increasingly important and demanding. Improved mind capacities, such as an increased capability of predicting different individual's actions in social and cooperative situations, and an improved memory of earlier outcomes of cooperation or conflict, were likely both advantageous and necessary (Oatley & Jenkins, 1996). Indeed, the large increase in human brain size over human evolution (430 cubic centimeters for Australopithecus afarensis, around 600 cc for early Homo, and about 1300 cc for us Homo sapiens) is believed to reflect a co-evolution of increasingly complex social relationships, increased brain size, and an improved capacity for tool-making craftsmanship (see e.g. Johanson & Edgar, 1996).

During evolutionary history, emotional responses have become a central part of human behavior, and a vital part of social behavior, cooperative goal-reaching and problem-solving. Emotional responses have become crucial in triggering proper response patterns for social cooperation or conflict. Although motivational and emotional systems dates further back into evolutionary history than the human species, the emotional responding of humans is believed to have been shaped and tuned markedly during the early history of Homo sapiens. Selected as advantageous response patterns over hundreds and thousands of generations, emotion has come to function as an important tool for setting priorities among parallel goals, and in initiating and maintaining problem-solving behavior in response to different environmental and social scenarios (Oatley & Jenkins, 1996).

In Damasio's (2000) words:

> I would say that emotions are specific and consistent collections of physiological responses triggered by certain brain systems when the organism represents certain objects or

> situations. ... Although the precise composition and dynamics of the responses are shaped by individual development and environment, the evidence suggest that the basic of most, if not all, emotional responses are preset by the genome and result from a long history of fine tuning. Emotions, in the broad sense, are part of the bioregulatory devices with which we come equipped to maintain life and survive. (Damasio, 2000, p. 15)

For social and emotional behavior, the human head and face have become the central non-verbal means to provide information, to communicate emotion, and to regulate cooperative behavior and establish social hierarchies. Indeed, by comparison, the human face has evolved to a unique level of complexity. While in animals, comparatively simple behavior can be predicted from relatively simple displays, in primates and humans, the complexity of facial displays has co-evolved with an increasing complexity in inner states (Cole, 1998)[1]. The head and face are, for example, used to recognize the age, sex, attractiveness and health of others (Bruce & Young, 1986; Cole, 1998). Most importantly, the head and face are also central in recognizing a person's identity, in conveying clues to motivational states, and in regulating social interactions. Nodding and shaking of the head are, together with shifts in the direction of gaze, used to efficiently establish intimacy and to exert social control (Bruce & Young, 1996). Also, during social interaction and cooperative behavior, facial emotional expressions of anger and friendliness can be efficient tools for regulating social cooperation, and for steering others to cooperative behavior (Hirschleifer, 1987; see also Schmidt & Cohn, 2001)[2]. As summarized by Oatley and Jenkins (1996):

> Human emotions are the language of human social life - they provide the outline patterns that relate people to each other. The smile - the best established universal signal of emotion – is the sign of social affirmation; happiness is the emotion of cooperation. The frown signals something not going well; anger is the emotion of interpersonal conflict...
> (Oatley and Jenkins, 1996, p. 87).

Facial expressions of anger and friendliness are cheap ways to avoid and resolve motivational conflict. By using a facial signal of gratitude, a maintained cooperation can be encouraged and reinforced (Hirschleifer, 1987), and by signaling imminent rage, conflicting individuals can avoid costly physical fighting (e.g. Krebs & Davies, 1993; Camperio Ciano, 2000), and cheating behavior can be counteracted. The importance of cooperation, specifically the importance of recognizing cooperative or cheating individuals, is further emphasized by data from Mealey, Daood, and Krage (1996). In their data, participants demonstrated enhanced memory for faces of individuals who had been presented as cheaters.

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[1] See also Endler (1992), Krebs & Davies (1993), and Enquist and Arak (1998) for a discussion of co-evolution between communicative signals, signaling behavior and the neural mechanisms involved in recognizing a signal.

[2] See Enquist, Arak, Ghirlanda and Wachtmeister (2002) for a discussion of the shortcomings of game theory in modeling evolutionary equilibrium.

1.1.4 Perceiving faces

The evolutionary importance of the face is reflected also in the general efficiency by which the human mind handles facial information. Despite the incredible complexity of facial information, and despite challenges such as high between-person similarities and transformations in viewing distance and viewing angle, facial information is processed with incredible efficiency. Within the blink of an eye, we extract information about each other's gender, age, identity, attention, speech and feelings. Without much effort, we also easily detect the identity of acquaintances in a large crowd of strangers.

Much clinical and experimental data (see e.g. Bruce & Young, 1986; Young, McWeeny, Hay, & Ellis, 1986) suggest that different types of facial information are extracted by separate processes, operating in parallel rather than sequentially. There is thus, for instance, one module for the recognition of identity, and independent one for the recognition of expression. The process of identity recognition has been theoretically modeled in quite some detail (see e.g. Bruce, & Humphreys 1994; Young, 1994; Bruce & Young, 1996), and according to the face-processing model by Bruce and Young (e.g. 1986), the recognition of identity relies on further sub-processes. There are, for instance, three sequentially dependent processes that are involved in identity recognition: face recognition, person identity recognition, and name recognition (thus, you can recognize that a face is familiar without remembering who the person is, and also recognize who the individual behind a face is without recalling the name, but not the other way around). Furthermore, Bruce and Young (1996) have suggested that face processing relies on separate modules for extraction of different aspects of facial information, such as single features, feature configurations and holistic shape. These modules match Marr's (1982) computational model of face perception. According to Marr, face perception involves a set of parallel filters of different spatial frequency, each of which extract information at different levels of detail (such as high-frequency features, configurations and holistic, low-frequency craniofacial structure). However, although these filters operate in parallel, the integration and interpretation of their output is not independent of each other (Marr, 1982). For instance, configuration exerts strong effects on the perception of single features. In face processing, configuration effects are particularly pronounced for upright faces, whereas it is weakened or lost if faces are presented upside-down (see e.g. Young, Hellawell, & Hay, 1987; Carey, & Diamond, 1994).

The processing of facial expression is believed to rely on a similar, and partly overlapping, modular system for parallel extraction of different types of information (such as single features, feature configuration, and holistic craniofacial structure; Bruce & Young, 1986; 96; cf. also Marr, 1982). Indeed, the "structural encoding" part of Bruce and Young's (1986) model, is a supposedly multi-purpose mechanism, which performs an initial encoding of facial information, the output of which can be used by all the subsequent differently specialized modules (such as speech analysis, identity and expression recognition). There is also some evidence of a similar sensitivity to inversion for expression recognition. For example, McKelvie (1995) concluded that while upright expressions are correctly recognized, inversion interferes with configurational processing, and any successful recognition of facial expressions presented upside-down has to rely on recognition of single features rather than holistic configurational properties (see however White, 1999).

1.1.5 Priority to threatening faces

In general, humans process, recognize and respond to faces very quickly. The general speed of responding to others facial emotional expressions has been illuminated by Dimberg (e.g. 1991; 1994). He measured the activity of specific muscles in participants' faces while they were exposed to pictures of facial expressions of emotion. Reactions to the viewed facial expressions was initiated almost instantly, and differed between expressions of anger and happiness as early as 300-400 ms after stimulus onset (see review by Dimberg, & Öhman, 1996). Within this time, participants perceived the specific features of a face, recognized its emotional expression, and activated a specific facial reaction to the viewed face. Further evidence for generally efficient processing of emotional facial expressions comes from information processing paradigms. For example, White (1995) examined the effect of facial expressions (happy or sad) on visual search latencies. His results showed that emotionally expressive faces among neutral distractor faces were efficiently detected in a crowd of faces, irrespectively of crowd size, suggesting a parallel processing of the faces in that crowd.

Although emotional faces can be processed very efficiently in general, the literature indicates that negative, threatening and angry faces are processed particularly efficiently. Threatening faces can, for instance, be exceptionally efficient cues for human fear conditioning (e.g., Öhman & Dimberg, 1978). Furthermore, such conditioning effects are not dependent on conscious identification of stimuli. Thus, responses may be both conditioned to (Esteves, Parra, Dimberg, & Öhman, 1994a) and elicited by (Esteves, Dimberg, & Öhman, 1994b) threatening and angry (but not happy) faces outside conscious awareness (see Dimberg, & Öhman, 1996, for a review of conditioning to facial stimuli). The particularly efficient processing of negative facial information can be interpreted from an evolutionary perspective. Fast responding and high priority could give an adaptive edge in coping with potentially threatening situations. In support for such a notion, recent brain imaging studies have demonstrated non-conscious activation of regional cerebral blood flow responses in the right amygdala to masked angry faces (Morris, Öhman, & Dolan, 1998; cf. LeDoux, 1996). Similar data on non-conscious activation of the amygdala in response to threatening or fear-evoking stimuli (snakes and spiders viewed by fearful participants) have also been reported by Carlsson, Petersson, Lundqvist, Karlsson, Ingvar, & Öhman (submitted). Morris, Öhman, and Dolan (1999) even suggest that this information may be conveyed to the amygdala via a subcortical visual pathway (between thalamus and amygdala).

The quick responding of threatening faces, and the generally more efficient handling of threatening compared to non-threatening information, stresses the importance of for accurate and easily perceivable features for a reliable recognition of emotional stimulus properties. A better understanding of how the human mind handles emotional expressions in general, and threatening expressions in particular, can improve the understanding of face perception and the relation between facial features and emotional properties.

From this perspective, it becomes a primary research priority to delineate the specific features that allow definition of threat, for example, in emotional facial displays.

1.1.6 Exploring facial features

Since the birth of the scientific study of faces, there have been several approaches to how facial expressions of emotion should be studied and understood. During the late 19:th century, Duchenne de Bologne and Charles Darwin established some of the dominating approaches to a scientific study of the relationship between facial communication and emotional responses. Duchenne De Bologne (1862/1990) investigated facial movements and expressions via a careful study of the anatomy of the face and facial muscles, and Charles Darwin (1872) formulated a theory about the evolutionary origin of facial expressions of emotion. During the 20:th and the very early 21:st century, much of the research concerning faces and facial expressions has been directly or indirectly based on the work of Duchenne De Bologne (1862/1990), and Darwin (1872).

Important contributions to Duchenne De Bologne's original anatomical approach (1862/1990) to face research were made by Hjortsjö (1969), who outlined a detailed account for what groups of facial muscles, so-called action units, that are active during different facial expressions. The work of Hjortsjö (1969) has been continued by Ekman and Friesen (e.g. 1977), and has also later inspired the development of detailed computer graphic models of how groups of facial muscles (or action units) deform the skin and the shape of the human face during different emotional expressions (the Candide project: see Rydfalk, 1987; Ahlberg, 2001). The anatomical design of the face even appears specifically evolved for efficient production of facial gestures. Unlike most other musculature, the facial muscles are designed to move skin tissue rather than bones (Dimberg & Öhman, 1996; Fridlund, 1994). With the exception of the jaw-muscles, all facial muscles are controlled by the same cranial nerve, which also suggest a common evolutionary origin (Cole, 1998).

Although the motives and evidence behind Darwin's (1872) evolutionary account for facial expressions of emotion have been questioned (see e.g. Cole, 1998), his theory has had a tremendous impact on contemporary views of faces and facial expressions. According to Darwin (1872), facial expressions of emotion originate in incidental movements and action preparations. Thus, the facial changes associated with, for instance, an expression of anger (deeply frowning eyebrows, intensely staring eyes and a shut mouth with lowered corners; see e.g., Ekman & Friesen, 1975) could be explained as originating in movements for protection of the eyes and a preparation to fight and bite. Within behavioral ecology (e.g. Tinbergen, 1954; Krebs & Davies, 1993) and signal evolution (see e.g. Endler, 1992, Enquist, & Arak, 1998), such a view on communicative signals is today generally accepted, and many signals in animals are thus considered to origin in incidental movements, which have allowed an observer to predict significant behavior (Tinbergen, 1954; Krebs & Davies, 1993; see also Enquist & Arak, 1998).

Primarily through the early work of Tomkins (1962), Ekman, & Friesen (e.g. 1971; see also Ekman, Friesen, O'Sullivan, Chan, Diacoyanni-Tarlatzis, Heider, Krause, LeCompte, Pitcairn, Ricci-Bitti, Scherer, Tomita, & Tzavaras, 1987), and Izard (1977), the theory of Darwin (1872) has later been used to establish a handful of facial expressions of emotion as unique and innate. Assembling cross-cultural evidence for how facial expressions of emotion are used and recognized, (see e.g. Ekman & Friesen, 1971) evidence was presented for a cross-cultural reliability in using and recognizing facial expressions of anger, happiness, surprise, disgust, grief, and fear. Ekman and Friesen (1977) have later also developed the facial action coding system (FACS), a manual for analyzing and specifying observed facial activity.

While many researchers have investigated facial emotional behavior from an explicitly face-specific perspective, either via facial muscles (such as Duchenne de Bologne, 1862/1990; and Hjortsjö, 1969; see also Dimberg, 1994) or observational facial changes (Ekman, & Friesen, 1977; Izard, Dougherty, & Hembree 1983), other researchers have approached the issue from a more non-specific perspective. Aronoff and coworkers (Aronoff, Barclay, & Stevenson, 1988; Aronoff, Woike, & Hyman, 1992) suggested that a general-purpose mechanism may underlie the recognition of facial expressions, and argued that the meaning in a facial expression could be reduced and explained by basic geometrical properties. Furthermore, the effect of these geometrical properties on perceived meaning would not be limited to faces, but influence the impression of visual shapes in general, even body movement patterns in dance (Aronoff et al., 1992).

Focusing on what geometrical properties that could provide the basis for recognition of threat and friendliness, Aronoff et al. (1988) demonstrated that different geometrical shapes create different emotional impressions (diagonal lines are, for instance, perceived as more negative than straight lines, and oval shapes as more energetic than circular shapes). The approach of Aronoff and coworkers have many antecedents in sociobiology, where the effect of craniofacial proportions and geometry on the impression of, for instance, female attractiveness (Cunningham, 1986; see also Enquist, Ghirlanda, Lundqvist, & Wachtmeister, 2002), cuteness and childishness (Berry, & McArthur, 1985), and age (Berry, & McArthur, 1986) have been demonstrated. Similar attempts to extract underlying geometry in facial expressions of emotions to those of Aronoff et al. (1988; 1992) have been made by Yamada and coworkers (Yamada, 1993; Yamada, Matsuda, Watari, & Suenga, 1993) who found that changes between facial expressions of emotion was associated with transformation in geometrical properties, such as curvedness and slantedness (cf. Aronoff et al., 1988). Similarly, Kappas, Hess, Barr, and Kleck (1994) investigated how geometrical properties that are manipulated by a viewers vertical angle of regard (relative to the face of the person that is viewed) affects recognition of facial expressions.

Although an evolutionary perspective on facial expressions (Darwin, 1872; Ekman, 1999) of emotion is accepted in general, particularly within signal evolution theory (see e.g. Krebs & Davies, 1993; Fridlund, 1994), some of the arguments and evidence for an exclusive and panhuman set of basic emotional expressions have been questioned. Thus, although most researchers acknowledge that there is convincing evidence of reliable recognition of photographed poses of (western) facial expressions in many non-western cultures, there is also evidence of differences in the type of expression used for an emotion both within and between cultures (e.g. Scherer, 1994), indicating that the relation between emotion and facial expressions is far from simple and reflex-like (e.g. Russell, 1997). Indeed, people may cry with joy, and be completely expressionless during strong grief, terror, or loathe (Cole, 1998). The variation in *how* and *when* humans express emotion via their faces does indeed appear to be large, but there also seem to be a solid core in the variation. According to Scherer (1994), the evidence of cross-cultural facial expressions relies heavily on a relatively small core of facial movements, primarily the corrugator and zygomatic major, the facial muscles involved in moving the eyebrows and the mouth (during, for instance, a frown or a smile).

Also, pictures of posed expressions can be criticized for lacking information about what facial displacement that a specific expression involves. Indeed, facial expressions can be effectively recognized from the movements in facial areas alone (Bassili, 1979), and the lack of that information is likely to affect recognition of faces more during some circumstances than other. Since a picture of a posed expression involve inferences of the displacement that has taken place (relative to a neutral, relaxed face), pictures are likely to cause problems in cases when participants are unfamiliar with the craniofacial norm of a particular population, such as when western expressions are shown to non-western participants or vice versa.

Strong arguments have also been presented against the existence of cross-culturally valid emotional verbal labels and cross-culturally valid emotional concepts. According to, for instance, Wierzbicka (1999), there *can be* no universal emotion concept since no emotion term can be accurately translated across diverse languages. Although this question remains controversial, the tacit definitions hidden in verbal labels for complex concepts such as emotions do pose translation problems. Even *if* a universal set of facial expressions exists, research on another human universal, color perception, demonstrates that concept borders and verbal labels do pose a problem. Thus, although perception of color appears to be reliably universal (Brown, 1991), the range of verbal labels (and underlying concepts) that map these perceptions vary much between languages and cultures. For instance, the Hopi people have only two words for colors, one for dark and one for light colors, while Indo-European languages in general have nine different color words (Brown, 1991). In this case, translation in any direction between language terms would result in poor reference and give an inexact picture of the underlying perception of color.

However, research on facial expressions must not necessarily be restricted to verbal labels. Some researchers have instead of lexical categories used an open, dimensional approach when assessing the emotional meaning of facial expressions (e.g. Schlosberg, 1954; Osgood, 1966; Russell & Bullock, 1985). The dimensional approach to facial expressions comes out to a long tradition.

1.1.7 Measuring emotional properties

The emotional properties of affective stimuli (such as faces, words, pictures, and behavior) have often been measures by means of verbal (Osgood, Suci, & Tannenbaum, 1957) or iconic (Lang, 1980) semantic differential scales. An important early contribution to this tradition was made by Osgood, et al. (1957). Performing factor analysis on a vast number of semantically contrasting adjective pairs, Osgood and coworkers found that three major semantic dimensions underlay the formation of affective impression. These three dimensions, named Evaluation, Potency and Activity (also known as the EPA-structure) have since the fifties repeatedly been found to underlie the formation of affective and emotional impression. They have, for instance, been found to underlie the emotional impression of facial expressions (Osgood, 1966; Russell et al., 1985), words (e.g., Russell, 1980; 1983), affective pictures (Bradley, Greenwald, & Hamm, 1993), and music (Wedin, 1969; for an overview, see Gabrielsson, & Juslin, 2003).

Reviewing the historical role of these three semantic dimensions, Heise (1992) concluded that:

> Crosscultural research among people speaking diverse languages in more than twenty-five nations ... revealed that any person, behavior, object, setting or property of persons evokes an affective response consisting of three components. ... The Evaluation, Potency, and Activity (EPA) structure in subjective responses is one of the best documented facts in social science, and an elaborate technology has developed for measuring EPA responses on semantic differential scales. (Heise, 1992, pp. 12-13)

Importantly, Lang and coworkers (see e.g. Lang, Bradley, & Cuthbert, 1997) have established a link between the EPA-measures and emotional psychophysiological response systems. For instance, a relation has been demonstrated between rated Valence (Evaluation) and the magnitude of the startle response, and between rated Activity (Arousal) and the magnitude of skin conductance responses (Lang et al., 1997). The emotional properties of the material used in those particular studies was assessed with the Self-Assessment Manikin (SAM), an iconic differential rating system that was designed by Lang (1980) to tap the three dimensions of Evaluation, Activity and Potency. The three SAM-dimensions have also been validated against the classical verbal semantic differential scales and the EPA-structure by Hamm (1993).

