Automaticity in Affective Face Processing

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Abstract

Emotional facial expressions are highly relevant stimuli in humans. It has thus been suggested that they are processed automatically by evolutionarily in-built mechanisms. However, to which extent such processing in fact arises automatically is still controversial. The current work feeds into this debate by showing a tendency to spontaneously allocate increased processing capacity to emotional, especially threat-related expressions, even when processed merely superficially and emotionality is irrelevant to the task at hand (Study 1 and 2). This bias was further tested with regard to key criteria of automaticity; that is the intentionality (Study 3) and the load-insensitivity criterion (Study 4 and 5) assuming automatic processing to arise irrespective of intention of the individual, and concurrent task demands, respectively. Event-related brain potentials (ERPs) revealed enhanced perceptual encoding of threat-related expressions to remain largely unaffected by intention. In contrast, at the higher cognitive level, enhanced encoding depended on whether stimuli were voluntarily processed more deeply (Study 3). However, when control over face processing was impaired by a concurrent task, while emotionality was deemed relevant, emotion effects were enhanced at both, the perceptual and early higher cognitive level (Study 4). Similar was observed for perceptual encoding of attractive faces (Study 5). In contrast, during late higher cognitive stages of in-depth face processing, enhanced encoding of threat was eliminated when control was reduced (Study 4). The present results speak against full automaticity in affective face processing but suggest that biologically prepared processing biases are modulated by task-oriented control mechanisms and their interplay with intention.

Key words: emotion, facial expressions, automaticity, event-related potentials

[Deutsche Zusammenfassung]

Emotionale Gesichtsausdrücke sind hochrelevante Reize für den Menschen. Es wurde daher angenommen, dass sie von evolutionär bedingten Mechanismen automatisch verarbeitet werden. Bis zu welchem Maße diese Verarbeitung tatsächlich automatisch verläuft ist noch immer kontrovers. Die vorliegende Arbeit schließt an diese Debatte an, indem sie eine spontane Tendenz aufzeigt vor allem bedrohlichen Gesichtsaudrücken vermehrt Verarbeitungsressourcen zuzuweisen, auch dann, wenn sie nur oberflächlich enkodiert werden und Emotionalität irrelevant für die gegebene Aufgabe ist (Studie 1 und 2). Diese Tendenz wurde bezüglich zweier Schlüsselkriterien von Automatizität untersucht, nämlich dem Intentionalitäts- (Studie 3) und dem Auslastungskriterium (Studie 4 und 5); diese nehmen an, dass automatische Verarbeitung unabhängig von der gegebenen Intention des Individuums, beziehungsweise konkurrierender Aufgabenanforderungen verläuft. Anhand ereigniskorrelierter Potenziale (EKPs) konnte gezeigt werden, dass verstärkte perzeptuelle Enkodierung emotionaler Gesichtsausdrücke weitgehend unabhängig von Intention auftrat, wohingegen verstärkte höhere kognitive Verarbeitung davon abhing, ob Reize vertieft verarbeitet wurden (Studie 3). Wurde die Kontrolle über die Gesichtsverarbeitung durch eine konkurrierende Aufgabe beeinträchtigt, während Emotionalität relevant war, so verstärkte dies emotionale Effekte auf der perzeptuellen und frühen, höheren kognitiven Ebene (Studie 4). Ähnliches konnte auch für die perzeptuelle Verarbeitung attraktiver Gesichter beobachtet werden (Studie 5). Hingegen war bei verminderter Kontrolle die verstärkte Enkodierung bedrohlicher Ausdrücke in späten kognitiven Verarbeitungsstufen unterdrückt. Die vorliegenden Befunde sprechen gegen eine Automatisierung affektiver Gesichtsverarbeitung und legen stattdessen nahe, dass biologisch vorbereitete Verarbeitungstendenzen durch aufgabenorientierte Kontrollmechanismen und ihr Zusammenspiel mit Intention moduliert werden.

Schlagwörter: Emotion, Gesichtsausdrücke, Automatizität, ereignis-korrelierte Potenziale

1. Introduction

1.1. Theoretical Background

Undisputedly, humans are social beings. Their remarkable ability to form social bonds, coordinate interactions, and learn from conspecifics is an important, if not the most important factor in the story of evolutionary success of humanity. By means of their social capabilities, members of this species were able to pass on and advance knowledge from one generation to the next, thus enabling the development of culture fostering the survival of human societies all over the world under most diverse environmental conditions.

Underneath those layers of cultural attainments acquired more recently, older mechanisms guarantee our susceptibility to biologically relevant signals in the environment. Typically, emotions are believed to reflect such innate predispositions for action (LeDoux, 1989; Plutchik, 1980; for review see, Hamm, Schupp, & Weike, 2003; Lang & Bradley, 2010). For instance, the detection of a predator in the environment followed by avoidant fear reactions, or of a member of our social group resulting in approaching, affiliative behaviour was likely associated with advantages for the organism in evolutionary selection. Given the high importance of social interaction in humans, emotional and social functioning may thus be strongly intertwined from early on in human history (see, Bar-On, Tranel, Drenburg, & Bechara, 2003; Frith, 2006; Frith & Frith, 2010). It has even been suggested that emotional facial expressions, being both emotionally and socially relevant, are processed in an *automatic* fashion by hard-wired mechanisms in our brain (e.g., Batty & Taylor, 2003; Dimberg, Thunberg, & Elmehed, 2000; Öhman, 2002; Öhman & Mineka, 2001; Vuilleumier et al., 2002; Vuilleumier, Armony, Driver, & Dolan, 2001).

