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Dissertation

# **Perception of Dynamic Facial Expressions of Emotion: Electrophysiological Evidence**

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## **Zusammenfassung**

Verhaltensstudien haben gezeigt, dass dynamische besser als statische Emotionsausdrücke erkannt werden. Im Einklang mit dieser dynamischen Vorteil Hypothese, haben fMRT Studien eine erhöhte und ausgedehnte Aktivierung für dynamische Emotionsausdrücke gezeigt. Die vorliegende Dissertation hatte das Ziel, die kognitiven Mechanismen, die den dynamischen Vorteil bedingen, zu klären, beziehungsweise die Spezifität dessen Wirkung für Gesichtsausdrücke der sechs Basisemotionen zu untersuchen. Studie 1 verglich Verhaltensdaten und kortikale Reaktionen zwischen dynamischen und statischen Emotionsausdrücken. Studie 2 behandelte methodischen Fragen des Timings der Stimuli und der neutralen dynamischen Bedingung. Studie 3 überprüfte die Hypothese, dass die Erhöhung der Menge von Bewegungen in den Gesichtsausdrücken die Zuweisung der Aufmerksamkeit erhöhen würde, und verglich die Wirkung in emotionalen und nicht-emotionalen Bewegungen. Study 4 konzentrierte sich auf die Frage der Emotionsspezifität der Hirnaktivierung in der Erkennung von Emotionen.

Die Ergebnisse bestätigten einen dynamischen Vorteil in der Klassifizierung von Emotionsausdrücken, vermutlich bedingt durch eine Erhöhung in der visuellen Aufmerksamkeit, und eine Verbesserung der Wahrnehmungsverarbeitung. Außerdem, erhöht sich dieser Effekt mit allmählichem Erhöhen der Stärke der Bewegung in beide emotionalen und neutralen Bedingungen. Solche Effekte sprechen für ein perzeptuellen Bias erhöhte Aufmerksamkeit emotionalen verglichen mit neutralen und dynamischen verglichen mit statischen Gesichtern zuzuweisen. Dieser Effekt war für Freude etwas erhöht und für Überraschung reduziert, aber insgesamt ähnlich für alle Emotionsausdrücken.

Schlagwörter:

Emotion, Gesicht Ausdrücken, Bewegung, ereigniskorrelierte Potenziale

## **Abstract**

Behavioral studies have shown that facial expressions of emotion unfolding over time provide some type of information that benefits the recognition of emotional expressions, in comparison with static images. In line with the dynamic advantage hypothesis, neuroimaging studies have shown increased and wider activation while seeing dynamic expressions. The present dissertation aims to clarify the cognitive mechanism underlying this dynamic advantage and the specificity of this effect for six facial expressions of emotion. Study 1 compared behavioral and brain cortical responses to dynamic and static expressions, looking for psychophysiological correlates of the dynamic advantage. Study 2 dealt with methodological issues regarding the timing of the stimuli and the dynamic neutral conditions. Study 3 tested the hypothesis that increasing the amount of movement in the expressions would increase the allocation of attention, and compared effects of intensity in both emotional and non-emotional movements. Study 4 focused on the question of emotion specificity of brain activation during emotion recognition.

Results confirmed a dynamic advantage in the classification of expressions, presumably due to more efficient allocation of attention that improved perceptual processing. The effect increased gradually by augmenting the amount of motion, in both emotional and neutral expressions, indicating a perceptual bias to attend facial movements. The enhancement was somewhat larger for happiness and reduced for surprise, but overall similar for all emotional expressions.

Keywords:

Emotion, Facial Expressions, Movement, Event-Related Potential

*“Actions speak louder than pictures when it comes to understanding what others are doing and feeling” Blake and Shiffrar, (2007) quoting Charles Darwin’s (1872) The Expression of Emotions in Man and Animals*

## **1. Introduction and Research Questions**

Faces are important signals for humans because they inform about fundamental aspects of social communication such as gender, race, social status, and emotional states. The processing of faces involves many different facets including, among others, the identification of acquainted persons, the interpretation of facial expressions and eye contact, or the synchronization of lip movement with speech. Although the information provided by faces is frequently dynamic, the majority of studies have investigated face perception with static stimuli. Some of the most influential authors in the field indicated long ago the importance of dynamic information in the processing of faces (Bruce & Young, 1986; Bruce & Valentine, 1988; Ekman & Friesen, 1982). However, the matter has received attention only recently, with many authors recommending consideration of the dynamic aspects in face processing (e.g., Johnson, 2011; Kanwisher & Barton, 2011).

