Diplomarbeit

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“Feedback-related brain potentials associated with symbolic or socio-emotional feedback and its interaction with socio-emotional personality constructs”

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Theoretical Background

1. Feedback Processing and Neurophysiological Correlates

Human beings show a wide variety of higher cognitive abilities making adaptation to various environmental conditions possible. The most important ability is probably the ability to learn. The term learning refers to a wide range of behavior-altering processes, reaching from basal forms like habituation, sensitization or classic conditioning, where next to psychological aspects even synaptic changes have been explored (Kandel, 2000), to more complex forms like contextual learning. Another important issue is error monitoring, i.e. learning from one's errors and from feedback indicating errors or, more general, unadapted behavior by changing to more adaptive behavior. Moreover, behavioral adjustment could also be associated with cognitive control.

1.1. The Error-Related and Feedback-Related Negativities (ERN/FRN)

Error monitoring is a prerequisite for adaptively altering one's behavior and can be investigated with electrophysiological methods like event-related potentials (ERPs) of the electroencephalogram (EEG). A specific event-related negativity after an erroneous response has been observed in previous studies (e.g. Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Gehring, Gross, Coles, Meyer, & Donchin, 1993; Holyroyd & Coles, 2002). This so-called error-related negativity (ERN or Ne) starts to develop around the time of the erroneous response and peaks about 100 msec later. This negativity was thought to result from the comparison between the appropriate response and the actual response or the internal collateral information from motor processing units. The ERN also correlates with corrective behavior and future performance, as Gehring et al. (1993) found the size of the ERN to be related to error-correction and error-compensation activities. However, it does not seem to be the neural representation of this correction. Miltner, Braun and Coles (1997) think it reflects the detection-process described above, because an ERN is also observed in errors of action in NoGo-Tasks, when correction is not possible (Scheffers, Coles, Bernstein, Gehring, & Donchin, 1996).

Apart from monitoring the performed action, reception of error-information via feedback also leads to a negative ERP deflection called feedback-related negativity (FRN) with a later onset (probably due to stimulus processing) at about 140 msec, a peak between 230-330 msec and an offset at about 400 msec in difference waves post-stimulus (Miltner et al., 1997). According to the authors, both the ERN and the FRN reflect a generic error-detection system for different kinds of errors and tasks. Additionally, it was found in different output modalities (visual, auditory, and somatosensory).

When self-generated information (comparison of actual and intended behavior) is sufficient, an ERN is generated, whereas an FRN is elicited when feedback contains information otherwise not available (Heldmann, Rüsseler, & Münte, 2008). Despite the functional interrelationship of these processes regarding error monitoring, there might be psychological and neural differences due to the different error information input (internal self-generated information vs. external feedback). Typical event-related potentials after negative and positive feedback are shown in Fig. 1.

As apparent in Fig 1., there is also a negative deflection after positive feedback, though of smaller amplitude. This CRN (correct-related negativity) has been repeatedly observed regarding both, ERN and FRN-eliciting paradigms (e.g. Vidal, Hasbroucq, Grapperon, & Bonnet, 2000).

Complementary to classical ERP analysis, EEG phenomena can also be studied in the frequency domain. Interestingly, Luu, Tucker, and Makeig (2004) found phase-locking of midfrontal theta band activity (4-7 Hz) to account for large portions of the ERN, suggesting a link to limbic theta activities and affective processing.

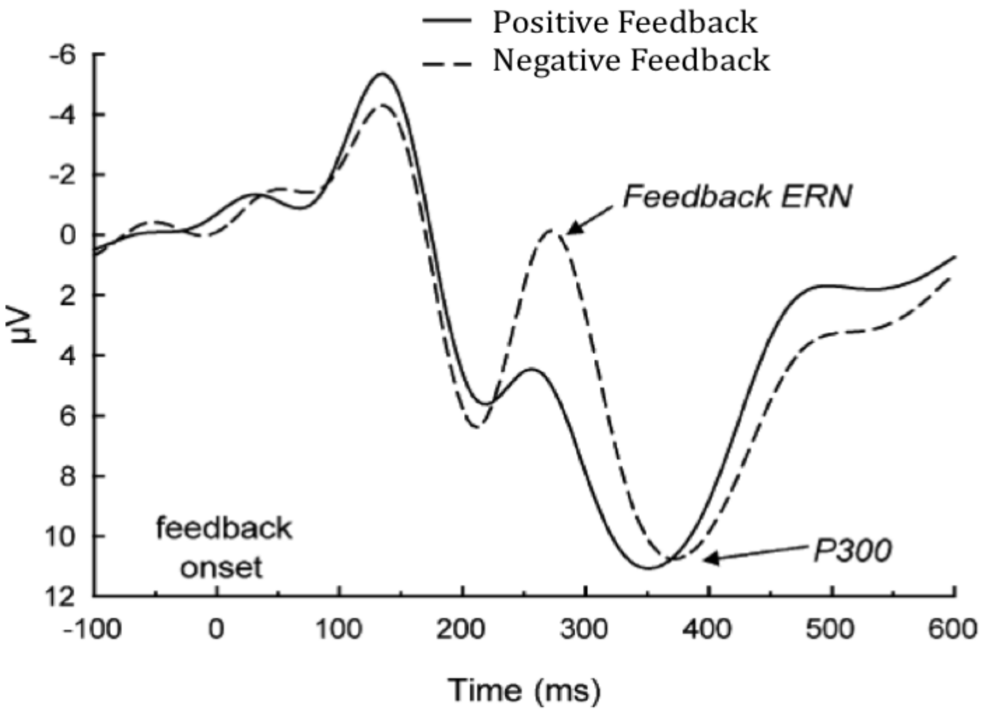

Fig. 1: Typical example of grand-average waveforms for negative and positive feedback (adapted from Nieuwenhuis, Holroyd, Mol, & Coles, 2004).

1.2. ERN/FRN and Anterior Cingulate Cortex (ACC)

There is considerable evidence that the anterior cingulate cortex (ACC) is involved in the generation of the ERN and FRN. The ACC is a structure situated adjacent to the corpus callosum on the medial surface of the frontal lobe and associated with diverse functions, reflected in its subdivision into more cognitive and more affective regions (Bush et al, 1998; Vogt, Finch, & Olson, 1992). Subdivisions of the ACC are illustrated in Fig. 2. Whereas the dorsal regions of the ACC are associated with rather cognitive processes as error processing (Carter et al, 1998), response inhibition (Bush et al., 1998) and higher-level motor control and action selection through interactions with premotor and supplementary motor areas among others (Devinsky, Morrell, & Vogt, 1995), the rostral-ventral ACC is considered a more affective subregion. The rostral ACC has connections with the hippocampus, amygdala, anterior insula, periaqueductal gray, nucleus accumbens, hypothalamus, and orbitofrontal cortex (Bissière et al., 2008; Devinsky et al., 1995; Taylor, Seminowicz, & Davis, 2009). For example, Bissière et al. (2008) studied the effects of exitotoxic lesions, temporal inactivation, and activation of a specific subregion of the rACC accounting for most of the connectivity with the basolateral amygdala in rats. Lesions and inactivation resulted in deficits in the early stages of classical fear conditioning, pointing to a modulatory influence on the basolateral amygdala. Taylor et al. (2009) suggested an emotional salience function for a network of the anterior insula and more rostral parts of the ACC detected through resting-state connectivity analysis of functional magnetic resonance imaging (fMRI) data, and a more general salience and action system for a network of the entire insula and more dorsal parts of the ACC.

However, caudal-dorsal regions also share connections with paralimbic and subcortical regions like the orbitofrontal cortex (Morecraft & van Hoesen, 1998; van Hoesen, Morecraft, & Vogt, 1993) and the mesencephalic dopamine system (Crino, Morrison, & Hof, 1993) pointing rather towards an interaction of affective/motivational and cognitive processes than cognitive processes alone.

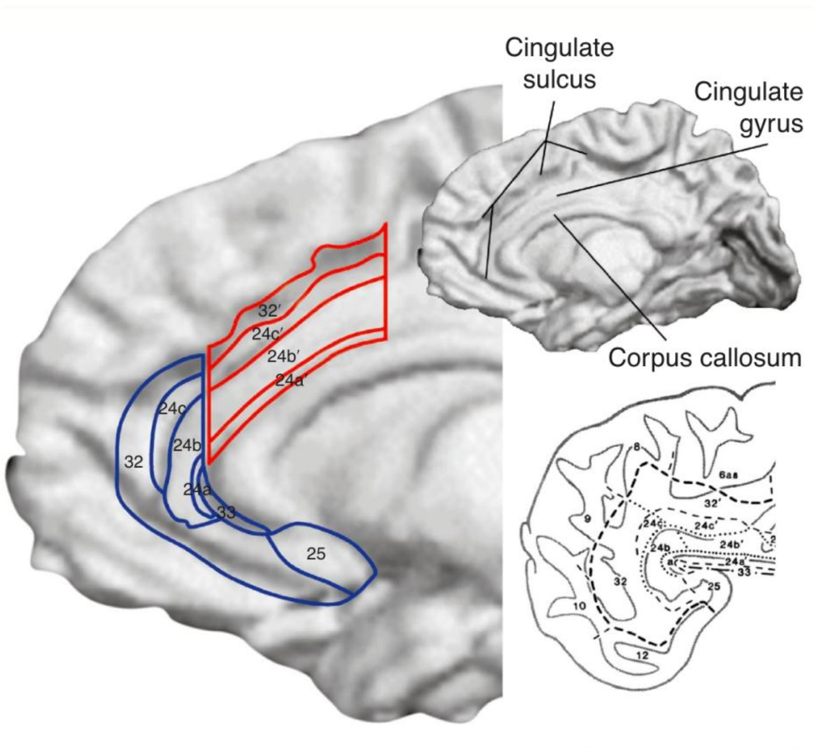

Fig. 2: Cytoarchitectural subdivision of the anterior cingulate cortex (ACC) in Brodmann areas – dorsal ACC in red and rostral ACC in blue (adapted from Bush, Luu, & Posner, 2000).

Both the ERN (Debener et al., 2005; Dehaene, Posner ,& Tucker, 1994; Holroyd, Dien & Coles, 1998; Ullsperger & Von Cramon, 2004) and the FRN after negative feedback (Gehring & Willoughby, 2002; Holroyd et al., 2004; Miltner et al., 1997; Ullsperger & Von Cramon, 2003) and after unexpected decreases in rewards (Bush et al., 2002; Holroyd et al., 2004) have been associated with dorsal regions of the ACC by means of EEG source localization and fMRI. Anatomically, the anterior cingulate sulcus is a plausible candidate for the generation of a frontocentral scalp potential like the FRN due to the orientation of its pyramidal cells (Holroyd & Coles, 2002).

1.3. Functions of the ERN/FRN

As for the ACC, there are various theories about the proposed function of the ERN/FRN. As described above Miltner et al. (1997) suggested a generic error-detection function for different kinds of errors and tasks as well as different output modalities (visual, auditory, and somatosensory).

In an attempt to explain cognitive control demands, Botvinik, Braver, Barch, Carter, and Cohen (2001) propose next to a regulative component of cognitive control an evaluative component that monitors information processing and signals the demand for recruitment, modulation, and disengagement of cognitive control mechanisms. Specifically a conflict monitoring system associated with the ACC and the generation of the ERN is thought to represent this evaluative component. In their computational modelling studies conflict was quantified as the degree of simultaneous activation of incompatible processing units.

In proposing their Reinforcement Learning Theory applying a dual approach, Holroyd and Coles (2002) compare simulation data from a model based on the method of temporal differences (Sutton, 1988) – a generalization of the Rescorla-Wagner model (Rescorla & Wagner, 1972) to the continuous time domain - and empirical findings of ERP-Studies indicating that a reward-prediction error signal is transmitted from the mesolimbic dopamine system to the ACC resulting in a negative ERP deflection, namely the ERN/FRN. It is thought that phasic decreases in activity of the mesencephalic dopaminergic system disinhibit the apical dendrites of motor neurons in the ACC, producing the ERN/FRN when outcomes are worse than expected (Holroyd & Coles, 2002; Holroyd & Yeung, 2003). The notion of negative reward-prediction error points to the findings of Schultz, Apicella, and Ljungberg (1993) and Schultz (2002) that the mesolimbic dopamine system compares the actual outcome/events to the expected ones. The proposed reinforcement function is reflected in the findings of Gehring et al. (1993) showing that the ERN predicts error-correction and error-compensation activities and that the FRN was shown to be associated with the degree of learning from negative feedback (Frank, D'Lauro, & Curran, 2007; Frank, Woroch, & Curran, 2005). Applying independent component analysis (ICA) to EEG data in combination with fMRI, Debener et al. (2005) found the single-trial ERN to be related to performance behavior in the subsequent trial and to be associated with activation in the ACC.

The Reinforcement Learning Theory has also been extended to positive feedback processing (Holroyd, 2004), as a negative deflection, though of smaller amplitude, has repeatedly been reported after correct performance or positive feedback (e.g. Vidal et al., 2000). The significance of this correct-related negativity and its characteristics remain a matter of debate, however evidence has accumulated that positive feedback processing is specifically modulated by experimental factors, e.g. expectancy and size of reward (San Martín, Manes, Hurtado, Isla, & Ibañez, 2010).

However, reinforcement of previously performed action may not be the only function of the ERN/FRN process, as other findings implicate that these components represent a more general evaluative and emotional-motivational process. Several studies (Donkers, Nieuwenhuis & van Boxel, 2005; Yeung, Holroyd, & Cohen, 2005) demonstrated that the FRN is also elicited by outcomes that are not contingent upon previous action. For instance, a similar negativity was also observed in trials with no response choice and in passive viewing tasks including outcome stimuli with negative reward value, thus not indicating the occurrence of an error, but rather reflecting outcome processing (Yeung et al., 2005). Therefore both the FRN and ERN seem to be only special cases of a broader motivational-affective outcome evaluation process and the terms "feedback" and "error" do not apply in cases where there is actually no action. Next to a reinforcement function in terms of instrumental conditioning, the underlying neural systems may therefore also be used to learn about contingencies in the external environment, i.e. for classical conditioning (Yeung et al., 2005).

1.4. The Feedback P3 Component

Apart from the ERN/FRN another typical error- and feedback-related component is a subsequent positive deflection. In ERN studies this component is often designated "error positivity" (Pe). With regard to the FRN the following positive deflection will be termed feedback P3 in this study (see Fig. 1), as it peaks in the typical P3 time range and might share characteristics with cognitive processing reflected in the classical P3 after presentation of a stimulus. The P3 (also P300, or classical P3b in contrast to novelty-related P3a) is typically largest at more posterior electrode sites, and peaks between 300 and 600 ms post-stimulus (Duncan-Johnson & Donchin, 1977; Johnson & Donchin, 1980). The classical paradigm to elicit this P3 component is the oddball task, in which occasional target stimuli have to be detected in a train of irrelevant non-target stimuli of higher frequency by some overt (e.g. pressing a button) or covert (e.g. counting) response.

Its amplitude depends on a variety of factors, such as categorical stimulus probability (Johnson & Donchin, 1980; Kutas, McCarthy, & Donchin, 1977), stimulus quality, attention (Polich & Kok, 1995), or task relevance of the stimulus (Coles et al., 1995). However, factors specifically shown to affect the feedback P3 will be presented below.