The documented reliability of the EPA-structure (Heise, 1992), and its link to emotional response systems (Lang et al., 1997) makes it a good and meaningful choice for assessment of emotional properties. Also, because the EPA-structure supplies an open, non-categorical set of measures, it is a particularly suitable choice when one will manipulate different features of emotional stimuli experimentally.

1.1.8 Purpose of Study I and II

Study I and II in this thesis joins the tradition of exploring and understanding facial features that was originally pioneered by Duchenne De Bologne (1862/1990) and Darwin (1872). The aim of both studies was to investigate the effect of different facial features and configurations on emotional impression.

The design of the stimuli used in Study I and II takes a relatively direct starting point in the work of Aronoff et al. (1988; 1992). The approach here is, however, quite opposite to the general-purpose perspective that Aronoff and co-workers apply to facial impression formation. Thus, while the effect of general craniofacial geometry on the impression of heads and faces is acknowledged, faces and facial expressions are in other respects viewed as specifically evolved signals for social communication of emotion and intention. The processes that underlie recognition of facial emotion are thus assumed to operate on specific signaling features in the face, and not mainly on general-purpose geometrical properties. To better understand the process of emotion recognition, specifically recognition of facial threat (see Öhman, 1992; 1993; 1997), it is important to delineate the specific and typical facial features that communicate anger and threat. Once facial threat is better understood, efficient emotional stimuli can also be produced and used for investigation of emotional effects on attention.

To allow experimental control of critical facial features, the features were depicted in simplified and stereotypical forms (cf. Aronoff et al., 1988; 1992) and combined into schematic facial expressions. In both Study I and II here, we

(Lundqvist, Esteves, & Öhman, 1999; 2004) systematically varied the shapes of facial features such as eyebrows, eyes, mouth, nose, direction of gaze and facial outline, and examined the effects of these variables on the semantic dimensions Negative Valence (a reversed Evaluation dimension), Activity, and Potency (the EPA-structure). Thus, the emotional effect of different facial features could be studied without restricting participants to particular emotional concepts or labels (e.g., anger, happiness, threat).

1.2 EXAMINING FACIAL THREAT: STUDY I AND II

1.2.1 General method

In Study I and II, a set of eleven adjective pairs was used to register the participants' emotional impression of different facial stimuli. The adjective pairs were adapted from Aronoff et al. (1988; 1992) and were selected to tap the semantic dimensions of Evaluation, Potency and Activity that were established by Osgood et al. (1957).

The stimuli were presented on top of a paper sheet, with the eleven adjective pairs placed below each stimulus (Fig. 1, upper left panel). For each experiment, the different sheets were assembled in a booklet. A front sheet with written instructions was attached to the booklet, and the instructions were also presented orally before each experiment. Participants were instructed to work their way through the booklets from beginning to end, and to score their spontaneous impression of the stimuli by using all the different adjective scales for every stimulus.

In both studies, factor analyses were performed to confirm that these adjective scales loaded on the expected underlying semantic dimension. Each subject's average rating over stimuli was calculated for the eleven different semantic scales, and these data were then submitted to a principal component factor analyses, rotated by the orthogonal varimax method and set to extract roots >1.0. In both studies, the analysis resulted in three factors with eigenvalues of >1.0, accounting for totally 65 % (Study I) and 68 % (Study II) of the variance. By calculating the mean values of the adjective scales that had the highest loadings on each of these factors, three composite semantic scales were then created (see Lundqvist et al., 2004, Table 1, for factor loadings from both studies). The adjective pairs good-bad, kind-cruel, friendly-unfriendly, pleasant-unpleasant were thus collapsed into a Negative Valence scale; the scales, light-heavy, small-large, weak-strong, and fragile-tough were collapsed into a Potency scale; and passive-active, inert-energetic and calm-excitable were collapsed into an Activity scale (Fig. 1, upper right panel).

After reducing the eleven response scales into the three semantic dimensions of Negative Valence (an inversion of the original Evaluation dimension), Potency and Activity, data were analyzed by factorial ANOVAs. Tukey HSD was used for follow-up tests when appropriate. Throughout both studies, an Alpha-level of $p<.01$ was used.

1.2.2 Study I: The Face of Wrath: Critical Features for Conveying Facial Threat

1.2.2.1 Outline of Study I

In Study I (Lundqvist, Esteves, & Öhman, 1999), we investigated the role of facial features (such as shape of eyebrows, eyes, mouth, nose and the direction of gaze) in conveying a threatening and non-threatening emotional impression. In two

FIGURE 1. Measuring emotion: Semantic differential scales and emotional dimensions.

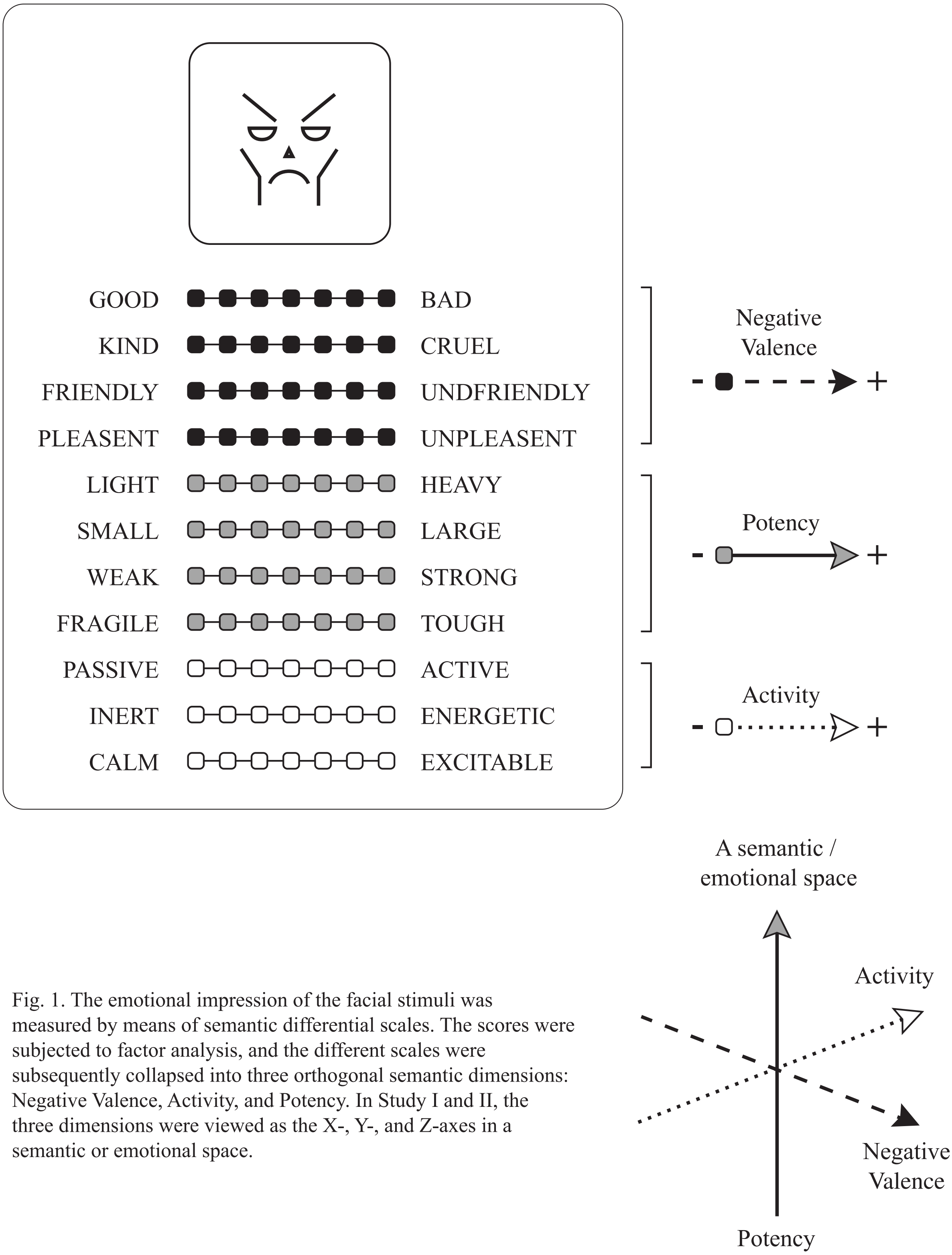


Fig. 1. The emotional impression of the facial stimuli was measured by means of semantic differential scales. The scores were subjected to factor analysis, and the different scales were subsequently collapsed into three orthogonal semantic dimensions: Negative Valence, Activity, and Potency. In Study I and II, the three dimensions were viewed as the X-, Y-, and Z-axes in a semantic or emotional space.

experiments, a total of 100 participants rated their emotional impression of two sets of schematic faces by means of semantic differential scales (Negative Valence, Activity, and Potency).

1.2.2.2 Experiment 1

In Experiment 1, we investigated the effect of different shapes of eyebrows, mouth, eyes and nose (see Fig. 2, upper left panel) on rated emotional impression (Negative Evaluation, Potency and Activity).

We found that eyebrows had the overall largest effect on emotional impression of faces. Also, when viewed in a three-dimensional emotional space defined by Negative Valence, Potency and Activity, the data showed multidimensional effects on emotional impression, and the different impressions of faces were found to cluster around specific configurations of features. The different facial features were furthermore found to affect the emotional impression of faces in a hierarchical way. The emotional impression of faces was thus defined in ranked order by eyebrows, mouth and eyes. Eyebrows defined faces as fundamentally threatening (v-shaped eyebrows) or non-threatening/friendly (^-shaped eyebrows), whereas further subdivisions within those threatening and friendly sections of the emotional space were made by different shapes of mouth and eyes. The clustering of faces was particularly evident around different configurations of eyebrows and mouth, which indicated that such configurations jointly determined much of the emotional impression of a face (Fig. 2, lower panel).

1.2.2.3 Experiment 2

The aim of Experiment 2 was to replicate Experiment 1, but also, following the observed importance of gaze direction on emotional reactions (e.g. Dimberg, 1986; Dimberg, & Öhman, 1983), to examine the effect of gaze direction on the emotional impression of faces. We thus investigated the effect of different shapes of eyebrows, mouth, eyes (similarly to Experiment 1) and gaze directions (see Fig. 2, upper right panel) on rated emotional impression.

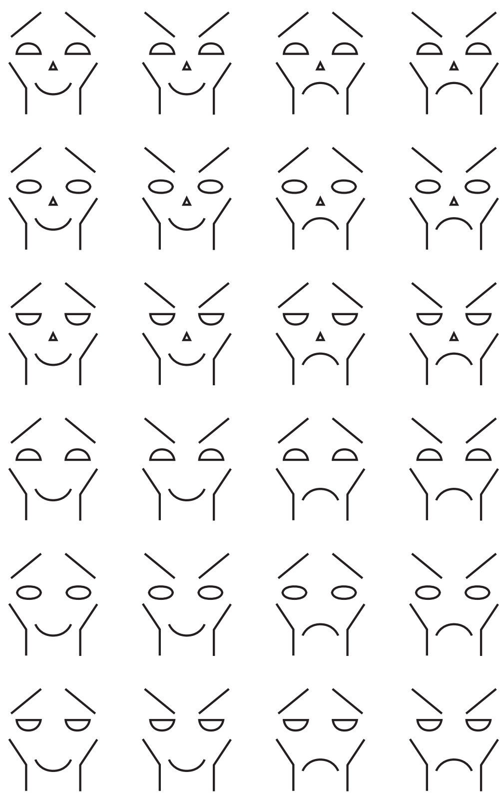
The general pattern of results was the same as in Experiment 1, and again, the shape of eyebrows had the largest effects on emotional impression. Viewed in the three-dimensional emotional space, faces clustered in a similar way as in Experiment 1. Thus, here too, the different facial features appeared to affect the emotional impression of faces hierarchically, in the rank order of eyebrows, mouth, and eyes. Gaze-direction modified the clustering of faces, but gave, by comparison, no fundamental effect on the emotional impression of faces.

1.2.2.4 Summary

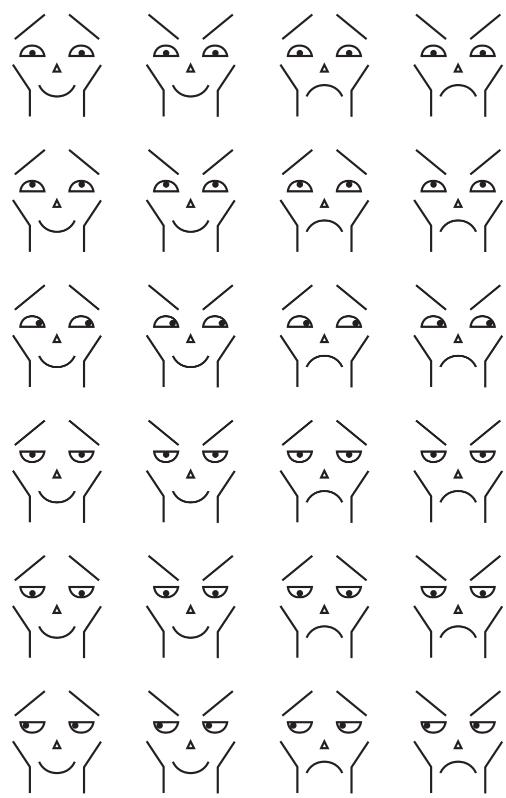
In both experiments, the shape of eyebrows came out as the most important feature for the emotional impression of a face, giving strong emotional effects on all three of the semantic dimensions Negative Valence, Potency and Activity. Furthermore, eyebrows were at the top of the hierarchy of features that emerged when the data was viewed as part of a three-dimensional emotional space. The shape of eyebrows thus fundamentally categorized faces as threatening or non-threatening,

FIGURE 2. Stimulus material and results from Study I.

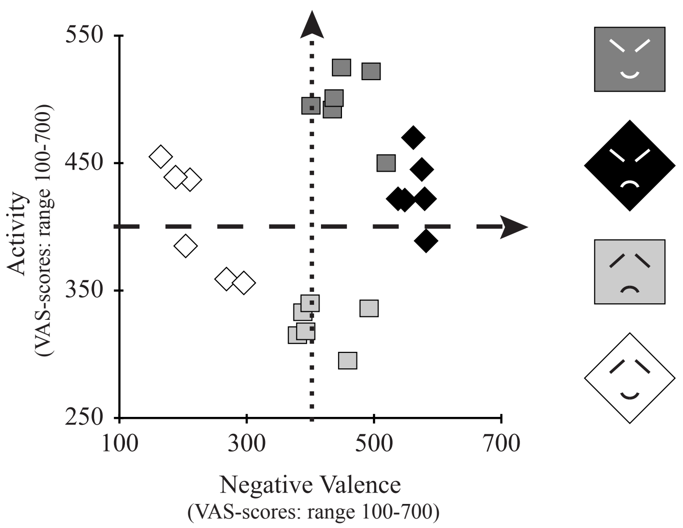
Stimulus material, Study I, Experiment 1.



Stimulus material, Study I, Experiment 2.



Results, Study I, Experiment 1.



whereas mouth and eyes, in rank order, provided successive subdivisions within these primary categories. The direction of gaze had a clear modulating effect on the emotional impression of faces, but it was subordinate to the effects of eyebrows, mouth and eyes.

The results showed that v-shaped eyebrows play a particularly central role in conveying a threatening impression, but also that mouth and eyes play important modulating roles. Moreover, the emotional impressions clustered markedly around specific configurations of eyebrows and mouth, and the eyebrows-mouth configurations hence appeared to be responsible for the most pronounced effects on emotional impression.

The results demonstrated that specific facial features, such as eyebrows and mouth, give strong effects on emotional impression, but also raised questions about to the degree to which the effects of those features depend on how these features were presented in facial context. Could, for instance, isolated eyebrows, mouths and eyes convey similar emotional impressions as when they are included in a face?

1.2.3 Study II: The Face of Wrath: The Role of Features and Configurations in Conveying Social Threat

1.2.3.1 Outline of Study II

The findings in Study I raised questions about the independence of the individual facial features, and of how much the emotional effect of a feature that depended on the context provided by a particular face. Even though the interdependence (the hierarchical relationship) between features could be taken to indicate holistic processing, Study I included neither a direct comparison of single features versus full facial configurations, nor a direct test of the effect of basic facial structure versus non-facial structure on the impression of facial features. Rather, because the primary aim of Study I was to investigate the role of and relation between features for conveying facial emotion and facial threat, the different features were always presented together in a face, in a standard relation to other features (i.e. eyebrows were always presented above eyes, and eyes above mouth etc.). A natural extension of Study I was thus to examine the hypothesis (Aronoff et al., 1988) that a specific shape of eyebrows that is presented alone would be as effective in affecting emotional impressions as the same feature presented in a facial configuration. As a part of investigating the role of configuration and face structure for conveying emotion, the effect of rotated versus upright configurations was investigated. In face processing, particularly in identity recognition, rotation of faces is known to interfere with configurational processing of facial features (for pictorial stimuli, see e.g. Bruce, & Young, 1986; for schematic stimuli, see e.g. Endo, Masame, & Maruyama, 1989).

In Study II (Lundqvist, Esteves, & Öhman, 2004), we thus continued the work initiated in Study I, by investigating the role of isolated features, feature configurations, and facial context for recognition of facial threat. Furthermore, we also used regression analysis to investigate the statistical contribution of single features and basic configurations on the emotional effect of full facial configurations. A total of 101 participants rated their emotional impression of schematic facial stimuli using semantic differential scales (Activity, Negative Valence and Potency). In three different parts, the ratings concerned single features, basic eyebrow-mouth configurations, and complete faces.

1.2.3.2 Part 1: Single features

In Part 1, we investigated the effect of isolated eyebrows, mouth, eyes and face (Fig. 3, upper left panel) on rated emotional impression (Negative Evaluation, Potency and Activity).

Presented isolated from a facial context, some of the single features (v-shaped eyebrows and u-shaped mouth) conveyed a relatively strong impression, whereas the effects of the other isolated features were comparatively small (see Fig. 3, upper right panel).

1.2.3.3 Part 2: Basic configurations

In Study I, configurations of eyebrows and mouth were found to strongly affect the emotional impression of faces. In Part 2 of Study II, we wanted to investigate whether such a basic configuration could convey an equally strong emotional effect outside a facial context. We also wanted to investigate the role of feature configuration on emotional impression, by testing how much of the emotional effect of an upright that remained when it was rotated and presented upside-down.

In Part 2, we thus investigated the effect of upright and rotated eyebrows-mouth configurations (Fig. 3, middle left panel) on rated emotional impression (Negative Evaluation, Potency and Activity.

The data showed that isolated configurations of eyebrows and mouth conveyed a comparatively strong emotional impressions when presented upright (eyebrows above mouth). The impact of the facial features in the basic configuration however strongly depended on configurational placement of features (whether eyebrows were placed above the mouth or vice versa), and the emotional effects of the rotated configurations were hence very small (see Fig. 3, middle right panel).

The results showed that (upright) basic configurations of eyebrows and mouth are very effective in conveying an emotional impression, but that even in such basic, isolated eyebrows-mouth configurations, the positioning of features overrides the effect of single features.

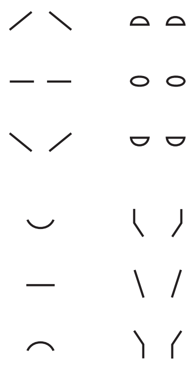
1.2.3.4 Part 3: Complete faces

The aim of Part 3 was to obtain reference data on complete faces, to enable comparisons between the emotional impressions of single features, basic configurations, and full faces. Also, the data on full faces provided the data for Part 4 of the study, in which regression analysis was used to investigate the relative contribution of single features and basic configurations to the emotional effect of full faces.