The present work focuses on four experiments on the perception of dynamic facial expressions of emotion. More specifically it tries to elucidate: (1) What is the neurocognitive mechanism underlying the benefit in the recognition of dynamic facial expressions over static ones and its electrophysiological correlates; (2) How specific are these effects of facial expressions of emotion and whether they differ among facial expressions; and (3) To what extent dynamic features, like rising time of the expressions, influence the recognition of emotion and the time course of emotion effects in brain cortical responses.

First, I will provide a short summary with some of the theories of emotion and face perception, describing recent findings from research upon dynamic aspects of facial expressions. Second, I will describe four studies designed to address the above-mentioned research questions. Finally, in the general discussion I will explain major findings of these four studies in relation with previous behavioural, electrophysiological, and neuroimaging research, putting emphasis on the novel aspects and potential contributions to the field, integrating these findings into different theories of emotion and face perception.

## **2. Theoretical Background and State of the Art**

### **2.1 Basic Emotions and the Question of Specialized Brain Systems**

Several theories of emotion propose the existence of a discrete number of emotions with distinct, fixed neurobiological and motivational components (see Tracy & Randles, 2011 for a review), including universally recognizable configuration of facial muscles (Ekman & Friesen, 1971), and specialized neural systems for different emotions (Adolphs, 2002). On the other hand, according to multidimensional models of affect emotions can be described according to their position in an affective space defined by two (or more) dimensions: arousal and valence (e.g., Lang, Bradley, & Cuthbert, 1997; Russell, 1980). In line with the former, some neuroimaging studies have shown activation in specific brain areas or networks for the perception and experience of certain emotions, for example the amygdala for fear or the insula for disgust (see Vytal & Hamann, 2010 for a meta-analysis). However, some controversies have also arisen, as numerous empirical studies found wide and overlapping networks across emotions (e.g., Fusar-Poli et al., 2009; Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012, among others). These findings would be in line with emotion theories postulating brain networks non-specific for different emotional categories, but to more general, basic psychological operations like conceptualizations of prior experiences, language, and executive attention (Barrett, 2011), or to positive and negative affect (Russell, 2003). To date the controversy regarding the existence of specialized brain substrates specific to each basic emotion or for more general categories still remain unresolved.

### **2.2 Time Course in the Processing of Facial Expressions**

According to Bruce and Young's (1986) influential model of face perception, when a face is seen view-centred descriptions of the global configuration and facial features are generated. The categorization of those descriptions of movements and features, denominated as *analyses of expressions*, produces expressions codes, which contain the information necessary to identify the expressions. This process is called *structural encoding*. The recognition of emotional expressions involves a decoding process in which expressions codes are compared with codes stored in memory.

Measures of event-related potentials (ERPs) have been useful to study serial cognitive processes, due to their high temporal resolution. For example, the P1, an early (ca. 100 ms) positive deflection, presumably generated in areas of the visual cortex such as V1 and V2 is considered to reflect the early processing of low-level features (e.g., Itier & Taylor, 2004). Following the P1 appears the N170 as a negative peak at temporo-occipital sites, which is taken as a correlate of structural encoding of faces generated in the fusiform face area (FFA), the occipital face area (OFA), and the superior temporal sulcus (STS; see Eimer 2011 for an overview). Some studies found emotional modulation of these early components (e.g., Batty & Taylor, 2003), suggesting that some form of emotional processing can occur before the structural encoding. However, this effect has not been consistently replicated (e.g. Eimer, Holmes, & McGlone 2003), generating a hitherto unsettled debate.

Consistent modulation of ERPs due to the facial expressions of emotion appears in the time range 200-300 ms, as enhanced posterior negativity (EPN) for emotional compared to neutral pictures. The amplitude of EPN is considered to reflect enhanced activation in the extrastriate cortex (Schacht & Sommer, 2009a), and functionally is taken as a shift in reflexive attention that enriches the perceptual processing of affective stimuli (Junghöfer, Bradley, Elbert, & Lang, 2001). At later stages of processing, from approximately 300 ms onwards some studies observed larger positivities at central and parietal electrode sites for emotional compared to neutral stimuli, the so-called late positive complex (LPC), which is interpreted as more evaluative processing and greater salience appraisal of emotional stimuli (see Schupp, Flaisch, Stockburger, & Junghöfer, 2006 for a review). Although emotional modulation of the EPN is relatively consistent across affective stimuli from different domains (e.g., Schacht & Sommer, 2009b), still studies differ considerably as to whether amplitude is larger for negative (e.g., Rellecke, Palazova, Sommer, & Schacht, 2011; Schupp et al. 2004), or positive expressions (e.g., Williams, Palmer, Liddell, Song, & Gordon, 2006), or for both negative and positive in relation to neutral expressions (e.g., Eimer et al., 2003; Sato, Kochiyama, Yoshikawa, & Matsumura, 2000). The factors determining differences across studies still remain elusive. In summary, evidence from ERPs does not clearly show unique patterns for basic emotions.