One influential theory proposes that the classical P3 indicates context-updating, i.e. incorporating unexpected, new or task-relevant information into the representation of the environment (Donchin & Coles, 1988, 1998; Polich, 2007). Also addressing working memory, Näätänen (1990) showed that the P300 amplitude refers to the match or mismatch of a consciously maintained memory trace.

Several possible neural generators have been suggested and comparison of fMRI and EEG source localization revealed multiple activations in the parietal, inferior temporal, and insular cortex for the visual P3 (Bledowski et al., 2004). In addition, the temporoparietal junction, the ACC as well as modality-specific activations (e.g. primary and secondary visual cortex) are involved (Linden, 2005; Linden et al., 1999).

As far as the Pe is concerned, it has been linked to later stages involving conscious error recognition whereas the ERN might not depend on error awareness (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000; Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001) suggesting a possible link to context-updating functions as proposed for the classical P3. This assumption is further corroborated and extended to feedback processing by recent results from Philiastides, Biele, Vavatzanidis, Kazzer, and Heekeren (2010), who suggest that updating of context in classical P3 paradigms and updating of reward expectations might share some common processes.

Source localization studies suggested possible generators in either caudal (Herrmann, Römmler, Ehlis, Heidrich, & Fallgatter, 2004) or ventral divisions of the ACC (Overbeek, Nieuwenhuis, & Ridderinkhof, 2005) for the Pe. However, later states of feedback processing were linked to separate components (Philiastides et al., 2010) as described in the next section.

1.5. Coding of Feedback Valence and Magnitude

As mentioned above, the FRN is thought to reflect a negative prediction error (Holroyd & Coles, 2002), and the FRN/CRN after positive outcomes has been associated with positive feedback processing (Holroyd, 2004; San Martín et al., 2010). However, the issues of feedback valence and magnitude coding, in particular regarding the feedback P3, remain matters of debate.

Yeung and Sanfey (2004) observed no differences between positive and negative feedback for the feedback P3 and proposed a dissociation of a FRN encoding reward value and a feedback P3 encoding reward magnitude. At least consistent with a magnitude independency of the FRN is the study of Hajcak, Moser, Holroyd, and Simons (2006), who consider the FRN to be a binary (i.e. worse-than-expected or not) and not a graded mechanism. However, as far as the feedback P3 is concerned, Hajcak, Moser, Holroyd, and Simons (2007) and Bellebaum and Daum (2008) reported larger feedback P3 amplitudes for positive rewarding stimuli. Bellebaum and Daum (2008) discuss a possible function of reflecting a positive reward-prediction error, in contrast to a negative reward-prediction error reflected by the FRN. On the other hand, larger feedback P3 amplitudes for negative outcomes were also reported (Cohen, Elger, & Ranganath, 2007; Mathewson, Dywan, Snyder, Tays, & Segalowitz, 2008).

These inconsistencies might be due to task characteristics or other experimental factors. However, Philiastides et al. (2010) suggest a more complex picture of separate valence and magnitude coding stages. Applying model-based single-trial analysis of EEG data collected during a reversal learning task, they proposed the existence of an initial categorical evaluation of feedback valence peaking around 220 ms with a broad spatial distribution over central electrodes, associated with the FRN, but both a later separate, second valence evaluation stage peaking around 300 ms with centrofrontal and occipitoparietal contributions, and a parallel quantitative evaluation of prediction error magnitude peaking around 320 ms post-stimulus with a central distribution. The different scalp distributions were thought to possibly reflect separate neural sources.

1.6. Socio-Emotional Factors influencing Feedback Processing

Although electrophysiological correlates of error monitoring and feedback processing could be investigated in various tasks and sensory modalities, there are various factors influencing their amplitudes. Some factors are associated with the experimental stimuli or task used, e.g. valence and magnitude, which were already addressed above.

On the other hand there are intra- and interpersonal factors affecting error monitoring and feedback processing. For example, although we are not aware of studies reporting gender differences, age-related differences have been reported. Mathewson et al. (2008) and Wild-Wall, Willemssen, and Falkenstein (2009) reported higher error rates and lower FRN amplitudes in older adults compared to younger controls. In the study of Mathewson et al. (2008) this was accompanied by lower and less differentiated activation in the ACC, reflecting age-related decline in ACC functioning.

In the following sections and the empirical investigation the focus will lie on socio-emotional aspects. The first factor, socio-emotional salience of the feedback stimuli, represents an environmental, task-related factor outside the person, whereas the subsequent sections deal with socio-emotional personality characteristics.

1.6.1. Socio-Emotional Salience of Feedback Stimuli

With regard to error monitoring and affective processing, little is known about the impact of socio-emotionality or salience of the feedback stimuli. It was shown that negative emotional induction via the presentation of emotional pictures of the International Affective Picture System (IAPS, Lang, Bradley, & Cuthbert, 1999) resulted in amplitude changes of the ERN. Unpleasant IAPS pictures led to an increase in ERN amplitudes after errors in a letter flanker task (Wiswede, Münte, Goschke, & Rüsseler, 2009). However, such an induction taking place prior to task performance could influence different psychological and neural processes than the emotionality of a feedback stimulus per se.

As far as feedback processing is concerned, Hajcak et al. (2006) claimed that the FRN is binary in reflecting positive and negative monetary outcome in a non-graded way. The FRN may reflect a rather fast and coarse evaluation process. Nevertheless, a socio-emotional feedback effect could be possible.

The aim of the present study was to examine this possibility by adapting the time estimation task used by Miltner et al. (1997) and presenting facial and symbolic feedback in a positive and negative manner, respectively. From an evolutionary psychological view the adaptation of behavior to (emotional) information in the faces of others would be advantageous, enhancing one's fitness. Therefore, a higher power of salient, social, and emotional stimuli like faces expressing emotions in enhancing feedback-related processes and subsequent learning and resource allocation for (more adaptive) behavior would be plausible. Anatomical connections and the functional interrelatedness of the ACC with subcortical and (para)limbic structures described above might allow for processing socio-emotional feedback stimuli in a more graded fashion.

Therefore, as far as the FRN is concerned, we hypothesize that amplitudes are larger when receiving negative feedback, which would be a replication of previous findings. Furthermore, we propose that the feedback-related negativity is also larger for faces than for symbols due to the differences in socio-emotional salience. As Philiastides et al. (2010) also suggested separate later evaluative components for valence and magnitude of prediction errors in the P3 time range, enhanced feedback P3 amplitudes for facial than for symbolic feedback conditions reflecting magnitude differences might be possible. However, there is no hypothesis regarding feedback valence (negative vs. positive) and the direction of amplitude modulation due to inconsistent findings of valence effects in literature reported above.

1.6.2. Socio-Emotional Personality Constructs

Relationships between personality factors and error monitoring or feedback processing are an important issue and were addressed in several studies. To name a few, Pailing and Segalowitz (2004) observed increased ERN amplitudes in people scoring high on Neuroticism, one of the so-called Big Five, reflecting emotional instability. Luu, Collins, and Tucker (2000) reported larger ERN amplitudes in subjects with higher levels of negative affect, at least in the initial phase of the experimental task. But also positive aspects are associated with error monitoring. In the study of Larson, Good, and Fair (2010) subjects with increased satisfaction in life exhibited lower ERN amplitudes.

The present empirical investigation and the following sections of this paper will focus on socio-emotional personality issues. On the one hand, psychopathy and social anxiety, both having importance for Clinical Psychology, but investigated as sub-clinical, naturally varying personality dimensions, will be covered. On the other hand, body-related emotional experience, and emotion regulation - traits as well as skills related to personality theories and emotional competence - will be investigated. The specific design applied – a comparison of stimuli with different socio-emotional salience like faces and symbols might be a useful experimental design to study the influence of socio-emotional personality factors.

1.6.2.1. Psychopathy

Emotional processing deficits such as lack of empathy, fearlessness and deficits in aversive learning might also be associated with altered feedback processing. Such and more characteristics are repeatedly aggregated under the construct of psychopathy, which was first clinically described by Cleckley in “The Mask of Sanity” (1941). A more reliable and probably more valid construct conceptualization and instrument has been provided by Hare, who developed the Hare Psychopathy Checklist (-Revised, PCL-R; Hare, 2003). In contrast to the clinical diagnosis of antisocial personality disorder (APD, *DSM-IV*; American Psychiatric Association, 1994), the concept of psychopathy, as well as the instruments to measure it, combine personality traits and antisocial behavior, whereas the emphasis in APD continues to be the latter (Hare & Neumann, 2008). The PCL-R combines information of the case history and a semi-structured interview. It is an instrument adequate for investigating criminal offenders and has often been used in this context (and in psychiatric contexts), whereas self-description instruments are more applicable for non-clinical, non-offender populations. There is a growing number of investigations in the general population, as psychopathy is a dimensional trait (Edens, Marcus, Lilienfeld, & Poythress, 2006) and can also be conceptualized as a naturally varying personality factor (Alpers & Eisenbarth, 2008). We also share this broader view, investigating a sample of mentally healthy (under)graduates.

The factor analytic structure of the PCL-R could be considered hierarchical. A two-factor solution reveals a factor 1: Interpersonal/Affective dimension with elements like grandios self-worth, superficial charm, lack of remorse or guilt, and lack of empathy, and factor 2: Lifestyle/Antisocial dimension with elements like impulsivity, stimulation seeking, poor behavioral control and criminal versatility. A four factor solution proposes a split in two sub-facets for each main factor (Hare, 2003; Hare & Neumann, 2008).

The dual-process model proposed by Fowles and Dindo (2009) also suggests two separate (but not exclusive) aspects in psychopathy – the emotional/interpersonal or “core” features of psychopathy (factor 1) and impulsive antisocial behavior (factor 2). Other researchers describe sub-types of psychopathy (or psychopaths) according to these factors. Primary psychopaths are scoring high on PCL-R factor 1 and could be considered as “classic psychopaths” characterized by emotional detachment and lack of empathy, whereas secondary psychopaths are those scoring high on PCL-R factor 2 who could be considered as more impulsive and with poor behavioral control (Lykken, 1995; Skeem, Johannson, Andershed, Kerr, & Louden, 2007). Primary and secondary psychopaths also differ in their level of trait anxiety with the former scoring lower and the latter higher on these measures (Skeem et al., 2007). One core feature repeatedly described in the psychopathy literature is a deficit in passive avoidance learning (i.e. “Don’t do that!”-learning), which could be of etiological importance for developing antisocial, norm-violating behavior. Arnett, Smith, and Newman (1997) illustrated that only primary psychopaths characterized by low levels of anxiety show this deficient passive avoidance learning.

The phenotypical categories of primary and secondary psychopathy are also associated with different underlying neural mechanisms. For example, a failure of the startle-reflex potentiation by aversive stimuli is uniquely associated with primary psychopathy (Patrick, Bradley, & Land, 1993). In a non-clinical college student sample using the self-description instrument PPI (*Psychopathic Personality Inventory*; Lilienfeld & Andrews, 1996) Gordon, Baird, and End (2004) found the emotional-interpersonal factor, reflecting primary psychopathy, to be associated with reduced activation in the inferior frontal cortex, right amygdala, medial prefrontal cortex in an emotion recognition task, and higher activation in visual cortex and dorsolateral prefrontal cortex probably reflecting the use of more cognitive strategies. Blair (2003) proposed an amygdala dysfunction to be a core characteristic in (primary) psychopathy, as amygdala dysfunctions are associated with the same impairments shown in (primary) psychopathy (e.g. instrumental conditioning, affective processing).

Interestingly, psychopaths scoring high on affective-interpersonal aspects also show reduced conditioned neurophysiological reactions in an aversive conditioning paradigm, pointing to reduced anticipatory learning (Birbaumer et al. 2005). Therefore both aversive instrumental and classical conditioning seem to be deficient in primary psychopathy. Moreover, this points to a possible involvement in feedback processing.

In contrast to the emotional-interpersonal factor, Gordon et al. (2004) reported a relationship between the social-deviance factor indicating secondary psychopathy and enhanced amygdala activity. In addition, secondary psychopathy seems to be more related to deficits in executive functioning (Sellbom & Verona, 2007) and orbitofrontal lesions result in impulsive, reactive behavior similar to secondary psychopathy (Malloy, Bihrle, Duffy, & Ciminio, 1993). An interaction between hypoactive frontal control areas and hyperactive amygdala thus might be important in secondary psychopathy.

In an attempt to provide an integrative view, Kiehl (2006) proposed a paralimbic system dysfunction model of psychopathy considering the orbital frontal cortex, insula, anterior and posterior cingulate, amygdala, parahippocampal gyrus, and anterior superior temporal gyrus to be implicated in psychopathy. Psychopathy is associated with abnormal ACC function particularly during affective information processing (Kiehl et al., 2001; Müller et al, 2003). The facets of psychopathy that appear to be associated with anterior cingulate dysfunction include affective (PCL-R facet 2) and lifeystyle (PCL-R facet 3) factors of the four-factor model of psychopathy (Hare, 2003). However, facet 2 is associated with primary psychopathy, whereas facet 3 is associated with secondary variants. Therefore, the possibility of specific associations between primary and secondary psychopathy on the one hand, and error monitoring and feedback processing mediated by the ACC on the other hand, remain to be addressed.

As mentioned above, error monitoring is crucial for adaptively altering one’s behavior and is associated with specific electrophysiological correlates and the ACC. Investigating neuronal correlates of error monitoring and feedback processing could shed light on possibly etiologically relevant neural processes associated with psychopathy. For example, Dikman and Allen (2000) found reduced ERN amplitudes in undergraduates scoring low in a socialization scale compared to participants scoring high, consistent with the avoidance-learning deficits seen in psychopathy. Although not addressing psychopathy per se, Frank, Woroch, and Curran (2005) found that the ERN/FRN is larger for negative learners, i.e. people focusing on negative outcomes. They reported that those people rather avoid negative stimuli in subsequent novel trials than choosing positive stimuli. Therefore a larger ERN/FRN seems to reflect avoidance learning (and an avoidance learning-type). In contrast, subjects with a focus on positive events showed a smaller ERN/FRN and could be classified as positive reinforcement learners (approaching-style). With regard to emotional processing, Munro et al. (2007) showed reduced ERNs in psychopathic offenders tested with the PCL-R in a face flanker task that required the discrimination between angry and fearful expressions, but equal amplitudes in a letter flanker task compared to controls. Therefore error-monitoring might not be deficient per se, but impaired due to an emotional reactivity deficit. However, the ERN-studies of Dikman and Allen (2000) and Munro et al. (2007) did not incorporate feedback processing, and the emotional content in the latter was associated with the flanker task beforehand and not with feedback, whereas our study might be the first to show altered feedback processing in subtypes of psychopathy in feedback situations with varying socio-emotional salience.

In this study the PPI-R (*Psychopathic Personality Inventory-Revised*, Alpers & Eisenbarth, 2008) is used instead of the PCL-R, as this instrument is more adequate for investigating non-offender, non-clinical samples. The instrument is described in the methods section below in more detail. Based on previous ERN studies showing decreased amplitudes (Dikman & Allen, 2000; Munro et al., 2007), an impaired passive avoidance-learning (Arnett et al., 1997), and deficient fear conditioning (Birbaumer et al., 2005) among other deficits associated with psychopathy as mentioned above, we hypothesized that psychopathy – especially affective/interpersonal facets or primary psychopathy (e.g. PPI-R subscale Social Influence or higher-order factor Fearless Dominance) – is associated with a general decrease in the FRN in the negative feedback condition. Moreover, a lower or missing amplitude modulation (as expected for the general population) by negative faces or even a lower FRN in this condition is expected, because of additional deficits in emotional face processing (Blair, 2001; Munro et al. 2007).