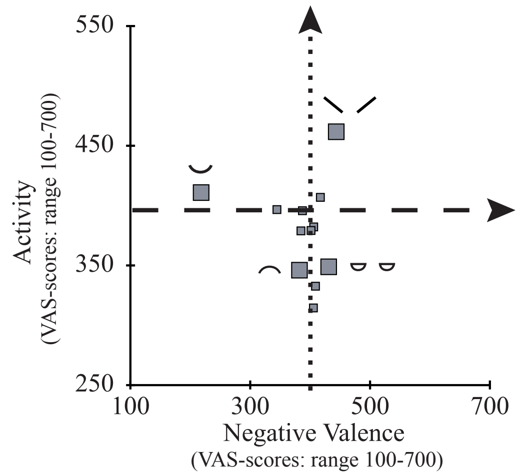
In Part 3 we thus investigated the effect of eyebrows, mouth, eyes and face outline, (Fig. 3, lower left panel) on rated emotional impression. The pattern of results replicate the results obtained for complete faces in Study I (see Fig. 3, lower right panel). The data of Part 3 also showed hierarchical effects of facial features on emotional impression, and the impressions of the different faces thus appear determined, in rank order, by eyebrows, mouth, and eyes.

FIGURE 3. Stimulus material and results from Study II.

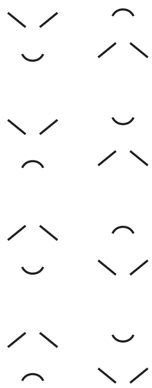
Stimulus material, Study II, Part 1.



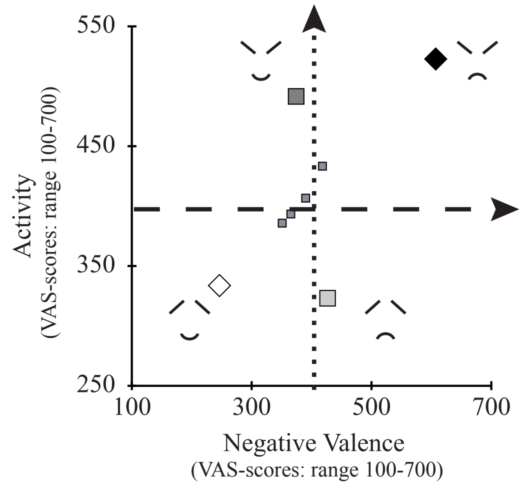
Results, Study II, Part 1.



Stimulus material, Study II, Part 2.

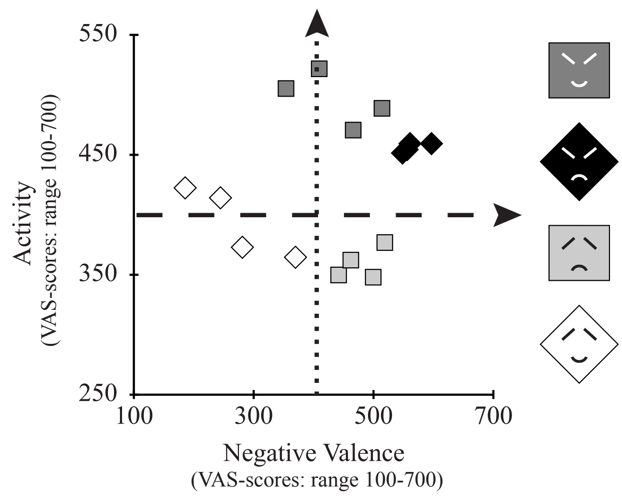


Results, Study II, Part 2.



Stimulus material, Study II, Part 3.

Results, Study II, Part 3.



1.2.3.5 Regression analyses

The regression analysis was used to examine whether the emotional impression of a single feature, or a basic eyebrows-mouth configuration could predict the effect of a complete face in which that feature or configuration was included.

The regression analysis showed that, among the isolated features, eyes were the best predictors of complete faces. V-shaped eyebrows and u-shaped mouth also hade *some* success as predictors, but only in one case each. The upright basic eyebrows-mouth configurations were the best predictors of full faces, and predicted the emotional impression in 5 out of 6 cases (for full detail see Lundqvist et al., 2004, where Fig. 5 shows β-weights for all significant relationships).

1.2.3.6 Summary

The results from Study II demonstrate that although some features (such as v-shaped eyebrows and u-shaped mouth) convey a relatively strong emotional effect when presented in isolation, basic configurations of eyebrows and mouth are much more efficient stimuli, sometimes even receiving higher emotion scores than complete faces (cf. Fig. 3, middle and lower right panels).

Eyebrows emerged as the most important and influential facial feature for conveying threat. Whether eyebrows were presented in isolation, in basic configurations or in complete facial configurations, they had a strong impact on emotional impression. Although this indicates that single facial features presented outside a facial context *can* convey an emotional impression independent of a facial context (cf. Aronoff et al., 1988; 1992), the results of Part 2 clearly showed that the effect of individual features was subordinate to the effect of configuration. Thus, the effect of eyebrows depended strongly on context, and had basically no effect when placed *under* a mouth instead of *above* it. The upright basic eyebrows-mouth configurations, however, proved able to convey threat in a corresponding degree to complete faces, and also reliably predicted the emotional impression of complete faces.

The results also show that while all involved facial features affected emotional impression in some degree, the features gave effects by a rank order. As in Study I, eyebrows thus had the most profound effect on emotional impression, followed in order by mouth, and eyes. The results of Study II are in general accordance with face processing theories (Marr, 1982; Bruce & Young, 1986; Haxby, Hoffman, & Gobbini, 2000), and indicate a sequential, hierarchic processing of facial features. For recognition of facial emotion, isolated facial features (especially v-shaped eyebrows and u-shaped mouth) *do* have some ability to convey emotional impressions outside a facial context, but the placement of features in a configuration with other features, in a face-like structure, is decisive both for the quality and strength of the emotional impression of the face.

1.3 A THREATENING IMPRESSION: DISCUSSION OF STUDY I & II

1.3.1 The threatening face

Study I and II showed that specific facial features are particularly effective in conveying a threatening emotional impression. In both studies eyebrows dominated the formation of emotional impression, and v-shaped eyebrows were central in conveying an impression of threat. The studies also demonstrated that configurations of eyebrow and mouth account for most of the conveyed impression, and that such configurations affected emotional impression similarly to complete faces, even when they were presented outside a general facial context.

When features were presented in isolation, v-shaped eyebrows and u-shaped mouth, respectively, gave the strongest effect. The importance of specifically v-shaped eyebrows for conveying threat has earlier been suggested by the work of, for instance, Aronoff et al. (1988; 1992). Similar features (frowning eyebrows) have also been found to be central means for conveying facial emotion in cross-cultural studies of facial expressions, for instance as a central component in expressing anger (Ekman, & Friesen, 1975). Indeed, according to Scherer (1994), much of the universality of facial expressions relies on movements by the corrugator and zygomatic major, the muscles involved in frowning (cf. v-shaped eyebrows) and smiling (cf. u-shaped mouth).

The studies showed that to be effective, facial features need to be presented in a face-like, upright structure. The studies also showed that when features were presented as part of a facial configuration, they affected the emotional impression in a hierarchical way. In ranked order, eyebrows were most important for conveying an emotional impression, followed in ranked order by mouth, and eyes. To specifically convey a threatening impression, v-shaped eyebrows are the best means, especially in combination with ∩-shaped mouth.

1.3.2 Why v-shaped eyebrows

According to Darwin (1872), facial expressions of emotion, similarly to many communicative signals in animals (see e.g. Krebs & Davies, 1993; Enquist & Arak, 1998), originate in action preparations. Accordingly, the looks of threat signals often originate in and reflect preparations for physical conflict (Tinbergen, 1954). In many animals, threat displays involve a lowering of the head (e.g. bulls, goats, seagulls), as a trace of the original movements involved in preparing and aiming for an attack. Conversely, submissive or friendly signals often involve the reversed components, such as raising the head and revealing the throat (Krebs & Davies, 1993) or averting the beak (Enquist, & Arak, 1998).

Similarly, in humans, a facial expression of anger often involve a slight bowing of the head, whereas friendly and submissive expressions involve a movement in the opposite direction, with a slight raising of the chin. Data by Kappas et al. (1994) suggests that the vertical angle of the head is central for recognition of facial emotion. Their results showed that facial expressions of anger were recognized best when viewed from above (corresponding to viewing a bowed head). Conversely, happy and sad expressions were best recognized when viewed from the front or from below, respectively.

A possible reason to why the vertical angle of the head is involved in conveying and recognizing facial expressions is that it modifies the geometrical properties of the signaling individuals face. As can be seen in Figure 4, a lowered head induces and amplifies u- and v-shapes, whereas a raised chin induces ∩- and ʌ-shapes. Thus, a slight bow emphasizes the v-shape of the eyebrows in a threatening face, whereas a raised chin counteracts or even reverses such a shape. Indeed, many of the typical features of a sad face emerge by a raising of the chin alone and, similarly, many features of a (diabolically smiling) scheming face are induced from bowing (see Fig. 4). By

FIGURE 4. The effect of vertical head angle on facial geometry.

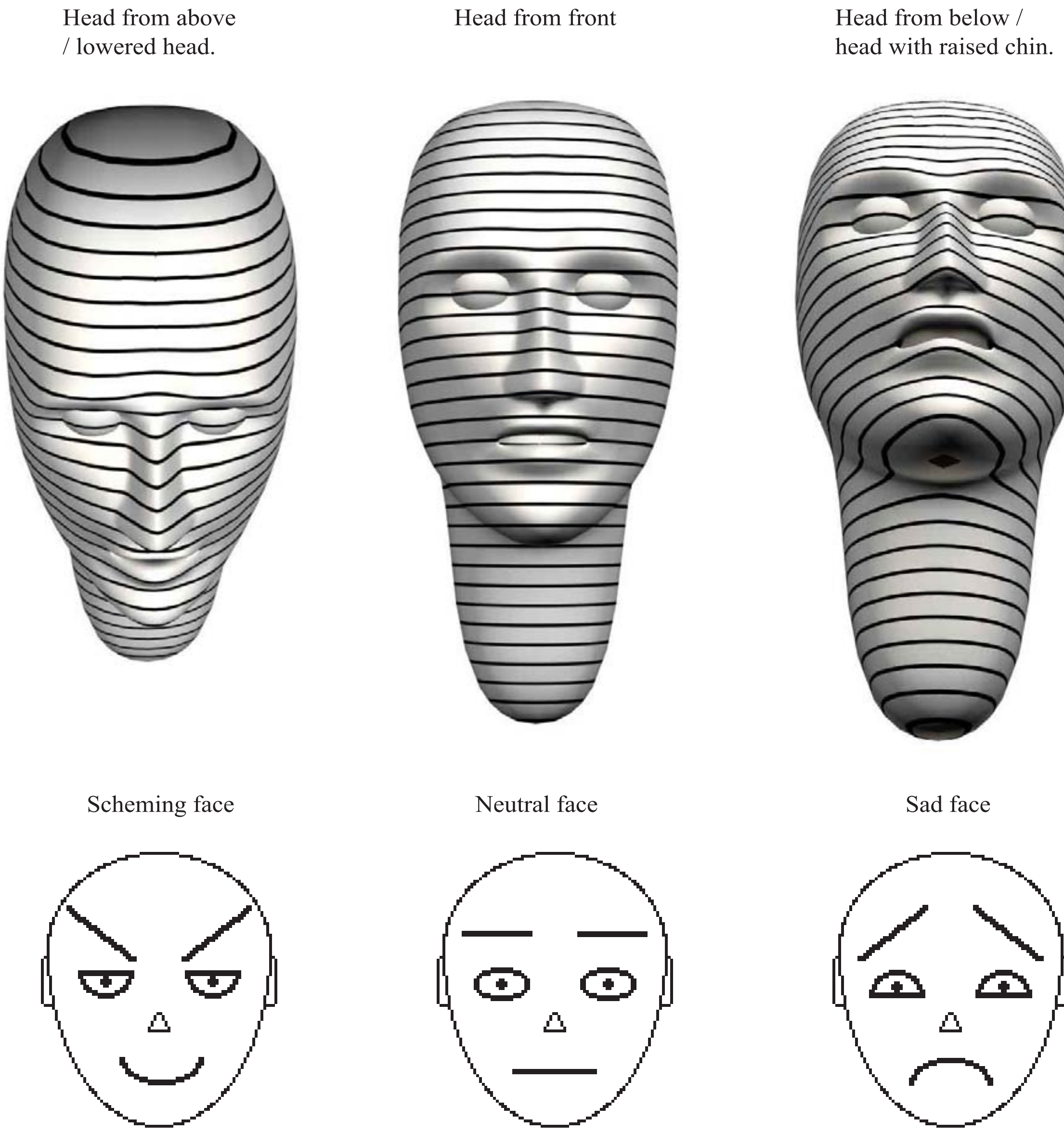


Fig. 4. The vertical angel of the head affects the perception of facial geometry. In animals, a lowered head is often a part of aiming an attack, and also often a part of threat displays. In humans, a lowering of the head is often involved in facial expressions of anger.

combining displacement of facial features with a vertical angel of the head, signals of threat (and friendliness) can thus be emphasized, disambiguated, and better recognized (see Kappas et al., 1994). However, whether the vertical angel of the head is the reason *why* threatening eyebrows are v-shaped, or if the vertical angle is a secondary component from signal ritualization (see Krebs & Davies, 1993; Enquist & Arak, 1998) is hard to say. The vertical angle can, however, contribute to making the facial signals easier to perceive and easier to discriminate.

The central role of v-shaped eyebrows in threatening faces, and that of u-shaped mouth in happy faces, is also supported by data from image analyses of Neutral, Happy and Angry faces (Lundqvist, & Litton, under preparation). Analyzing the difference between neutral and emotional averaged faces from the AKDEF set (Lundqvist, & Litton, 1998), the largest changes between the neutral and the angry face was found in the eyebrows area, whereas the largest changes between the neutral and the happy face was found in the mouth area (Fig. 5).

In accordance with these image analyses, eye-tracking data from participants that freely viewed schematic threatening and friendly faces (unpublished data) show that fixations directed to the threatening face were mainly directed to the upper part of the face (eyebrows and eyes), whereas for happy faces, fixations were directed mainly to the mouth area (Fig. 5).

1.3.3 Hierarchical effects of facial features

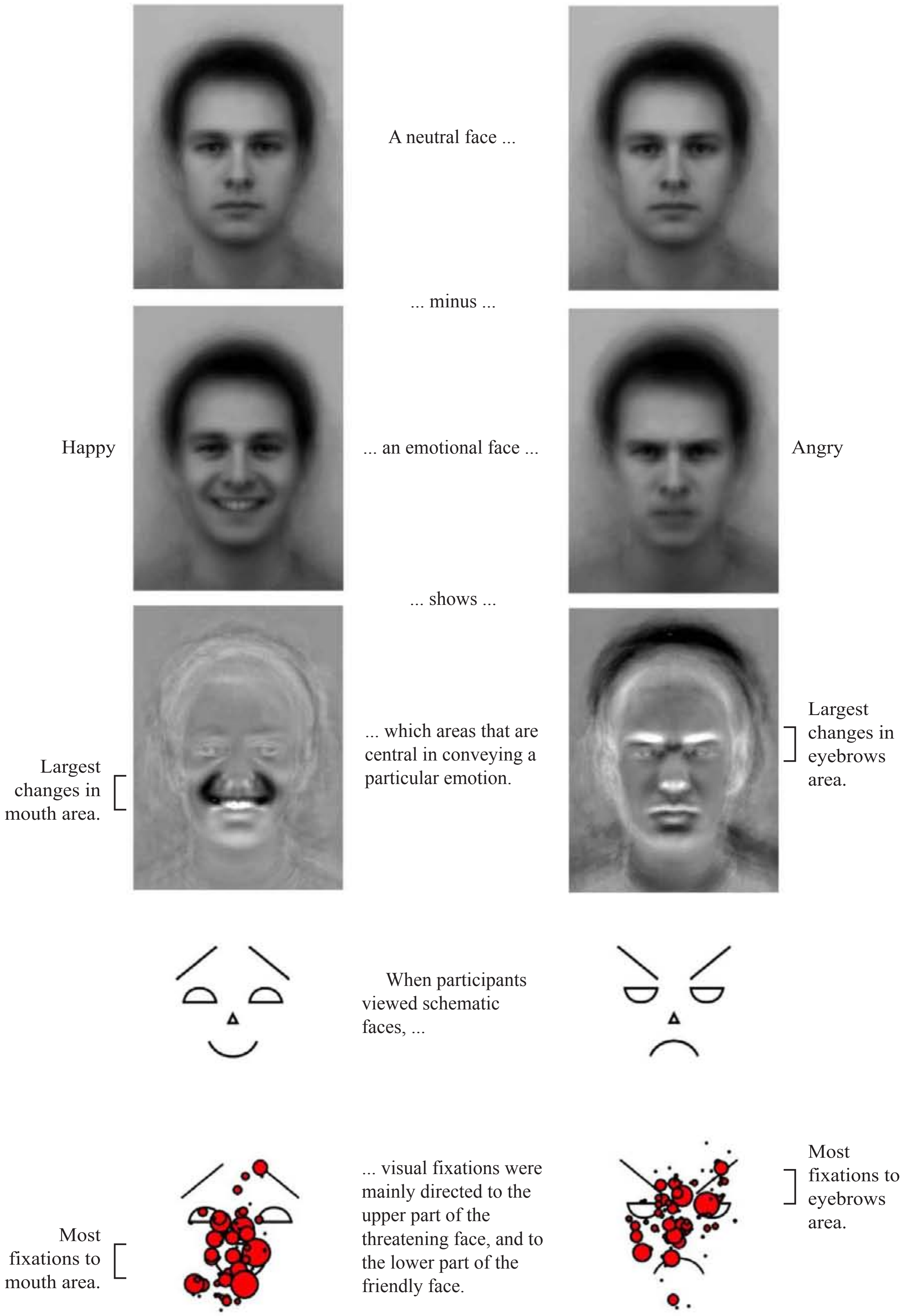
The hierarchical order by which facial features conveyed threat in Study I and II indicates that facial emotion may be defined by sequential categorization. According to Maynard Smith & Szathmáry (1995), hierarchical categorization of information is a fundamental aspect of human semantic representation[3], and is a natural consequence of internal representation of information. Such hierarchically organized representations are found also in animals, and can even be found in lowly life forms such as the sea anemone.

Importantly, categorization of semantic representation is closely related to behavioral responses, and reflects a grouping of information that requires similar behavior combined with a discrimination from information that requires dissimilar responses (Maynard Smith & Szathmáry, 1995). The hierarchical effects of facial features on emotional impression might thus mark a successive organization of behavioral responses, where eyebrows (v-shaped or ^-shaped) denote conflict or submission, and mouth and eyes signify different alternative actions within these behavioral directions (cf. Hirschleifer, 1987). The facial features in a threatening and friendly face can thus be viewed as a series of stimulus evaluations (cf. Scherer, 1994), such as the goal-congruency and the pleasantness of the situation.

The literature on face perception suggests that categorization is indeed involved in perception of *facial expressions* of emotion (showing enhanced between-emotion discrimination, and diminished within-emotion discrimination). Etcoff and Magee (1992) have, for instance, demonstrated categorical perception of line-drawn facial

[3] A problem with such a hierarchic organization is however that representations often have multiple functions, and thus may be part of several hierarchies. Any organizational system must thus accomplish processing and organization of information according to several parallel criteria (see e.g. neural networks in Churchland, 1996).

