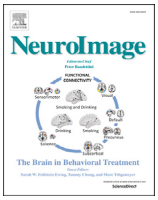
NeuroImage 179 (2018) 235–251

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/neuroimage



Tuning functions for automatic detection of brief changes of facial expression in the human brain

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ARTICLE INFO

Keywords:
EEG
FPVS
Sweep-VEP
Facial expression
Intensity
Tuning function

ABSTRACT

Efficient decoding of even brief and slight intensity facial expression changes is important for social interactions. However, robust evidence for the human brain ability to automatically detect brief and subtle changes of facial expression remains limited. Here we built on a recently developed paradigm in human electrophysiology with full-blown expressions (Dzhelyova et al., 2017), to isolate and quantify a neural marker for the detection of brief and subtle changes of facial expression. Scalp electroencephalogram (EEG) was recorded from 18 participants during stimulation of a neutral face changing randomly in size at a rapid rate of 6 Hz. Brief changes of expression appeared every five stimulation cycle (i.e., at 1.2 Hz) and expression intensity increased parametrically every 20 s in 20% steps during sweep sequences of 100 s. A significant 1.2 Hz response emerged in the EEG spectrum already at 40% of facial expression-change intensity for most of the 5 emotions tested (anger, disgust, fear, happiness, or sadness in different sequences), and increased with intensity steps, predominantly over right occipito-temporal regions. Given the high signal-to-noise ratio of the approach, thresholds for automatic detection of brief changes of facial expression could be determined for every single individual brain. A time-domain analysis revealed three components, the two first increasing linearly with increasing intensity as early as 100 ms after a change of expression, suggesting gradual low-level image-change detection prior to visual coding of facial movements. In contrast, the third component showed abrupt sensitivity to increasing expression intensity beyond 300 ms post expression-change, suggesting categorical emotion perception. Overall, this characterization of the detection of subtle changes of facial expression and its temporal dynamics open promising tracks for precise assessment of social perception ability during development and in clinical populations.

Introduction

During social interactions, humans communicate a wealth of information through non-verbal behavior, among which facial expression of emotions constitutes a critical cue to infer the affective states of conspecifics and adjust behavior. Charles Darwin suggested in his seminal work on the expression of emotions that the ability to recognize emotional expressions has been selected during evolution to increase survival in social groups (Darwin, 1872). Following this rationale, Paul Ekman considered six basic emotions eliciting specific patterns of facial actions universally categorized by humans: anger, disgust, happiness, fear, sadness and surprise (e.g., Ekman, 1992). Despite some variations (Jack et al., 2012; Miellet et al., 2013), it is generally acknowledged that these facial expressions of emotions are quite well-recognized across cultures (Elfenbein and Ambady, 2002 for a meta-analysis; Sauter and Eisner, 2013).

In the large body of research about facial expression perception, most studies focus on highly expressive faces. However, despite their evident contribution to our knowledge of the function, full-blown prototypical expressions are not the most frequently encountered in everyday-life

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https://doi.org/10.1016/j.neuroimage.2018.06.048
Received 5 October 2017; Received in revised form 3 May 2018; Accepted 15 June 2018

(Horstmann, 2002; Motley and Camden, 1988), and their exaggerated nature has long been criticized by some authors (e.g., Carroll and Russell, 1997). Delineating our sensitivity to subtle facial cues is therefore critical for a comprehensive understanding of facial expression perception in both healthy and pathological participants (Calder et al., 2000a; Calvo et al., 2016; Etcoff and Magee, 1992; Gao and Maurer, 2010; Hess et al., 1997; Leleu et al., 2016; Marneweck et al., 2013). In particular, parametric manipulations of expression intensity by means of a linear continuum of morphs between a neutral and an expressive face allow to determine a detection threshold (i.e., the lowest intensity for accurate categorization of the expression) and the shape of a tuning function (i.e., linear vs. abrupt detection) to any facial emotional signal (e.g., Etcoff and Magee, 1992; Gao and Maurer, 2010; Hess et al., 1997; Leleu et al., 2016).

Detection thresholds are a sensitive measure of expression perception abilities. For instance, while all facial emotions are well-recognized at full intensity, only a subset are still recognized above chance level at very low intensity (e.g., happiness *vs.* other emotions, Calvo et al., 2016). During typical development, 5-year old children reach adult-like accuracy to categorize some full intensity expressions (anger, fear, sadness) but they need higher intensities than adults (Gao and Maurer, 2010). The sensitivity of detection thresholds is also particularly relevant for investigating syndromes associated with social-cognitive deficits. For example, while high-intensity happy faces are well categorized by children and adolescents with 22q11.2 deletion syndrome, they need greater intensity of happiness to reach the same accuracy than healthy participants (Leleu et al., 2016).

Regarding the shape of the tuning functions to facial expressions, behavioral studies generally found that emotions in faces are detected categorically, that is, with an abrupt perception of the emotion with increasing expression intensity (Etcoff and Magee, 1992; Leleu et al., 2016; Utama et al., 2009), consistent with other findings obtained with morphs between two emotional expressions (Calder et al., 1996; Vernet et al., 2008; Young et al., 1997). This has been shown with both identification tasks asking for verbal labeling of the emotion (Etcoff and Magee, 1992; Utama et al., 2009) and visual matching or discrimination tasks (Etcoff and Magee, 1992; Leleu et al., 2016), thus suggesting that expression categories have sharp boundaries. However, studies using an emotional intensity rating task rather found linear response profiles (Calder et al., 2000a; Hess et al., 1997; Utama et al., 2009). This dissociation between emotion categorization reaching high accuracy level through abrupt increase *vs.* linear increment of intensity ratings points to the critical influence of the explicit task performed when measuring the output of the cognitive system, a mixture of perceptual (e.g. visual categorization) and post-perceptual (e.g., motivation, decision) processes.