As far as the P3 component is concerned, a meta-analysis of Gao and Raine (2009) showed that whereas antisocial behavior seems to be rather consistently associated with reduced P3 amplitudes in several tasks, probably reflecting neurocognitive impairments, amplitudes in psychopaths seem to be moderated by the specific task used, as decreased amplitudes where only reported for oddball tasks. According to Gao and Raine (2009) this decrement might be due to the less stimulating nature of oddball tasks for psychopaths, but not due to cognitive impairments. Moreover, as also pointed out by the authors, there were no specific findings for primary and secondary variants of psychopathy. Therefore possible personality effects on feedback P3 were explored without specific hypotheses.

1.6.2.2. Social Anxiety

In contrast to psychopathy, fear and anxiety are characterized by higher emotional reactivity. Social anxiety, i.e. anxiety in social situations like public performance or social interactions, is also associated with altered neural processes when it comes to processing of emotional faces. Exaggerated amygdala activation to the presentation of emotional faces has been shown in people with social anxiety disorders (Birbaumer et al., 1998), as well as an increased bilateral amygdala activity to emotional faces in individuals with increased anxiety-related traits not seeking treatment (Stein, Simmons, Feinstein, & Paulus, 2007).

Social anxiety is especially triggered by situations of social evaluation. Fear of negative evaluation plays a key role in social anxiety, letting individuals expect critical and negative evaluations as well as higher required standards in social encounters (Rapee & Heimberg, 1997), and was shown to be associated with a higher increase in anxiety and performance deficits in social evaluative situations, especially when accompanied with other cognitive vulnerabilities (Haikal & Hong, 2010). In addition, social anxiety is associated with increased activations in emotion-related brain areas (amygdala, medial OFC, subgenual cingulate, parahippocampal gyrus) especially after facing social threatening stimuli, e.g. harsh faces, and reduced dorsomedial and dorsolateral PFC when trying to regulate emotions compared to controls (Goldin, Manber, Hakimi, Canli, & Gross, 2009).

Apart from the brain areas mentioned, neural structures specifically associated with error processing also seem to be involved in fear and anxiety. Hajcak, McDonald, and Simons (2003) reported that undergraduates scoring high in a measure of general anxiety and worry exhibited larger ERN amplitudes. Therefore, increased ERNs are not specific to obsessive-compulsive disorder (OCD), a relation previously discovered in patients (e.g. Gehring, Himle, & Nisenson, 2000). OCD is characterized by obsessions and compulsions, and anxiety is considered an important aspect (*DSM-IV*; American Psychiatric Association, 1994)

Feedback stimuli could be regarded as more or less social, or at least as externally provided, evaluative stimuli, and feedback processing may be altered in individuals with high social anxiety. Especially the use of even more social forms of feedback like faces, especially displaying negative, socially threatening emotions (e.g. anger) as feedback, might result in a different processing in these individuals. Therefore, it is hypothesized that subjects with higher levels of social anxiety (measured with the *LSAS - Liebowitz Social Anxiety Scale*;

Stangier & Heidenreich, 2005) display larger FRN amplitudes in both feedback conditions and even larger amplitudes for angry faces associated with higher socio-emotional salience.

1.6.2.3. Body-Related Emotional Experience

An important aspect in various emotion theories is the perception of physiological states of the body, i.e. interoceptive or proprioceptive processes, such as heart beat, respiration, blood pressure, gastrointestinal and urogenital perceptions (Domschke, Stevens, Pfleiderer, & Gerlach, 2010). Historically, the James-Lange theory of emotions first considered interoceptive processes as relevant for emotion generation (James, 1884; Lange, 1885). Schachter and Singer (1962) emphasized the role of cognitive appraisal of perceived physiological arousal and most modern emotion theories highlight the interaction of cognitive, behavioral, peripheral-physiological, and neuronal processes. In addition, interoceptive sensitivity has clinical implications: Domschke et al. (2010) report substantial effect sizes for the relationship between heartbeat perception and trait anxiety as well as panic disorder. Trait anxiety refers to a general and stable tendency to react with anxiety to environmental events perceived as threatening. Panic disorder is characterized by recurrent unexpected panic attacks and worries about these attacks or their consequences (*DSM-IV*; American Psychiatric Association, 1994).

Neural correlates of interoceptive sensitivity operationalized as heartbeat sensitivity were also detected via fMRI, indicating involvement of the insula, somatomotor and cingulate cortices (Critchley, Wiens, Rotshtein, Ohman, & Dolan, 2004; Pollatos, Schandry, Auer, & Kaufmann, 2007). Interoception was also investigated with EEG: Pollatos, Kirsch and Schandry (2005) observed higher heartbeat-evoked potentials (HEPs) in subjects showing high heartbeat detection accuracy and an association with activity in the right insula, anterior cingulate, prefrontal cortex and left secondary somatosensory cortex using dipole-source analysis. However, interoceptive sensitivity is also associated with event-related potentials reflecting processing of emotional stimuli. According to Herbert, Pollatos, and Schandry (2007), sensitivity to heartbeat is positively related to P3 amplitudes after viewing pleasant, neutral and unpleasant pictures as well as to subjective intensity of emotional experience.

Feedback processing also depends on the processing of the emotional content of the stimulus and consequently feedback P3 could also be influenced by interoceptive sensitivity. Instead of measuring the sensitivity to specific visceral mechanisms, such as in a heartbeat detection task, one could also measure body-related emotional personality traits. The Body-Related Symbolization-Subscale of the SEE (*Emotional Experiences Scale*; Behr & Becker, 2004) reflects the attention one pays to body-related responses to emotional events. We hypothesized that subjects scoring higher in this subscale elicit larger P3 amplitudes for negative and positive feedback in both the facial and symbolic feedback conditions. However, this modulation is thought to be larger for faces displaying emotions as they probably elicit larger emotional responses.

1.6.2.4. Emotion Regulation

In some personality theories as well as in emotional competence concepts emotion regulation plays an important role. The term emotion regulation refers to a heterogeneous set of regulation mechanisms. Researchers often focus on more conscious, cognitive strategies such as cognitive reappraisal, i.e. regulating emotions by altering thoughts related to emotion-evoking events (Gross & Thompson, 2007). Emotion regulation is also of clinical importance, as being able to successfully regulate your emotions is positively associated with physiological and psychological well-being (Gross & John, 2003) and negatively with psychopathology (Eftekhari, Zoellner, & Vigil, 2009).

As far as neural correlates are concerned, Goldin, McRae, Ramel, and Gross (2008) found engagement of prefrontal cognitive control areas (medial and dorsolateral PFC, and lateral OFC) with subsequent reductions in amygdala and insula activity in subjects applying cognitive reappraisal strategies, whereas suppression of emotional expression was associated with similar activations and reductions, but at later processing stages. This is consistent with the “modal model” of Gross and Thompson (2007) proposing multiple stages of emotion generation with different regulation strategies influencing processing at different stages/time points. Investigating temporal dynamics with ERPs, reduced LPPs – late positive potentials (i.e. P3) were found in subjects applying cognitive reappraisal strategies, also consistent with the modal model mentioned above (Hajcak & Nieuwenhuis, 2006; Moser, Hajcak, Bukay, & Simons, 2006; Moser, Krompinger, Dietz, & Simmons 2009)

In the context of feedback processing, emotion regulation is probably also associated with event-related potentials. Negative feedback stimuli might be regarded not as negative in subjects with high emotion regulation skills. In light of the ERP-studies discussed above, an effect on the feedback P3 is hypothesized. Effects of emotion regulation will be explored by means of the Emotion Regulation-subscale of the SEE (*Emotional Experiences Scale*; Behr & Becker, 2004). Higher scores are hypothesized to be associated with reduced feedback P3 amplitudes, especially but not uniquely for facial stimuli because of their higher socio-emotional salience. However, there might also be an impact on earlier processing stages reflected in the FRN, which will be explored.

Methods

2. Subjects

To avoid any gender influence we included only female participants in the present study. Women tend to show lower levels of psychopathy in the self-descriptive questionnaire of psychopathy applied (Alpers & Eisenbarth, 2008). Nevertheless, natural variation in levels of psychopathy is considerable and possible effects may be even more interesting, as women have been studied to a lesser extent compared to men as far as psychopathy is concerned.
Twenty-four right-handed women (21-29 years of age, mean age: 24.27 years, SD = 1.91 years), all students or graduates of diverse disciplines, served as participants for this study. However, two subjects had to be excluded from analysis due to EEG artifacts leaving twenty-two subjects for final analysis. All participants were healthy and with normal or corrected-to-normal vision. In addition to general selection criteria such as left-handedness, etc., a SCID-Screening (*Structured Clinical Interview for DSM-IV-Screening;* Wittchen, Wunderlich, Gruschwitz, & Zaudig, 1996) was applied in order to include only mentally healthy subjects. The only exceptions were subjects with higher rates of social anxiety because of research interests. Handedness was assessed with the *Edinburgh Handedness Inventory* (Oldfield, 1971). All participants gave written informed consent. The study was conducted in accordance with the revised *Declaration of Helsinki* (1983) and local guidelines of the University of Vienna. A detailed sample description is displayed in Table 1. The considerable natural variation in all personality factors makes this sample suitable for investigating personality issues. The psychometric inventories applied are described in detail in the section "Psychometric Instruments" below. Subjects did not receive financial benefits for participation.

Table 1: Sample Description

	Mean	**SD**	**Min-Max**
Age	24.27	1.91	21-29
PPI-R:			
Total Score[a]	50.18	8.81	31-67
Fearless Dominance	99.64	11.95	76-120
Self-Centered Impulsivity	147.50	20.38	107-192
Blame Externalization[a]	50.41	10.52	37-76
Rebellious Nonconformity[a]	52.32	10.23	37-80
Stress Immunity[a]	51.18	9.51	35-75
Social Influence[a]	50.27	9.30	27-67
Coldheartedness[a]	47.86	9.15	37-70
Machiavellian Egocentricity[a]	49.32	6.30	34-61
Carefree Nonplanfulness[a]	48.09	8.65	34-65
Fearlessness[a]	47.73	10.08	31-68
LSAS:			
Total score	41.82	20.43	10-93
Fear/Anxiety	20.59	10.78	5-50
Avoidance Behavior	21.23	10.59	2-43
SEE:			
Emotional Acceptance[a]	51.50	12.94	15-70
Emotional Flooding[a]	51.64	11.69	34-72
Lack of Emotions[a]	48.73	9.67	34-67
Body-Related Symbolization[a]	48.45	12.23	23-67
Imaginative Symbolization[a]	52.82	11.43	33-70
Emotion Regulation[a]	56.00	9.16	36-72
Self-Control[a]	50.12	12.14	22-67
[a] For these factors T-norms were available and are reported here.			

3. Task and Stimuli

The task was administered on a Pentium IV 3.00 GHz computer, using E-Prime 2.0 (Psychology Software Tools, Inc.) to control the synchronization of stimulus presentation. Subjects were comfortably seated about 70 cm in front of a 19-inch CRT monitor in a sound-attenuated room.

The experimental task applied in the present study is an adaptation of the task used by Miltner et al. (1997). The trial sequence timeline is displayed in Fig. 3. Subjects were asked to estimate the duration of one second by pressing a button on the keyboard as the subjective time period had elapsed following the presentation of a visual cue on a monitor (centered star) after a fixation intertrial interval (ITI). Regarding accuracy, the kind of feedback provided to the subjects was a function of whether the duration of the estimate fell within a time window, the width of which was adjusted automatically from trial to trial (by ± 10 msec, initial width: ± 100 msec) on the basis of the subjects' performance on the preceding trial (cf. Johnson & Donchin, 1978). As performance improved the window became narrower, as performance deteriorated the window became wider. This procedure was applied because of three reasons: 1) because of the difficulty to estimate exactly 1 sec. 2) this results in a global probability of correct and incorrect feedback stimuli of nearly 50%, which is optimal for analysis. 3) the adjustment of the time window might be crucial for the elicitation of the FRN, because subjects might build up (e.g. positive) expectations, which probably would be violated because of a change in the time window. Reward-prediction errors seem to be central for the FRN as described in the introduction section above (Holyrod & Coles, 2002).

In addition to the valence dimension (negative vs. positive feedback), feedback stimuli also varied on a form dimension (face vs. sign). The stimuli applied are presented in Fig. 4. As far as this dimension is concerned, a block design with the variants ABAB (face-sign-face-sign, each block consisting of 100 items) and BABA (sign-face-sign-face), counterbalanced across participants, was applied. For facial feedback, two photos of the same female of the *Pictures of Facial Affect* (Ekman & Friesen, 1976) were used, one displaying anger (negative feedback condition) and one displaying happiness (positive feedback condition). These faces have the advantage to be normalized in position and to be equiluminescent. For symbolic feedback equiluminescent symbols (X and O) were used. The signs were associated with the meaning of feedback valence in the instruction of the experiment in a balanced manner (XO – X negative and O positive, and OX vice-versa). There are various methods of feedback presentation that could be applied. For example, Nieuwenhuis, Slagter, Alting von Geusau, Heslenfeld, & Holroyd (2005) used a fixed interval after presentation of the cue before estimation (the centered star in this case), but this might result in a systematic bias, because as the estimation period becomes longer (shorter) this would lead systematically to an earlier (later) feedback presentation, which could have an influence on the FRN not addressed in previous experiments. Taking the button press as a reference point would avoid systematic influences of interval length to feedback. Thus feedback was presented 600 ms after button-press as in Miltner et al. (1997).

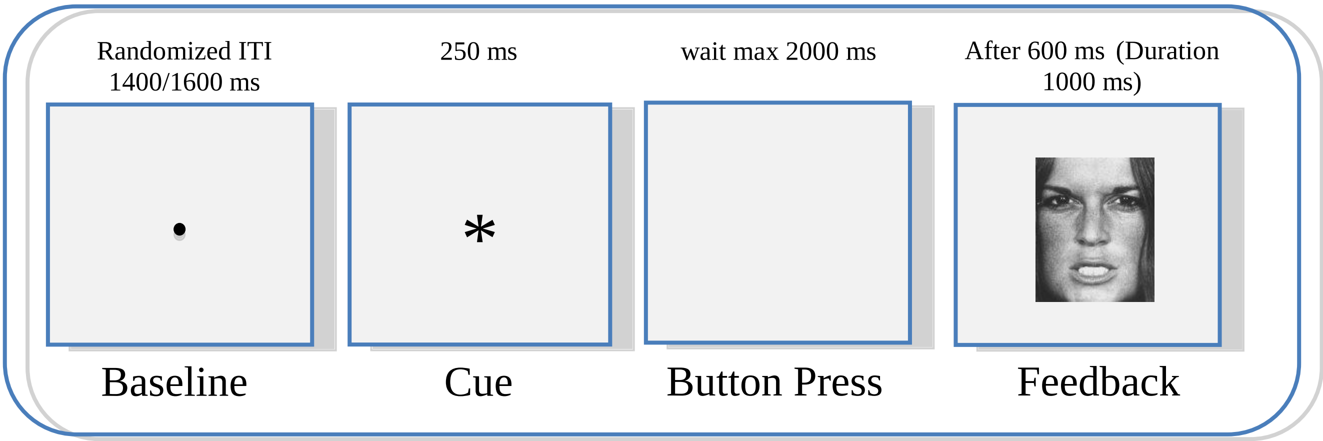

Fig. 3: Trial Sequence Timeline

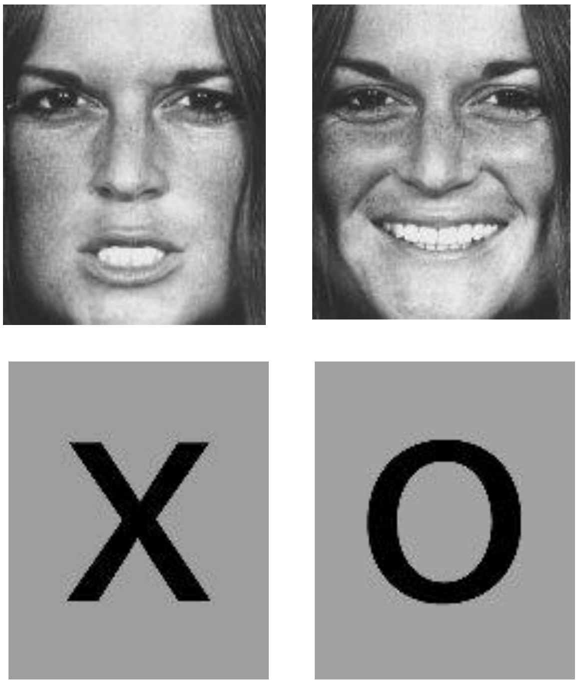

Fig. 4: Facial and symbolic stimuli applied in the experiment. Photos of *the Pictures of Facial Affect* (Ekman & Friesen, 1976) were used as facial stimuli. Faces and signs are of equal luminescence and size.