### **2.3 Dynamic Advantage in the Recognition of Emotional Expressions**

In everyday life we are confronted with pictures of emotional expressions, for example, reading the newspaper we recognize the suffering in pictures of people that just lived a

tragedy, or walking to work we see on a hoarding a smiley politician asking for votes for the next election. Most of the time however, facial expressions of emotion are not found as static pictures showing the apex or point of maximal intensity (Carroll & Russell, 1997), instead they normally appear in movement and at different intensities showing from subtle to exaggerated movements.

The neurocognitive model of Haxby, Hoffman, and Gobbini (2000) made an anatomical and functional distinction between the processing of variable and invariant facial features in areas of the STS and fusiform gyrus respectively. Many studies have confirmed the role of the STS and areas of the mirror motor system in the perception of facial movements and other types of human motion (see Blake & Shiffrar, 2007 for a review).

It has been demonstrated that dynamic information is sufficient to identify facial expressions of emotion (Bassili, 1978) and that dynamic expressions provide some form of information that is available only over time (Cunningham & Wallraven, 2009). A number of behavioural studies have indicated an advantage in the recognition of dynamic compared to static facial expressions of emotion (e.g., Ambadar, Schooler, & Cohnm 2005; Cunningham & Wallraven, 2009; Wehrle, Kaiser, Schmidt, & Scherer, 2000). Others have shown more efficient visual search (Horstmann & Ansorge, 2009), and augmented intensity and arousal in ratings of dynamic expressions (Biele & Grabowska, 2006; Sato & Yoshikawa, 2007; Yoshikawa & Sato, 2008).

Neuroimaging studies have reported enhanced and more widespread activation patterns for dynamic than static facial expressions in brain areas related to the perception of emotion (e.g., amygdala), biological movement (e.g., hMT+/V5 and STS), and – contrary to Haxby et al. (2000)’s model – also in the FFA (see Arsalidou, Morris, & Taylor, 2011 for a review).

Few electrophysiological studies have found enhanced mimicry for dynamic expressions (Sato, Fujimura, & Suzuki, 2008); or an impact on early visual components (P1, N170) suggesting that dynamic expressions and gaze direction guide spatial attention (Fichtenholtz, Hopfinger, Graham, Detwiler, & LaBar, 2007; 2009); or a late reduction in neural processing in the temporal lobe for dynamic in relation to static face stimuli (Mayes, Pipingas, Silberstein, & Johnston, 2009). To the best of my knowledge, the impact of dynamic facial emotional expressions in ERP components consistently modulated by emotion (i.e., EPN, LPC) had never been explored before the present series of experiments.

Despite the benefit for dynamic emotional expressions (but see Fiorentini, & Viviani, 2012 for data questioning this finding), very few studies have systematically investigated the cognitive mechanism underlying this facilitation. Ambadar and co-workers suggested that the benefit for dynamic expressions relate to the enhanced perception of change (Ambadar et al., 2005). In an interesting study, Yoshikawa & Sato (2008) proposed that dynamic presentation enhances the perceptual processing of the shape of the facial expressions because movements induce representational momentum. That is to say, the last image of a dynamic sequence is perceived in an exaggerated form (see also Freyd & Finke, 1984). Apart from that, studies showing more efficient visual search for dynamic facial expressions have suggested that the perceptual processing of facial expression of emotion benefits from visual dynamic features because there is a natural bias to attend both motion and emotion (Horstmann & Ansorge, 2009).

According to the *sensory-bias hypothesis* humans adapted first to low-level perceptual features like motion, and later to emotional expressions. Differences in perceptual features among facial expressions, and more particularly, in the amount of movements, can explain the impact in attention of emotional expressions, including the negative bias observed in some studies (e.g., Horstmann & Bauland, 2006).

Still, the neurocognitive correlates of these behavioural results are unclear, and some questions remain open: How do dynamic facial expressions impact the time course and magnitude of emotional effects typically observed with static images? (Study 1) Are all basic facial expressions of emotion equally well classified when presented briefly with a fast rise time? (Study 2) Do emotional movements capture the allocation of attentional resources in a stimulus-driven way? What is the contribution of motion per se? (Study 3) Is this effect similar for all emotional expressions? (Study 4) The main focus was given to attentional and perceptual cognitive processes. ERPs were analysed, as high-temporal resolution measures of such processes.

### **3. Summary of studies**

#### **3.1 Study 1: Electrophysiological Evidence for the Facilitation of Dynamic Expressions**

In everyday conversations body movements contribute to communication, modifying or even replacing the meaning of words and directing attention. For example, moving the arms inwards and outwards over the head is understood as call for attention, and gaze movements direct spatial attention (e.g., Fichtenholtz et al., 2009). Study 1 tested the notion that dynamic expressions might be particularly salient because both emotion and motion attract the allocation of attentional resources per se because they pop out. We compared behavioural and ERP responses to static and dynamic expressions, trying to determinate the electrophysiological correlates and the time course involved in the dynamic advantage for the recognition of expressions.