To overcome these issues, electroencephalographic (EEG) activity has been recorded in response to facial expressions varying in intensity. A first study tested three facial expressions (anger, disgust, fear) expressed at three intensities (50, 100, 150%) and found gradual enhancement of electrocortical activities with increasing intensity for all expressions from the N170 event-related potential (ERP) and until 600 ms post-stimulus in occipito-temporal regions (Sprengelmeyer and Jentzsch, 2006). The face-sensitive N170 was interpreted as early saliency coding favoring later visual categorization of the expressions. However, no similar effect was found for happiness in a subsequent study (Leppänen et al., 2007), suggesting that the saliency coding system is only dedicated to negative facial expressions. In contrast, another study using five nonlinear intensity levels (i.e., selected from a preliminary behavioral experiment) for happy and disgusted facial expressions showed ERP enhancement with increasing intensity already at the level of the sensory P1 component (i.e., from 90 ms after stimulus-onset) and further in the time-range of the face-sensitive N170 (i.e., 140–190 ms) for both expressions (Utama et al., 2009). Dissociation between the P1 and the N170 was found by correlating their amplitude with the data from two preliminary behavioral tasks. P1 increase was only significantly associated with abrupt categorization of facial expression, whereas the N170 intensity effect showed significant relation only with the gradual rating of expression intensity. However, strong correlations with behavioral measures were evident for both ERP responses. Moreover, the use of nonlinear increment of intensity hampered direct estimation of the abrupt *vs.* linear increase of ERP amplitude. Finally, a more recent study assessed anger detection at three linear intensity levels (i.e., 20, 60, 100%) and revealed enhanced amplitudes of both the P1 and N170 with increasing intensity (Wang et al., 2013). The authors suggested an early gain control of visual resources indexed by the P1 before the perceptual coding of facial configuration deformation at the level of the N170, but the absence of differential effects between the two components precludes strong support for a functional dissociation.

In summary, while a few ERP studies have investigated the visual processing of facial expression perception as a function of intensity, no firm conclusion could be drawn from these observations. In particular, important discrepancies remain about the advent of facial expression intensity effects throughout the processing stream, and many issues are unresolved such as the generalizability *vs.* specificity across emotion categories, the different functional mechanisms indexed by the electrocortical responses and also the shape of the tuning functions depending on intensity. These discrepancies may be partly due to the low signal-to-noise ratio (SNR) of the standard ERP approach, which requires many trials for the same condition to reach acceptable levels of SNRs for most components (Luck, 2005). Unfortunately, these long recording sessions prevent from testing various emotions expressed at various intensities in a single experiment. Moreover, subjective definitions of ERP components within more or less broad time-windows of interest reduce the generalizability of the results across studies. Besides, expression-specific activities (i.e., excluding general visual mechanisms common to both neutral and emotional expressions) are extracted by *post-hoc* subtraction of averaged ‘neutral’ trials from averaged ‘expression’ trials. This manipulation thus only indirectly captures the neural activities subtending the discrimination of an expression from neutrality (note that two studies cited above have circumvented this issue by measuring ERPs during the presentation of a facial expression that directly follows a neutral face with no blank interval in between; Utama et al., 2009; Wang et al., 2013). Finally, visual responses occurring beyond 200 ms post-stimulus are not well-captured by ERPs, due to various sources of additional noise. This is particularly the case when stimuli are – as often – presented for relatively long durations and visual exploration (i.e., leading to accumulating neural responses elicited by new retinal patterns of activity at each fixation) as well as non-perceptual processing (e.g., verbal labelling) contaminate the electrophysiological responses. This is an important point since different facial expressions elicit different patterns of visual exploration when they are presented for long durations (e.g., Bombari et al., 2013). In addition, if a behavioral response is required at each stimulus-onset, post-perceptual (e.g., decisional) processes may also contaminate the signal.

Considering these limitations, here we aimed at providing a quantified electrophysiological measure of the detection of facial expressions as a function of their intensity in the human brain with a fast periodic visual stimulation (FPVS) approach. FPVS-EEG is based on the old observation that a periodic sensory input elicits a same-frequency periodic EEG response over corresponding sensory cortices (Adrian and Matthews, 1934), the so-called *steady-state visual evoked potentials* (“SSVEP″, Regan, 1989; Norcia et al., 2015 for review). This approach is particularly well suited to quantify brain responses because of its objectivity (i.e., response are measured at pre-experimentally defined frequencies) and high SNR, providing significant responses in a few minutes of recording often quantifiable in every individual participant. It has been recently adapted to investigate high-level visual processes such as generic face categorization (Rossion et al., 2015), face individualization (Liu-Shuang et al., 2014), and most importantly for the purpose of the current study the detection of brief facial expression changes (Dzhelyova et al., 2017). In the latter study, an “FPVS oddball paradigm” inspired by the well-known