However, during the ontogenesis, the individual acquires a more refined, higher level of (self-) reflection – based on the common grounds of the culture it is raised in (Mauss, Bunge, & Gross, 2008; Siegel, 2001). By imbedding events into a broader context of socially shared knowledge, we make sense of our bodily responses and internal states, as well as the behaviour of others. For instance, fear-inducing stimuli in a potentially harmful situation of imminent attack or in the cinema while watching a horror film with friends will very likely yield different reactions. Therefore, the influence is not unidirectional: It is not just biological preparedness determining our experiences, but by experience we learn to regulate biologically rooted responses according to contextual factors (cf., Gross, 1998; Scherer, 1984, 1993). Such *interpretative* process allows for a dynamic adjustment of emotions, challenging the idea of automaticity in affective stimulus processing.

Nevertheless, to date, the debate on the automaticity of affective stimulus processing has not yet been settled. Feeding into this controversy, the aim of the current work is to shed light on the interrelation of in-built, affective and higher cognitive, regulative processes. Since emotional facial expressions can be considered a stimulus class of high biological significance in humans (Öhman & Mineka, 2001), they appear a suited candidate to address this question. The herein presented studies were thus designed to:

(1)   Assess the status of phylogenetically prepared compared to ontogenetically acquired emotionality as found in facial expressions and written words, respectively.

(2)   Test key criteria of automaticity for emotional facial expression processing.

(3)   Test criteria of automaticity for other biologically relevant dimensions in faces (i.e., attractiveness) to attain a more global perspective on the nature of predisposed processing biases.

The following section will summarize relevant findings from the previous literature before main results from own experiments will be presented. In fact, the herein presented own data will show that prepared mechanisms do *not* proceed in a fully automatic fashion, but only give rise to certain response tendencies that can be adjusted according to situational requirements. Thus, in the last concluding section, most important findings will be discussed and integrated in an attempt to outline a unifying account of affective face processing under the influence of higher cognitive, regulative control processes.

1.2. Previous Research

Several studies suggest privileged processing of emotional relative to neutral stimuli across a wide range of domains – such as pictures of complex scenes, written words, and facial expressions (for review, Kissler, Assadolahi, & Herbert, 2006; Schupp, Flaisch, Stockburger, & Junghöfer, 2006; Vuilleumier & Pourtois, 2007). Besides specific processing characteristic for these domains (Britton, Taylor, Sudheimer, & Liberzon, 2006; Keightley et al., 2003; Schacht & Sommer, 2009a), previous research has generally shown increased neural activation for emotional relative to neutral stimuli. The most prominent theoretical account to explain such effects suggests in-built mechanisms that guarantee biologically relevant stimuli to gain privileged access to limited processing capacity (Lang, Bradley, & Cuthbert, 1997; Pessoa, Kastner, & Ungerleider, 2002a; cf. Desimone & Duncan, 1995). Some researchers have suggested that such enhanced activation occurs *automatically* for threat-related faces, as their facilitated detection likely fostered the physical integrity of the organism in the evolutionary past (for review, Palermo & Rhodes, 2007).

Critically, the concept of automaticity is somewhat obscure. In fact, it is not used in a consistent manner throughout the literature (see, Pessoa, 2005). Some researchers found increased brain activations to emotional expressions during a task that did not explicitly require processing of emotion (e.g., Batty & Taylor, 2003), while others reported emotion effects in the absence of conscious perception (e.g., Öhman, 2002) or attention (e.g., Vuilleumier et al., 2001) – all claiming their results to reflect automatic emotion processing. Santangelo & Spence (2008) postulated that such different criteria for automaticity can be subsumed under two key concepts: The *intentionality* and the *load-insensitivity* criterion. The former reflects the involuntary and inflexible nature of automatic processes, occuring irrespective of the intention or current goal of an individual in a given situation. The latter claims that automatic processing does not require limited capacity, thus takes place in parallel with other cognitive processes, and is not interfered with by concurrently demanding tasks (see also, Bargh, 1994).

A few studies *directly* assessed the intentionality criterion by statistically comparing brain responses to emotional facial expressions between different intentional states (task conditions). This line of research has yielded increased emotion-related brain activations in conditions where emotionality was *explicitly* relevant to the task at hand (i.e., emotional categorizations) relative to an *implicit* processing of emotions (e.g., gender decisions; Gorno-Tempini et al., 2001; Knyazev, Slobodskoj-Plusnin, & Bocharov, 2009; Straube et al., 2004; Van Strien, De Sonneville, & Franken, 2010). These effects were accompanied by a different timing (Knyazev et al., 2009) or neuro-anatomical configuration of emotional brain responses (Van Strien et al., 2010). Such findings indicate that the intention towards emotional facial expressions affects the way these are processed, challenging the intentionality criterion.

As to the load-insensitivity criterion, many studies manipulated concurrent *perceptual* load by a more or less demanding visual task (e.g., Pessoa et al., 2002a). For instance, in the same display a visual discrimination task was required either for faces or non-emotional objects presented in parallel. Overall, this line of research has revealed that the more demanding the concurrent visual task, the less pronounced were the emotion-related brain activations (Bishop, Jenkins, & Lawrence, 2006; Eimer, Holmes, & McGlone, 2003; Holmes, Vuilleumier, & Eimer, 2006; Hsu & Pessoa, 2007; Lim, Padmala, & Pessoa, 2008; Mitchell et al., 2007; Morawetz, Baudewig, Treue, & Dechent, 2010; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002b; Silvert et al., 2007) – indicating that the encoding of emotional facial expressions, like any other visual stimulus, draws on visuocortical resources (e.g., Handy, Soltani, & Mangun, 2001).

More interestingly, some researchers manipulated concurrent load at the higher cognitive level during emotional face processing by varying the amount of unrelated information maintained in memory in parallel (e.g., Holmes, Kragh Nielsen, Tipper, & Green, 2009) or by varying the temporal overlap with a concurrent task from a different sensory modality (e.g., auditory tone discrimination; see, Tomasik, Ruthruff, Allen, & Lien, 2009). These mainly behavioural studies have yielded that increasing concurrent load on higher cognitive functions impairs explicit labelling of emotional expressions (Phillips, Channon, Tunstall, Hedenstrom, & Lyons, 2008; Tomasik et al., 2009) but at the same time enhances rather implicit emotion effects like, for instance, emotional priming (i.e., larger effects of previously presented emotional expressions on a subsequent, unrelated affective evaluation of unfamiliar Japanese ideograms; see, Rotteveel & Phaf, 2004).