Participants matched facial expressions of different valence (anger, happiness, neutral) presented in static and dynamic fashion with labels with the name of the expressions. Face stimuli were morphed artificially with computer-software FACEgen 2.2. Movement was created with three pictures presented in a row in an interval of 150 ms after stimulus onset, increasing intensity progressively. Static images showed only the picture with maximal intensity.

Results replicated facilitation in the classification of happiness expressions presented in dynamic fashion in both RTs and accuracy. Dynamic and static expressions did not differ in early components (P1, N170); however, the EPN and LPC components were enhanced and prolonged when participants evaluated dynamic expressions. These results indicated that the dynamic facilitation occurred after the structural encoding, and related to enhanced activation in visual areas starting as early as 200 ms after stimulus onset. This was presumably due to shifts of visual attention that facilitated the perceptual processing and the subsequent elaborative processing and appraisal of dynamic emotional expressions. The distribution of emotional effect in the scalp differed between static and dynamic indicating partially separable neural sources. In summary, Study 1 showed larger and prolonged emotional effect for dynamic expressions, supporting thus the view that motion increases the impact of emotional expressions and that dynamic faces are ecologically more valid than static ones.

### **3.2 Study 2: Testing the Optimal Rising Time in the Expression**

Results from Study 1 held new insights into the cognitive mechanism underlying the facilitation of dynamic faces but yielded also new challenges regarding the construction of the dynamic stimuli. In everyday social communication emotional expressions are normally dynamic but do not follow linear temporal rules, as in Study 1. Indeed, studies indicate that emotional expressions differ in their temporal characteristics affecting many different aspects like simultaneousness (e.g., Gosselin, Kirouac, & Dore, 1995), regularity (e.g., Tomkins, 1962), asymmetry (e.g., Richardson, Bowers, Bauer, Heilman, & Leonard, 2000), duration (e.g., Weiss, Blum, & Gleberman, 1987), and speed (e.g., Kamachi et al., 2001). Given evidence that speed affects the recognition (Kamachi et al. 2001) and naturalness of the expressions (Sato & Yoshikawa, 2004), a rising time of 150 ms may be too short for some slow expressions like sadness (see also Hoffmann, Traue, Bachmayr, & Kessler, 2010). On the other hand, ERP studies normally use a short presentation time of 1 s or even shorter. Emotional expressions unfolding over a longer period than 1 s might be inappropriate to estimate early effects. Study 2 addressed these methodological issues, trying to optimize rise times for six basic emotional expressions for its use in ERP experiments. We further examined three types of neutral movements, aiming to obtain a neutral dynamic condition with a similar amount of movements that in emotional expression, appearing in upper and lower areas of the face.

In Study 2, thirty-four participants classified static pictures and dynamic videos showing six basic emotional expressions (anger, disgust, fear, happiness, sadness, and surprise) and three types of non-emotional facial movements (blinking, phoneme /that/, and both together simultaneously). Dynamic expressions differed in the rising time from neutral to maximal intensity (fast, 200 ms; moderate, 500 ms; and slow, 900 ms). All stimuli were artificially generated with a more sophisticated morphing-software (FACSGen 2.0; Krumhuber, Tamarit, Roesch, & Scherer, 2012) that allows for control of action units separately and other temporal variables like speed and intensity.

Results showed good classification rates for most morphed expressions, especially when they were presented at their optimal speed. Recognition rates and pattern of errors tended to replicate classical findings to a large extent, showing better classification for happy faces and confusions among morphologically similar expressions, e.g., sadness-fear, disgust-anger. Some expressions like disgust and happiness, replicated the dynamic advantage observed in

Study 1, whereas expressions of sadness were better classified at slow speed confirming the notion that the dynamics of sadness is rather slow (e.g., Kamachi et al., 2001; Sato & Yoshikawa, 2004). Importantly, speed per se had an impact only in classification of sadness, being rather slow, and fear, being rather fast. Thus, rise times ranging between 200 and 500 ms would be a good compromise for all expression but sadness. Animations displaying a blink were rated as neutral more often than those showing the phoneme /tha/, which were confused with happiness and surprise.

### **3.3 Study 3: The Interplay between Motion and Emotion in the Allocation of Attention**

In Study 3 we further investigated the neurocognitive mechanisms that may be involved in the behavioural effects observed for dynamic facial expressions. We tested the hypothesis that the impact of dynamic faces is stronger than static because motion facilitates visual processing and helps to discriminate between emotional expressions. If this holds true, then increasing the degree of motion should enhance the discriminability of emotional expressions and its impact on attention (Horstmann & Ansorge, 2009). In Study 3 we also examined whether the EPN is specific for movements displaying emotions, or if non-emotional salient movements can also elicit this component (Schupp et al., 2006; 2007).