FIGURE 5. The role of eyebrows and mouth in threatening and friendly faces.



expressions. Similarly, for pictorial stimuli, categorical perception of emotional facial expressions (happiness, surprise, fear, sadness, disgust, and anger) has been demonstrated by Young, Rowland, Calder, Etcoff, Seth and Perrett (1997), and similar results have been reported by Campanella, Bruyer, Crommelinck, & Guerit (2002). Categorical perception of facial information has been demonstrated also for *facial identity* (Biele & Keil, 1995), where it appears to exist only for upright, and not for rotated, faces (McKone, Martini, & Nakayama, 2001)[4].

1.3.4 Perception of outline stimuli

Although the results of study I and II suggest that recognition of schematic faces is consistent with general face-processing theory (e.g. Bruce & Young, 1986; 1996), an important question is to what degree the results from line-drawn faces are applicable to real faces.

From a face-perception perspective, line-drawn faces are psychologically less unlike photographs than they first appear. An important difference between line-drawings and photographs is that line-drawings typically lack low-frequency information (such as skin texture and shadows) and mainly contain high-frequency information (such as edges and contours). However, the differently frequenced spatial filters of the visual system (Marr, 1982) can extract low-frequency information from the high-frequency information. This means that, although line-drawings are simplified and reduced, the visual system compensates for this and utilizes *similar* types of information from line-drawings and photographs (see Sergent, 1986).

The ability of the visual system to understand outline representations is a side of the visual system that naturally extends far beyond the line-drawings of the faces used in these studies. Throughout the history of art, as far back in as the 30 000 year old cave-drawings of Chauvet-pont-d'arc and the up to 9 000 year old Scandinavian rock art, humans have accurately depicted and recognized tools, animals, humans and faces by line-drawings. Indeed, even chimpanzees are able to accurately recognize line-drawn representations of individuals (Itakura, 1994). Thus, there is little reason to believe that processing of line-drawn facial stimuli is much different from processing of live or photographed faces.

1.3.5 Emotion of outline stimuli

One of the advantages of using schematic facial stimuli is that they allow precise control and manipulation of different features that are involved in creating a facial emotional impression. Conversely, the risk of using such simplified stimuli is that they might lack some critical information that is present in real faces. In the current context, a central question is how *emotional* the schematic faces really are.

In the current set of studies, the answer to this largely depends on whether the semantic dimensions in the EPA-structure (Negative Valence, Potency and Activity) are accepted as measures of emotion. The documented reliability and stability of these measures for assessing affective and emotional properties (see Heise, 1992), and the documented link between the EPA-structure and psychophysiological emotional response systems (Lang et al., 1997), suggest that the stimuli in Study I and II are

[4] See Ellison and Massaro (1997) for a discussion of the categorical perception approach versus a fuzzy logical model of perception (FLMP) on emotional facial expressions.

emotional. Because the faces gave consistent effects on the emotional measures in both studies, the effects of faces on emotional impression also appear to be very reliable. In Study I, faces showed a distribution over the emotional measures that were consistent across both experiments, and corresponding effects and distributions were also found across the different parts of Study II. Furthermore, two-dimensional plots of faces over the dimensions of Negative Valence and Activity revealed a circumplex distribution of the faces. A corresponding circular distribution of stimuli over corresponding semantic dimensions has earlier been reported for emotional facial expression (e.g., Osgood, 1966; Russell & Bullock, 1985), words (e.g., Russell, 1980; 1983), and emotional pictorial stimuli (Bradley, et al., 1993). Thus, the schematic facial stimuli used in Study I and II showed the type of distribution across the Activity - Negative Valence space that is commonly observed with other classes of emotional stimuli, which can be taken as further support for the emotionality of these schematic faces.

There is also some closely related evidence for neural emotional responses to these schematic faces. In an fMRI experiment, Wright, Martis, Shin, Fischer and Rauch (2002) demonstrated that responses to threatening[5] and friendly schematic faces involve activation of the amygdala. A significant increase in the activation of left amygdala was found both for the threatening and the friendly face, indicating emotional responses to both of these stimuli. The data also showed a significant difference in activation between the threatening and friendly face in the left occipitotemporal cortex, a cortical area involved in processing of facial features (see Adolphs, 2002; Haxby et al., 2000).

Indeed, one might even argue that the stereotypical features of schematic faces may be even more effective than the features of a real face in causing emotional responses. As a parallel example from the animal signaling literature, artificial, *supernormal* signals, which exaggerate the features of the real signals, have been found to be more efficient stimuli than the natural stimuli itself (Enquist & Arak, 1998). Supernormal stimuli generally represent information that is extremely effective for the receivers neural responding to the stimuli, and such stimuli thus provide both a maximally disambiguated recognition and an efficient differentiation from other stimuli. Indeed, the data presented by Wright et al. (2002) support the notion that schematic faces might be better than the real thing. In their data, the emotional responses to the schematic faces sustained an expected habituation effect, and thus gave more emotional effects than emotional faces normally do. The authors suggested that the maintained effect might be due to the schematic nature of the stimuli (Wright et al., 2002, p. 789).

[5] The stimuli used by Wright, Martis, Shin, Fischer, and Rauch (2002) were originally designed by Lundqvist, Esteves, and Öhman (1999; 2004) for use in Study III and IV. See section 2 below.

2 FINDING IT

2.1 BACKGROUND

2.1.1 The face is a magnet

Visual perception and attention processes do not treat all information equally. The result is that some visual aspects of the world around us are easier to detect than others, and that we focus more on some visual patterns rather than others. Certain aspects, such as the color, axis, location, curvature, size, motion, shape, and three-dimensional depth of objects are discriminated particularly efficiently by visual attention processes (Wolfe, 1998), and regarded as *basic* visual dimensions with regard to attention[6]. But even among more complex types of information, such as multi-part objects, animals and humans, certain types of visual compositions are processed more efficiently than others. The human face is one such composition.

Faces appear to have an intrinsic gravity on our visual attention, and humans are strongly drawn to look at the face of others. When humans interact, much of the attention is directed to the faces of others (Bruce & Young, 1996; Cole, 1998). When faces are shown in pictures or placed in advertisements, they function, in a sense, as visual magnets, and thus attract much of our attention (see Fig. 6). The gravity of faces even appears to be innate (Bruce, Green, & Georgeson, 1996). Newborn infants (with an average age of nine minutes) direct more attention to face-like patterns than they do to comparable non-face like control patterns (Goren, Sarty, & Wu, 1975). Furthermore, infants appear prepared not only to attend to faces, but also to recognize and communicate facial gestures. Within days, they show a great ability to imitate the facial gestures of a face in front of them (Meltzoff, & Moore, 1977). Directing attention to faces before non-faces is a preference that also remains in adults. When compared in experimental visual search tasks, attention is directed more efficiently to facial compositions than to corresponding features in non-face like patterns (Suzuki, & Cavanagh, 1995).

The central role of faces is also revealed in that they are handled by specific neuroanatomical structures along the visual processing pathways. To give a background to how faces are processed and attended, a basic outline of visual perception and attention is given below.

2.1.2 Visual pathways

The visual information that we receive through our eyes follows two main pathways through the nervous system (see e.g. Livingstone & Hubel, 1987; Bruce et al., 1996; see also Gegenfurtner, & Sharpe, 1999; Goldstein, 2002; Rosensweig, Breedlove, & Leiman, 2002). Importantly, the two pathways are quite different in anatomy as well as in function. The division begins in the retina, from where the two major types of ganglion cells, parvocellular (P) and magnocellular (M) ganglia[7], connect to two structures in the midbrain on the way to cortex: the lateral geniculate

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[6] Cf. the basic *perceptual* dimentions of color, shape, movement, distance, and size (e.g. Gegenfurtner & Sharpe, 1999)

[7] There is also a third visual pathway, the koniocellular (K) pathway. See Hendry & Reid (2000) for a discussion of the role of the koniocellular pathway in primate vision.

FIGURE 6. Faces in advertisements attract attention.

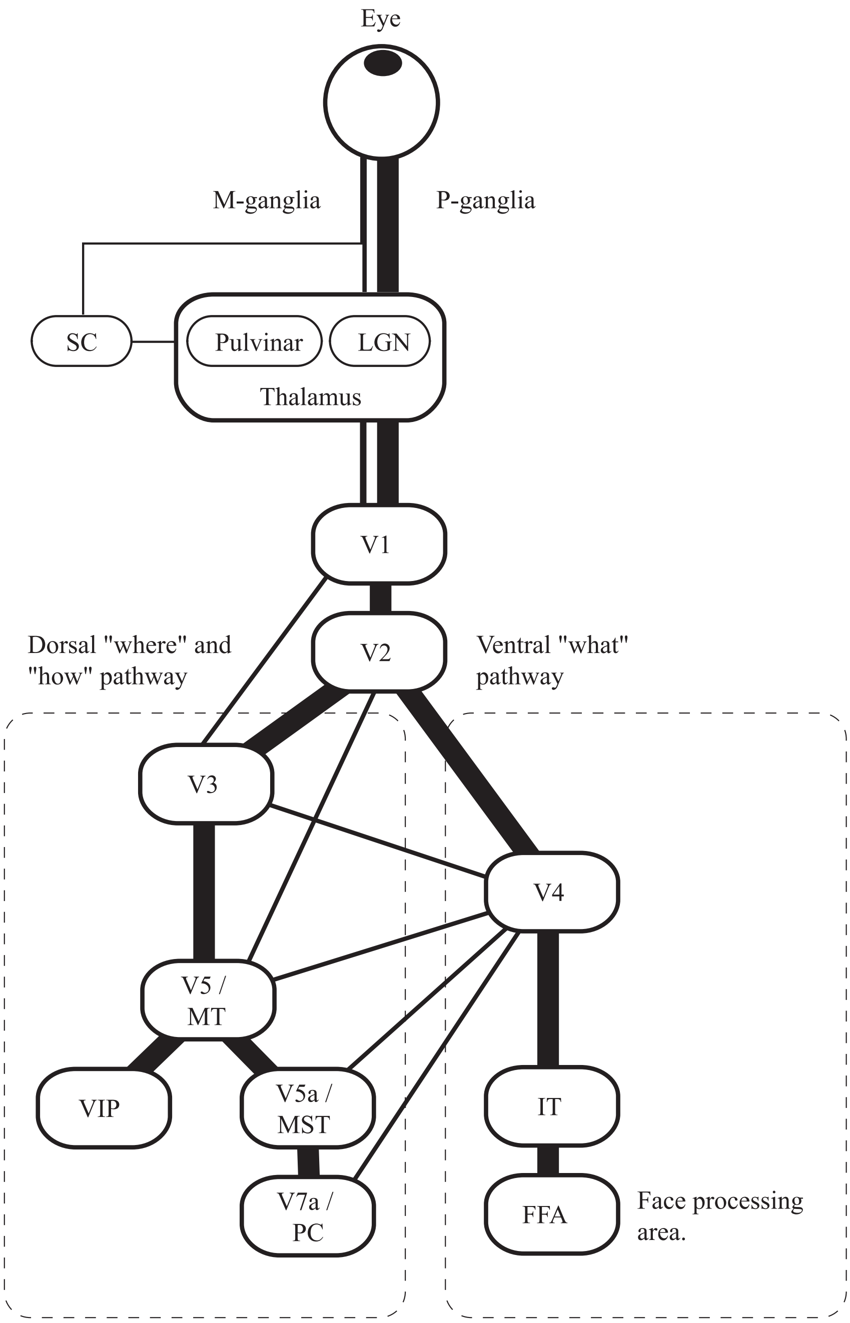
Fig. 6. Much of the visual attention that is directed to advertisements is focused on faces.

nucleus (LGN) of thalamus and the superior colliculus (SC). From all the ganglion cells in the optic tract, about 90% are P cells, and only about 10% are M cells, and while the many P cells have small receptive fields, basically mapping one retinal cone receptor each, the fewer M-cells typically have large and color-insensitive receptive fields. However, one could say that what is lost in receptive resolution is gained in speed. The M ganglia are superior to the P ganglia both in transmission speed (approximately 15 versus 6 meters/second) and signaling frequency (approximately 60 versus 30 Hz; Afifi, & Bergman, 1998). The majority of all of these ganglia (all the P-cells and most of the M-cells) then synapse in different retinotopic layers of the lateral geniculate nucleus (LGN) of thalamus, and only some of the M-cells synapse in the superior colliculus (SC). These relay structures thus have access to quite different types of information: while LGN has all the information about detail and color (P-cells) and most of the large-scale information (M-cells), SC only have access to some color-blind large-scale information. Both structures are extremely central in visual perception and attention. While the post-synaptic axons in LGN then project to different layers in area V1 of our visual cortex, all connections from SC first synapse in thalamus before continuing to area V1 and V2 of the visual cortex. Noteworthy, most connections along the visual pathways are reciprocal, and LGN actually receives more input from the visual cortex than it does from the retina. As a result, the thalamus can regulate the flow of information from the retina to V1. Much of early integration, modulation and control of visual information thus takes place in the thalamus (see Bruce et al., 1996; see also Gegenfurtner & Sharpe, 1999; Goldstein, 2002; Rosensweig, Breedlove, & Leiman, 2002; LaBerge, 1998).

After combining and reorganizing the M and P pathways in areas V1 and V2, the visual stream is again divided into two separate pathways: a dorsal and a ventral pathway (Fig. 7). Due to their functional distinction, these pathways are also called the *where* and *what* pathways. The dorsal pathway continues from area V2 via V3 and the medial temporal lobe (MT) to area V7a in the parietal cortex (PC). The *where*-name of this pathway comes from its central role in analysis of a stimulus' location, motion and position in depth (the dorsal pathway is also called the *how* pathway, due to its involvement in directing ones action in relation to the stimulus; Bruce et al., 1996; Goldstein, 2002; Rosensweig et al., 2002). The ventral *what* pathway continues from area V2 via V4 to the inferior temporal cortex (IT). The *what* name of the ventral pathway, in turn, originates from its strong involvement in color and form analyses, and (particularly of IT) in object and face processing. Processing of faces, in particular processing of facial identity, has been found to reliably involve the fusiform gyrus in the inferior temporal lobe, an area subsequently called the fusiform face area (FFA; see e.g. Kanwisher, McDermott, & Chun, 1997). However, although many researchers have reported a reliable activity of this area during face processing (see e.g. Adolphs, 2002), there is also evidence that, rather than being specific for face processing, the area is more generally central in demanding within-category object discrimination, such as recognition of facial identity. There is hence reason to believe that recognition of other type of objects that also require the same level of discrimination as faces also involve this area (see e.g. Bruce & Young, 1996; Bruce et al., 1996).

The notion that faces are processed by specific neural structures has also been demonstrated by several reports on lost ability to recognize faces following brain damages. Thus, damages to the ventromedial regions of the occipitotemporal cortex typically cause prosopagnosia, a loss of face recognition ability, (e.g. Sergent &

FIGURE 7. Visual pathways.



FFA - Facial Fusiform Area
(in the temporal fusiform gyrus)
IT - Inferior Temporal cortex
LGN - Lateral Geniculate Nucleus
M-ganglia - Magnocellular ganglia
MST - Medial Superior Temportal cortex
MT - Medial Temporal cortex

P-ganglia - Parvocellular ganglia
PC - Parietal Cortex
SC - Superior Colliculus
V1, 2, 3, 4, 5, 5a, 7a - Visual
cortical area 1, 2, 3, 4, 5, 5a, 7a
VIP - Ventral Intraparietal cortex

Fig. 7. A simplified model of the visual pathways. The data behind such models come from both humans, primates, and other animals.

Signoret, 1992; Young, 2001; see also Marotta, Genovese, & Behrmann, 2001). In these cases, other object recognition skills are often, but not always, lost (depending on the extension of the damage). There are thus reported incidents where human face recognition is completely lost while other complex discrimination skills remain. One patient was, for instance, reported not to recognize the face of his wife, but nevertheless learned to recognize each of his sheep (McNeil, & Warrington, 1993).

2.1.3 Increasingly complex analysis

The general underlying principle of the vision pathways is that the complexity of analyses increases the further down the pathways you go. Thus, while basic visual features (such as form and color properties) are processed in early cortical areas, such as V1 and V2, more complex objects are processed in IT. Accordingly, complex visual compositions are processed at the "far end" of the ventral pathway, in the inferior temporal cortex (FFA). Similarly, advanced analyses of movement and locations are performed in area MT, down the dorsal stream. Also, the size of the receptive field increases the further down the vision pathways you go, and the receptive fields of in IT are up to 100 times larger than those in area V1 (Bruce et al., 1996). Thus, neurons in IT can respond to objects across a large portion of the visual field.

In many aspects, the analysis of visual information is modular in design (see e.g. Marr, 1982), so that the output of early processes (e.g. basic feature analyses in V1 and V2) supplies the input for subsequent processes (e.g. object recognition in IT). Processing of faces appears to follow the same principle. According to the theoretical model of Bruce and Young (see e.g. Bruce & Young, 1986; 1996), face processing relies on a common core, which extracts and processes all the low-level features of a face that are necessary for the different subsequent analyses of facial information. This core is thus believed to feed the separate modules that process, for instance, lip-reading during speech perception, facial identity, and facial expressions. Haxby, et al. (2000) have extended the model of Bruce and Young (e.g. 1986) and suggested a set of neural structures that matches the different modules in Bruce and Young's model (1986). According to Haxby et al. (2000; see also Adolphs, 2002), the inferior occipital cortex (IOC; bordering to the low-level feature processing areas in early visual cortices) is involved in the core processing of facial features. The module for processing of facial identity is located in the established FFA-area in the inferior temporal lobe, whereas the module for processing of dynamic facial information, such as facial expressions, is believed (Haxby et al., 2000) to be located to the superior temporal sulcus (STS)[8].

2.1.4 Feature integration

The modularity of the visual system constitutes a quick and efficient system for parallel processing of vast numbers of visual sources across many simultaneous stimulus dimensions. Information about an object's color, position, shape and many other properties can thus be processed independently in parallel. But the decomposition of visual information into its constituents also creates a (theoretical) problem: how are

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[8] The differential involvement of IT and STS in processing of identity and expressions has also been demonstrated for the macaque monkey (see e.g. Hasselmo, Rolls, & Baylis, 1989).

all the different visual aspects of a stimulus unified into a perceived unitary object? Just as processes for other visual objects, face processing relies on the output of low-level processes (Bruce et al., 1986; Haxby et al., 2000), but to be processed and recognized as complex and uniform items, the decomposed facial features thus need to be assembled into appropriate configurations.

Treisman (e.g. 1988; 1995; 1998) have suggested that the task of binding features across independent stimulus dimensions is a problem that is solved by attention. By emphasizing a specific spatial window, attention would link the features within a specific area across different information dimensions (such as color, shape and position), while temporarily excluding information at locations outside that window. This way, the *what* and *where* of an object would be put together, and an object's physical properties would be integrated with its position, motion, and interaction properties. Treisman's theory of how the binding problem is solved has been supported by both experimental and clinical data (see Treisman 1998, for an overview). However, the feature-integration theory has also been questioned.

Indeed, saying that attention is the solution to the binding problem immediately raises a new question: What *is* attention?

