NeuroImage 179 (2018) 557–569

Contents lists available at ScienceDirect

NeuroImage

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

Implicit reward associations impact face processing: Time-resolved evidence from event-related brain potentials and pupil dilations

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ARTICLE INFO

Keywords:
Event-related brain potentials (ERPs)
Implicit associative learning
Motivational context
Motivational salience
Pupil dilations

ABSTRACT

The present study aimed at investigating whether associated motivational salience causes preferential processing of inherently neutral faces similar to emotional expressions by means of event-related brain potentials (ERPs) and changes of the pupil size. To this aim, neutral faces were implicitly associated with monetary outcome, while participants ($N = 44$) performed a face-matching task with masked primes that ensured performance around chance level and thus an equal proportion of gain, loss, and zero outcomes. During learning, motivational context strongly impacted the processing of the fixation, prime and mask stimuli prior to the target face, indicated by enhanced amplitudes of subsequent ERP components and increased pupil size. In a separate test session, previously associated faces as well as novel faces with emotional expressions were presented within the same task but without motivational context and performance feedback. Most importantly, previously gain-associated faces amplified the LPC, although the individually contingent face-outcome assignments were not made explicit during the learning session. Emotional expressions impacted the N170 and EPN components. Modulations of the pupil size were absent in both motivationally-associated and emotional conditions. Our findings demonstrate that neural representations of neutral stimuli can acquire increased salience via implicit learning, with an advantage for gain over loss associations.

To support adaptive behavior in complex environments, the human brain developed efficient selection mechanisms that bias perception in favor of salient information. In order to address the variety of different sources of salience, conventional attention theories focusing on goal- and salience-driven attention mechanisms (Corbetta and Shulman, 2002; Connor et al., 2004) were extended by the assumption of a fundamental value-driven attention mechanism (Anderson, 2013; for a recent review, see Failing and Theeuwes, 2017). This mechanism is discernible not only in stimuli inherently carrying salience, but also in stimuli associated with motivational valence, all sharing similar attentional prioritization. In line with this account, not only physical stimulus features but also emotional and motivational factors have been demonstrated to determine increased salience of certain stimuli and directly impact attention and visual processing capacities (e.g., Zeelenberg et al., 2006), resulting in a facilitated sensory encoding at initial processing stages (e.g., Della Libera and Chelazzi, 2006). Stimuli of particularly high inherent salience are faces, for which involuntarily capture of attention and preferential processing has been documented, presumably due to their crucial role in human social interactions. This face-superiority effect has been reliably demonstrated on a behavioral level in object recognition/perception tasks (e.g., Langton et al., 2008), and moreover in studies employing visual search tasks or attentional blink paradigms including facial expressions of emotions (Eastwood et al., 2001; Anderson, 2005; for a review, see Vuilleumier, 2005; Calvo and Lundqvist, 2008). Particularly, facial expressions of emotions convey various types of relevant information in social interactions (for a review, see Frith, 2009) and are regarded as evolutionarily prepared stimuli (e.g., Öhman and Mineka, 2001). Faces with and without emotional expressions are thus ideal stimuli in experiments investigating effects of inherent versus associated salience as they allow for a direct comparison of these effects within an overall relevant stimulus domain.

Due to their high temporal resolution, event-related brain potentials

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https://doi.org/10.1016/j.neuroimage.2018.06.055
Received 31 December 2017; Received in revised form 8 June 2018; Accepted 19 June 2018
Available online 22 June 2018
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(ERPs) allow segregating different processing stages and therefore gaining insights to the mechanism underlying the face-superiority effect as well as the processing advantage of facial expressions of emotions over time. Attentional priority for facial expressions of emotion and their sustained preferential processing over neutral faces is reflected in several dissociable ERP components (e.g., Schupp et al., 2004; Rellecke et al., 2012). Especially two ERP components have been linked to subsequent stages of emotion processing in humans: the EPN and the LPC. The Early Posterior Negativity (EPN), a relative negativity over posterior electrode sites, typically starting around 150–200 m s after stimulus onset (e.g., Junghöfer et al., 2001; Rellecke et al., 2011), has been suggested to reflect enhanced sensory encoding of facial expressions of emotion. The EPN is typically followed by the Late Positive Complex (LPC) or Late Positive Potential (LPP, e.g., Cuthbert et al., 2000; Schupp et al., 2004) over centro-parietal electrodes, starting around 300 m s after stimulus onset (e.g., Rellecke et al., 2011). This long-lasting ERP response has been assumed to reflect higher-order elaborate and evaluative processes (for a review, see Olofsson et al., 2008; Schacht and Sommer, 2009; Rellecke et al., 2011). In addition, two earlier components were recently found to be modulated by emotional expressions. First, the P1 component, peaking around 100 m s after stimulus onset, consists of bilateral occipital positivities and reflects the activation of extrastriate visual areas via selective attention (Di Russo et al., 2003). Some studies reported enhanced P1 amplitudes for emotional facial expressions in comparison to neutral facial expressions (e.g., Batty and Taylor, 2003; Rellecke et al., 2011), indicating that emotional salience impacts early perceptual encoding. Second, the N170, consisting in a negativity over temporooccipital electrodes, has been functionally linked to holistic face perception (e.g., Bentin et al., 1996) and has been shown to be modulated by emotional expressions (for reviews, see Rellecke et al., 2013; Hinojosa et al., 2015).