In order to assess these questions, in Study 3 we presented six emotional expressions (anger, disgust, fear, happiness, sadness, surprise) at three different intensities (low, moderate, full intense), and three different types of neutral movements (blinking, chewing, or both together simultaneously). Expressions were obtained from a validated database (Radboud Faces Database; Langner et al., 2010) and morphed with a computer program to create the movements. Intensity in emotional expressions was produced by manipulating the rate of expressional from neutral to emotional and the maximal reached intensity. The rise time of emotional and non-emotional facial expressions varied within a short range (200-370 ms).

Analyses of participants' performance with unbiased hit rate, a measure corrected for possible response bias which is more informative of the ability to distinguish among categories (Wagner, 1993), confirmed most accurate classification of happiness and neutral expressions, and confusions of negative expressions with each other. ERP data showed that neither emotional expressions nor intensity affected the P1 and N170 components. Differences in ERP amplitude between emotional and neutral expressions started at 200 ms and were

sustained during most of the presentation time. Between 200-350 ms all emotional expressions elicited larger EPN than the neutral and the effect was similar in amplitude and scalp distribution for all six expressions. Between 350-500 ms results showed enhanced LPC effect for expressions of fear, anger and surprise in relation to neutral. Moreover, LPC for fear and anger differed from other expressions in amplitude and scalp distribution, suggesting a more elaborate processing for expressions that indicate danger (e.g., Schupp et al., 2004).

In general, performance improved with intensity in the expressions, confirming that increasing the amount of movement enhances the discriminability of expressions – with the exception of disgust that showed the opposite pattern. Congruent with the behavioral effect and with our hypothesis, the amplitude of EPN augmented linearly with intensity, reflecting shifts in reflexive attention and enhanced sensory processing of more intense expressions. The amplitude of LPC also increased with intensity, evidencing a greater impact and appraisal of emotional expressions at full-intensity. The effect of intensity did not interact with emotional expressions. Thus, Study 3 established that the benefit of dynamic expressions seems to rely on low-level sensory processing driven by the larger amount of movement, and the greater expressional change in more intense expressions. Study 3 further showed enhanced EPN-like activity for larger neutral movements (blinking plus chewing) in relation to more subtle ones (chewing), and the distribution in the scalp for this “neutral-EPN” did not differ statistically from the distribution of the “emotional-EPN”. This finding indicates an independent contribution of non-emotional movements to the EPN component and suggests the existence of a perceptual bias at a neural level to attend facial movements (Horstmann & Ansorge, 2009).

### **3.4 Study 4: Emotion Specificity of Emotional Effects in ERPs**

Study 4 aimed to replicate and extend the findings of Study 3 in a larger sample of participants ( $N = 102$ ). The larger sample size served to increase statistical power in the detection of emotion effects in early components and of emotion specificity in EPN and LPC. Emotional expressions at low intensity were omitted due to their ambiguity, and the neutral condition “blinking plus chewing” due to its greater impact in ERPs. To rule out the possibility that the irregular rise time of emotional expression in Study 3 caused the absence of emotion effects in early components, in Study 4 all expressions were presented with the same linear, quick rise time from neutral to maximal intensity.

Same as in Studies 2 and 3, participants were asked to classify six emotional expressions. Both behavioural and ERP results basically replicated Study 3. However, in Study 4 emotional effect – although small in size – started 100 ms after stimulus onset as a shift in P1 and later N170 amplitudes, similar for all emotional expressions. Some aspects from the results of Study 4 indicated differences among emotional expressions. For example, the EPN (200-350 ms) was larger in amplitude for happiness, and shorter for surprise, and these differences were also significant for comparisons of the topographic distribution. Between 350 and 500 ms amplitudes at central electrodes were enhanced for negative in relation to positive and neutral expressions, and the effect was larger for fear than other expressions. Comparisons of topographies also revealed differences among expressions, but in general the distribution in the scalp was atypical for the LPC, instead seemed a continuation of the EPN. Results further showed differences in the scalp distribution between the N170 to neutral faces and the emotional modulation of this component, suggesting that the processing of emotional expressions occurred in parallel with the structural encoding.

Study 4 confirmed thus the findings from Study 3. Increasing statistical power revealed an earlier impact of emotional expressions, and differences among emotional expressions in EPN and later components.