Such different effects may indicate distinct stages of emotion processing to be differently affected by concurrent load on higher cognitive functions. However, since behavioural data reflects the global outcome of multiple processing stages, it is difficult to locate those different effects more precisely. In contrast, event-related brain potentials (ERPs) offer the opportunity to observe ongoing processing at high temporal resolution, and to examine the effect of concurrent task load on distinct emotion processing stages separately. ERPs are recorded from the scalp surface, stemming from the summed activity of postsynaptic cortical potentials of relatively large cell assemblies. ERP amplitudes indicate the degree of activation at different latencies, with their distribution across the scalp informing about the relative location of active cell assemblies. Such activity patterns or *components* can be associated with specific processing stages. Studies using ERPs have yielded enhanced processing of emotional relative to neutral stimuli at multiple, successive stages – from early perceptual to mnemonic processes (for review, Olofsson, Nordin, Sequeira, & Polich, 2008). ERP components that have proven most relevant in research on emotional face processing are presented by the P1, the N170, the early posterior negativity (EPN), and the late positive complex (LPC).

An enhancement of the P1 – a positive amplitude peaking over lateral occipital electrodes around 80 to 100 ms after stimulus onset – has been found primarily for negative, threat-related relative to other expressions (e.g., Holmes, Kragh Nielsen, & Green, 2008; Pizzagalli, Regard, & Lehmann, 1999; for review, Vuilleumier & Pourtois, 2007). In contrast, the ensuing EPN – a relatively increased posterior negativity over temporo-occipital sites typically emerging from 150 ms onwards (for review, Schupp et al., 2006) – has been reported for both, negative and positive relative to neutral expressions, respectively (e.g.,

Holmes et al., 2009). Although the P1 and EPN have both been associated with enhanced perceptual encoding of emotional stimuli in extrastriate visual cortex (see e.g., Pourtois & Vuilleumier, 2006; Schupp et al., 2007a), their sensitivity to different emotions suggests a functional dissociation. Falling within the time window of the EPN, the N170 – a negative amplitude peaking around 170 ms after stimulus onset – has been related to stages of face-specific structural encoding (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eimer, 2000a, 2000b; Itier & Taylor, 2004) rendering a holistic face representation used for later recognition processes (e.g., Eimer, Gosling, Nicholas, & Kiss, 2007). There is an ongoing debate on whether this component is affected by emotion, since according to traditional models of face perception emotion is encoded in parallel and independently from structural characteristics (Bruce & Young, 1986; Calder & Young, 2005). So far, studies have yielded evidence for (e.g., Batty & Taylor, 2003) and against a modulation of the N170 by emotional facial expression (see, Eimer & Holmes, 2007).

Usually following those perceptual, earlier ERP components, the LPC emerges as a centro-parietal positivity that is enhanced for emotional relative to neutral stimuli typically around 300 ms after stimulus onset, which lasts for several hundred milliseconds. The LPC is believed to reflect processing in *working memory* (for review, Polich, 2007; Schupp et al., 2006), that is, the short-term retention of information for further processing. By enabling the comparison of incoming with stored information, working memory is vital for the translation of perceptual input into the meaning of stimuli and inferring implications for action (Baddeley, 2003; Postle, 2006; cf., Pashler & Johnston, 1998). The LPC can be subdivided into the P3a and P3b, reflecting initial detection and sustained maintenance of stimulus information in working memory, respectively (for review, Polich, 2007). In analogy, early and late emotion effects on the LPC were assumed to indicate enhanced detection and maintenance of emotional expressions in working memory, respectively (Holmes et al., 2009; cf., Schupp et al., 2006). Notably, early emotional LPC effects partly overlap with the EPN in time (see, Holmes et al., 2009). Since polarity reversals of the EPN may yield centro-parietal positivities as well (see, Junghöfer, Peyk, Flaisch, & Schupp, 2006; Schupp et al., 2006), it is essential to disentangle contributions of this component from genuine LPC activity over centro-parietal electrodes.

Previous ERP research suggests that early and late emotion processing stages are automated to different degrees. One study showed that for emotional expressions presented at fixation, early emotional ERP effects (< 220 ms) were preserved while late ones (> 220 ms) were eliminated when a concurrently demanding visual task was performed in the visual

periphery in parallel (Holmes, Kiss, & Eimer, 2006). Both, early and late emotion effects consisted in fronto-centro-parietal positivities that were not referred to typical emotion-sensitive ERP components; they may reflect a polarity reversal of the EPN earlier and actual LPC activity later. In line with this suggestion, two ERP studies using words (Kissler, Herbert, Winkler, & Junghöfer, 2009; Schacht & Sommer, 2009b), and one with pictures of complex scenes (Schupp et al., 2007b) *directly* showed that EPN effects persisted whereas LPC effects disappeared when the task was changed from a deeper (i.e., semantic decision / fixated stimulus belonging to the attended target category) to a more superficial encoding of emotional stimuli at fixation (i.e., structural font decision / fixated stimulus not belonging to the attended target category). Only a single ERP study using emotional facial expressions has manipulated concurrent load on higher cognitive functions (Holmes et al., 2009). During a continuous stream of face presentation trials, concurrent load was varied by a 1- versus 2-back face identity matching task (memory task). Increased concurrent load (2-back) did not alter emotional P1 and EPN effects, but eliminated emotional LPC effects. In sum, ERP findings thus seem to indicate that enhanced processing of emotional stimuli occurs rather automatically at the perceptual level (P1, EPN), while it depends on depth of processing and the availability of higher cognitive functions during working memory encoding (LPC).