4. Psychometric Instruments

Subsequent to the experimental task and EEG recording subjects completed the following personality inventories:

4.1. PPI-R – Psychopathic Personality Inventory-Revised

The PPI-R (German Version, Alpers & Eisenbarth, 2008; original version: Lilienfeld & Widows, 2005) is a self-report questionnaire measuring several facets of psychopathy. Its self-descriptive, economic and dimensional characteristics make it very well suited for research. Internal consistency is satisfying with a Cronbach's alpha of .85 (retest-reliablity of the original version, 20 days: rel=.93). The PPI-R provides scores for eight subscales and a total score. The subscales will be described below and item examples (translated into English) will be given.

Social Influence: People scoring high on this scale describe themselves as having a high resistance against social anxiety, being self-confident and able to influence and impress other people in positive ways.

"I feel self-confident when I am among people."

Stress Immunity: High scoring people consider themselves to have a high resistance against stressors of many kinds.

"I am functioning well under stress."

Fearlessness: This scale refers to proneness to risky behavior. People scoring high report liking risky sports and adventures.

"*It would be fun to fly a small plane myself."*

Blame Externalization: People scoring high on Blame Externalization characterize themselves as having an external attribution style, i.e. attributing their behavior and its consequences to other people or other external factors. Other people are blamed for negative events and bad luck.

"I am blamed for a lot of things I am not responsible for."

Rebellious Nonconformity: This scale refers to an extravagant, non-conform and exalted lifestyle, and a search for special experiences. High scoring people describe themselves as having such a lifestyle.

"If my life starts to gets boring, I am willing to take risks."

Machiavellian Egocentricity: This scale refers to egocentric, egoistic and materialistic behavior. High scoring people report such behaviors to a large extent.

"I am getting angry if I do not receive privileges that I deserve."

Carefree Nonplanfulness: People scoring high on Carefree Nonplanfulness characterize themselves as being careless and unreliable, and not planning their life.

"I am acting first and thinking later."

Coldheartedness: People scoring high on this subscale consider themselves as having lower levels of empathy and having lower compassion for people suffering.

"If other people are hurt by something I say or do it's their problem."

To address the hypotheses stated above, the focus will be on affective and interpersonal characteristics of primary psychopathy, as well as a comparison of such aspects with facets of secondary psychopathy and their associations with neural mechanisms. In the case of the PPI-R the respective theoretical and empirical constructs would be the higher-order factors Fearless Dominance and Self-Centered Impulsivity, although only modestly related with the PCL-R, but with distinct relationships with diverse external criteria and not intercorrelating, thus probably reflecting components of psychopathy in a more differentiated fashion (Edens & McDermott, 2010; Patrick, 2007). Fearless Dominance (FD) is marked by the subscales Social Influence, Fearlessness, and Stress Immunity, reflecting a more affective-interpersonal dimension – especially Social Influence -whereas Self-Centered Impulsivity (SCI) consists of the subscales Machiavellian Egocentricity, Carefree Nonplanfulness, Rebellious Nonconformity and Blame Externalization, reflecting more impulsive characteristics. As there is no specific algorithm for calculating FD and SCI-scores in the German Version, the sum of the scores of the particular subscales was used. Mean T-values of all subscales are presented in Table 1.

4.2. LSAS – Liebowitz Social Anxiety Scale

The LSAS (German Version, Stangier & Heidenreich, 2005) includes items enquiring about performance situations and social interaction situations, and a social evaluative aspect is apparent. The inclusion of two aspects – the emotional experience of anxiety/fear and avoidance behavior – could probably help to better address variability, especially in a non-clinician sample. Fresco et al. (2001) found Cronbach's alphas for the LSAS (self-report version) of .95 in individuals with social anxiety disorder and .94 in non-anxious controls. In the following some item examples (translated into English) are given. People had to indicate their level of Anxiety/Fear (first subscale) and Avoidance Behavior (second subscale) for each social situation.

"Acting, performing, or giving a talk in front of an audience."

„Calling someone you don't know very well."

„Looking at people you don't know very well in the eyes."

4.3. SEE – Emotional Experiences Scales

This self-report questionnaire (German Version, Behr & Becker, 2004) measures how people perceive their emotions, how they evaluate them, and how they regulate them on seven dimensions. Internal consistency is satisfying with Cronbach's alphas of .7-.86., and retest-reliability from 2-14 weeks of .6-.9. In the following the seven subscales of the SEE will be described and item examples (translated into English) will be given.

Emotional Acceptance: People scoring high describe themselves as being able to accept their emotions and not feeling ashamed of them.

"I feel what I feel and that's OK."

Emotional Flooding:	This scale describes the subjective experience of having too many emotions. High scoring people feel overwhelmed by their emotional experiences in a negative way. *"I wish I were not always so affected by my emotions."*
Lack of Emotions:	People scoring high consider themselves as not or only partly feeling their inner experiences. *"I don't often feel my inner world."*
Body-Related Symbolization of Emotions:	People scoring high on this scale consider their body states as reflections of their psychological experiences and important for decisions. *"Feelings of a beating heart, knots in my stomach and itchy skin can give me a good idea what I want."*
Imaginative Symbolization of Emotions:	This scale describes the extent to use fantasies and (day) dreams to deal with emotional issues. *"My dreams clarify my feelings."*
Emotion Regulation:	People scoring high on this scale characterize themselves as capable of regulating their emotional state, being able to calm themselves down or activate themselves if necessary *"Most of the time I know how to calm down when I'm het up.*"

Self-Control: This scale refers more to the extent to control one's emotional expression. People scoring high consider themselves to be able to hide emotions.

"Even when things are bubbling up inside me I can pretend to be calm."

5. EEG Recording

EEG was recorded from 61 Ag/AgCl ring electrodes, arranged equidistantly in an elastic cap (EASYCAP GmbH; model M10). A sterno-vertebral site (electrodes placed above the seventh vertebra and the right clavicular junction) served as reference site during data acquisition (Stephenson & Gibbs, 1951). For off-line eye movement correction, a vertical and horizontal electrooculogram (EOG) was recorded using a bipolar setting, where electrodes were placed one cm above and below the left eye and on the outer canthi (Bauer & Lauber, 1979). To ascertain stable and homogenous electrode impedances below two kΩ, the skin was slightly scratched in order to remove dead skin cells by using a sterile single-use needle at each electrode site prior to EEG recording (Picton & Hillyard, 1972). Degassed electrode gel (Electro-Gel, Electrode-Cap International, Inc.) was filled into each electrode. Individual three-dimensional electrode coordinates of 17 pre-defined electrode positions (referenced to nasion, inion, and the two preauricular electrodes) were measured for all participants with a photogrammetric scanner (3D-PHD; Bauer et al., 2000). Off-line, a standard head model was fit into these predefined locations, whereupon the remaining electrodes were interpolated using a radial basis function, based on the equidistant montage of the electrode cap. EEG signals were recorded within a frequency range of 0.1 - 125 Hz and sampled at 250 Hz for digital storage.

Artifacts due to eye movements were removed by successive subtraction of the weighted horizontal and vertical EOGs from each EEG channel trial by trial. Weights were calculated as the ratio of the covariance between each EEG channel and the EOG, and the variance within the EOG channels. These parameters were derived from two pre-experimental calibration trials where subjects performed guided vertical and horizontal eye movements (Bauer & Lauber, 1979). Subsequently, blink coefficients were calculated using a template matching procedure to identify and remove blink artifacts (Lamm, Fischmeister, & Bauer,

2005) In two critical cases, independent component analysis (ICA) was applied in order to exclude blink components because of substantial improvement (Jung et al., 2000). EEGLAB 6.03b (Delorme & Makeig, 2004), a Matlab (The MathWorks, v. 7.5.0) based software, was used for further analysis. The data were filtered with a 30 Hz low-pass filter (roll-off 6 dB per octave). EEG data were epoched starting 200 ms prior to the presentation of the feedback stimuli to 900 ms post-stimulus. The first 200 ms served as baseline interval. Subsequently, a semi-automatic artifact removal procedure was applied to the epoched data. Trials containing muscular-, residual eye-, or movement-related artifacts with voltage values exceeding +/- 75 μV in any channel, or trials with voltage drifts of more than 50 μV in any channel were labelled automatically and rejected after visual inspection.

6. Data Analyses

6.1. Descriptive Statistics

In addition to the following inferential statistics mean ERP latencies were calculated. As far as behavioral data are concerned, the time-estimation task applied was considered inadequate for investigating performance behavior effects of feedback processing (Miltner et al., 1997). However, behavioral data was inspected to avoid inclusion of participants with unusual performance behavior (e.g. a large number of response omissions). None of the subjects displayed substantial deviating performance behavior.

6.2. ERP Analysis

The FRN was quantified in the averaged ERP waveforms after negative and positive, facial and symbolic feedback at electrode sites Fz, FCz and Cz for each participant as the peak-to-peak difference in voltage between the most negative peak 140-600 ms after stimulus onset and the average voltage of the immediately preceding P2 and following P3 peaks, similar to Yeung and Sanfey (2004). This procedure was applied as the FRN is superimposed on these positivities and might be better regarded relative to them. Moreover, there is evidence that the ERN/FRN reflects phase-locking of midfrontal theta-band activity (4-7 Hz) and the preceding and following positivities might be regarded as being at least in part the result of such theta waves (Luu et al., 2004; Tzur & Berger, 2009).

Feedback P3 amplitude was quantified as the most positive peak in the averaged ERP waveforms at electrode site Pz in the same time range in all four conditions. Parietal electrode sites were repeatedly used in studies investigating the feedback P3 (e.g. Bellebaum & Daum, 2008; Yeung & Sanfey, 2004). Moreover, Philiastides et al. (2010) found one valence-encoding component associated with occipitoparietal scalp distribution around 300 ms post-stimulus.

Prior to testing the experimental hypotheses, possible electrode location effects (Fz, FCz, Cz) concerning the FRN analysis, and effects of the allocated block (ABAB/BABA) or type of sign-valence allocation (XO/OX) concerning FRN and P3 analysis had to be explored. The assumption of sphericity was tested with Mauchly's W, and Greenhouse-Geisser correction was applied where necessary.

The general model for testing the experimental hypotheses was a 2 x 2 repeated measures ANOVA, with the within-subject factors valence (negative vs. positive) and form (face vs. sign). This general model was extended by an additional between-subject factor when analyzing the effects of the diverse personality factors separately.

The continuous personality variables were transformed into subgroups of high and low scores by applying median split. Subjects with scores representing the median were included to the high scoring subgroup. Independent t-tests comparing the median split subgroups reached significance in all personality factors ($p < .001$), which indicates that the natural variation of this sample (see also table 1) makes the median split technique suitable for the analysis. The assumptions of normal distribution and homogeneity of variances were tested statistically where necessary. No significant violations can be reported, allowing for parametric statistical tests.

Partial eta-squared (η^2) is reported indicating the effect sizes of the ANOVA models ($\eta^2 < .05$ representing small effects, scores around .10 representing medium effects, and $\eta^2 > .20$ representing large effects; Cohen, 1973).

6.3. Source Analysis

Source localization was conducted by means of sLORETA (standardized low resolution brain electromagnetic tomography; Pascual-Marqui, 2002). sLORETA is an inverse solution technique that estimates the distribution of the electrical neuronal activity in three-dimensional space by assuming that neighboring neurons are simultaneously and synchronously activated, followed by an appropriate standardization of the current density, producing images of electric neuronal activity without localization bias (Greenblatt, Ossadtchi, & Pflieger, 2005; Pascual-Marqui, 2002). sLORETA does not require any assumptions about the number, localization, configuration, or extent of neuronal sources. sLORETA computes the electric activity at each voxel (solution space contains 6239 voxels in total) as the squared standardized magnitude of the estimated current density. Mean amplitudes between 100 ms before and 600 ms after stimulus onset with a step size of 20 ms were transformed subject- and condition-wise into a three-dimensional distribution of cortical activation. The sLORETA solution space is restricted to cortical gray matter and hippocampus, defined via the MNI (*Montreal Neurological Institute*) reference brain and subdivided into 6239 voxels, with a spatial resolution of 5 x 5 x 5 mm. The previously acquired individual electrode positions were then cross-registered to the standard Talairach space (Talairach & Tournoux, 1988) and reconciled with the estimated cortical activation patterns. A regularization parameter of zero was used for transformation, thus achieving the smoothest of all possible solutions. Overall signal-to-noise-ratio was set at 100 during the transformation process. Differences in activation patterns between conditions were obtained by calculating paired-sample t-values using log-transformed sLORETA values. The first contrast of interest was negative feedback vs. positive feedback for which the two (i.e. facial and symbolic) negative and the two positive feedback conditions were averaged, respectively. Neural activations in the FRN and P3 time range were investigated using Statistical non-parametric Mapping (SnPM; Nichols & Holmes, 2002), implemented in the sLORETA software. In addition several between-subjects contrasts were applied in order to detect personality effects. These analyses were carried out for sLORETA averages (negative vs. positive or all conditions averaged). The resulting T_{max} statistic is based on 5000 permutations, i.e. randomly drawn configurations of data of conditions tested against the original configuration. The significance level was set at $p \leq .05$, two-tailed.

6.4. Questionnaire Data

In order to account for meaningful theoretical relationships between personality factors Pearson correlations between personality factors being associated with ERP amplitudes were calculated. In addition, correlations between the PPI-R higher-order factors were calculated for theoretical reasoning.

Results

7. ERP Analysis

7.1. Electrode Site, Block, Sign-Valence Allocation

The inclusion of an additional within-subject factor electrode site (Fz, FCz, Cz) for the FRN analysis revealed main effects for valence and form not reported here because these were explored at the electrode site of the largest FRN amplitude. Here, only the interactions with electrode site and main effects of electrode site were of interest.