## **4. General Discussion**

### **4.1 Dynamic Facial Expressions Enhance Perceptual Processing and Emotional Appraisal**

Study 1 confirmed the dynamic advantage for expressions of happiness in behavioural data and showed enhanced and prolonged EPN and LPC effect for dynamic in comparison with static emotional expressions in the ERP data. This finding indicated that the movements unfolding over time in the face increased reflexive attention, benefiting the perceptual processing and further recognition and appraisal of emotional expressions. Studies 3 and 4 revealed that intensity in dynamic expressions also triggered the allocation of reflexive attention (EPN) in a bottom-up, stimulus-driven way, resulting in enriched perceptual processing. Intensity also enhanced the discriminability and appraisal of emotional expressions at higher order stages of processing (LPC). Since the effect of intensity did not interact with emotional expression, we established that the degree of movements in emotional

expressions enhances the emotional response without changing its quality. Early visual components (P1, N170) were unaffected by dynamic presentation or rises in intensity. This finding was robust across Study 1, where motion stopped before the N170 peak (150 ms); Study 4, where motion stopped afterwards (200 ms); and Study 3, where rising time was irregular. Only Study 4 with large statistical power and controlled rise time showed emotional modulation of P1 and N170.

How do presented findings relate to previous behavioural studies? The larger EPN amplitude for dynamic in relation to static expressions in Study 1, and for full intense in comparison to subtle expressions in Studies 3 and 4, reflecting enhanced attention to these conditions, is in line with the *sensory-bias hypothesis* suggesting that the dynamic advantage relies on a gain in attention driven by the amount of movement, which boosts the discriminability and visual processing of emotional expressions (Horstmann & Ansorge, 2009). An explanation of the dynamic advantage in terms of better detection of expressional change (Ambadar et al., 2005) is also compatible with the ERP data presented here because intensity co-varies with the amount of expressional change from neutral to emotional.

Yoshikawa & Sato (2008) observed that emotional expressions unfolding over time were perceived as more intense than they actually were. As the effect was stronger when expressions were presented at fast speed, and when intensity was moderate, the authors concluded that the effect was not based on low-level sensory processing. Intensity effects in the EPN and LPC epochs suggesting a bottom-up modulation, argue against an interpretation of the data in terms of representational momentum and top-down impact of intensity in the expression. At least these components do not seem to reflect this visual effect.

How do presented findings relate to previous ERP studies? The larger EPN and LPC for dynamic expression is a novel finding, since no previous studies had systematically compared ERPs to static and dynamic facial expressions. Increases in ERPs associated with intensity of expression confirmed in part research with static pictures (Sprengelmeyer & Jentzsch, 2006) but were not limited or larger to negative expressions (Leppänen, Kauppinen, Peltola, & Hietanen, 2007). The impact of intensity in the processing of dynamic facial expressions is comparable to the way other spatiotemporal features impact upon the processing of affective stimuli of other kind, like font size in word reading (Bayer, Sommer, & Schacht, 2012), or image complexity in affective images (De Cesare & Codispoti, 2006).

How do presented findings relate to previous neuroimaging studies? A very plausible origin for the larger EPN for dynamic rather than static expressions, increasing also gradually with the intensity in the emotional movements, would be in the amygdala via its connections with the visual cortices (Pourtois, Schettino, & Vuilleumier, 2012). Many studies have indicated the important role of the amygdala in the processing of emotional stimuli (e.g., Le Doux 2007), and it has been proposed that the amygdala processes, not only emotional, but salient stimuli in general (e.g., Sander, Garfman, & Zalla, 2003). Due to its multiple connexions the amygdala might serve as a hub for the integration of salient motion information in the processing of emotional relevance (Hindi Attar, Müller, Andersen, Büchel, & Rose, 2010). This view would reinforce an explanation in terms of the *sensory-bias hypothesis*.

On the other hand, the contribution of brain areas responsible for the perception of movement and variant face features (STS; Haxby et al., 2000) should be considered to account for the presented results. Some studies have showed greater activation in STS for dynamic than static facial expressions (e.g., Haxby & Gobbini, 2011), others, however, have consistently found enhanced activation in both STS and FFA (e.g., Arsalidou et al., 2011). A recent study also observed augmented activation in hMT+/V5 and FFA as a function of intensity in dynamic expressions (Sarkheil, Goebel, Schneider, & Mathiak, 2012). Moreover, other areas of the human mirror motor system (i.e., frontal operculum) are also more enhanced for dynamic facial expressions of emotion than for chewing and blinking movements, and this enhancement seems to modulate activity in perceptual regions like the STS (Montgomery, Seeherman, & Haxby, 2009). Given the similarities with the movements employed here, the role of the mirror motor system should also be considered to explain the differences between emotional and neutral expression. Both STS and frontal operculum are suggested to be involved in the decoding of facial expressions, and the perception of similarities among expressions (Said, Moore, Engell, Todorov, & Haxby, 2010).