However, all of those studies on the automaticity of emotion processing reviewed so far addressed only one of the two key criteria at a time. Besides, not all of them in fact employed emotional facial expressions – although these appear an ideal candidate to test automaticity. Critically, different intentional states may draw on different functions to varying degrees. Most relevant for the current research aim: Processing of emotional facial expressions very likely recruits biologically prepared mechanisms (see, Ardila, 2008; Vuilleumier, 2005). Therefore, the intention to process emotionality may utilize other brain circuits than for instance processing of identity (e.g., gender) in faces (cf., Chiu, Estermann, Han, Rosen, & Yantis, 2011). Thus, concurrent load on higher cognitive functions may yield different effects in explicit (emotional categorizations) versus implicit emotion processing tasks (e.g., gender categorizations), so the intentionality and the load-insensitivity criterion may have to be assessed in combination for emotional expression processing.

Bridging gaps in previous research, the present work aimed to assess automaticity in affective face processing with regard to both, the intentionality and the load-insensitivity criterion at different, separable processing stages as indicated by the P1, N170, EPN, and LPC in ERPs. Ancillary questions, whether the N170 is influenced by emotion, and how LPC activity may be differentiated from polarity reversals of the EPN were also addressed.

2. Testing Automaticity in Affective Face Processing

2.1. Evolutionary Preparedness

2.1.1. Domain Comparison: Emotion Processing in Words and Faces

Addressing the research aim mentioned under (1) in the Introduction, **Study 1** was designed to assess the status of phylogenetically prepared as compared to ontogenetically acquired emotional meaning in facial expressions and written words, respectively. Only a single previous study by Schacht and Sommer (2009a) attempted to compare emotion effects between these domains during an implicit processing of emotionality. However, emotion effects in faces and words emerged from different preconditions as different tasks were used in each domain. For words, lexical decisions were required in which phonologically legal pseudo-words had to be detected. For faces, intact and manipulated (partially smeared) portraits had to be discriminated. These tasks likely induced different kinds of processing in both domains, with deeper, semantic analyses in words, whereas a superficial perceptual analysis was sufficient to comply with task demands in faces. In contrast, the current experiment attempted to equate task requirements in faces and words, so emotion effects would arise equally spontaneously in both domains. Respecting the intentionality criterion of automaticity, a task was used that did not require explicit processing of emotions in either domain.

Thus, 150 faces and 150 words of negative (angry), positive (happy), or neutral valence in equal proportion (50 stimuli per emotional category per domain) were presented to 24 participants in an easy, superficial face-word discrimination task. Per button press participants had to indicate whether the presented stimulus was a face or a word, requiring an equal depth of processing in both domains. ERPs yielded an emotion-related increased negativity over posterior electrodes as typically described for the EPN (Schupp et al., 2006), occurring only for faces between 150 and 450 ms after stimulus onset, primarily for angry expressions. Apparently, superficial processing was insufficient to trigger an EPN in words. Usually, the EPN in words is believed to arise during lexico-semantic analysis, with the activation of semantic representations spontaneously recruiting lower, emotion-sensitive brain areas (see, Kissler, Herbert, Peyk, & Junghöfer, 2007; Schacht & Sommer, 2009a, 2009b; Palazova, Mantwill, Sommer, & Schacht, 2011). Despite previous research suggesting words to be read automatically (Brown et al., 2002; LaBerge & Samuels, 1974; MacLeod, 1991) and the EPN to occur spontaneously during reading (Kissler et al., 2009), results from Study 1 indicated that lexico-semantic analysis and the extraction of emotional meaning in words is

voluntary. In contrast, activation of emotional meaning in faces appears rather obligatory, probably due to an in-built mechanism spontaneously linking a perceived stimulus to its affective connotation, even when the stimulus is processed only superficially.

Interestingly, in both domains, an increased positivity at parieto-occipital electrodes occurred for emotional relative to neutral stimuli between 50 and 100 ms after stimulus onset. In faces this very early effect was significant for happy relative to neutral expressions, consistent with reports of an early happy-face advantage due to the facilitated detection of certain salient visual features in this expression (Calvo & Nummenmaa, 2008, 2009). In words, the early effect emerged for both, negative and positive relative to neutral words. To date, the exact mechanisms accounting for such rapid, pre-semantic detection of emotional significance remain largely unknown. However, it might be suggested that a learned association of perceptual features of a stimulus with motivational value (rewarding or punishing) enables a preliminary, rapid stimulus evaluation prior to a more fine-grained recognition of specific emotional content (cf., Rauss, Schwartz, & Pourtois, 2011; Schacht, Adler, Chen, Guo, & Sommer, 2012).

2.1.2. Face-specificity of Emotion Processing

Given the special status of emotional facial expressions, it was tried to assess in how far emotion processing in this domain can be considered face-specific. As outlined in the Introduction, the N170 is believed to reflect structural face encoding. By studying this component, **Study 2** pursued two aims: First, from a more general, theoretical point of view it was tried to assess whether encoding of emotional information in faces is carried out by face-specific mechanisms as indicated by the N170. Importantly, coinciding with the N170 over temporo-occipital electrodes, the domain-general EPN occurs with an increased negativity for emotional, primarily threat-related expressions. Thus, it has to be taken into consideration that apparent emotion effects on N170 amplitudes may in fact reflect superimposed EPN activity. Second, methodologically, it was aimed to find an explanation as to why previous research on face processing has so far reported conflicting results regarding emotional modulations of the N170. It has already been shown that amplitudes of both the N170 (Joyce & Rossion, 2005) and the EPN (Junghöfer et al., 2006) depend on the site of reference, with voltages over posterior electrodes being generally less pronounced when references are located closer to the back of the head (i.e., earlobes or mastoids) than when the average activity across all electrodes is used for reference (average reference). Such different referencing procedures may offer a possible solution to the conflicting reports on modulations of the N170 by emotional facial expression.