As far as the main effect of electrode site is concerned, Mauchly's W (2) indicated a violation of the assumption of sphericity (p = .009). Therefore Greenhouse-Geisser correction was applied and revealed a significant main effect of electrode site ($F_{(2,42)}$ =10.737, p = .001, η^2 = .331). Post-hoc Bonferroni tests indicated that Fz differs significantly from FCz ($p < .001$) and Cz (p = .01) but FCz and Cz do not differ significantly (p = 1.000). However, descriptive statistics show the largest FRN amplitude at Cz. In addition, applying Greenhouse-Geisser correction after detected violation of sphericity (p = .001), there was a significant interaction of electrode site x form ($F_{(2,42)}$ = 10.139, p = .002, η^2 = .326), indicating a trend of divergence of faces to be of higher amplitude at Cz.

Therefore, electrode site Cz seems to be more sensitive for answering the research questions of interest and FRN main analyses will focus on this electrode location only. Cz was repeatedly used to analyze the feedback-related negativity in former studies (e.g. Holroyd and Coles, 2002).

The inclusion of the additional factors block or sign did not reveal any significant effects at both electrode site Cz regarding FRN or electrode site Pz regarding P3 amplitude.

7.2. Peak Latencies

Mean latencies of the peaks of the FRN at electrode site Cz were 213.91 ms in the negative facial feedback condition, 214.36 ms in the negative symbolic feedback condition, 210 ms in the positive facial feedback condition, and 216.20 ms in the positive symbolic feedback condition. For the positive feedback conditions trials where no feedback related negativity was detectable were excluded from this analysis.
Mean latencies for the peaks of the P3 at electrode site Pz were 388 ms in the negative facial feedback condition, 336.36 ms in the negative symbolic feedback condition, 364.55 ms in the positive facial feedback condition, and 326.18 ms in the positive symbolic feedback condition.

7.3. FRN – Peak-to-Peak-Amplitudes

The general statistical ANOVA model with valence and form as repeated measures revealed a significant main effect of valence ($F_{(1,21)} = 11.780$, $p = .003$, $\eta^2 = .359$) indicating that FRN amplitude was larger for negative than for positive feedback. Moreover, there was also a significant main effect for the factor form ($F_{(1,21)} = 18.831$, $p < .001$, $\eta^2 = .473$) indicating that faces elicited larger negativities than signs. The valence x form interaction was not significant ($p = .41$). Grand-average waveforms at Cz of all four conditions are displayed in Fig. 5.

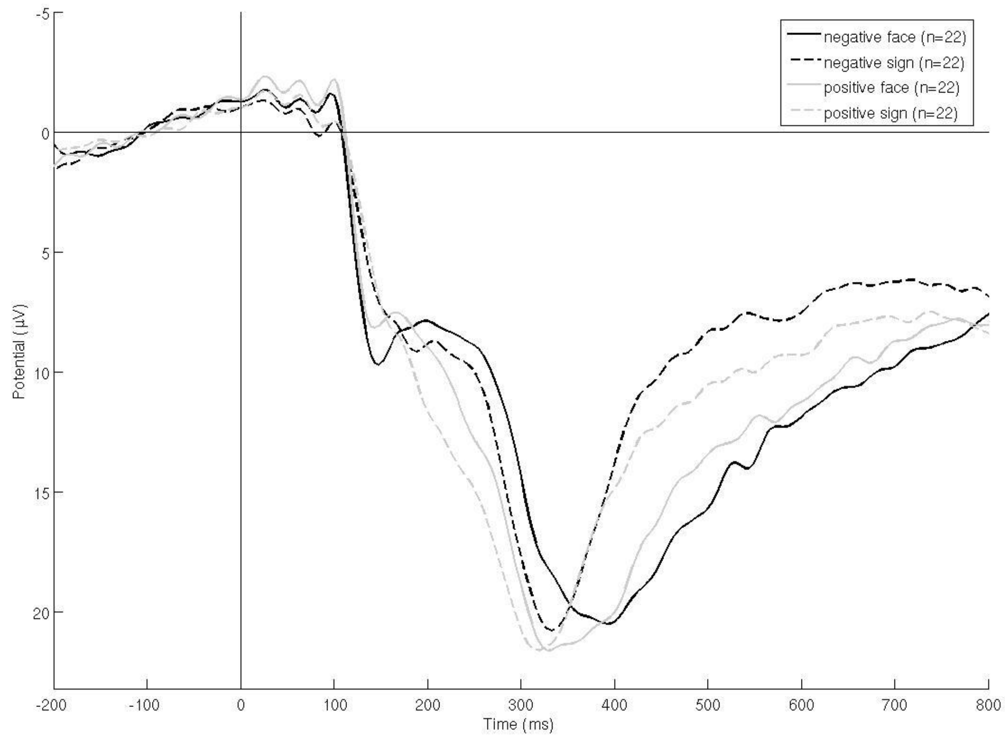

Fig. 5: Grand-average waveforms at Cz for all four conditions (negative facial feedback, negative symbolic/sign feedback, positive facial feedback and positive sign feedback).

As far as personality factors are concerned, the general linear model was extended with additional between-subject factors, one extended model for a single personality factor. The theoretically based approach regarding psychopathy was first to test the effects of the higher-order PPI-R factors Fearless Dominance and Self-Centered Impulsivity. None of these higher-order factors revealed significant interaction or between-subject effects. However, descriptive statistics showed a lower FRN for subjects higher in Fearless Dominance and vice versa for Self-Centered Impulsivity. The next step was to analyze the specific sub-factors with a special interest in the socio-emotional factors that constitute Fearless Dominance, especially Social Influence. There was a significant between-subjects effect of Social Influence ($F_{(1,20)} = 9.06$, $p = .007$, $\eta^2 = .312$), indicating smaller FRN amplitudes in subjects scoring high on Social Influence. This finding remains significant when comparing with a more conservative alpha-adjusted significance threshold of $p = .016$, considering the three subfactors of Fearless Dominance. Grand-average waveforms for subjects scoring high and low in Social Influence are shown in Fig. 6. Please note for figures of personality effects the doubling of the n-number compared to the actual number of subjects in the subgroups due to inclusion and averaging of both face and sign conditions, i.e. n = 22 represents 11 subjects.

As far as the subfactors of Self-Centered Impulsivity are concerned none had a significant effect. However, from a liberal perspective, there was a trend to significance for the between-subject effect of Carefree Nonplanfulness ($F_{(1,20)} = 3.36$, p (no alpha-adjustment) = .082, η^2 = .144), indicating that there might be a trend for higher Carefree Nonplanfulness being associated with higher FRN amplitudes. There were no significant findings for the other PPI-R subdimensions.

The main effects for valence (p = .003) and form (p < .001) remained significant when including these PPI-R subfactors.

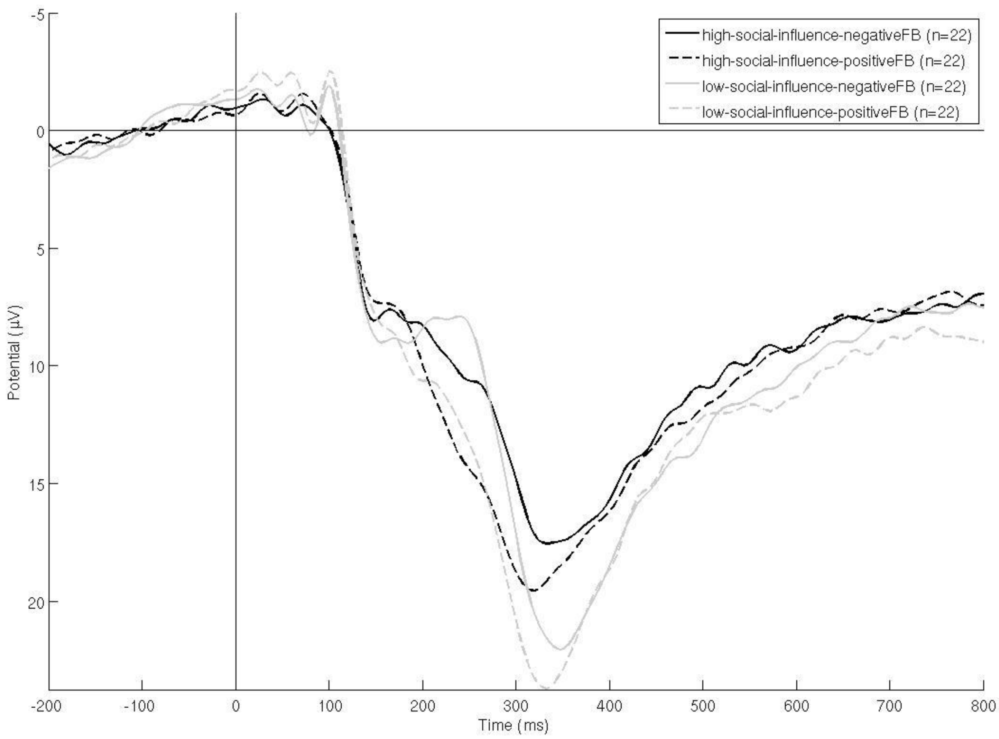

Fig. 6: Grand-average waveforms at Cz for subjects scoring high and low on PPI-R Social Influence for negative and positive feedback (face and sign conditions averaged).

As far as the LSAS is concerned, there were no significant effects for the LSAS total score. However, there was a significant between-subjects effect for the subscale Avoidance Behavior ($F_{(1,20)} = 6.302$, $p = .021$, $\eta^2 = .24$), indicating that higher social anxiety is associated with higher FRN amplitudes. Main effects for valence ($p = .003$) and form ($p < .001$) remained significant. At least in the descriptive statistics the same trend exists for the second subscale Fear/Anxiety, but is not statistically significant ($p = .557$). Grand-average waveforms for the subscale Avoidance Behavior are shown in Fig. 7.

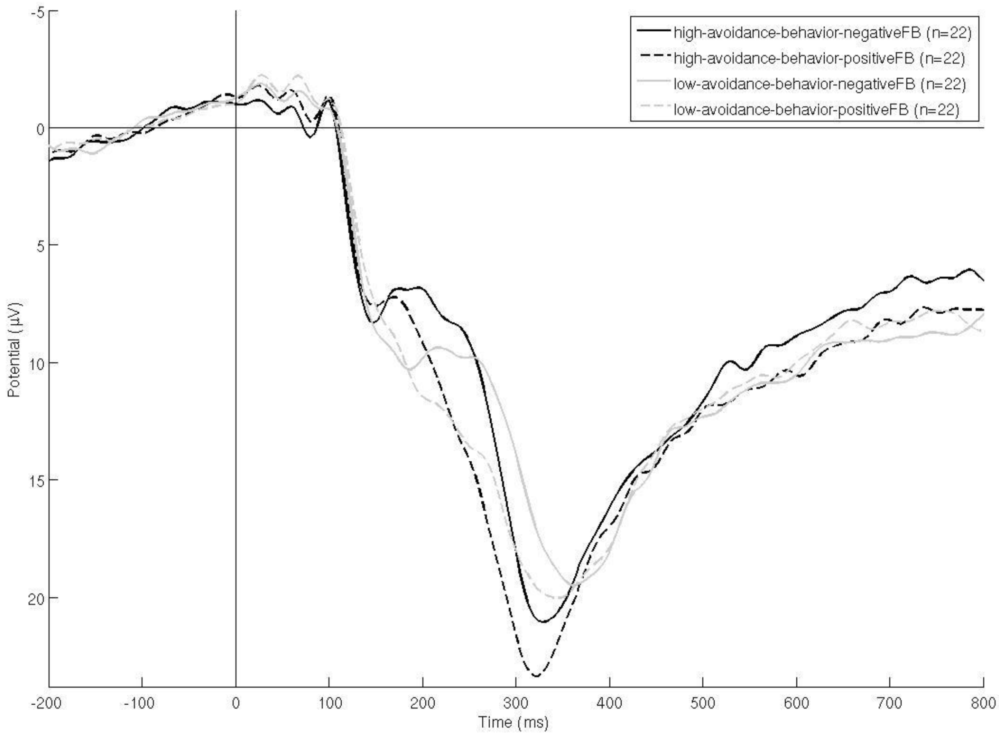

Fig. 7: Grand-average waveforms at Cz for subjects scoring high and low on LSAS Avoidance Behavior for negative and positive feedback conditions (face and sign conditions averaged).

As far as the SEE is concerned, there were no significant personality effects. However, from a very liberal perspective, there was a trend for the between-subject effects of Emotion Regulation ($F_{(1,20)} = 2.815$, $p = .109$, $\eta^2 = .123$) with higher Emotion Regulation being associated with smaller FRN amplitudes. The main effects for valence ($p = .006$) and form ($p = .001$) remained significant.

7.4. P3 – Base-to-Peak-Amplitudes

The general statistical ANOVA model with valence and form as repeated measures revealed a significant main effect of valence ($F_{(1,21)} = 4.456$, $p = .047$, $\eta^2 = .175$) indicating that P3 amplitude was larger for positive than for negative feedback. Moreover, a significant main effect for form emerged ($F_{(1,21)} = 4.419$, $p = .048$, $\eta^2 = .174$) indicating that faces elicited a larger P3 than signs. The valence x form interaction was not significant ($p = .836$). Grand-average waveforms for all four conditions are shown in Fig. 8.

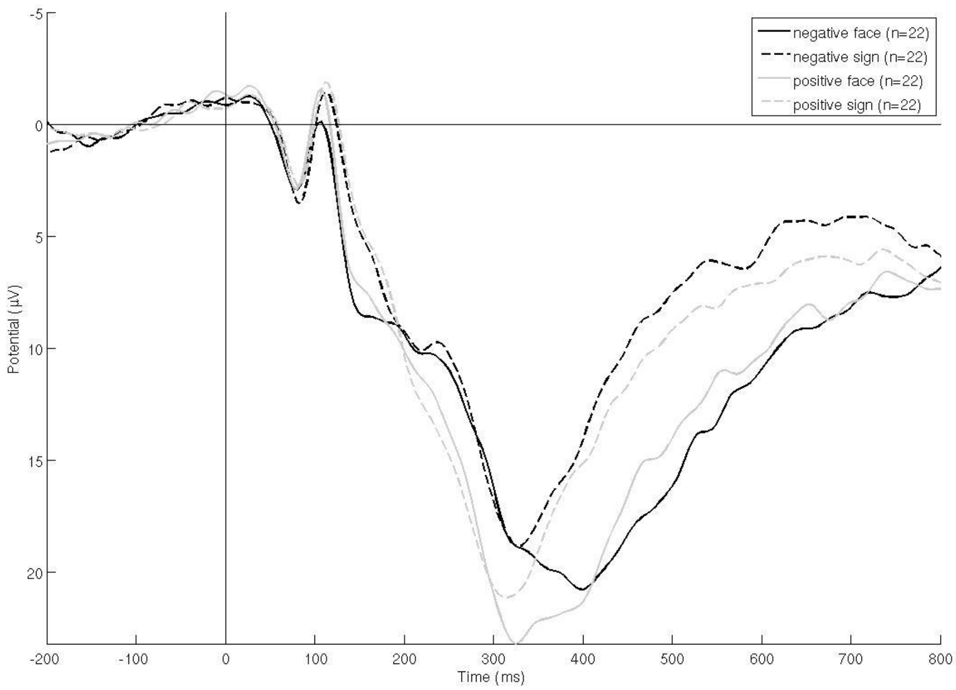

Fig. 8: Grand-average waveforms at Pz for all four conditions (negative facial feedback, negative symbolic/sign feedback, positive facial feedback and positive sign feedback).