How do these findings fit into models of emotion and face processing? Observed results fit well with Levenson's *two-system model of emotion*, composed by a *core of emotion system*, defined as an old, automatic, rigid mechanism detecting events and selecting the most prototypical emotional responses, and a *control system* that operates "changing the ways we appraise incoming information" and modulating emotional responses (Levenson, 1999, p. 488; see also Levenson, 2011). One functional element of the core system is described as a very fast, low-level pattern detector that maximizes attention to challenging events and minimizes it to irrelevant ones. The EPN could possibly reflect the attentional component in

this mechanism searching for meaningful patterns in incoming sensory information. On the other hand, the role of the LPC as a correlate of emotional appraisal and its relation with higher-order processing, fits well with Levenson's descriptions of the *control system*. Other theorists of emotion also indicate a link between a basic or core component involving body reaction (e.g., *basic emotion*, Ekman, 1999; *first-order emotion*, Izard, 2011; *core affect*, Barrett, 2011) and higher-order cognition. It is possible to speculate that the LPC might represent cognitive processes associated with this bridge between body and mind.

Effects of dynamic presentation in Study 1, and of intensity in Studies 3 and 4, can also be explained in the context of multidimensional models of emotion (e.g., Russell, 1980), and more particularly, as an effect of arousal. It is therefore possible that dynamic expressions resulted more arousing, especially when they were presented at full intensity, and that this augmented arousal contributed to the larger EPN and LPC components. It should be noted that the LPC enhancement has also been attributed to differences in arousal (e.g., Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). In line with this interpretation, behavioral studies suggest that dynamic presentation increases the perceived intensity of the expressions (Biele & Grabowska, 2006) and the emotional experience in terms of arousal, but it does not affect the perception of valence (Sato & Yoshikawa, 2007). Moreover, autonomic responses seem to be larger for dynamic than for static facial expressions (e.g., Sato et al., 2008).

Regarding models of face processing in general, the lack of effects of both dynamic presentation and intensity in early visual components (P1, N170) across studies, confirms that the initial structural encoding of face is not mediated by dynamic components and perception of expressional changes (Bruce and Young, 1986).

## **4.2 Emotion Specificity**

Regarding the question of emotion specificity, Study 1 showed differences in amplitude and scalp topography between anger and happiness in the EPN and the LPC. Study 3, however, did not show clear differences in amplitude, or scalp distribution of the EPN, but only larger amplitude of LPC for threat-related expressions. The finding of an EPN-like component to neutral movements in Study 3, suggest that the EPN might be not a good marker to estimate emotional specificity.

Study 4, with larger statistical power, indicated enhanced EPN amplitude for happiness and diminished for surprise, and significant differences in the scalp distribution, suggesting partially separable brain sources. In the later time window, Study 4 showed differences in amplitude and scalp distribution between negative expressions and both happiness and neutral. However, the unusual topography of the LPC complicates the interpretation of this finding.

It should be noted that the size of the effect for the differences between emotional expressions with each other in amplitude and in scalp distribution was very little, especially when compared with the size of the differences in amplitude between emotional and neutral. In summary, results presented from these studies do not support separable neural networks for different facial expressions (e.g., Adolphs, 2002; Vytal & Hamann, 2010). The fact that differences between facial expressions tended to group expressions of the same valence, would fit better with approaches suggesting general brain mechanism detecting positive and negative valence rather than unique brain systems for each discrete emotion (e.g., Barrett, 2011; Russell, 2003). Recent evidence suggests that cortical areas like the STS and frontal operculum being involved in the representation of perceptual similarities and dissimilarities among facial expressions show activation across several emotions (e.g., Said et al., 2010).

### **4.3 Impact of Dynamic Features in Processing of Emotional Faces**

Besides the dynamic advantage revealed in Study 1, data also showed the impact of specific dynamic features in both behavioral and ERP data. Study 2 showed that most expressions could be well recognized when presented within a short interval with in fast rising time. Fast dynamics only compromised the recognition of sadness. Other aspects of the data speak about an impact of fast speed in the ERPs too. For example Study 4, where rising time in the expression was controlled, showed larger P1 and N170 amplitudes for all emotional expressions in relation to neutral ones. This effect was not observed in Study 3 with same stimuli material but variant rising time, suggesting that a short, regular, fast speed in the rise of the expressions might account for emotional modulation of early components. However, the small size of the effect, and the lack of emotional modulation of these early components in Study 1, where rising times were slightly shorter than in Study 4, also suggests an explanation in terms of the larger statistical power. This would also explain the unsystematic modulation of early components observed in previous studies.

Study 4 also showed that the processing of emotional expressions partially overlapped the structural encoding. Parallel processing might be enhanced for dynamic facial expressions because different processes involved in the early visual perception rely on morphological changes developing throughout a temporal sequence in which incoming information is derived and continuously updated (Bruce & Young, 1986). This would also be in line with neuroimaging models of early visual processing of emotion, indicating connections between occipital and temporal lobes in which detailed representations of the face are constructed, and other areas like the orbitofrontal cortex, amygdala, and anterior cingulate cortex, in which the representations are evaluated in terms of emotional meaning (Adolphs, 2002).