Data from Study 1 was reanalyzed focussing on the N170 component. First, to test whether face- and emotion-specific processes are dissociable, overall scalp distributions of the N170 and temporally coinciding emotion effects were compared. Different scalp distributions would indicate that processes associated with the N170 and emotional expression draw on at least partly different brain source activities. Second, the effect of reference on emotional modulations at typical temporo-occipital N170 electrodes was assessed by comparing ERPs referred to the mastoids versus average reference. Further data was collected in an additional experiment employing the same task and stimuli as used in Study 1, but also including inverted images of each stimulus. Since inversion is known to disrupt recognition of emotional expressions while preserving low-level physical characteristics of the stimuli (e.g., Eimer & Holmes, 2002), it tests for the validity of particularly early emotion effects in ERPs. If effects of emotional expressions during the N170 amplitude occur only for upright faces, this proofs early ERP effects to be based on the processing of emotional meaning rather than physical differences between expression categories.

In fact, results showed emotion effects during the N170 peak amplitude to occur only for upright faces. Emotion-related amplitude modulations at typical N170 electrodes were more pronounced in average- than mastoid-referenced data, suggesting different referencing procedures to account for at least some of the conflicting reports regarding emotional N170 modulations in the literature. Critically, scalp distributions of the N170 and coinciding emotion effects differed, indicating face- and emotion-specific processes, respectively, to be at least partly associated with distinct neural source activities. Previous reports on emotional N170 modulations thus seem questionable; they may not reflect activity of the N170 component itself but superimposed EPN activity coinciding with the N170 amplitude over temporo-occipital electrodes. Hence, face and emotion encoding involve different functions (see e.g., Palermo & Rhodes, 2007). This way, neural mechanisms that account for the human proficiency in face processing do not encode emotionality but may facilitate the quick detection of emotional significance by other, parallel mechanisms.

2.2. The Intentionality Criterion

According to the main aim presented under (2) in the Introduction, **Study 3** tested the intentionality criterion of automaticity in emotional facial expression processing more firmly. Although Study 1 and 2 had shown enhanced processing of emotional stimuli to occur spontaneously in faces, a true test of the intentionality criterion could only be accomplished by comparing different intentional states. So far, previous research suggests that at least the

LPC to emotional expressions benefits when emotionality is task-relevant, that is, when one intends to explicitly process emotional information in faces (Van Strien et al., 2010). No study with facial expressions has yet directly examined the effect of task relevance of emotionality on other important components, such as P1 and EPN. Further, as outlined in the Introduction, studies that employed words or complex pictures suggest depth of processing to affect working memory (LPC) but not perceptual stages (EPN) of emotion encoding (Kissler et al., 2009; Schacht & Sommer, 2009b; Schupp et al., 2007b). Thus, Study 3 was designed to clarify the role of both, the task relevance of emotionality and the depth of stimulus processing (superficial, perceptual vs. deep, semantic analysis) for the encoding of emotional facial expressions. Moreover, to distinguish LPC- from EPN-related activity, an *independent component analyses* (ICA) was performed on the ERP data. This method allows separating components based on their maximal temporally independent contributions to the overall activity on the scalp surface.

One hundred and fifty faces with angry, happy, or neutral expression in equal proportion (the same face stimuli as in Study 1 and 2) were presented to 24 participants under five different task conditions (intentional states). The effect of depth of processing was tested by comparing emotion effects in a superficial face-word discrimination task (the same as in Study 1 and 2) to those in gender and emotional expression categorizations. The comparison of the latter two tasks – both requiring deeper face analysis – allowed assessing the effect of task relevance of emotionality. In addition, passive viewing blocks were conducted where participants had to simply look at the faces, with and without mentioning of their emotionality in task instructions. These two conditions were employed to assess some kind of *default mode* of emotional face processing (cf., Vuilleumier & Huang, 2009), most likely to occur when no other specification how to deal with faces is given. By comparing the two passive viewing blocks it was further aimed to test whether merely changing the instruction without changing the overt task was sufficient to alter default emotion processing.

Behavioural data confirmed the face-word decision to be the easiest task (shortest reaction times, lowest error rates), consistent with the assumption that it required only superficial, swift processing to classify a given stimulus. ERP results yielded that enhanced perceptual encoding of angry expressions as indicated by emotional P1 and EPN effects occurred irrespective of task condition. In contrast, for happy expressions, no P1 effect was observed, and the EPN (150-300 ms) only occurred in tasks of deeper (gender and emotional categorizations) not superficial stimulus processing (face-word decision). Thus, according to the intentionality criterion, perceptual encoding is automatically enhanced for angry faces –

consistent with an in-built processing bias for threat (see, Schupp et al., 2004; Vuilleumier & Pourtois, 2007) – whereas happy faces require voluntary, deeper stimulus processing. However, enhanced working memory encoding of angry expressions as reflected by the LPC (400-600 ms) only emerged during deeper (gender and emotional categorizations) not superficial stimulus analysis (face-word decision) as well. Thus, a voluntary, deeper processing of threatening faces is necessary to guarantee their privileged access to working memory capacity. Apparently, as categorizations of gender and emotionality both entail deeper stimulus analysis, effects of emotional expressions did not differ between those two task conditions – so task relevance of emotionality seemed unimportant for emotion encoding. Further, emotion effects during passive viewing were more similar to conditions of deeper rather than superficial stimulus processing, and merely changing the instruction did not alter them. This suggests in-depth processing of faces and enhanced encoding of emotional expressions to occur spontaneously when no other task is given.

Notably, the ICA allowed separating LPC from EPN activity. According to the ICA data, emotion effects on the EPN showed a positive polarity reversal at typical LPC electrodes; in contrast, emotion effects on the LPC were not associated with any meaningful activity at typical EPN electrodes. Therefore, emotion-related positivities over centro-parietal sites as typically attributed to the LPC need to be carefully separated from polarity reversals of the EPN in standard ERPs. This needs to be taken into account particularly when reporting early LPC effects within the typical EPN time window (~150-300 ms).