As far as personality factors are concerned, the same procedure was applied as for the FRN. The general linear model was extended with additional between-subjects factors, one extended model for a single personality factor. The theoretically based approach regarding psychopathy was first to test the effects of the higher-order PPI-R factors Fearless Dominance and Self-Centered Impulsivity. Neither these higher-order factors, nor their subscales revealed significant effects.

However, for Coldheartedness, a factor not being associated with Fearless Dominance or Self-Centered Impulsivity from a factor-analytic point of view, an exploratory analysis revealed a significant valence x Coldheartedness-interaction ($F_{(1,20)} = 6.156$, $p = .022$, $\eta^2 = .235$), indicating that the subjects scoring higher on Coldheartedness displayed smaller P3 amplitudes for negative feedback stimuli, but not for positive ones. The main effects for valence ($p = .047$) and form ($p = .035$) remained significant. Grand-average waveforms for subjects scoring high and low on the Coldheartedness scale in the PPI-R are shown in Fig. 9.

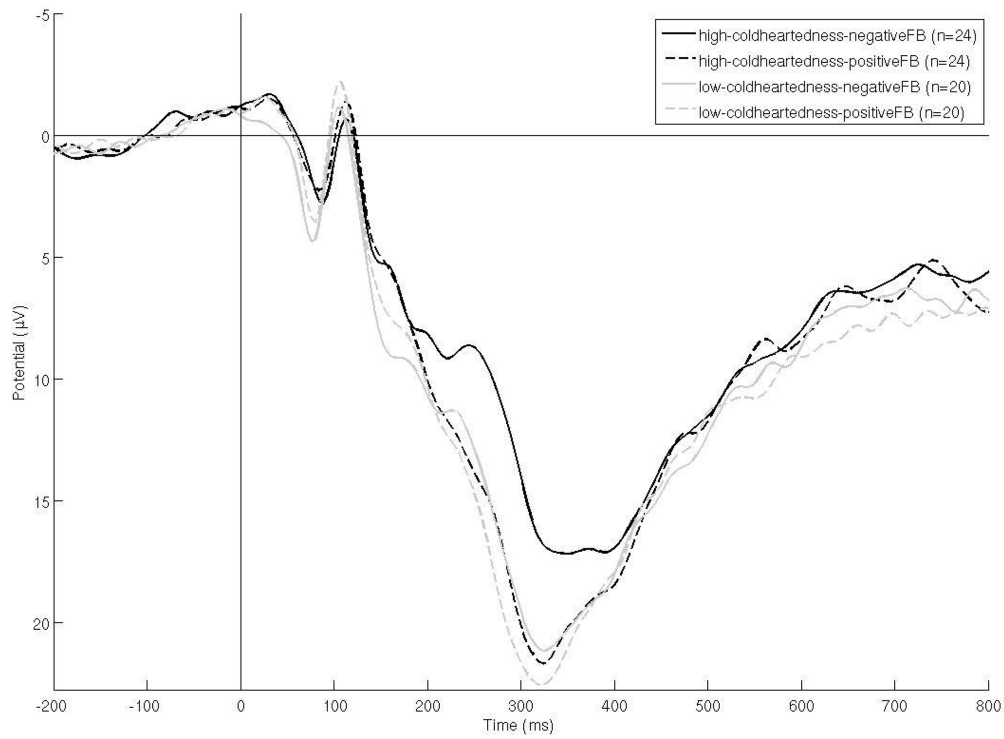

Fig. 9: Grand-average waveforms at electrode site Pz for subjects scoring high and low on PPI-R Coldheartedness for negative and positive feedback conditions (face and sign conditions averaged).

As far as the LSAS is concerned, there were no significant results. When testing SEE-subscales, two significant between-subject effects were evident, one for Body-Related Symbolization ($F_{(1,20)} = 9.358$, $p = .006$, $\eta^2 = .319$) with higher Body-Related Symbolization scores being associated with larger P3. However, a valence x Body-Related Symbolization interaction was also significant ($F_{(1,20)} = 16.466$, $p = .001$, $\eta^2 = .452$), indicating that subjects scoring lower on this scale showed lower P3 amplitudes particularly for negative feedback. The main effect for valence ($p = .012$) remained significant and the main effect for form ($p = .051$) with a trend to significance. The second between-subjects effect was for Emotion Regulation ($F_{(1,20)} = 4.383$, $p = .049$, $\eta^2 = .180$), indicating that the P3 is smaller for subjects scoring higher on Emotion Regulation. Here the main effects for valence ($p = .088$) and form ($p = .063$) remained with a trend to significance. Grand-average waveforms for subjects scoring high and low in the Body-Related Symbolization scale are shown in Fig.10, for the Emotion Regulation scale see Fig. 11.

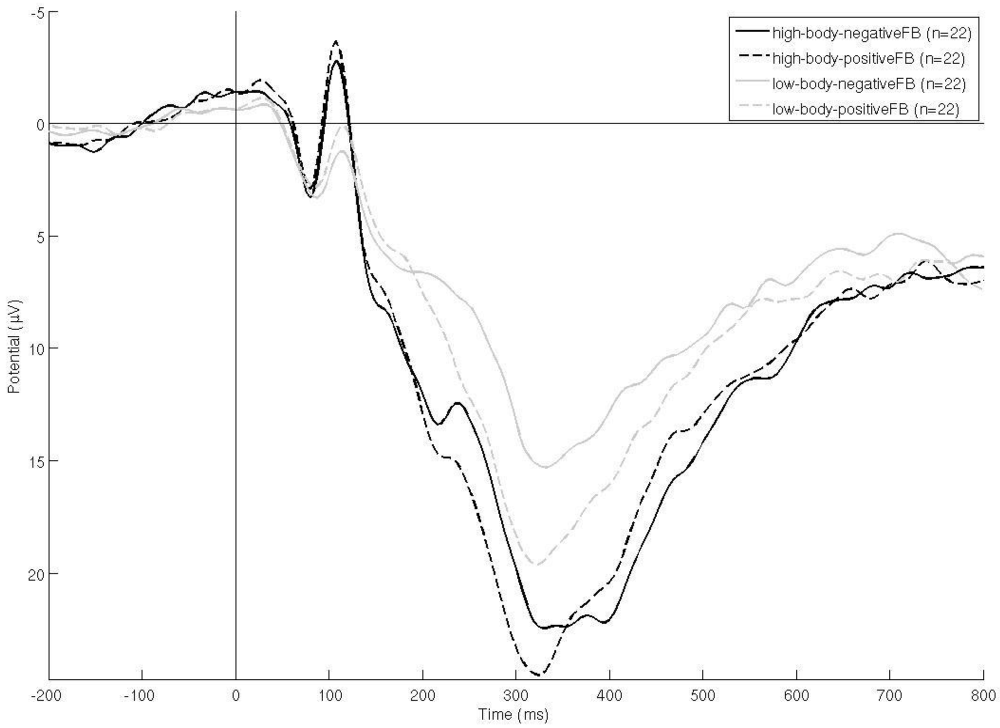

Fig. 10: Grand-average waveforms at electrode site Pz for subjects scoring high and low on SEE Body-Related Symbolization for negative and positive feedback conditions (face and sign conditions averaged).

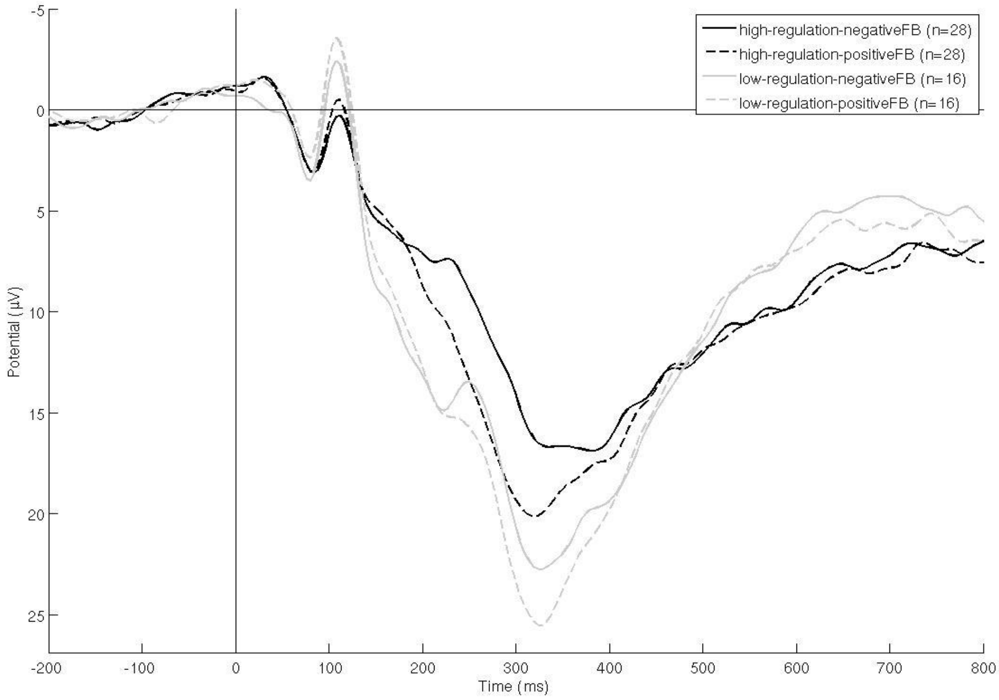

Fig. 11: Grand-average waveforms for subjects scoring high and low on the Emotion Regulation scale of the SEE for negative and positive feedback conditions (face and sign conditions averaged).

8. Source Analysis

A comparison of sLORETA averages for negative and positive feedback with SnPM reached significance in the following activation maxima and time frames: higher activity in the right insula (BA 13) for positive faces, 260-280 ms post-stimulus, as well as in the right precentral gyrus (BA 4), 300-320 ms post-stimulus, in the left lingual gyrus (BA 19), 320-340 ms post-stimulus, and in the left parahippocampal gyrus (BA 36), 340-360 ms post-stimulus after positive feedback (Table 2 and Fig. 12-15). The specific comparison between negative faces and positive faces revealed significant higher activation for positive faces in the right insula (BA 13), 260-280 ms post-stimulus and in the left inferior parietal lobule (BA 40), 320-340 ms post-stimulus.

The comparison of SLORETA averages for faces and signs with SnPM reached significance in a number of visual areas amongst others (see Table 3 for details). Faces revealed higher activity in most of these brain areas except for the right superior frontal gyrus (BA 8), showing more activation for signs in a time range of 280-340 ms post-stimulus.

Table 2: Between-conditions sLORETA comparisons (p < .05) showing areas with larger activation in the positive feedback than in the negative feedback condition.

Interval after Stimulus Onset	T-Value	MNI coordinates (x, y, z)	Brodmann area	Description
260-280 ms	-7.32	35, -20, 15	13	Right Insula
300-320 ms	-8.50	45, -10, 55	4	Right Precentral Gyrus
320-340 ms	-6.51	-15, -60, -5	19	Left Lingual Gyrus
340-360 ms	-7.20	-35, -30, -20	36	Left Parahippocampal Gyrus

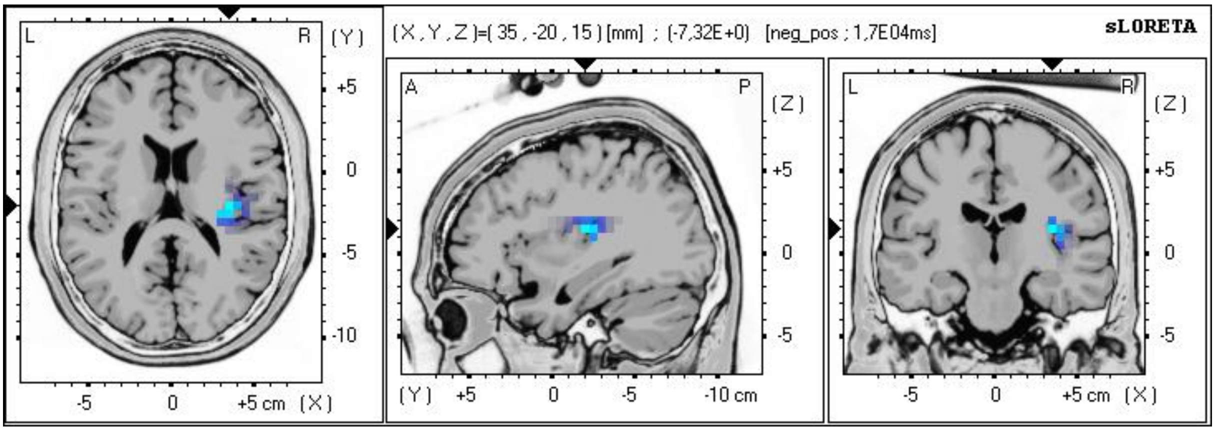

Fig. 12: sLORETA-based SnPM images: Higher activation in the right insula for positive feedback compared to negative feedback, 260-280 ms post-stimulus. Estimated cortical activation is shown from three perspectives (axial, sagittal, and coronal view), displayed with a scale exponent of 6.4.

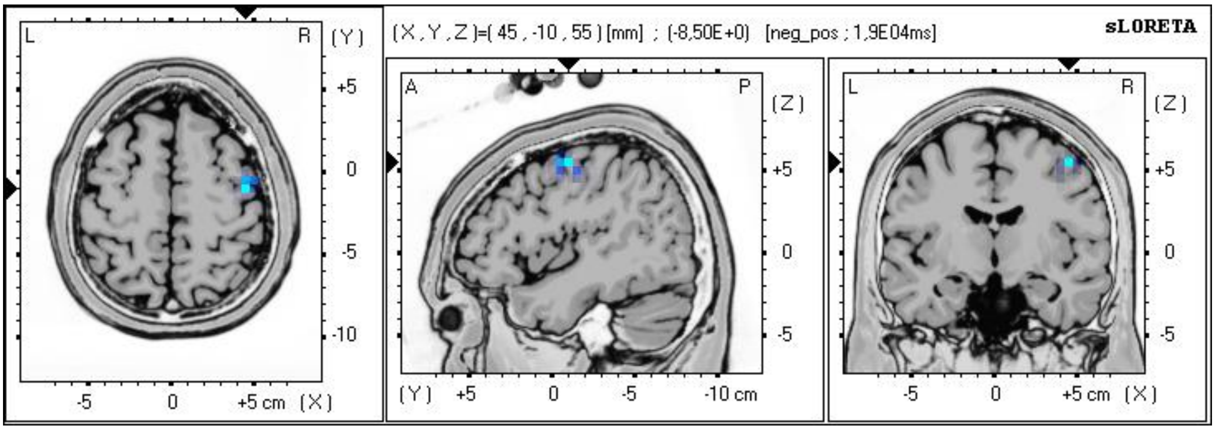

Fig. 13: sLORETA-based SnPM images: Higher activation in the right precentral gyrus for positive feedback compared to negative feedback, 320-340 ms post-stimulus. Estimated cortical activation is shown from three perspectives (axial, sagittal, and coronal view), displayed with a scale exponent of 6.4.