#### **4.4 Limitations of the Present Work and Future Directions**

All studies in the series employed the same emotion classification task with forced choice format, an approach that has been criticized (e.g., Russell, 1994). The main finding of attention allocation to salient emotional expressions could be a consequence of this particular task, because attention was explicitly directed to the expressions. Other experiments should demonstrate if observed effects extend to other tasks where emotion is implicit. Moreover, although it is generally assumed that the EPN is an index of reflexive attention, the emotion classification task employed here does not provide attentional probes at behavioral level, restricting the hypothesis of attentional enhancement because conclusion can only be drawn upon ERPs. For example, a task judging the similarity of the expressions might provide additional clues regarding the question of emotion specificity, and help to determine whether the brain responses to different facial expressions reflect the activation of a perceptual similarity (or dissimilarity) structure (e.g., Said et al., 2010).

We made an effort to develop a neutral condition with a similar amount of movement as in emotional expressions, however, we did not exhaustively control spatiotemporal differences, neither between emotional and neutral expressions nor between emotional expressions with each other. Given that emotional effect in ERPs is often defined as the difference between two conditions, it should be important to understand the impact of those low-level spatiotemporal features in attention.

Despite the similarities of intensity effects with those observed with static pictures (e.g., Sprengelmeyer & Jentzsch, 2006), it is reasonable to assume a different processing of intensity in dynamic expressions because intensity is related with all aspects considered to

account for the dynamic advantage, namely, expressional change (Ambadar et al., 2005), representational momentum (Yoshikawa & Sato, 2008), and degree of motion (Horstmann & Ansorge, 2009). Studies comparing the effects of intensity in static and dynamic expressions would help to better understand the benefit for dynamic expressions. As mentioned, the effects of intensity in the ERPs can be interpreted in terms of expressional change (Ambadar et al., 2005), however, to confirm this conclusion would necessitate a condition showing expressional changes but no movements unfolding over time, e.g., showing only the first and last frames of the sequence or masking the movements in between.

In general, future research should aim to explain face processing approaching real conditions of social communication, and integrating the context into the study of emotions. New developments in technology should help to create more realistic and complex multimodal stimuli, controlling for variables in various perceptual domains, including the social context (e.g., augmented reality, avatars, conversational context), and the environment (e.g., smell disposal systems) in which stimuli appear. Recording brain activity online and the co-registration of EEG and fMRI should help to combine temporal and spatial resolutions.

## **5. Conclusion**

The present study helped to elucidate the neurocognitive mechanisms underlying the perception of dynamic expressions. We established an advantage in dynamic over static emotional expressions, that could be explained in terms of enhanced reflexive attention, more elaborate perceptual processing, and higher appraisal of facial movements. The allocation of attention increased gradually with intensity in the expression in a bottom-up, stimulus-driven way, indicating a perceptual bias to attend facial movements. This effect was similar for all emotional expressions, and could be observed for non-affective movements, suggesting that the EPN is neither emotion specific, nor sensitive to particular emotional expressions. The use of facial expressions of emotion at maximal intensity in most studies on facial expressions has been criticized because expressions rarely appear in such an extreme form (Carroll & Russell, 1997). The present work demonstrated that the effect of emotional facial expressions was stable across variations in the rising time and in intensity, gaining thus ecological validity. The relative large number of participants allowed assessment of the research questions with large statistical power.

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## **Eidesstattliche Erklärung**

Hiermit erkläre ich an Eides statt,

- dass ich die vorliegende Dissertation selbständig und ohne unerlaube Hilfe verfasst habe,
- dass die vorliegende Dissertation an keiner anderen Universität eingereicht habe und keinen Doktorgrad in Fach Psychologie besitze,
- dass mir die Promotionsrdnung Nr. 34/2006 der Mathematisch-Naturwissenschaftlichen Fakultät II vom 03. August 2006 bekannt ist.

Berlin den 26.09.2012

Guillermo Recio

# Appendix

## Submitted Manuscripts

### Study 1

Recio, G., Sommer, W., & Schacht, A. (2011). Electrophysiological correlates of perceiving and evaluating static and dynamic facial emotional expressions. *Brain Research, 1376*, 66–75

### Study 2

Recio, G., Schacht, A., & Sommer, W. (in review). Classification of dynamic facial expressions of emotion presented briefly.

### Studies 3 and 4

Recio, G., Schacht, A., & Sommer, W. (submitted). Recognizing dynamic facial expressions of emotion: specificity and effects of intensity in event-related brain responses.