2.3. The Intentionality and Load-Insensitivity Criterion

Further focussing on the main aim mentioned under (2) in the Introduction, **Study 4** was designed to test both key criteria of automaticity, that is, the intentionality and the load-insensitivity criterion in emotional expression processing. So far, only a single ERP study has varied concurrent load on higher cognitive functions by a 1- versus 2-back face identity matching task in which emotional expressions were (implicitly) processed; emotion effects during perceptual stages (P1, EPN) were preserved whereas they were completely eliminated for working memory stages (LPC) when concurrent load was increased (2-back condition; see Holmes et al., 2009). No study has yet attempted to combine the manipulation of concurrent load on higher cognitive functions with a variation of the intentional state, although it is feasible that the intention to process emotional information in explicit emotional categorizations recruits other mechanisms than emotion-unrelated tasks. Thus, it was sought

to compare emotion effects in an explicit versus implicit emotion processing condition while concurrent load was varied at the higher cognitive level.

Gender categorizations were chosen for the implicit processing condition, yielding emotion effects similar to emotional categorizations without concurrent load in Study 3. Faces were presented in three separate experiments including 24 participants each. Experiment I presented artificially generated stimuli (N = 486 with angry, happy, or neutral expression in equal proportion) in a gender categorization task. In Experiment II and III, the same stimuli as used in the preceding three studies plus some additional natural expressions were included, yielding a total set of 450 items with angry, happy, or neutral expression in equal proportion. While Experiment II required ratings of emotionality, Experiment III employed binary decisions in both, emotional (emotional vs. non-emotional) and gender categorizations (male vs. female) to allow for a direct comparison of the two pertaining intentional states under concurrent load. Concurrent load was manipulated by means of the *psychological refractory period* (PRP) paradigm (for review see, Pashler & Johnston, 1998), varying the stimulus onset asynchrony (SOA) between one of two randomly presented tones in a pitch (high vs. low) discrimination, primary task and subsequent face presentation in the emotion/gender categorization, secondary task (SOA in Experiment I: 350, 650, and 950 ms; in Experiment II and III: 100, 400, and 700 ms). The shorter the SOA, the more would primary tone processing overlap with the secondary task, thus increase concurrent task load and impair face processing. Since both, the tone and face task were of different sensory modality and targeted different effectors (e.g., hand vs. foot), any interference would occur due to limitations at the higher cognitive level. Given findings from Study 3, in the following, the LPC was considered distinguishable from polarity reversals of the EPN in standard ERPs when activity at typical LPC and EPN electrodes varied differently for the same time point.

Behavioural results yielded that emotion and gender categorizations were of similar difficulty (Experiment III). Response times in these secondary face tasks increased with a decrease in SOA – the typical PRP effect – indicating greater concurrent load by the primary task to effectively impair task-relevant face processing. Strikingly, emotion-related EPN effects remained unaffected by concurrent load in gender decisions (Experiment I and III), but were enhanced for angry relative to neutral (Experiment III) and happy expressions (Experiment II), respectively, under greatest concurrent load (SOA 100) in emotional decisions. Similarly, emotion effects on the early LPC (~220-500 ms) occurred only when emotionality was explicitly task-relevant (Experiment II and III), and seemed to benefit from greater concurrent task load (insignificant at longest SOA, i.e. 700 ms); however, they

emerged with a certain temporal distance from tone onset (> ~350 ms). Late LPC effects (> ~500 ms) were only observed for angry expressions, and eliminated by an increase in concurrent task load (shortening of SOA) in both, gender and emotional categorizations (Experiment III).

The benefit for threat-related EPN and early LPC effects in emotional categorizations at shorter SOA suggests that the intention to process emotionality in faces recruits a biologically prepared pathway more effectively the greater the concurrent task load. More precisely, considering the functional role of the EPN and early LPC, it seems that encoding of threatening faces is facilitated at the perceptual and early working memory level, respectively, when emotionality is deemed relevant and higher cognitive functions are loaded by a concurrent task. Since increased emotion effects in ERPs were not associated with any benefit at the behavioural level (e.g., shorter reaction times), it seems that enhanced neural processing of emotional faces was rather irrelevant for face labelling. Increased emotion effects on early ERPs to occur precisely when labelling performance was most severely impaired (longest reaction times at shortest SOA) even suggest that emotion- and task-related face processing draw on opposing mechanisms, with the former prevailing when higher cognitive functions are concurrently loaded – at least during early stages. In contrast, emotion effects on the late LPC reflected the PRP effect in secondary face task performance more closely (Experiment III), being increasingly reduced the greater the concurrent task load. This suggests that sustained working memory encoding (late LPC) – entailing the enhanced encoding of threat (see, Study 3) – might be relevant for in-depth face labelling (gender and emotional categorizations); at least both seem to rely on the availability of higher cognitive functions.

In sum, emotion effects on ERPs depended on concurrent load on higher cognitive functions, which interacted with the task relevance of emotionality during early processing stages. Therefore, emotional facial expression processing cannot be considered fully automatic – neither in terms of the load-insensitivity nor the intentionality criterion.

2.4. Automaticity in Facial Attractiveness Processing

Due to its relevance for mating and social status, attractiveness might be suggested another important dimension in faces that is encoded by biologically prepared mechanisms (cf., Little, Benedict, Jones, & DeBruine, 2011; Thornhill & Gangestad, 1999). In fact, ERP research in faces has yielded similar results for attractiveness and emotionality, with also attractive faces being associated with enhanced neural processing as indicated by EPN and LPC effects (Werheid, Schacht, & Sommer, 2007). However, it was shown that such

enhanced processing may only occur when explicit judgements of attractiveness are required (Schacht, Werheid, & Sommer, 2008), challenging the intentionality criterion of automaticity in attractive face processing. Nevertheless, given findings from Study 4, it was considered that even if biologically prepared mechanisms were not fully automatic, they could still become more effective when higher cognitive functions were loaded by a concurrent task while attractiveness was explicitly task-relevant. Therefore, **Study 5** observed processing of attractive faces during an attractiveness rating, secondary task in the PRP paradigm. As devised under aim (3) in the Introduction, studying processing of attractiveness under concurrent task load may offer a more general perspective on the interplay of biologically prepared and higher cognitive, regulative mechanisms.