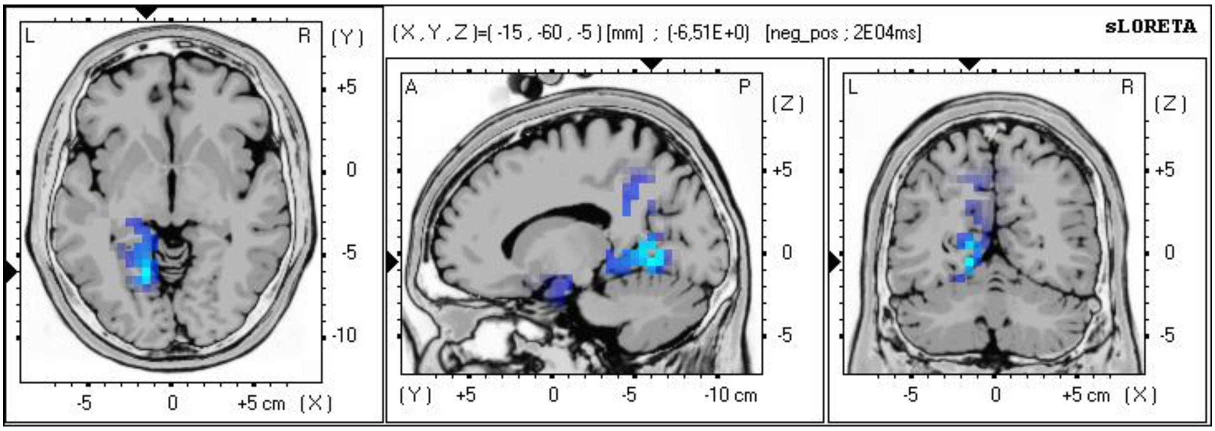

Fig. 14: sLORETA-based SnPM images: Higher activation in the left lingual gyrus for positive feedback compared to negative feedback, 320-340 ms post-stimulus. Estimated cortical activation is shown from three perspectives (axial, sagittal, and coronal view), displayed with a scale exponent of 6.4.

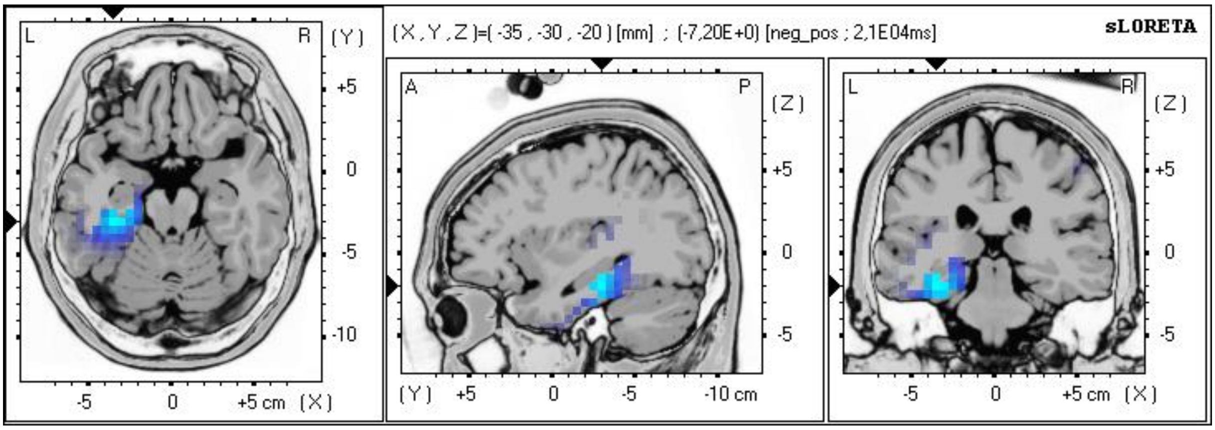

Fig. 15: sLORETA-based SnPM imges: Higher activation in the left parahippocampal gyrus for positive feedback than for negative feedback, 340-360 ms post-stimulus. Estimated cortical activation is shown from three perspectives (axial, sagittal, and coronal view), displayed with a scale exponent of 6.4.

Table 3: Between-conditions sLORETA comparisons (p < .05) showing areas with larger activation in the facial feedback than in the symbolic feedback condition with the exception of superior frontal gyrus activity, which was larger for sign feedback.

Interval after Stimulus Onset	T-Value	MNI coordinates (x, y, z)	Brodmann area	Description
80-100 ms	7.42	35, -40, 70	2	Right Postcentral Gyrus
120-140 ms	6.75	35, -40, 70	2	Right Postcentral Gyrus
160-180 ms	9.05	5, -65, 25	31	Right Precuneus
180-200 ms	6.71	-5, -75, 20	31	Left Precuneus
200-220 ms	8.68	-20, -95, 20	19	Left Cuneus
220-240 ms	8.79	-25, -95, 20	19	Left Cuneus
240-260 ms	8.63	-40, -70, 35	39	Left Precuneus
280-300 ms	-6.97	5, 35, 55	8	Right Superior Frontal Gyrus
300-320 ms	-8.94	5, 35, 50	8	Right Superior Frontal Gyrus
320-340 ms	-7.79	5, 40, 55	8	Right Superior Frontal Gyrus

As far as personality factors are concerned, there was only one effect of significantly higher activation in the left superior temporal gyrus (BA 22) for negative feedback for subjects scoring lower compared to higher scoring subjects on PPI-R Social Influence (Fig. 16). Additionally, there was higher activity in the left inferior parietal lobule (BA 40) 200-220 ms post-stimulus for subjects scoring higher in SEE Body than for lower-scoring subjects for all conditions (Fig. 17).

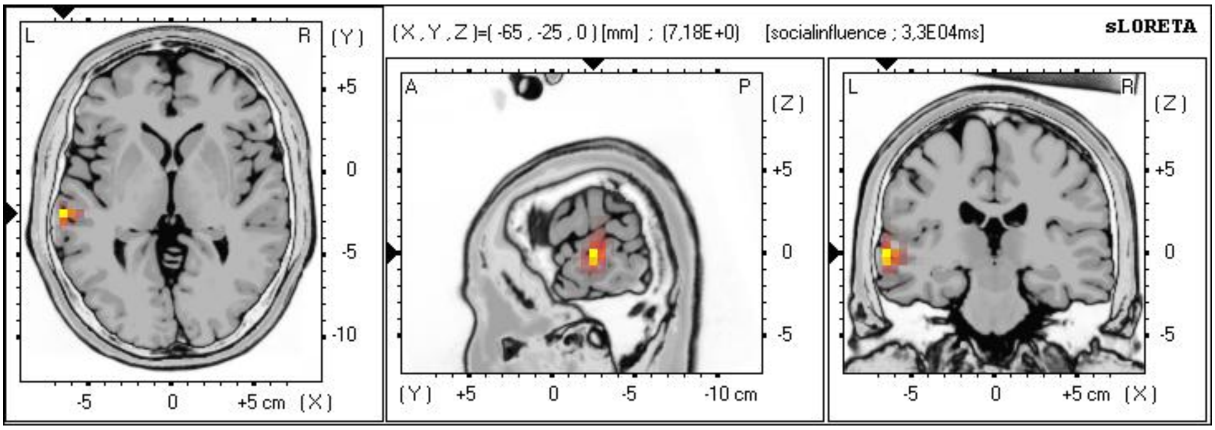

Fig. 16: sLORETA-based SnPM images: Higher activation in the left superior temporal gyrus for subjects scoring lower in Social Influence, 580-600 ms post-stimulus. Estimated cortical activation is shown from three perspectives (axial, sagittal, and coronal view), displayed with a scale exponent of 6.69.

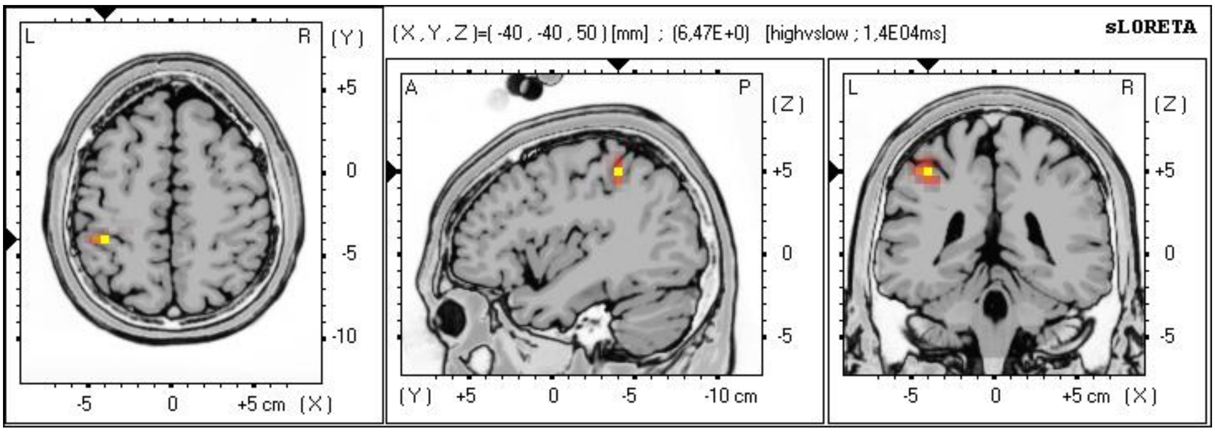

Fig. 17: sLORETA-based SnPM images: Higher activation in the left inferior parietal lobule for subjects scoring higher in Body-Related Symbolization, 200-220 ms post-stimulus. Estimated cortical activation is shown from three perspectives (axial, sagittal, and coronal view), displayed with a scale exponent of 6.4.

9. Questionnaire Data

The PPI-R higher-order factors Fearless Dominance and Self-Centered Impulsivity are negatively correlated, although not significant (r = -.209, p = .349). The respective subfacets Social Influence and Carefree Nonplanfulness are also negatively but not statistically significantly correlated (r = -.106, p =.639).
The LSAS total score is negatively correlated with PPI-R Fearless Dominance (r = -.67, p = .001) and Social Influence (r = -.583, p = .004) and positively with PPI-R Self-Centered Impulsivity (r = .447, p = .037) and Carefree Nonplanfulness with a trend to significance (r = .366, p = .094).
In addition there is a substantial correlation between LSAS total score and SEE Emotion Regulation (- .460, p = .031).

Discussion

The aim of this study was to investigate the effects of differences in the socio-emotional salience of feedback stimuli as well as influences of socio-emotional personality factors on feedback processing reflected in electrophysiological processes such as the FRN and feedback P3.

10. Socio-Emotional Salience of Feedback Stimuli

Regarding the impact of socio-emotional modulation of feedback processes, the finding of an increased FRN for negative feedback reported by Miltner et al. (1997) could be replicated. We also observed higher FRN amplitudes for negative compared to positive feedback, both in faces and symbols. Therefore, next to symbolic feedback, emotional faces can also serve as feedback stimuli since they elicit distinct FRN amplitude deflections for negative and positive feedback conditions and faces displaying emotions may serve as an adequate tool for investigating the interaction between affective processing and functions associated with the FRN.
Moreover, the FRN is larger for emotional faces than for signs in both positive and negative feedback conditions. Wiswede et al. (2009) observed increased ERN amplitudes after

negative emotional induction by unpleasant IAPS images preceding performance errors. On the other hand, Larson, Perlstein, Stigge-Kaufman, Kelly, and Dotson (2006) reported increased ERN amplitudes after presenting flanker stimuli superimposed on pleasant compared to unpleasant or neutral IAPS pictures. The effect was attributed to the mismatch between pleasant stimuli and errors, but Wiswede et al (2009) consider the unusually long response times in the study of Larson et al. (2006) to indicate an attentional shift away from the flanker stimuli to the affective pictures leading to more salient errors and an increase in the ERN. Whereas Wiswede et al. (2009) and Larson et al. (2006) focused on error monitoring in tasks where subjects are able to self-monitor errors, feedback processing reflected in the FRN might also be emotionally modulated with regard to the different socio-emotional salience of facial and symbolic feedback.

The amplitude increase in the FRN was not restricted to the negative feedback condition. Faces elicited higher FRN amplitudes in both the negative and positive feedback condition and the valence x form-interaction was not significant. It is not surprising that socio-emotional salience also modulates the FRN/CRN after correct feedback, as smaller negative deflections after correct performance or feedback have been reported previously (e.g. Vidal et al., 2000) and have also been shown to be modulated by short-term emotional induction (Wiswede et al., 2009) or affective traits (Hajcak et al., 2003) as well as their negative feedback counterparts. Whether these negativities are uniquely associated with processing of negative valence or index both processing of negative and positive reward value remains a matter of debate.

One important issue is the nature of the neural mechanisms underlying this affective modulation of the FRN. Ashby, Isen, and Turken (1999) propose that affect influences cognition via changes in the dopamine release in the mesencephalic dopamine system projecting to other areas. However, there is a variety of emotional and neurotransmitter systems and probably more of them are involved in emotional modulation. The noradrenergic system has also been suggested to play a role in modulating error monitoring, which was also pointed out by Wiswede et al. (2009). The ACC receives noradrenergic projections from the locus coeruleus (Berger, 1992) and noradrenergic stimulation has been shown to increase ERN amplitudes (Riba, Rodriguez-Fornells, Morte, Münte, & Barbanoj, 2005). One function of the noradrenergic system could be to enhance signal-to-noise ratio in information processing (Servan-Schreiber, Printz, & Cohen, 1990). Such neurotransmitter effects and the involvement of associated structures should be addressed in future investigations, e.g. in fMRI studies and modeling of possible effects from one structure on the other, PET-studies with the possibility to image neurotransmitter effects, or in animal single-cell recording studies.

As far as source analysis is concerned, sLORETA findings indicate a variety of brain areas differentially activated by faces and signs, but not in the ACC. With regard to the role of the mesencephalic dopamine system or locus coeruleus suggested above, EEG source analysis is not an adequate instrument to investigate subcortical activation. Among others sLORETA revealed more activation in visual cortices for faces (e.g. BA 19, see Table 3).

Whereas the FRN was larger for negative feedback stimuli, there appears to be a larger feedback P3 for positive stimuli, consistent with results from Hajcak et al. (2007) and Bellebaum and Daum (2008), but in contrast to findings of no difference (Yeung & Sanfey, 2004) or larger P3 for negative stimuli (Cohen et al., 2007; Mathewson et al., 2008). Yeung and Sanfey (2004) regard the P3 as valence-independent as there was no difference for negative and positive feedback, but coding for reward magnitude. However, in addition to the studies reporting valence effects, Philiastides et al. (2010) also found a valence-coding component in the P3 time range in a model-based single-trial EEG analysis with occipitopartieal scalp contributions overlapping with electrode site Pz investigated in our study. Taken together, there is strong evidence for a later valence-evaluation. According to Bellebaum and Daum (2008), feedback P3 might reflect a positive reward-prediction error in contrast to the FRN as a negative reward-prediction error, a view that would be consistent with the findings reported here.

As far as source analysis is concerned, sLORETA revealed higher activations of several cortical areas (right insula, right precentral gyrus, left lingual gyrus, and left parahippocampal gyrus) for positive compared to negative feedback in the P3 time range. Insular activity has been associated with P3 generation (Bledwoski et al., 2004), as well as the parahippocampal gyrus (Saletu et al., 2008). In addition, modality specific contributions in P3 generation have been reported (Linden, 2005), which might explain activity in the lingual gyrus as part of the visual associative cortex. Taken together, these activations add additional evidence for enhancement of feedback P3 by positive feedback.

Feedback P3 amplitudes are also higher for faces than for signs. Therefore, there might also be a modulation effect of the feedback P3, extending the notion of magnitude coding by the feedback P3 (Yeung & Sanfey, 2004) and the magnitude-related component found by

Philiastides et al. (2010) to magnitude coding in terms of differences in socio-emotional salience.