Previous studies have demonstrated that even inherently neutral faces can gain salience through associated emotional context information, reflected in augmented EPN (e.g., Suess et al., 2013; Wieser et al., 2014) and LPC amplitudes (Klein et al., 2015; Xu et al., 2016). Also modulations of the early P1 component were demonstrated (Abdel Rahman and Sommer, 2012) elicited by faces associated with biographical knowledge. However, in particular motivational salience might arise from a variety of other sources, driven by an explicit motivational context or by acquired associations. Contexts might determine motivational dispositions – e.g., the readiness to act in given situations – as they can confront a person with appealing opportunities and daunting obstacles (Scheuthle et al., 2005) and thus directly influence behavior. An increase of the motivational salience of a given context can be generated by introducing reinforcements as incentives (Meadows et al., 2016). In a recent ERP study, Wei and colleagues (Wei et al., 2016) showed that the expectation of monetary gain - indicated by motivationally relevant cues - impacted the processing of negative and neutral target words over consecutive stages from sensory encoding (EPN) to higher-order evaluation (P3/LPC). Interestingly, motivational incentives have been recently demonstrated to affect the processing of abstract target symbols even before effects of spatial attention (Bayer et al., 2017). In addition, a "*cue-P3*" component directly elicited after cue onset with enhanced amplitudes for reward-indicating as compared to loss-indicating cues was reported (Zheng et al., 2017).

Driven by the compelling evidence for impacts of motivational contexts and inherent emotional valence, the question arises under which conditions salience can be acquired. A fruitful approach to test this assumption is provided by associative learning paradigms that allow investigating the influences of acquired salience without interference with stimulus-driven salience. Aiming at a direct comparison between inherent and associated saliences, Hammerschmidt and colleagues (Hammerschmidt et al., 2017) reported that explicit reward-associations to inherently neutral faces elicited increased P1 responses during delayed testing. The elicitation of typical emotion-related ERP components at longer latencies (EPN and LPC), was, however, restricted to facial expressions of emotion. In contrast, employing a highly similar learning paradigm as in the study by Hammerschmidt et al. (2017), Rossi and colleagues (Rossi et al., 2017) detected an increase of the P3 to reward-associated unknown single letters from unfamiliar alphabets. Importantly, the processing advantage reported for stimuli associated with motivational salience is not restricted to rewards but has also been demonstrated for associations with aversive events, gratings associated with negative affective pictures (Stolarova et al., 2006), auditory shocks (Hintze et al., 2014) or unknown single letters associated with monetary loss (Rossi et al., 2017), mainly present on the perceptual level.

ERPs reflect processing differences on the neural level whereas physiological arousal – one of the key components of emotions (Scherer 2005, 2009; Lang and Bradley, 2010) — is reflected amongst other indicators in changes of the pupil size, which have been related to norepinephrine release in the locus coeruleus (Berridge and Waterhouse, 2003; Einhäuser et al., 2008; Gilzenrat et al., 2010; Laeng et al., 2012; Murphy et al., 2014). Therefore, pupil activity can be used as a measure of attentional, cognitive and emotional processing (Smallwood et al., 2011; Kang et al., 2014), with increased pupil size in response to emotionally arousing pictures (Bradley et al., 2008) and auditory stimuli (Partala and Surakka, 2003). In particular, inherently angry faces paired with an angry body induced larger pupil dilations than fearful and happy face-body pairs (Kret et al., 2013). Moreover, motivational modulations through outcome associations, in addition to stimuli of inherent emotional salience, can also increase pupil size, demonstrated for both reward (e.g., Massar et al., 2016) and loss incentives (Pulcu and Browning, 2017). Interestingly, modulations of pupil dilation further depend on task difficulty, manipulated through mental effort (Mathôt et al., 2015; Peysakhovich et al., 2015), and decision uncertainty (Kahneman, 1973; Satterthwaite et al., 2007; Brunyé and Gardony, 2017; Urai et al., 2017), with greater pupil dilations occurring with increasing task difficulty. The parallel measurement of ERPs, pupil dilations and behavioral data might help to elucidate the multiple components involved in emotion processing (e.g., Grandjean et al., 2008).

In line with Anderson's assumption (Anderson, 2013) of a value-driven attention mechanism, previous research, including our previous study (Hammerschmidt et al., 2017), clearly indicated that both emotional and motivational aspects have a direct impact on visual stimulus processing. Nevertheless, the specific conditions, under which learning mechanisms or different contexts can modify a certain stimulus' salience, are not fully understood, presumably contributing to heterogeneous findings in the past. Despite the great progress in this area of research, there are a number of open questions that we aimed to address in the present study: Firstly, effects of associated motivational salience occurred during several processing stages mainly in explicit associative learning paradigms (e.g., Stolarova et al., 2006; Schacht et al., 2012; Hintze et al., 2014; Hammerschmidt et al., 2017; Rossi et al., 2017). However, it seems reasonable that inherent, motivation- or emotion-based salience might have been acquired implicitly, that is without explicit knowledge about the hedonic value of the certain stimulus. Hence, one of the yet unresolved questions is whether implicit and explicit associations of motivational salience have similar effects on stimulus processing. Implicit learning is generally linked to participants'/learners' problems with an explicit recall (Berry and Dienes, 1993), often characterized as a 'complex form of priming' (Cleeremans et al., 1998). Further, it was argued that implicit representations possibly need more time and cognitive resources to be generated than information learned explicitly (Batterink and Neville, 2011). Recently, it could be demonstrated that reward associations have a direct impact on spatial attention – even when presented implicitly (Bourgeois et al., 2016). The authors implicitly associated target symbols with a reward cue and could show that reaction times were slower when a previously reward-associated symbol was presented together with distractors indicating that reward associations might be learned without awareness. Using the Stroop task, Krebs and colleagues (Krebs et al., 2010) could show that task-irrelevant stimuli might gain salience through implicit

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