For this purpose, 366 face stimuli were presented to 20 participants while the SOA (100, 400, and 700 ms) between tone and face onset was varied. The primary tone task was identical to the one used in Study 4. In the secondary task, after 1500 ms of face presentation, a rating scale appeared requiring participants to select one of seven values according to their own attractiveness judgement for the previously presented face (very non-attractive, non-attractive, rather non-attractive, neither-nor, rather attractive, attractive, very attractive). Behavioural results again yielded the typical PRP effect, with increased reaction times in the secondary face task at shorter SOA. Given that responses for the rating task were required in a time window only after primary tone responses had been given, the persistence of the PRP effect suggests a sustained impairment of the face task beyond concurrent task processing (see also, Experiment II in Study 4). ERPs to attractive (highest ratings), intermediate (medium ratings), and unattractive faces (lowest ratings) were determined for each participant separately based on a ranking of the individually assigned rating values. Results yielded a benefit for the EPN in attractive relative to intermediate faces under highest concurrent task load; more precisely, the EPN was significant between 516 and 572 ms only at shortest SOA (100 ms). Thus, like Study 4, results of this experiment suggested biologically prepared mechanisms to benefit when higher cognitive functions were concurrently loaded.

Note that with identical primary tone task and SOA conditions the benefit for the EPN occurred considerably later for attractive faces (516-572 ms) than emotional expressions (220-280 ms in Experiment II of Study 4). However, attractiveness generally affected ERPs later than emotionality (from 260 vs. ~140 ms, respectively). If attractiveness processing is less rapid, also its interaction with concurrent task load may emerge at a later point in time. Further, as effects of attractiveness were not present for the LPC in the present study, and only emerge when attractiveness judgements are in fact required (cf., Schacht et al., 2008), it

appears that enhanced processing of attractive faces is less hard-wired into the human brain than it is the case for threat-related faces. Nevertheless, when deemed relevant, attractiveness processing seems to also recruit biologically prepared, in-built mechanisms more effectively when higher cognitive functions are concurrently loaded.

3. Integrative Model and Outlook

The current results can largely be integrated with established models of attentional control (for review, Corbetta & Shulman, 2002; Lavie, 2005) where lower bottom-up and higher top-down mechanisms both determine the allocation of processing resources. Since processing capacity is limited, its targeted allocation is necessary to prioritize relevant over irrelevant information in the environment (Desimone & Duncan, 1995; Kastner & Ungerleider, 2001; Pessoa et al., 2002a). The need of certain stimuli to gain privileged access to limited processing capacity might be due to their biological significance but also situational goals of the individual. Thus, the human brain is endowed with both, in-built mechanisms (Lang et al., 1997) spontaneously facilitating the encoding of biologically relevant stimuli, as well as higher cognitive mechanisms allowing to flexibly adjust selection criteria on a moment-to-moment basis according to current tasks and contexts (Desimone & Duncan, 1995). In a way, in-built and higher cognitive selection could be conceived as complementary mechanisms that compete over the allocation of limited processing capacity (cf., Corbetta & Shulman, 2002; Pessoa et al., 2002a; Vuilleumier & Driver, 2007).

Study 1 and 2 showed that superficial processing of faces, without focussing on their emotionality, is sufficient to trigger enhanced perceptual encoding (EPN) of emotional, primarily angry expressions. Such finding is in line with an in-built processing bias spontaneously facilitating the allocation of perceptual resources to threat-related expressions, which are likely of highest biological relevance as they signal potentially harmful events in the environment. However, spontaneously enhanced processing does not rule out that this bias still depends on the intention of the subject. Only the variation in Study 3 directly showed that enhanced perceptual encoding of threat (P1, EPN) is independent from the task thus can be considered automatic with respect to the intentionality criterion. In contrast, enhanced encoding of angry faces in working memory (LPC) depended on a voluntary, deeper processing. Although deeper face processing seemed to occur per default when no other task was given (passive viewing), stimuli could voluntarily be processed only superficially, so emotional expressions would not gain privileged access to working memory capacity (LPC). Since working memory is directly linked to action planning (e.g., Postle, 2006), functionally,

such voluntary mechanism may guarantee that biologically relevant but *currently irrelevant* information will not interfere with purposeful behaviour. However, when stimuli are intentionally processed more deeply, this entails enhanced working memory encoding of threat-related expressions (LPC), probably to keep the organism prepared for action while monitoring biologically relevant events in the environment.

Intention seems to recruit biologically prepared and higher cognitive selection mechanisms to varying degrees, depending on the exact intentional state (task) and concurrent task demands (see, Ardila, 2008). Study 4 and 5 showed that when emotionality and attractiveness, respectively, were deemed relevant while load on higher cognitive functions was increased, enhanced processing of biologically relevant stimuli benefited at the perceptual (EPN) and early working memory level (early LPC). This suggests that intention reverts to biologically prepared mechanisms more strongly when higher cognitive functions are otherwise engaged – reflecting the competition of in-built (bottom-up) and higher cognitive (top-down) selection over the allocation of processing capacity. This is in line with findings from attentional control theories, where spare processing capacity is consumed by intrinsically salient distractors more strongly when higher cognitive functions for stimulus selection are concurrently loaded (e.g., Lavie, Hirst, De Fockert, & Viding, 2004).