2.1.5 Attention

From a neural perspective, attention can be described as a modulation of firing rates along the visual pathways of the nervous system, creating larger neural responses to attended compared to unattended objects (Goldstein, 2002). Such modulation of neural responses can be achieved either by enhancing the activity of an attended object, by suppressing the activity of unattended objects, or by doing both (LaBerge, 1998). Attention can thus be regarded as a neural emphasis of one out of many simultaneously present objects or sources of information (LaBerge, 1998; cf. James, 1890). In theory, the accomplishment of such an emphasis will depend heavily on the properties of the target object's neural representation relative to the neural “noise” of surrounding distractor objects and background information (cf. also the miss-match concept by Näätänen, 1992).

The different types of attentional emphasis, enhancement and suppressment, are also achieved by different neural circuits (see LaBerge, 1998). One circuitry rely on the superior colliculus (SC) and comparatively low-resolved receptor input (M-ganglia) for coding of stimulus location and for orienting of attention to relatively large-scale, conspicuous and transient object discrepancies. The other circuitry, relying on the pulvinar of thalamus, having access to high-resolved sensory information (all P and most M ganglia), is central in performing detailed discriminations between competing objects. Although these two mechanisms are uniquely active during some circumstances (see LaBerge, 1998) both mechanisms cooperate to produce attentional emphasis during others. The role of the SC circuit is often to perform an initial orientation of attention to large-scale aspects of the retinal information, so that it is brought into foveal focus where the density of receptors is higher. The thalamus-circuit then perform detailed analysis of that location once the foveal attention has been directed towards it (see e.g. Wright, & Ward, 1998; Adolphs, 2002). Also in Posner's work (e.g. Posner & Fan, in press), the different midbrain structures (LGN, SC) are outlined as central in different aspects of sequential attention shifts: SC in moving attention from one location to another, and the pulvinar of thalamus in engaging attention to the arrived destination.

But not only subcortical areas are central in attention processes. The two midbrain structures also connect to cortical areas, for control of both stimulus driven (a.k.a. exogenous or bottom up) and subject driven (a.k.a. endogenous or top down) attention shifts. Thus, the frontal eye fields and pulvinar work together to, for instance, control attentional filtering, while the posterior parietal cortex (PPC) work with the pulvinar for engaging and maintaining attention, and with superior colliculus (SC) for control and initiation of saccades between different spatial locations (see Wright & Ward, 1998; LaBerge, 1998). The anterior cingulate cortex (ACC) also plays an important role for attention, particularly in attention tasks that involve error detection and monitoring. Different parts of ACC have reliably been found to be specifically active in attention tasks that involve cognitive and emotional components, respectively (Bush, Luu, & Posner, 2000).

2.1.6 Preattention

Importantly, Treisman's (e.g. 1995) suggestion that feature integration, and hence object processing, depend on the allocation of spatial attention also imply that we only recognize the objects that we attend to (which is much of Treisman's point, and which is, for instance, supported by the fact that discrimination of compound objects often require serial inspection). Drawn to the extreme, this means that only the most basic stimulus dimensions of an object (e.g. primitive geometry and color) would be recognized pre-attentively (before attention is spatially located to the position of an object) and that we hence only would recognize more complex stimulus properties when attention is already directed to an object.

The consequences of Treisman's theory have been the topic of much discussion (see e.g. Wolfe, Olivia, Butcher, & Arsenio, 2002; Wolfe, 2003), and have also (together with many other metaphorical conceptualizations of attention, such as Posner's, 1980, spotlight metaphor) been challenged by models of greater explanatory power, such as the Distributed Activity Model (see LaBerge & Brown, 1989; LaBerge & 1998). In short, the Distributed Activity Model combines a neural account for how several objects may be processed in parallel at a preattentive level with a conception of how a unitary focus of conscious attention is accomplished. Although the model does not explicitly cover to what degree of complexity objects may be processed preattentively, it presents a more dimensional view on attention and information processing than, for instance, the spotlight metaphor and the feature integration theory allow for (see also LaBerge, 2002).

The issue of how extensively objects may be processed preattentively has been illuminated by, for instance Morris et al. (1998; 1999), Carlsson et al. (submitted); Esteves et al. (1994a; 1994b). These data (see also chapter 1.1.5 Priority to threatening faces, above) show that even complex stimuli, such as faces, snakes and spiders, can be processed extensively at a preattentive level. Such processing suggests that we do indeed "see" rather complex objects even before we consciously attend to them. Pre-attentive processes thus appear to recognize more than just basic stimulus dimensions, and involve recognition of the emotional properties of the stimulus.

Other support for emotional effects on attention was presented by Öhman, Flykt and Esteves (2001; see also Öhman, Flykt & Lundqvist, 2000). In visual search experiments, emotionally fear-evoking stimuli, such as snakes and spiders, was found to capture participants' attention more efficiently than emotionally neutral stimuli, such as flowers and mushrooms. Moreover, emphasizing the importance of emotion and personal significance, the snake and spider stimuli captured attention even more efficiently for participants that were selected to be highly fearful of these stimuli than they did for low-fear participants. A similar modulation of emotion and personal significance on attention has also been reported by Juth, Lundqvist, Karlsson, and Öhman (submitted), who demonstrated that externally induced social fear facilitated attention to threatening faces of socially anxious, but not of non-anxious participants.

In concert, attention data and attention theory suggest that information may be processed extensively outside consciousness. The effect of emotion on attention capture suggests that the emotional properties of stimuli affect attention before attention is spatially directed to the location of the emotional stimuli. Indeed, emotional significance may be an important factor drawing attention to a particular spatial location. Such effects on attention require some type of stimuli recognition at a preattentional level.

2.1.7 Purpose of Study III and IV

Study III and IV in this thesis addressed the issue of how emotion affects visual attention. Using facial stimuli of different emotion, a visual search task was used to investigate the relation between facial features, facial emotion and visual attention.

2.1.7.1 The visual search paradigm

The visual search paradigm was used to investigate visual attention in pioneering experiments already by Neisser (1964), and has since then been used in numerous attention experiments.

A visual search task typically involves searching of specified target objects among irrelevant so-called distractor items. Participants might, for instance, be instructed to search for a letter O that is presented among a number of distracting letter C's. The presentation of objects may be performed in two principle ways: with *constant* (a.k.a. consistent) or *varied* mapping of objects. In constant mapping, a specific set of objects is always used as targets (e.g. O and G), and another set is always used as background (e.g. C). In varied mapping, the type of background may vary from trial to trial, and objects might be used both as target (e.g. O, G, and C) and distractor (also O, G, and C) objects.

The visual search paradigm has been a central and common tool for investigating how visual low-level features can be discriminated by attention processes. Perceptual properties, such as color, size, angle and closure, have hence emerged as primary and highly efficient stimuli-dimensions for visual attention (see e.g. Wolfe, 1998). The paradigm has also been central in investigating how separate visual features are combined into global perceptual objects (see e.g. Treisman, 1995; 1998), and to investigate how attention can be directed to visual patterns such as faces, compared to equally complex non-facial patterns (Suzuki & Cavanagh, 1995).

In addition to being used to investigate the relation between perceptual discriminability and attention, the visual search paradigm has also been used to examine how emotion affects attention. Öhman et al. (2001) used the paradigm to investigate how fear-evoking stimuli, such as snakes and spiders, affected attention compared to emotionally neutral stimuli. Visual search has also been used for investigating how facial expressions of emotion differ in their ability to capture attention, both with pictorial (e.g. Hansen & Hansen, 1988; Fox, Lester, Russo, Bowles, Pichler, & Dutton, 2000) and line-drawn stimuli (e.g. White, 1995)[9]. The approach and use of stimuli in those reports were however different from the studies presented below.

The visual search paradigm has proven a very sensitive tool for measuring how attention operates on different types of visual stimuli. However, since the visual system is highly efficient in discriminating stimuli from basic perceptual dimensions (see e.g. Wolfe, 1998; Duncan and Humphrey, 1989), there are many considerations that must be made for the stimuli that is used during visual search, so that facial stimuli are not discriminated by some unintended perceptual dimension (see e.g. the criticism by Purcell et al., 1996, concerning possible perceptual confounds in Hansen and Hansen's, 1988, visual search with pictures of facial expressions).

2.1.7.2 *Design of facial stimuli*

The stimuli used in the visual search studies (Study III & IV, below) were designed with regard to the results of Study I. A threatening face was created by assembling the most threatening version of each facial feature (eyebrows, mouth and eyes) into one face. By assembling the most friendly version of each feature into another face, a non-threatening or friendly configuration was also created. A neutral control face was created as an exact midpoint between the threatening and non-threatening shapes (see Fig. 8).

Importantly, the threatening and friendly faces were designed to be perceptually equal and equidistant from the neutral control face. The threatening and friendly configurations thus contain exactly the same type of geometrical shapes, presented at the exact same location in the face. Each individual feature in the threatening and friendly configurations was thus equally different from the corresponding feature in the neutral control face (see Fig. 8). In terms of basic perceptual distance, one would expect that a threatening and a non-threatening/friendly face should be equally easy or difficult to discriminate from the neutral control face.

2.2 DETECTING THREATENING FACES: STUDY III AND IV

2.2.1 Method

In Study III and IV, a visual search paradigm was used to investigate the effect of stimulus emotion on visual attention. The visual search task was adapted from Hansen and Hansen's (1988) report of using pictorial facial emotional stimuli in a visual search task.

The visual search task used in Study III and IV involved ocular inspection of arrays of faces that were presented on a computer screen. When an array of faces was

[9] See also Tipples, Atkinson, & Young (2002). The experiments reported by Tipples, et al., was however designed and performed after Study III and IV were performed and Study III (Öhman, Lundqvist, & Esteves, 2001) was published. The article by Tipples et al (2002) explicitly examines the results presented in Study III, using adaptations of the stimuli used in Study III.

FIGURE 8. Stimulus design, Study III.

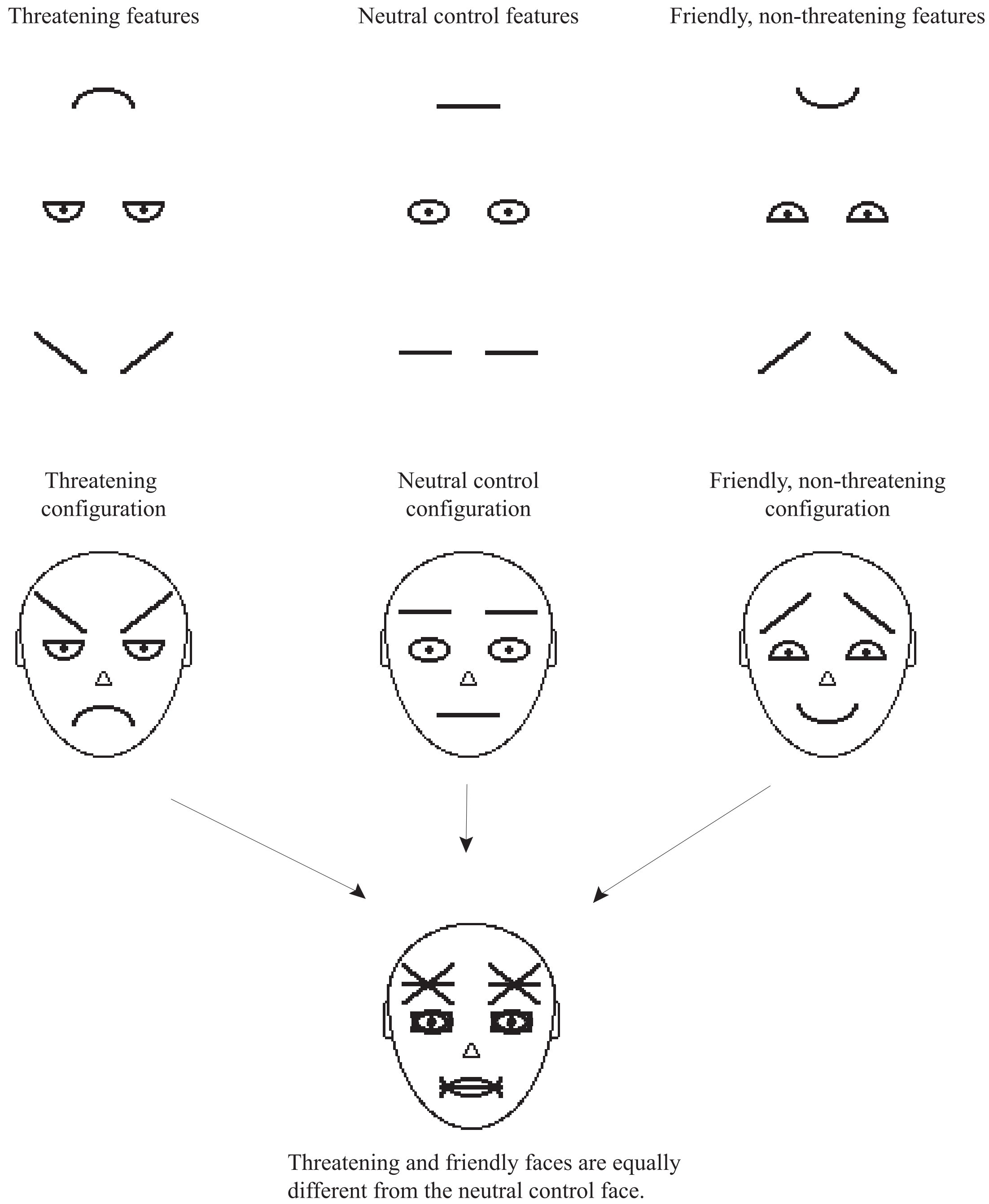


Fig. 8. The stimuli used in the visual search studies (Study III & IV, below) were designed with regard to the results of Study I. A threatening face was created by assembling the most threatening version of each facial feature (eyebrows, mouth and eyes) into one face. By assembling the most friendly version of each feature into another face, a non-threatening or friendly configuration was also created. A neutral control face was created as an exact midpoint between the threatening and non-threatening shapes.

presented, participants were instructed to as quickly as possible decide whether all faces were similar or if one of the faces was different from the other. In the experiments reported here, the balance between arrays with and without a deviating face was always 50/50.

Participants made responses by pressing one of two keys on the computer keyboard, using the left index finger to register that all faces were similar, and the right index finger to register that one face was deviating (see Fig. 9). Responses were then analyzed in terms of response accuracy and response latencies. The analyses reported below are mainly focused on the responses related to deviating faces, so-called target conditions.

In all visual search experiments, data on response latencies were transformed to logarithmic (log10) values to meet the requirements of a normally distributed data.

FIGURE 9. Measuring attention.

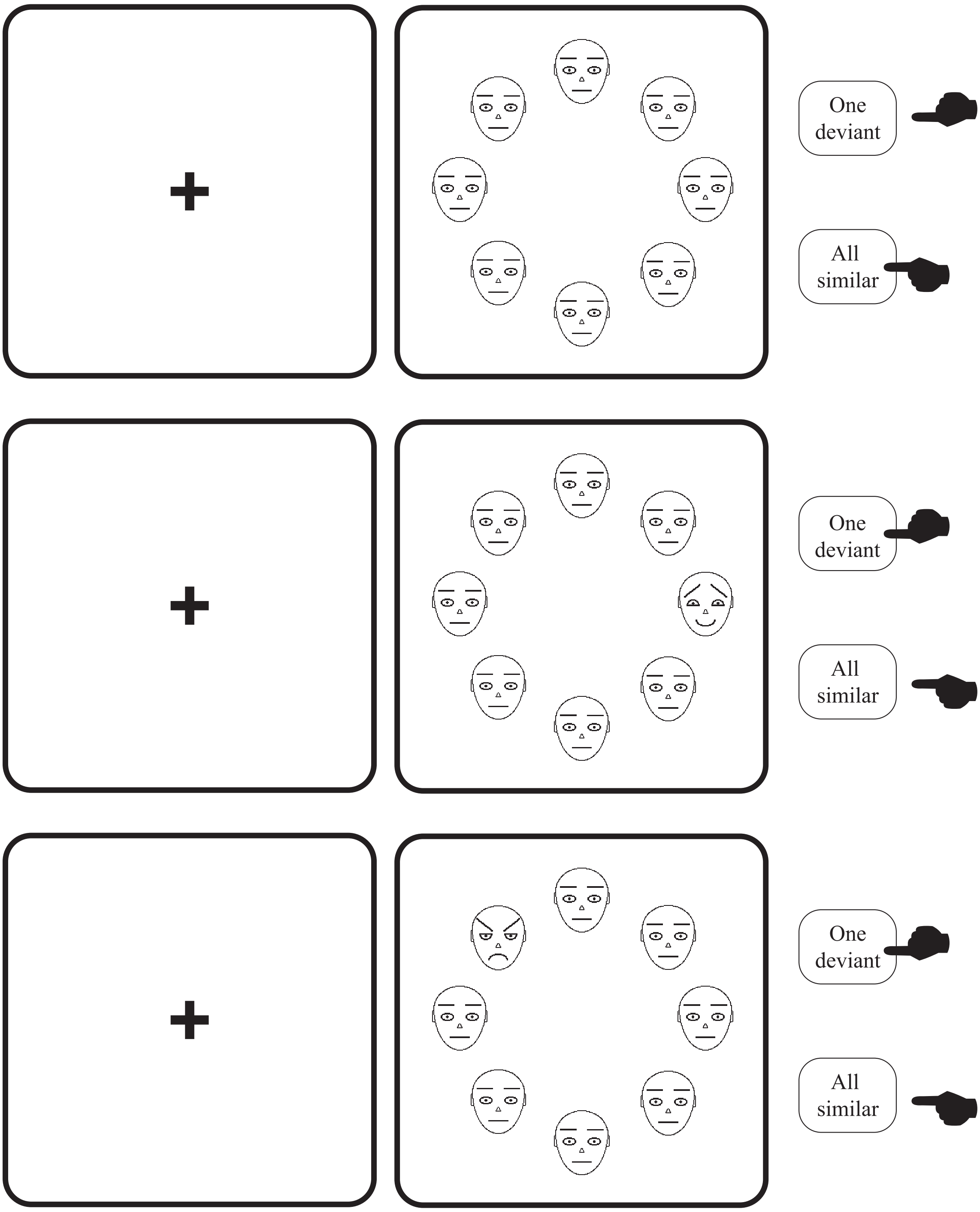


Fig. 9. Participants were instructed to first focus on the pre-trial fixation cross. As soon as a crowd of faces was exposed, participants should decide (as quickly as possible) whether all faces in a crowd were similar or if one of the faces was different from the others.

Participants made responses by pressing one of two keys on the computer keyboard, using the left index finger to register that all faces were similar, and the right index finger to register that one face was deviating.

Study III: The Face in the Crowd Revisited: A Threat Advantage with Schematic Stimuli

2.2.1.1 Outline of Study III

In Study III, we (Öhman, Lundqvist, & Esteves, 2001) used schematic threatening, friendly and neutral faces to test the hypothesis that humans preferentially orient their attention towards threat. Using a visual search paradigm, we let participants search for discrepant faces in matrices of otherwise identical faces. Schematic threatening, friendly and neutral faces were used as stimuli. In Experiment 6, schematic scheming and sad faces were also included.

2.2.1.2 Experiment 1

In Experiment 1, we investigated the effect of threatening and friendly faces on visual attention. Using a task adopted from Hansen and Hansen (1988), schematic threatening, friendly and neutral faces were used in a visual search task with varied mapping of targets and distractors. Crowds of faces were presented in matrixes of 3*3 faces, and were exposed for either 1 or 2 seconds.

When presented as a discrepant target face, threatening faces were reliably detected faster and more accurately than friendly faces, both in crowds of neutral and crowds of emotional faces. However, when all faces in a matrix were similar (during so-called no-target conditions), the matrixes of threatening and friendly faces were searched with equal speed and accuracy.

The results thus show superior detection of threatening faces, but equally efficient search of matrixes of threatening and friendly faces that are presented without any target (Fig. 10, upper panel).

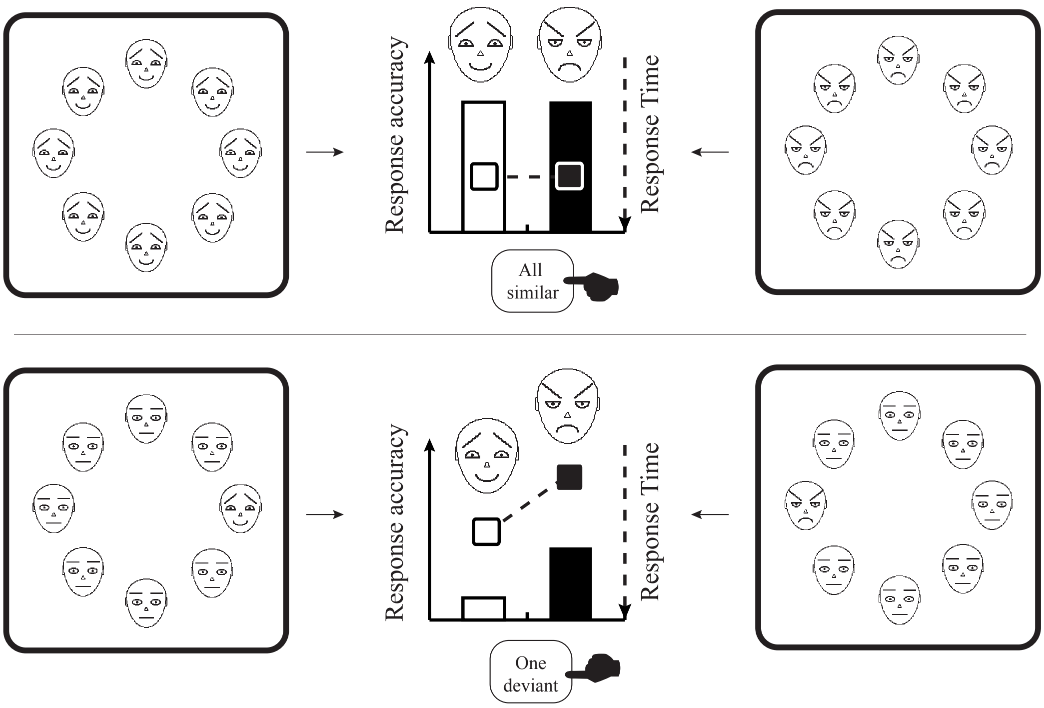
2.2.1.3 Experiment 2

In Experiment 2, we investigated how the effect of threatening and friendly faces on visual attention was related to the number of faces that were used as distractors. We therefore used crowds of 2x2, 3x3, 4x4 and 5x5 faces in a visual search task with constant mapping of distractor emotion. Targets were hence always either a threatening or a friendly face, and the background always consisted of a matrix of neutral faces. The exposure of matrixes was terminated by the participant's response.

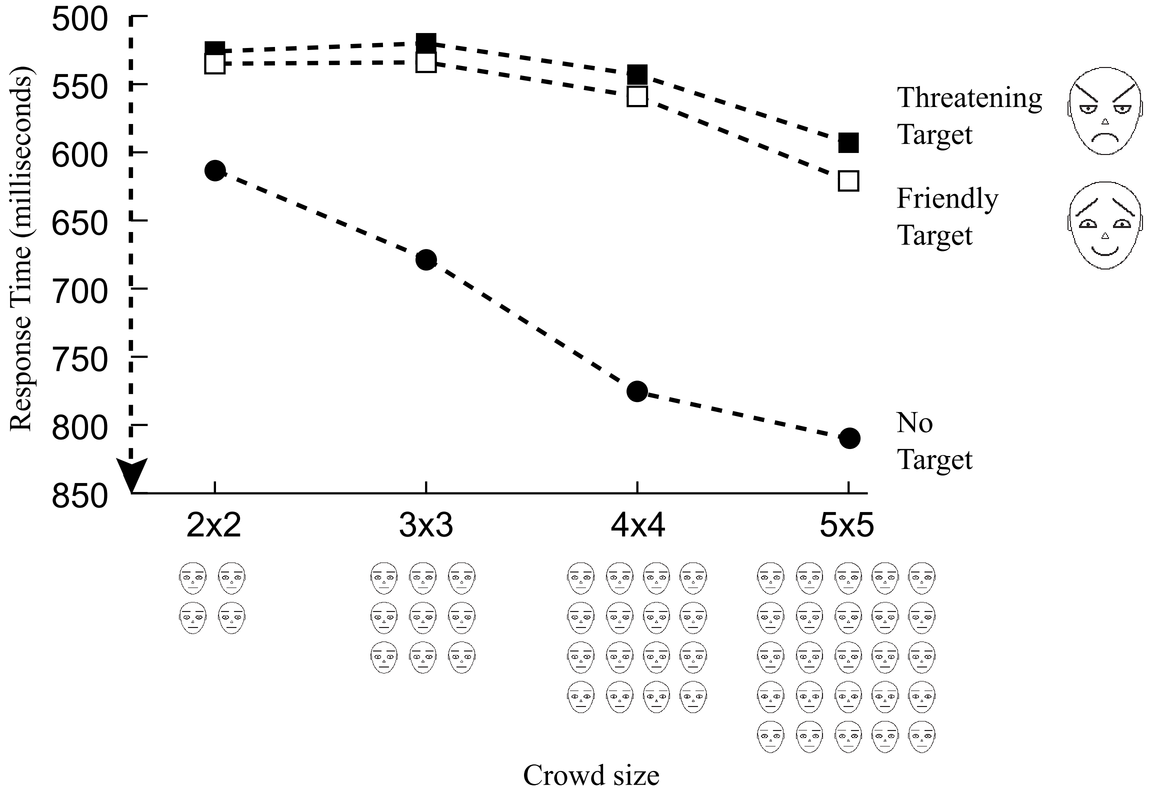
Threatening faces were detected faster and more efficiently than friendly faces across all crowd sizes. Response latencies for detection of faces increased little over matrix sizes, indicating a generally efficient detection of target faces under these search conditions. Search times for no-target matrixes however increased with the numbers of items in each matrix (4, 9, 16, 25), showing that the time required to determine that all faces in a matrix were similar increased with the number of faces that had to be searched (Fig. 10, lower panel). The results indicate that the effect of threatening faces on attention can be created largely independent of the number of distractor faces.

FIGURE 10. Results from Study III.

Typical pattern of results in Study III.



Results, Study III, Experiment 2



2.2.1.4 *Experiment 3*

The design of Experiment 3 was a mix of the design of Experiments 1 and 2, and examined the effect of threatening and friendly faces in different crowd sizes. However, contrary to Experiment 2, targets were here presented against different backgrounds. Threatening and friendly faces were thus presented in crowds of 2x2, 3x3, and 4x4 faces, in a varied mapping visual search task. Crowd exposure was terminated by the participant’s response.

The results showed that, for all three crowd sizes, threatening faces were detected faster and more accurately than friendly faces, both when presented in crowds of neutral and when presented among emotional faces (threatening targets presented in friendly crowds and vice versa). The increase in response latencies with crowd size was steeper for emotional crowds than for neutral ones. Small (2x2) matrixes with neutral background faces thus resulted in the fastest responses, while the largest matrixes (4x4) with emotional distractors resulted in the slowest responses. Although the response latencies thus clearly varied with the demands of the search task, threatening faces were reliably detected more efficiently than friendly faces.

2.2.1.5 *Experiment 4*

Experiment 4 compared the effect of threatening and friendly faces when they (the faces) were presented upright to when they were inverted and presented upside-down. One group of participants was presented to upright faces, and another group was presented to inverted faces. The design of the experiment was, apart from stimulus rotation, the same as Experiment 1, except that here, crowds were exposed until the participant responded.

Threatening faces were detected more efficiently than friendly faces even when they were presented upside-down (Fig. 11, upper panel). The results are in some disagreement with theories of face processing, where inversion of faces usually seriously impair correct recognition (e.g. Hay & Young, 1982; see also Endo, et al., 1989) most inversion studies have however dealt with identity recognition, not emotion recognition). The results might hence indicate that emotion recognition is less affected by inversion than recognition of identity.

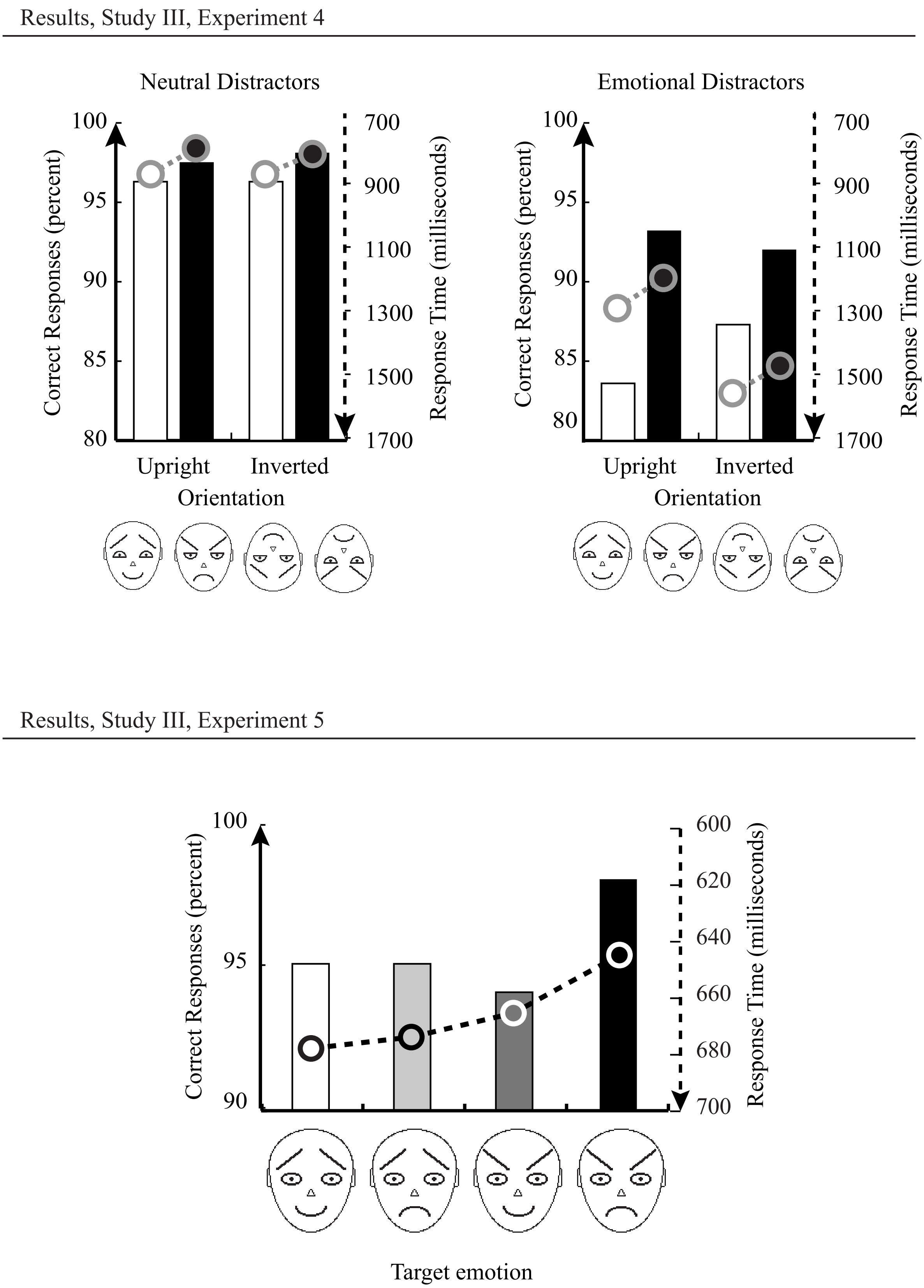
2.2.1.6 *Experiment 5*

Experiment 5 investigated whether the superior detection of threatening compared to friendly faces could be explained by differences in stimulus exposure (i.e. by the influence of participants having more experience with friendly faces and that they therefore would direct attention quicker to the comparatively novel threatening faces; see Bond & Siddle, 1996) or if the effect was related to the emotional valence of the stimuli.

Schematic threatening, friendly, scheming, and sad faces were used as targets in crowds of neutral faces. Matrixes of 3*3 faces were used in a constant mapping visual search task, and matrix exposure was terminated by the participant’s response.

A novelty account (based on the exposure data by Bond, & Siddle, 1996) predicts that faces would be detected in the order of scheming, sad, threatening and friendly. However, the data from Experiment 5 showed that threatening faces were

FIGURE 11. More results from Study III.



detected significantly faster than the other faces (scheming, sad, friendly). Although the RTs of the other faces differed from each other on a descriptive level, they were not statistically different. On a descriptive level, faces were detected in following rank order of speed: threatening, scheming, sad, friendly (Fig. 11, lower panel), and the largest difference was hence between the threatening and the friendly face.

The results ruled out a novelty account and indicated that detection of faces may rather be related to the emotional valence of the stimuli.

2.2.1.7 Summary

Across five experiments we consistently found faster and more accurate detection of threatening than friendly faces. The threat advantage was reliable irrespective of whether the target faces were presented among neutral or emotional faces, and was also reliable across crowd sizes ranging from 4 to 25 faces.

Threatening angry faces were also detected faster and more accurately than other negative faces (scheming or sad) which suggests that the threat advantage can be attributed to the emotional impression of the face rather than to the differences in uncommonness and novelty between the different faces. Furthermore, the quicker and more accurate detection of faces was maintained even when faces were presented upside-down, which indicate that recognition of facial emotion may be less sensitive to inversion than recognition of facial identity.

The results show that, despite the basic physical-geometrical equality of threatening and friendly faces, these facial stimuli affect attention differently. Specifically, while both type of faces are searched equally efficient when used as crowds without any target, threatening faces capture attention faster and more accurately than friendly faces when they are presented as targets.

The results are in accordance with related emotion-attention literature, where potentially threatening information such as snakes and spiders has been found to be detected more efficiently than corresponding non-threatening information (see Öhman et al., 2000; 2001).

The results show that faces that contain threatening facial features capture attention more effectively than faces that contain corresponding friendly/non-threatening facial features. The results motivated a closer examination of how facial threat is recognized and processed, and also a more direct investigation of the relation between facial features, facial emotion and visual attention.

2.2.2 **Study IV: Emotion Regulates Attention: The Relation between Facial Configurations, Facial Emotion and Visual Attention**

2.2.2.1 Outline of Study IV

The results from Study I-III jointly support some general conclusions, but also raise some questions. Study I and II, above, reliably demonstrated that certain facial features were effective in conveying a threatening emotional impression. In Study III, facial configurations composed from such features were then found to consistently capture attention more efficiently than corresponding friendly configurations.

The experiments in Study IV were planned to further investigate the relationship between facial configurations and visual attention. Across four experiments, we used visual search tasks to examine what facial features and configurations that are necessary and/or sufficient to produce an emotional effect on attention. In addition to the visual search tasks, we collected emotional ratings on the stimuli that were used in each experiment. This allowed us to relate the emotional impression of a variety of facial stimuli to their effect on attention. We used threatening, friendly and neutral schematic facial stimuli, in which 1, 2 or 3 features conveyed the facial emotion, to test the hypothesis that humans preferentially orient attention towards threat, and to examine the relation between facial features, facial emotion and visual attention.

In the visual search task, circular displays of 8 faces were used in a varied (Experiment 1, 2 and 3) or constant (Experiment 4) mapping mode. Subsequently to the visual search task, participants also rated their emotional impression of faces, using semantic differential scales (similarly to Study I & II, above).

2.2.2.2 Experiment 1

In Experiment 1 we investigated the effect of threatening and friendly faces on attention and emotion. In this experiment, faces conveyed the facial emotion via two instead of three expressive features (Fig. 12, top left panel). Across three different stimuli sets, one of the three expressive features (eyebrows, eyes or mouth) in the threatening and friendly faces was deleted (Fig. 12, top right panel).

The different sets of facial stimuli with two expressive features showed reliable threat-advantage effects on attention, similarly to faces with three expressive features (cf. Study III, above). Threatening faces were thus detected reliably faster and more accurately than friendly faces. However, follow-up tests showed that the effects on attention from the different two-feature faces were relatively unreliable, and that there, for instance, was no significant effect for the eyebrows-mouth configuration.

A risk of unexpected side-effects on face processing from deleting facial features, such as loosing face-like, structural aspects of the stimuli that may be critical for efficient face processing, motivated a rerun of the experiment, with re-designed stimuli.

2.2.2.3 Experiment 2

As in Experiment 1, Experiment 2 investigated how threatening and friendly faces, in which two facial features expressed the facial emotion, influence emotion and attention. Across three stimuli sets, one of the three expressive features (eyebrows, mouth or eyes) in the threatening and friendly faces was replaced by a neutral feature (instead of being deleted; Fig. 12, middle left panel).

The different sets of two-feature stimuli created a reliable threat-advantage on attention. Furthermore, follow-up tests showed that for these stimuli sets, the threat-advantage effect was comparable to the effect of three-feature stimuli reported in Study III. The potential to convey a significant threat-advantage effect on attention was thus better when a to-be-excluded feature was replaced with a neutral control feature (Experiment 2) than if the same feature was deleted (Experiment 1). A possible reason for this is that deleting a facial feature causes a loss of critical structural aspects of the faces, which may undermine efficient face processing (cf. Marr, 1982; Bruce & Young 1986; 1996; see also Tipples, Atkinson, & Young, 2002).

The reliable effects on attention with two-feature stimuli motivated investigation of how one-feature facial stimuli may affect emotion and attention.

FIGURE 12. Stimulus material used in Study IV.