Critically, working memory itself is considered to reflect higher cognitive processes. Thus, the finding that increasing concurrent load on higher cognitive functions enhances encoding of emotional expressions in working memory (early LPC) may sound contradictory. Importantly, at the higher cognitive level, processing *capacity* (working memory) versus *control* functions need to be distinguished (see, Baddeley, 2003; Postle, 2006). Working memory may usually be controlled by higher cognitive selection mechanisms, which guarantees that the correct response is selected for a perceived stimulus. However, when such control mechanisms are occupied by a concurrent task, the allocation of spare working memory capacity is determined by in-built default biases. As working memory is required at least during response selection, early emotional LPC effects only occurred with a certain temporal distance from tone onset in the PRP paradigm – very likely *after* the response for the primary task had been selected (cf., Pashler & Johnston, 1998). Shifting control from one task to the next, however, takes further time (cf. Schneider & Chein, 2003) as the PRP effect remained effective even after response selection in the primary task (Experiment II of Study 4, and Study 5). Apparently, only late, sustained working memory encoding of emotion (late LPC) requires higher cognitive control mechanisms, while initial consumption of working memory capacity can be promoted by in-built, affective mechanisms alone. The previous

study by Holmes and co-workers (2009) did not find *any* emotion-related LPC effect when concurrent load was increased, probably because – unlike the PRP paradigm – their backward face identity matching task constantly depleted working memory capacity.

Future studies should try to refer these ERP effects on the scalp to precise brain regions. Plausible substrates for biologically prepared selection mechanisms could lie within subcortical structures, such as the amygdala. This area located in the medial temporal lobe has long been suggested to be part of a phylogenetically old brain circuit relevant for the quick detection of biologically relevant stimuli (LeDoux, 1989). It entertains excessive connections to other brain areas (Pessoa, 2008), that may account for a facilitated encoding of affective stimuli in extrastriate visual cortex (EPN), raising the likelihood that they initially attract also spare working memory capacity (early LPC). Working memory encoding might be reflected by activity in a more distributed fronto-temporo-parietal network, consistent with the idea that it involves concerted interactions of different sub-functions (Baddeley, 2003; Corbetta & Shulman, 2002; Polich, 2007; Postle, 2006). Given the importance of working memory for action planning (see also, Pashler & Johnston, 1998), its control by higher cognitive functions is essential to coordinate behaviour according to situational goals and contexts. Such control mechanisms are very likely located in dorsolateral prefrontal cortex (e.g., Ardila, 2008; MacDonald, Cohen, Stenger, & Carter, 2000).

Perceptual (EPN) and early working memory encoding (early LPC) of emotional expressions were facilitated under concurrent load only when emotionality was in fact considered relevant by the subject. Thus, functionally, while the subject is engaged in a separate, face-unrelated task, intention acts as a 'gatekeeper'; so threat-related stimuli gain facilitated access to limited processing capacity when a situation is in fact deemed potentially harmful. For the processing of attractive faces this benefit seemed limited only to the perceptual level, probably as attractiveness does not require quick behavioural responses (cf., Little et al., 2011). A plausible neural substrate integrating such intentional complexity in stimulus selection might be located in the ventromedial prefrontal/orbitofrontal cortex. This part of the brain processes the motivational value of stimuli based on both, their affective and task relevance (for review, Bechara, Damasio, & Damasio, 2000; see also, Potts & Tucker, 2001) – which also fits its enervation by subcortical and prefrontal brain areas (Pessoa, 2008); it is also involved in early object recognition (Bar et al., 2003). When higher selection mechanisms are deficient, subcortical modulations of the orbitofrontal cortex may prevail, so stimulus selection is tuned to affective significance more strongly, resulting in an enhancement of the EPN and early LPC to threatening faces (see Figure 11 in Study 4).

Notably, in the PRP paradigm, no emotion effect occurred for the P1 component; in contrast, single task trials in Study 3 yielded larger P1 amplitudes for angry relative to other facial expressions. The absence of emotional P1 modulations in the PRP paradigm could be due to dual task demands constantly loading mechanisms that are relevant for the P1 (cf., Corbetta & Shulman, 2002; Pourtois & Vuilleumier, 2006). Accordingly, Holmes et al. (2009) who did not use a face-unrelated, separate task to induce concurrent load found preserved emotional P1 effects across load conditions. Further, EPN and LPC have traditionally been assumed to reflect serial processing stages (see, Schupp et al., 2006). However, present results showed emotion effects on the EPN and LPC to occur in parallel. Future research will have to asses the precise boundary conditions and interrelation of those different emotion-sensitive ERP components.

Future research should also try to relate the enhanced neural processing of emotional facial expressions to concrete behavioural tendencies. No consistent emotion effect could be found at the behavioural level across experiments in the present work. Probably, overt categorizations of a single face are insensitive to its enhanced cortical processing. Other paradigms and parameters might be more sensitive. In previous research, priming (Rotteveel & Phaf, 2004) and distraction paradigms (e.g., De Fockert, Rees, Frith, & Lavie, 2001) have yielded robust effects of biologically relevant stimuli at the behavioural level that could be related to their enhanced cortical processing. A future study could combine these approaches with the PRP paradigm. One possibility might be a secondary task requiring participants to decide for the affective connotation of a word while emotional facial expressions are presented in the background. At higher concurrent load (shorter SOA) enhanced expression-related EPN and early LPC effects might be expected, with reaction times being delayed when the word and face have different emotional values but decreased when they share the same affective value.

In sum, results of the present work suggest a competition between biologically prepared and cognitively controlled selection mechanisms over the allocation of limited processing capacity, with intention recruiting both these complementary functions. Cognitive control allows adjusting stimulus processing according to current task demands, so human experience and behaviour are not solely determined by biological drive but also situational goals of the individual. Therefore, affective stimulus processing is only biased in a certain direction per default but cannot be considered fully automatic, reflecting the nature of humanity between evolutionary past and cultural accomplishment.

4. References

4.1. Original Articles

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Danksagung

Eidesstattliche Erklärung

Hiermit erkläre ich an Eides statt,

1. dass ich die vorliegende Arbeit selbständig und ohne unerlaubte Hilfe verfasst habe,
2. dass ich mich nicht anderwärts um einen Doktorgrad beworben habe und noch keinen Doktorgrad der Psychologie besitze,
3. dass mir die zugrunde liegende Promotionsordnung vom 3. August 2006 bekannt ist.

Berlin, den 14. September 2012

Julian Rellecke