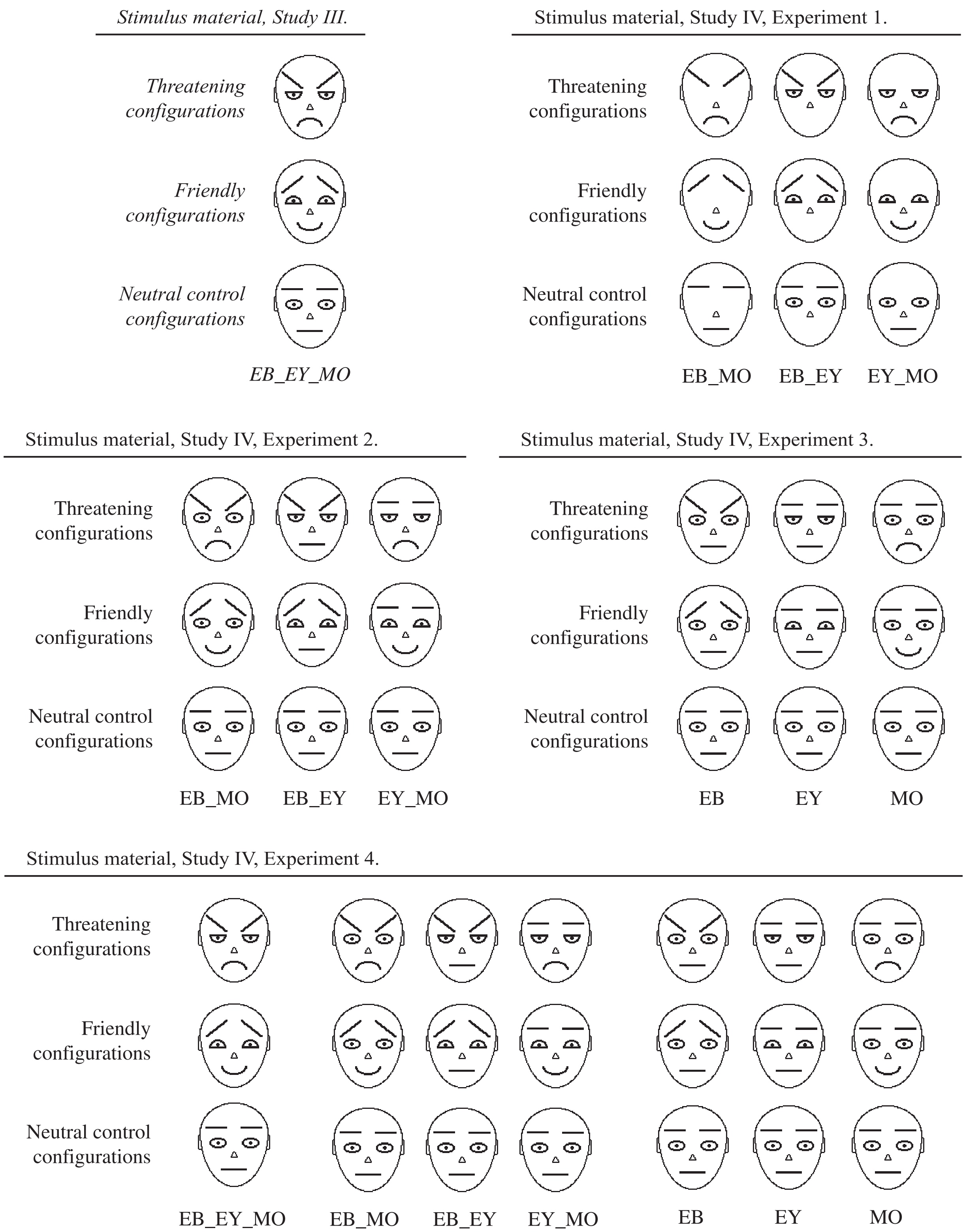


Fig. 12. The code under each set of stimuli signifies what feature(s) that conveyed the facial emotion. EB = Eyebrows; EY = Eyes; MO = Mouth.

2.2.2.4 Experiment 3

In Experiment 3 we investigated the effect of threatening and friendly faces, in which only one facial feature expressed the facial emotion, on attention and emotion. In three different stimulus sets, two of the three expressive features in the threatening and friendly faces were thus replaced with a neutral feature (Fig. 12, middle right panel).

The different sets of one-feature stimuli showed a reliable threat-advantage on attention, similarly to Experiment 2. However, follow-up tests revealed that the effects were less reliable for the one-feature stimuli than for the two-feature stimuli in Experiment 2. There were, for instance, significant effects only for faces where facial emotion was conveyed by the mouth or eyes, and not where emotion was conveyed with eyebrows.

Although the face set with expressive eyebrows did not cause significant emotional effects on attention, eyebrows clearly affected attention capture in another way. Analysis of search latencies across stimuli sets showed that the different facial features enabled detection of targets with rank ordered efficiency, so that stimuli that contained expressive eyebrows were discriminated from distractors both fastest and most accurately, followed in order of efficiency by faces that could be discriminated by the shape of mouth, and eyes. Also, a reanalysis of the response latencies in Experiment 2 indicated a similar pattern for those stimuli.

These results motivated a more elaborate examination of how different facial features affect attention and emotion.

2.2.2.5 Experiment 4

The aim of Experiment 4 was to more carefully investigate the rank ordered effect of facial features on emotion and attention measures that was observed in Experiment 3. A second aim was to enable a more direct analysis of the covariance between emotion and attention data. A total of 7 different stimuli sets were used. In these sets, faces conveyed emotion with either 3 (one set), 2 (three sets) or 1 (three sets) expressive features (Fig. 12, bottom panel).

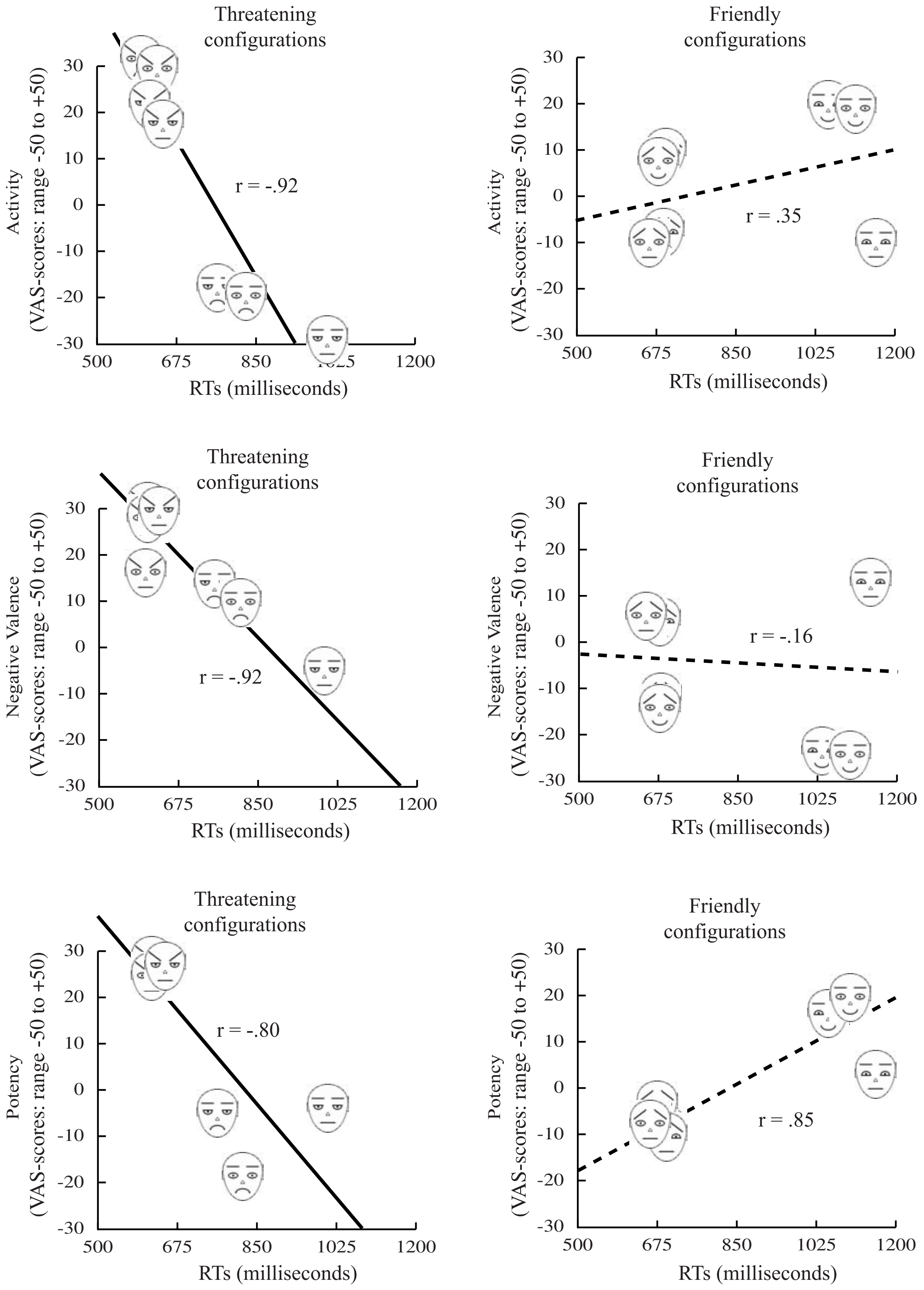
The results reliably demonstrated that threatening faces with 1, 2 and 3 expressive features were detected quicker and more accurately than corresponding friendly configurations. The data also showed that facial features affected both emotion and attention measures with rank ordered efficiency. The order by which facial features affected emotion and attention was eyebrows, mouth, and eyes, the same order that was observed for formation of emotional impression of faces in Study I and II.

The results motivated a closer correlation analysis of emotion and attention measures.

2.2.2.6 Correlation analysis of attention and emotion measures

A correlation analysis of emotion and attention revealed a close relation between these measures. In Figure 13, it can be seen how, for threatening faces, high emotion scores were associated with short response latencies. Closer analysis of these measures revealed that the contrast between a compared pair of threatening and friendly faces on attention measures correlated with the differences between these faces on

FIGURE 13. Results from Study IV: The relation between emotion and attention data.



emotion measures (see Fig. 14). Thus, a large difference in emotions scores for a contrasted pair of threatening and friendly faces was associated with a large difference between these faces on attention measures.

The results thus reveal a very close relation between emotion and attention measures, and show that a threat advantage effect is closely linked to the emotional contrast between the compared stimuli.

2.2.2.7 Summary

Across four experiments, we demonstrated that the stereotyped threatening facial features extracted from Study I and II are efficient both in conveying threat and in capturing attention. Threatening faces were thus consistently detected quicker and more accurately than friendly faces (Study III), even when only one facial feature conveyed the facial emotion (Study IV).

The data in Study IV showed that the facial features affected both attention and emotion with rank ordered efficiency, where eyebrows were the most important feature, followed by mouth, and eyes. The hierarchical effects of facial features on emotional impression were in accordance with the results from Study I and II.

Finally, correlation analysis of emotion and attention data revealed a very close relation between the emotional properties of a face, and its effect on attention. The analyses showed that the emotional impression of a face was closely related to that the effect of that face on attention, and that the emotional properties of a stimulus thus predicted its effect on attention.

The results show that the more efficient detection of threatening compared to friendly faces could neither be attributed to the effect of single high-threatening key-features, such as v-shaped eyebrows (see Tipples et al., 2002), nor to a basic configuration of eyebrows and mouth (which was suggested by the way such configurations were found to dominate the emotional impression of faces in Study I and II). Rather, the results suggest that the threat-effect on attention was closely related to the involved stimuli’s emotional properties. Such a relation between emotion and attention stresses the general importance of emotion in emphasizing important things in our environment.

FIGURE 14. More results from Study IV: Differences on attention measures follow differences on emotion measures.

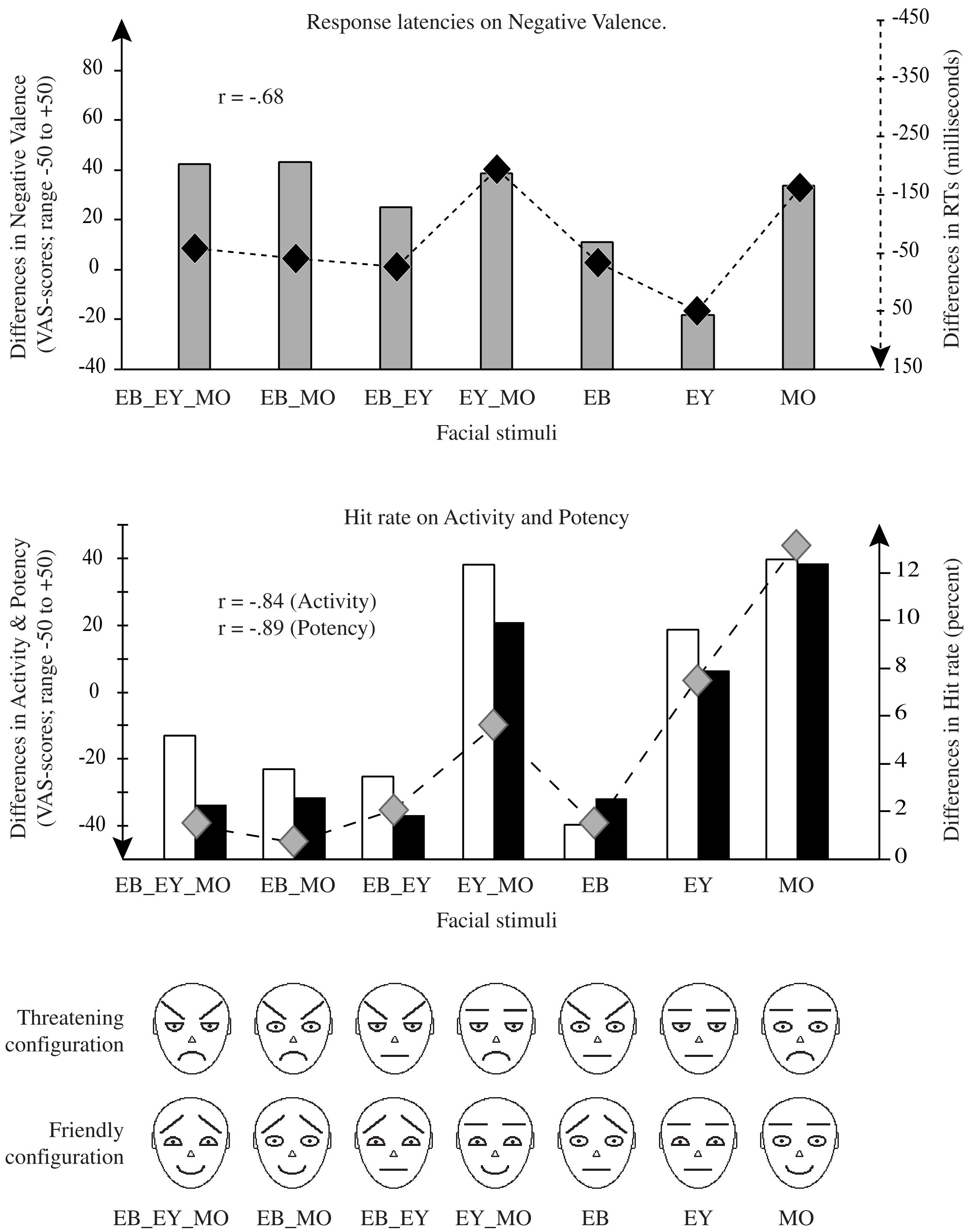


Fig. 14. How differences between threatening and friendly faces on attention measures followed the differences on emotion measures. The code under each set of stimuli signifies what feature(s) that conveyed the facial emotion: EB = Eyebrows; EY = Eyes; MO = Mouth.

2.3 HOW FACIAL EMOTION CAPTURE VISUAL ATTENTION: DISCUSSION OF STUDY III AND IV

2.3.1 Threatening faces reliably capture attention

Study III and IV showed that, in terms of quicker and more accurate detection, threatening faces capture attention more efficiently than corresponding, physically-geometrically equivalent, friendly faces. Study III showed that this threat-advantage effect on attention was reliable across varying crowd sizes (4 to 25 faces) and different search conditions (varied or constant mapping of distractor emotion). Study IV showed that the threat-advantage was evident even when only one facial feature conveyed the facial emotion. Furthermore, Study IV revealed a close relation between emotion and attention data.

Together with the reliable effects of threatening and friendly faces on attention, the data from Study III and IV show that several factors are involved in determining how efficiently faces are searched and detected.

2.3.2 About the search of faces

2.3.2.1 Discriminational distance and search demands

Compared to visual search tasks that involve discrimination of basic stimulus properties (such as color; see Wolfe, 1998), visual search of faces is considered to be a generally inefficient process. Nevertheless, search of faces is more efficient than search of equally complex compositions of corresponding features in non face-like patterns (Suzuki & Cavanagh, 1995), and face processing also involves a set of specialized and efficient neural structures (see Bruce & Young, 1996; Haxby et al., 2002; Adolphs, 2002).

In the visual search literature, the efficiency of a search process is considered to depend on the complexity of the visual search task. In Duncan and Humphrey’s (1989) terms, the efficiency of a search process reflects the discriminational distance in a multidimensional stimulus-space. In that stimulus-space, the ease by which a target stimulus (e.g. a red square; or a threatening schematic face) is discriminated from the distractors (e.g. green circles; or neutral faces) is thus defined by the sum of all target/distractor dissimilarities. The larger and more conspicuous differences there are, the more efficient can a search process be. However, the efficiency of a search process also varies with the design of the search task. Variations in the set size (here, number of faces in a crowd) and mapping mode (here, constant or varied background emotion) define both the depth and complexity of the information that has to be analyzed to detect a discrepant face. The demands of the search task hence determine the scale at which the items (here, faces) are processed (Nakayama, 1990).

Thus, when constant mapping mode was used in a visual search task, and background faces were always the same, the emotional targets “popped out” through a very efficient search, even when they were presented among 24 distractor faces (see Fig. 10, lower panel). When, on the other hand, the type of background faces varied, and targets even had to be searched among emotional distractors that contained the same type of basic geometry, the detection efficiency deteriorated markedly with increased crowd size. Thus, in the data of Study III and IV, search of faces was most efficient during constant mapping conditions with small crowds, where targets also could be discriminated from distractors via unique stimulus dimensions; and least efficient during varied mapping with large crowds, when the crowd size was large, particularly during conditions when emotional targets were presented in emotional crowds (a threatening target in a friendly crowd, or vice versa) and targets had to be detected among large numbers of distractors that contained the same geometrical properties.

At a large scale, the search of faces thus appear to follow relatively basic rules that are dictated by factors such as crowd size, discriminational distance, and the mapping mode used in the specific search task. However, the rules of search do not apply equally to all things.

2.3.2.2 Symmetrical and asymmetrical search of faces

The data from Study III and IV show an interesting mix of symmetric and asymmetric search of threatening and friendly faces.

On the one hand, data from no-target conditions (i.e. when all faces in an array are identical) show *symmetric*, equally efficient, search of sets of threatening and friendly faces. On the other hand, the data from conditions *with* targets (i.e. when there is one discrepant face in an array of otherwise identical faces), the data show *asymmetric* search efficiency of threatening and friendly faces. Thus, discrepant threatening faces among neutral distractors were detected more efficiently than friendly faces. The asymmetry of how threatening and friendly faces were searched was particularly pronounced when an emotional target was presented among emotional distractors (a threatening face among friendly distractors, or vice versa). Thus, when a threatening target was presented among friendly distractors, approximately 90% of the threatening targets were accurately detected, typically at about 1200 milliseconds. During the reversed conditions, when a friendly face was presented among threatening distractors, approximately 80% of the friendly conditions were detected, at about 1300 milliseconds.

Taken together, the symmetrical and asymmetrical aspects of the search data indicate that the emotional properties of these schematic faces only affected attention when there were discrepancies in a stimulus array (a miss-match in Näätänen’s terms, 1992), and not when faces were searched for confirmation of equality.

2.3.3 The role of facial features for search of faces

As concluded above, the data showed that threatening faces, which conveyed the facial emotion with expressive eyebrows, eyes, or mouth (or any combination of two or three of these features), captured attention more efficiently than corresponding friendly configuration. However, the data also showed that the different features affected the search of faces quite differently.

Detection of faces was hence most efficient if faces could be discriminated by the shape of eyebrows, followed in ranked order of efficiency by mouth and eyes. The effects of facial features on attention appeared to be hierarchical, and a face that contained expressive eyebrows was hence detected more efficiently than a face that contained both expressive mouth and eyes. Faces that only expressed facial emotion via the eyes were detected with the least efficiency.

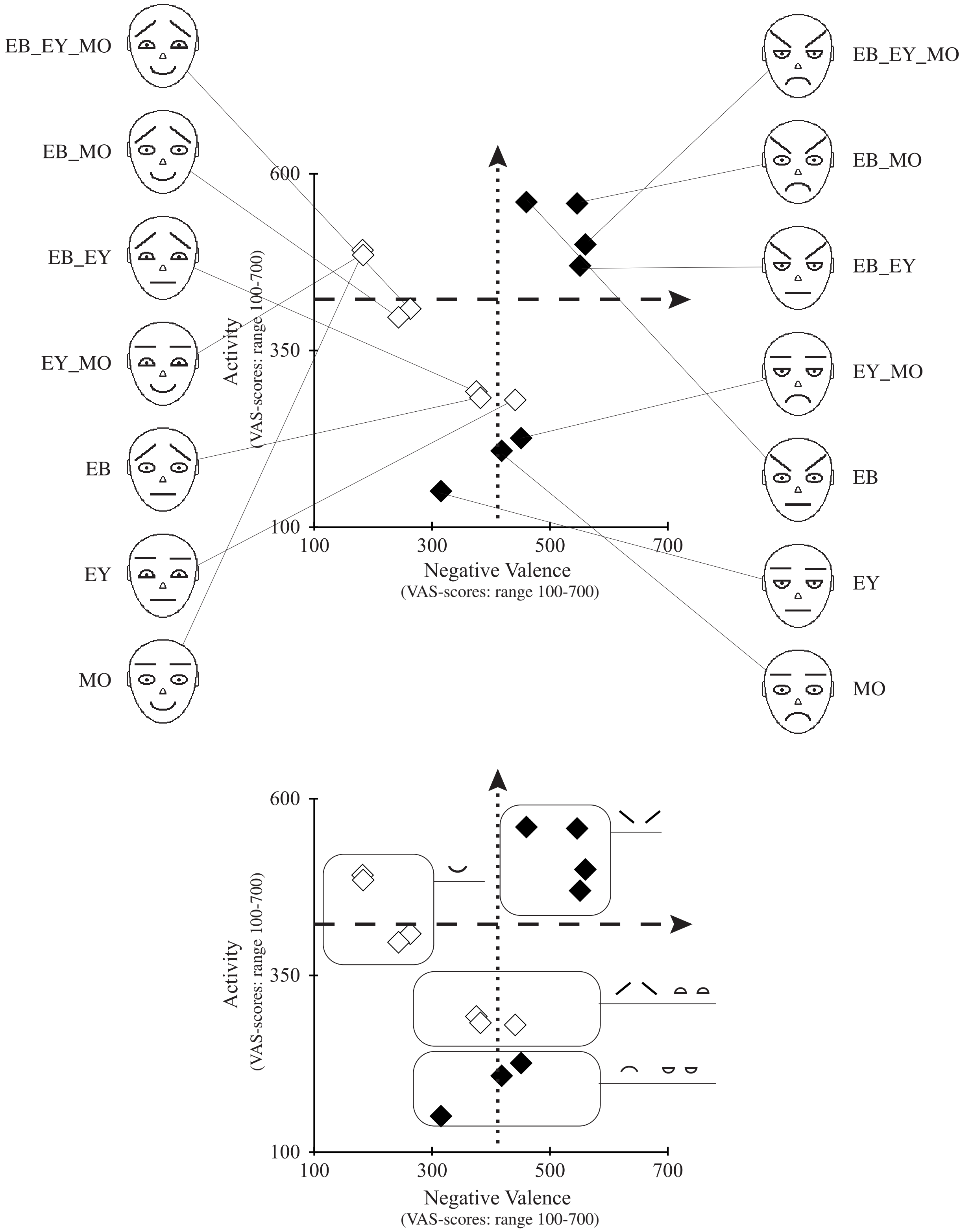
As described in the first section of this thesis (1. Looking for trouble), a similar hierarchical arrangement of facial features was also found for how facial features affected the emotional impression of faces (Study I and II), and also in the emotion data of Study IV in this section of the thesis. What such a hierarchical relationship between facial features reflects is difficult to say. Above (section 1.3.3. Hierarchical effects of features), parallels were drawn to possible hierarchical arrangement of internal representation, behavioral responses, and also to possible serially performed stimulus evaluations. The hierarchical arrangement might however also reflect how the different facial features relate to the particular structural description that may underlie the recognition of the facial emotion. From such a perspective, the rank ordered effects of the different features might be a direct consequence to how well these different features match the specific structural description of a threatening/angry and friendly/happy face, respectively. It may however also be that the features are differently weighted according to how useful they are for discrimination of facial emotion. Such a notion would be supported by the image analysis of pictorial emotional stimuli, where the main change of information between a neutral and threatening face was found in the eyebrows region, and between a neutral and a friendly face, in the mouth region (see section 1.3.2 Why v-shaped eyebrows, above). Indeed, plotting the emotional scores (Negative Valence over Activity) of the different stimuli in Study IV also suggest that eyebrows and mouth are differently important for conveying a threatening and friendly impression, respectively. In Figure 15, it can be seen how high emotion scores (High Negative Valence) for threatening faces are associated with v-shaped eyebrows, whereas “positive” emotion scores (low Negative Valence) are associated with u-shaped mouth.

Yet another factor that might be involved in hierarchical effects of facial features on attention, specifically for the schematic stimuli that were used here, are differences between the different facial features (eyebrows, mouth, eyes) in perceptual discriminability. The hierarchical order of features would in that case reflect the magnitude of the difference between an emotional shape of a feature and the neutral control shape. However, although discriminational factors are evidently involved in how faces are searched and discriminated, the close relation between attention and emotion measures show that the superior effect of threatening faces on attention is linked to the emotional properties of the facial stimuli.

2.3.4 Emotional effects on attention capture

In Study III, the design of the facial stimuli was based on the emotional data from Study I and II. In the data of Study III, the more efficient detection of threatening than friendly faces indicated that the emotionality of the schematic faces affected attention differently. In Study IV, analysis of covariation between attention and emotion measures revealed a close relation between these measures. These analyses revealed that a strong emotional impression (e.g. high scores on Negative Valence) was associated with efficient detection (short RTs and high Hit rate), and vice versa. Furthermore, the data indicated that the superior detection of threatening faces was closely related to the emotional contrast between the threatening and friendly configurations. Correlating emotional contrast (the emotional scores of a threatening face minus the scores of corresponding friendly face) with contrasts on attention measures (the response latencies and response accuracy of a threatening face minus

FIGURE 15. Even more results from Study IV: How eyebrows and mouth affect the emotional impression of faces.



those of the corresponding friendly face) revealed that large differences in emotion scores were accompanied by large threat-advantage effects on attention, and vice versa (Fig. 14). The relation between emotion and attention measures emerged most clearly between, on the one hand, Negative Valence and RTs (r=.68), and, on the other hand, between Hit rate and both Activity, and Potency (r=-.84; r=.-89, respectively).

These data strongly suggest that the emotional impression of a facial stimulus regulates how that face affects attention. Such conclusions are also in accordance with other reports of emotional effects on attention, such as the pronounced effects on attention capture in fearful compared to low-fear participants that was demonstrated both with snake and spider stimuli (Öhman et al., 2001) and schematic faces (Juth et al., submitted). In those data, the difference between participants in emotional attribution of stimuli (low-fear vs. high-fear) was also reflected in group effects on attention measures and hence appeared to modulate the effect of these stimuli on attention.

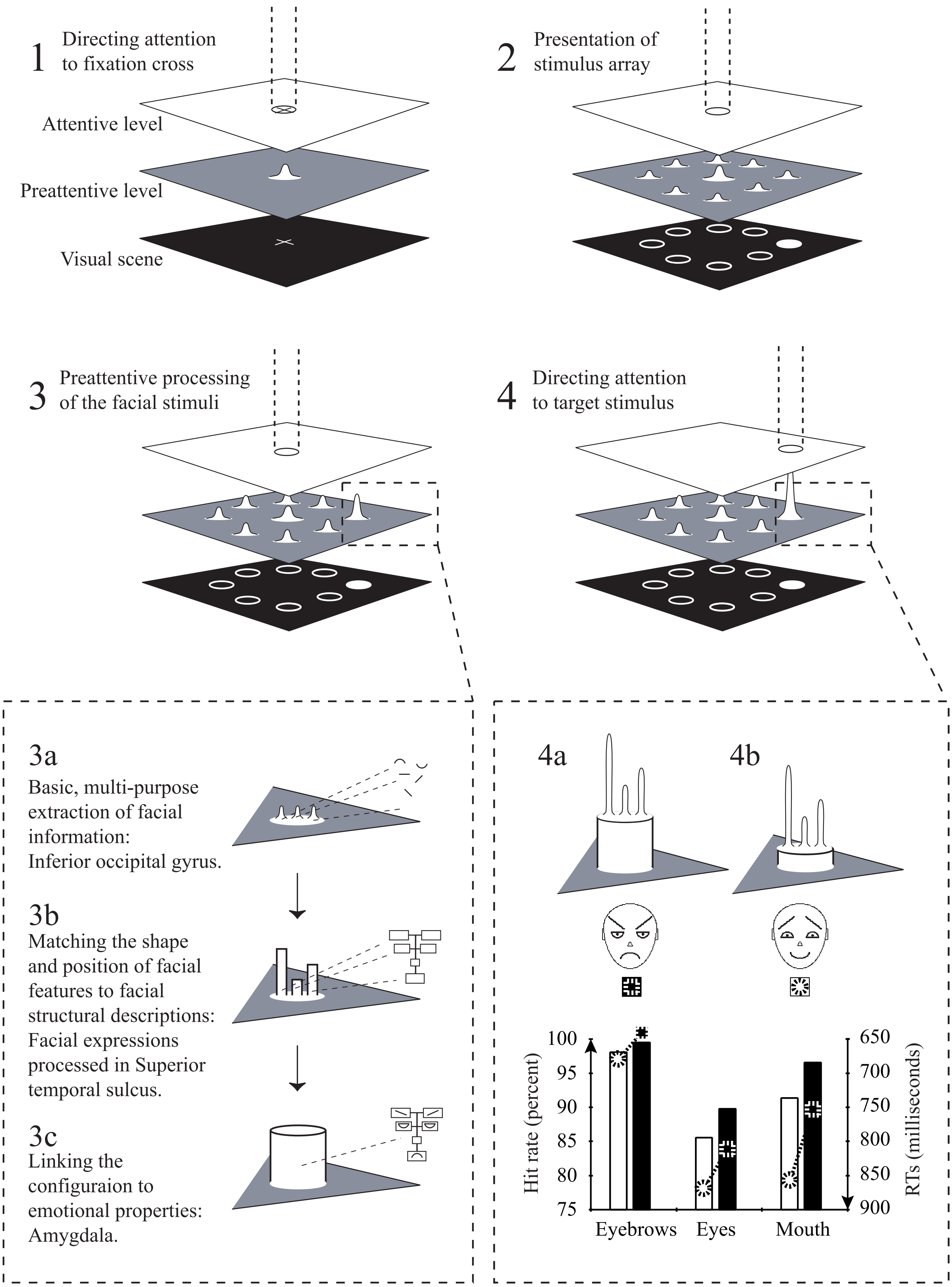
2.3.5 Emotion regulates attention

The emotion literature contains related evidence of how emotional significance of a stimulus affects various activity-aspects of the nervous system. Lang et al. (1997) suggest that Negative Valence and Activity (actually Valence and Arousal, two semantic dimensions that correspond to Negative Valence and Arousal; see e.g. Hamm, 1993) reflect the activity of central motivational systems, and signify a fundamental dimensionality that underlies human emotion. Generally, their data suggests that an emotional impression of a stimulus that corresponds to high Negative Valence and high Activity is associated with increases in psychophysiological responses. Conversely, low Negative Valence and low Activity is associated with comparatively smaller, sometimes even inhibited, psychophysiological responses. Lang et al. (1997) demonstrated the effect of stimulus emotion on the activity of the nervous system with data over several psychophysiological measures. Their data showed strong positive relations both between Negative Valence and electromyographical responses in corrugator supercilii (the facial muscle mediating the eyebrow frown) and between Negative Valence and the magnitude of the Startle reflex (measured by eye-blink responses to loud noises). Their data also revealed strong positive relations between Activity (Arousal) and skin conductance palmar sweat responses (Lang et al., 1997).

Interpreting the data from Study IV from a similar perspective, the data suggest that the more efficient attention to threatening compared to friendly configurations reflects a similar modulation of neural activity as that shown by the data of Lang et al. (1997). In theory, the neural representation of each facial configuration would thus be modulated according to that face’s emotional properties. A face conveying a threatening impression (e.g. high Negative Valence) would hence be modulated to an increased level, and thus stand out more from the background and be easier to detect. Conversely, a friendly configuration (e.g. low Negative Valence) would be modulated to a lower, possibly even inhibited, level and thus stand out comparatively less from background information.

Figure 16 illustrates how the neural representations of threatening and friendly faces may be modulated according to their emotional significance. The figure describes the data of Study III and IV, and is freely based on models of visual perception (e.g. Marr, 1982; Gegenfurtner, 1998), face processing (Bruce & Young, 1986; Haxby et al.,

FIGURE 16. A model of how facial emotion affects visual attention.



2000), and visual attention (Wright & Ward 1998; LaBerge, 1998). According to the models of Bruce and Young (1986) and Haxby et al. (2000), face processing works sequentially, with increasing complexity over serial, modular levels. First, a basic component analysis of facial information is performed, the outcome of which is used for any subsequent specialized facial processes, such as identity and expression recognition. This core system then involves other neural structures depending on what the task at hand demands. Haxby et al. (2000) suggest that the basic, multi-purpose extraction of facial information is carried out in the inferior occipital gyrus. The subsequent handling of facial emotional configurations is then performed in the superior temporal sulcus. Finally, connections between the superior temporal sulcus and the limbic system, foremost the amygdala, then link emotional properties to the facial configuration. Similar involvement of amygdala in processing of emotional facial stimuli has been demonstrated by several authors, for instance, Morris et al. (1998; 1999) and Carlsson et al. (submitted).

The involvement of amygdala in the emotional recognition of emotional facial stimuli, such as the schematic faces used here, is also supported by and fMRI experiment by Wright et al. (2002). They presented participants to blocks of schematic threatening, friendly and neutral faces (using our three-feature schematic stimuli; cf. the EB_EY_MO stimuli in Fig. 14). The results showed significant increase in the activation of left amygdala for both the threatening and the friendly face, compared to a neutral face. The data also showed a significant difference in activation between the threatening and friendly face in the left occipitotemporal cortex (OTC). These data thus imply that the speculated activity modulation of threatening and friendly faces takes place in inferior occipital cortex (IOC) in OTC. The fact that the significant difference in activity is found in OTC (Wright et al., 2002) does not necessary mean that the difference in neural activity is caused by that area, only that it is expressed there. According to the attention theory of LaBerge (1998; 2002), the expression of attention takes place at cortical areas, while it is *produced* by subcortical structures. LaBerge (2002) argues that the accomplishment of attention to visual stimuli generally involves triangular circuits between the thalamus, the different visual cortices, and frontal control cortices (particularly the prefrontal cortex), for modulation, expression and control of visual attention, respectively (see LaBerge, 2002). A major determinant to how attention initiated, modulated and controlled in these circuits is the degree to which a particular stimulus is interesting to the individual (LaBerge, personal communication). Because faces are important social stimuli, and because they can convey different strong emotional responses, faces are particularly interesting to humans, and hence very effective in capturing attention.

The data from Study III and IV demonstrate that the emotional properties of facial stimuli are important for how they affect visual attention. The data also show that it is not just a matter of conveying emotion in general: different types of emotional impression affect attention differently. Thus, faces that conveyed a threatening emotional impression (high Negative Valence) were consistently detected more efficiently than corresponding faces that conveyed a non-threatening or friendly impression (low Negative Valence). The effects of emotion on visual attention suggest that the facial emotion of the schematic stimuli was recognized preattentively, and that the recognized emotional properties of a particular face determined how attention was directed to that face (see Fig. 16). However, the data also showed that emotional properties are not the only determinants of how faces are searched and detected. The complexity of the visual search task, and the similarity between target and distractor faces are other factors that were clearly involved in how efficiently attention could be directed to a particular face. The efficiency by which facial emotion affected visual attention thus appeared determined both by perceptual and emotional dimensions. The data illustrate the role of emotion in discriminating and prioritizing between different types of information according to perceived emotional significance.

3 SUMMARY OF THE THESIS

The data from Study I and II (section 1. Looking for trouble, above) show that particularly eyebrows, and mouth, but also eyes, are central in conveying facial emotion. Specifically, v-shaped eyebrows and ∩-shaped mouth are central in conveying a threatening emotional impression, while the reversed shapes (^-shapes eyebrows and u-shaped mouth) are central in conveying a friendly, non-threatening impression.

The data also show that certain *individual features* are important. In particular, v-shaped eyebrows and u-shaped mouth can convey a relatively strong emotional impression even when presented outside a facial context. The general importance and involvement of these features in expressing facial emotion have been reported by, for instance, Darwin, 1872; Duchenne de Bologne, 1862/1990; Ekman, & Friesen, 1971; Oatley & Jenkins, 1996; Aronoff et al., 1998; Scherer, 1994; and Tipples et al. 2002. Importantly, however, the data also showed that *facial configuration*, how features are placed in a configuration, overrides the effect of individual features, and also provide stronger and more complex impressions. Moreover, when presented together in a facial configuration, facial features were found to have hierarchical effects on the emotional impression, and appeared to define the impression of a face in the ranked order of eyebrows, mouth, and eyes.

The data from Study I and II were interpreted in terms of an evolutionary perspective on human facial expressions and emotions, and discussed in relation to, for instance, face processing, facial stimuli, and signal evolution theory.

In Study III and IV (section 2. Finding it, above) data showed that threatening faces were detected more efficiently than friendly faces. The threat-advantage was maintained across a range of experimental conditions, and was evident for facial stimuli in which only one facial feature (eyebrows, mouth or eyes) conveyed the facial emotion. The effects of emotion on visual attention suggest that the facial emotion of the schematic stimuli was recognized preattentively, and that the recognized emotional properties of a particular face determined how attention was directed to that face.

The facial features were furthermore found to have hierarchical effects on visual attention. Detection of faces was thus made with a rank ordered efficiency, depending primarily on *what* feature in that feature hierarchy that could be used for discrimination, not on the number of features that could be used. Faces were thus searched most efficiently if they contained expressive eyebrows, followed by mouth, and eyes. Thus, both facial emotion (Study I & II) and facial attention (Study III & IV) appear to have hierarchical relations to the facial features. Expressive eyebrows thus resulted both in strong effects on emotional impression and in generally efficient directing of attention, whereas expressive mouth and eyes, in ranked order, resulted in lesser effects on emotional impression and also allowed for less efficient directing of attention.

A closer look at the parallel measures of emotion and attention in Study IV showed that visual attention to faces was closely related to the emotional properties of the faces. Thus, high scores on Negative Valence were, for instance, associated with short and accurate response latencies, whereas low scores were associated with slower and more inaccurate responses. The difference in discrimination efficiency between a compared pair of threatening and friendly faces was thus closely related to the emotional contrast between these stimuli. The relation between emotion and attention data was most evident for, on the one hand, Negative Valence and Response latencies, and on the other hand, between Activity/Potency and Response accuracy.

The data from Study III and IV were viewed against a background of visual perception and visual attention theories, and were interpreted in relation to face processing and emotion theory.

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5 ILLUSTRATION CREDITS

Cover design by Klas Holmlund.

Figure 4. 3-D graphics by Johan Mörén.

Figure 5. Average faces from AKDEF (Lundqvist & Litton, 1998). Fixation data from Lundqvist Psykologikonsult.

Figure 6. Courtesy of MarketWatch. Illustration and fixation data from Lundqvist Psykologikonsult.

All other illustrations by Daniel Lundqvist.

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