11. Socio-Emotional Personality Factors

11.1. Psychopathy

Results indicate differential contributions of subdimensions of psychopathy to feedback processing. PPI-R subfactor Social Influence (*Psychopathic Personality Inventory-Revised*; Alpers & Eisenbarth, 2008), a socio-emotional facet related with primary psychopathy, is associated with reduced FRN amplitudes, but not with P3 amplitudes. Social Influence is characterized by high resistance against social anxiety, high self-confidence, and by the use of communicative abilities to become the center of attention and to impress other people (Alpers & Eisenbarth, 2008). This finding corroborates and extends previous psychopathy research indicating impaired passive avoidance learning (Arnett et al. 1997), alterations in emotional processing (Blair, 2001; Munro et al., 2007), and reduced ERN amplitudes (Dikman & Allen, 2000, Munro et al., 2007). Arnett et al. (1997) found passive avoidance learning deficits specifically for PCL-R factor 1/primary psychopathy. Processing of negative feedback and adaptively altering subsequent behavior is a case of passive avoidance learning and the ERN/FRN have been linked to instrumental learning (Holroyd & Coles, 2002). The finding of reduced FRN amplitudes in Social Influence might therefore indicate deficient feedback processing and impaired passive avoidance learning in primary psychopathy. Moreover, as ERN/FRN-like deflections were also found for tasks with no action (Yeung et al., 2005) the FRN differences reported here could also indicate and explain differences in aversive (classical) conditioning (Birbaumer et al., 2005). Behavioral effects could be addressed in further research, as the task applied might not be adequate to study adaptive behavior changes as mentioned by Miltner et al. (1997).

ERN-studies investigating error-monitoring in tasks without feedback processing found reduced ERN amplitudes for individuals scoring high on psychopathy or related measures (Dikman & Allen, 2000; Munro et al., 2007). Dikman and Allen (2000) reported reduced ERN amplitudes for low-socialized individuals in conditions of punishment. The findings presented here extend this view to primary psychopathy and feedback processing, which is also related to punishment in the case of negative feedback. Munro et al. (2007) on the other hand found reduced ERN amplitudes related to psychopathy only in an emotional face-flanker task, but not in a standard letter-flanker task and referred to an emotional reactivity deficit and not a general error monitoring deficit. However, in the case of feedback processing, there seems to be a more general deficit, as both, symbolic and facial feedback processing, are equally affected. This might be due to the fact, that in the study of Munro et al. (2007) affective processing was associated with the task before error processing, whereas in our study socio-emotional information was provided in the feedback phase. Primary psychopathy might therefore be related to the (affective) processing of feedback stimuli and the FRN, but not self-provided error monitoring and the ERN. However, Munro et al. did not investigate subtypes of psychopathy. Therefore, there remains the possibility that primary psychopathy is also associated with the ERN, similar to the findings of Dikman and Allen (2000) regarding indicators of low socialization.

Contrary to the hypothesis, the effect of primary psychopathy was not larger on emotional face stimuli than on symbolic stimuli. Blair (2001) described emotion processing impairments particularly for fearful and sad faces. However, processing of angry faces might not be affected. Munro et al. (2007) included angry faces in their face flanker paradigm, but angry and fearful faces were pooled for ERP analysis, whereas behavioral data indicated no differences in error rates for angry faces. Moreover they did not investigate feedback processing. Another possible aspect is that feedback, although provided by a computer, still contains an interactive evaluative component or subjects scoring higher in Social Influence might react to the general feedback context rather than the socio-emotionality of the stimuli per se. On the other hand adaptation to the socio-emotional content of the repeatedly presented faces or insufficient statistical power for detecting interaction effects due to small sample size might be an issue.

Whereas Social Influence, theoretically linked to primary psychopathy, is associated with lower FRN amplitudes, Carefree Nonplanfulness, related to secondary psychopathy, showed a trend for higher FRN amplitudes. It is possible that that the impulsive, reactive characteristics of this subdimension result in enhanced processing of negative feedback.

Although the possible relationship between secondary psychopathy and the FRN need to be further explored, results clearly indicate that the distinction of subtypes of psychopathy is essential. The necessity of distinguishing subtypes is also highlighted by the questionnaire data. Carefree Nonplanfulness and Social Influence are negatively related, although not statistically significant. In addition, PPI-R and LSAS scores show specific correlations.

Whereas Social Influence and Fearless Dominance (primary psychopathy) are negatively related with LSAS scores, Carefree Nonplanfulness and Self-Centered Impulsivity (secondary psychopathy) are positively related with social anxiety scores. This corresponds to findings of Skeem et al. (2007) reflecting distinct phenotypical patterns of primary and secondary psychopathy.

Previous research demonstrated a significant impact of psychopathy and its subtypes on several neurobiological mechanisms and structures. Kiehl (2006) proposed a paralimbic system dysfunction model of psychopathy considering the orbital frontal cortex, insula, anterior and posterior cingulate, amygdala, parahippocampal gyrus, and anterior superior temporal gyrus to be implicated in psychopathy. Investigating subtypes of psychopathy, several researchers found differential activations in the amygdala (Blair, 2003; Gordon et al., 2004) and the present FRN findings indicate differential effects on feedback processing mediated in the ACC.

The amygdala (LeDoux, 2003) as well as the ACC (Knight, Cheng, Smith, Stein, & Helmstetter, 2004) have also been both associated with aversive conditioning, a behavioral characteristic also related to primary psychopathy (Birbaumer et al., 2005) as well as reflecting a possible functional characteristic of the FRN (Yeung et al., 2005). Bissière et al. (2008) studied the effects of exitotoxic lesions and temporal inactivations of a specific subregion of the rACC accounting for most of the connectivity with the basolateral amygdala in rats. Lesions and inactivation resulted in deficits in the early stages of classical fear conditioning, pointing to a modulatory influence of the ACC on the amygdala. In light of our FRN results, such an interaction of the ACC and amygdala in aversive conditioning might also be an important neural pathway in primary psychopathy. This possibility should be addressed in future research applying fMRI and connectivity analysis.

Apart from this “output path” related to aversive conditioning, investigations of “input paths”, i.e. how socio-emotional personality characteristics influence feedback processing, are desirable. Here, dopaminergic or noradrenergic contributions proposed for short-term socio-emotional effects above might also be central for longer-lasting personality effects.

With regard to the neural structures involved in the paralimbic psychopathy system proposed by Kiehl (2006) one sLORETA result deserves mention. We found lower activation in the left superior temporal gyrus in subjects scoring higher in Social Influence 580-600 ms post-stimulus (see Fig. 17). Not being in a typical time range for FRN processes, this activation might only contribute to later stages in information processing but was not accompanied by feedback P3 differences. Peak amplitude measurement led to a focus on earlier stages (see section 7.2. Peak Latencies), which might not be affected by this later activation. This sLORETA finding is interesting, as Kiehl (2006) considers the superior temporal gyrus as one structure of the paralimbic system, which is dysfunctional in psychopaths. More specifically, Kiehl et al. (2004) found reduced activations in the (right) superior temporal gyrus during processing of abstract words with fMRI. A possible involvement and functional significance of the superior temporal gyrus in feedback processing and primary psychopathy should be addressed in future research.

An additional remark should be made to the fact that FRNs for both negative and positive feedback condition were affected by the personality factors reported, a finding expected, because both ERN and CRN (correct-related negativity) were shown to be influenced by personality factors before (Hajcak et al., 2003).

As far as the feedback P3 is concerned, neither one of the PPI-R higher-order factors Fearless Dominance and Self-Centered Impulsivity nor their subfactors are associated with the P3 amplitude at electrode site Pz. However, when exploring PPI-R subdimensions, there was an unexpected significant effect: Coldheartedness, a PPI-R subfactor not being associated with Fearless Dominance or Self-Centered Impulsivity in previous factor analyses, as pointed out by Alpers & Eisenbarth (2008), seems to be related to reduced processing of negative feedback reflected in the P3. Coldheartedness is described as a more conscious empathy construct (Alpers & Eisenbarth, 2008). Interestingly, Leng and Zhou (2010) found interpersonal relationship to modulate P3 but not FRN. Participants were confronted with monetary feedback to one’s own behavior, to the performance of a friend or of a stranger in a gambling task. Although feedback related to one’s own performance was accompanied by the largest P3 amplitudes, the P3 was larger when observing feedback for friends compared to strangers, which might reflect empathic processes modulating later cognitive appraisal processes but not earlier in part automatic processes. There were no differences in interpersonal relationships in our experiment, but lower PPI-R Coldheartedness scores might index lower conscious empathy, possibly explaining the P3 modulation effect.

11.2. Social Anxiety

Our findings indicate that social anxiety is associated with feedback processing reflected in the FRN. The Avoidance Behavior subscale of the LSAS (*Liebowitz Social Anxiety Scale*; Stangier & Heidenreich, 2005) is associated with higher FRN amplitudes, but not related to the P3. This is in line with previous ERN findings showing higher amplitudes for subjects scoring higher on a questionnaire measuring general levels of worry and anxiety (Hajcak et al., 2003).

Fear of negative evaluation plays a key role in social anxiety, letting individuals expect critical and negative evaluations as well as higher required standards in social encounters (Rapee & Heimberg, 1997). This cognitive vulnerability may play a fundamental role in feedback processing, as feedback context is of evaluative nature.

As already mentioned in the previous section, the ACC and amygdala are both associated with fear conditioning (Bissière et al., 2008). Enhanced amygdala activation to the presentation of emotional human faces has been shown in people with social anxiety disorders (Birbaumer et al., 1998). In addition, our FRN results suggest a contribution of the ACC. A possible etiological factor in social anxiety may therefore be an interaction of ACC and amygdala in fear conditioning to social stimuli, which could be further investigated in both subclinical social anxiety as well as social anxiety disorders.

However, issues of specificity remain, i.e. whether there are differences compared to other anxiety disorders or whether there are underlying general personality traits (e.g. negative affect, Luu et al., 2000). Hajcak et al. (2003) found no increase in ERN amplitudes for undergraduates scoring high on measures of specific anxiety toward snakes or spiders. Social anxiety may differ from these specific anxieties. Another explanation would be that the increased FRN for social anxiety is due to the evaluative aspect of feedback. Further research could address this issue by investigating the ERN in experimental paradigms without feedback and special care to create a non-evaluating atmosphere.

Contrary to our hypothesis, the modulation was not larger for facial feedback than for symbolic feedback. Increased activations in emotion-related brain areas (amygdala, medial OFC, subgenual cingulate, parahippocampal gyrus) especially after facing social threatening stimuli, e.g. harsh faces, but not physical threat stimuli, were reported in individuals with high social anxiety compared to controls (Goldin et al., 2009). However, symbolic feedback used in our study may be processed as socially relevant as angry faces, due to the general evaluative nature of feedback. Moreover, in terms of feedback processing, socially anxious individuals might react to the general feedback context rather than the socio-emotional salience of the stimuli per se. Other explanations for equal FRN modulations by faces and signs would be adaptation to repeated exposure to feedback stimuli equalizing socio-affective salience or insufficient statistical power for detecting interaction effects due to smaller sample size.

11.3. Body-Related Emotional Experience

Our results indicate that self-reported sensitivity to body-related emotional processes is associated with feedback processing reflected in the FRN. As far as the SEE (*Emotional Experiences Scale*; Behr & Becker, 2004) is concerned, there was a significant effect for the Body-Related Symbolization subscale indicating that higher body-related emotional experience or awareness seems to be related with increased processing of feedback, with lower attention to emotions especially affecting negative feedback processing reflected in the P3. This is partly in line with findings of higher P3 amplitudes as well as higher subjective intensity of emotional experience for subjects showing higher interoceptive sensitivity indexed as sensitivity to heartbeat after viewing pleasant, neutral and unpleasant images (Herbert et al., 2007), whereas the SEE subscale seems to be more strongly related to the processing of negative than positive feedback in terms of P3. However, inspection of the subscale items reveals that the focus lies on body-related processes mainly related to negative emotions (itchy skin, knots in the stomach, etc.). Contrary to our hypothesis there is no difference regarding facial and symbolic feedback. Both stimuli types might elicit at least similar emotional responses.

The Body-Related Symbolization-Subscale of the SEE (Emotional Experiences Scale; Behr & Becker, 2004) reflects the attention one pays to body-related responses to emotional events. Behr and Becker (2004) illustrate that this subscale also correlates with the TAS (*Toronto Alexithymia Scale*; Kupfer, Brosig, & Braehler, 2001) subscale Difficulties in Describing Feelings (r = -.38) and with Attention to Feelings (r = .53) of the TMMS (T*rait Meta Mood Scale*; Otto, Döring-Seipel, Grebe, & Lantermann, 2001), thus also indicating that this subscale reflects more attentive and conscious aspects of emotion processing, which might suggest a link between cognitive processing of body-related emotional processes considered important in modern emotion theories and the (feedback) P3 component.

11.4. Emotion Regulation

We observed event-related potentials to be related to emotion regulation. There was a significant effect for the SEE subscale Emotion Regulation, statistically significant at least for the P3, indicating emotion regulation to be associated with lower P3 amplitudes.

Investigating temporal dynamics with ERPs, reduced LPPs – late positive potentials (i.e. P3) were reported in subjects applying cognitive reappraisal strategies, also consistent with a modal model of emotion processing proposing several processing stages (Hajcak & Nieuwenhuis, 2006; Moser et al., 2006; Moser et al., 2009) There are several strategies of emotion regulation and they may have different effects on neural and psychological processes. In light of the P3 findings mentioned, the SEE subscale applied might reflect a more cognitive later-stage emotional regulation strategy modulating feedback processing.

However, some studies studying effects of cognitive reappraisal instructions found modulating effects on ERPs 200 ms after presentation of affective stimuli (e.g. Hajcak & Nieuwenhuis, 2006) in situations where participants had more time to reappraise the stimuli, which could lead to an earlier impact, as Moser et al. (2009) pointed out. In the experimental paradigm applied in this study, subjects faced the same stimuli/events and had the possibility to apply the same emotion regulation strategy. Therefore, the individual tendency to regulate emotions might result in applying strategies modulating earlier feedback processing stages. From a very liberal perspective, there was a trend to significance for the between-subjects effect for SEE Emotion Regulation for the FRN, indicating decreased amplitudes for higher scoring subjects. sLORETA findings also show an earlier modulation of feedback processing 200-220 ms after feedback onset in the left inferior parietal lobule (Fig. 17). However, this area has been associated with the generation of the P3 (Bledowski et al., 2004). Therefore possible FRN effects need to be further investigated in future studies.

As far as the functional significance of P3 modulation by emotion regulation is concerned, Deveney and Pizzagalli (2008) suggested that lower P3 amplitudes might indicate a decrease in the amount of cognitive resources available, as they found reduced P3 amplitudes in verbal processing after participants were instructed to up-regulate unpleasant emotions compared to down-regulating or maintaining unpleasant emotions. However, the Emotion Regulation subscale of the SEE should rather be associated with a tendency to down-regulate and not to up-regulate negative emotions. Thus, the finding of decreased P3 amplitudes might not indicate reduced cognitive resources, but rather reduced affective feedback processing.

Functional and behavioral characteristics would be promising to be addressed in future research. For instance, the P3 has been related to attention (Polich & Kok, 1995) and context-updating in working memory (Donchin & Coles, 1988, 1998), and the Pe to conscious error awareness (e.g. Falkenstein et al., 2000).

12. Limitations

Although FRN and P3 differences in faces and signs could be attributed to differences in socio-emotional salience, there are possible alternative explanations. One shortcoming is that participants were not asked to rate the affective intensity of the stimuli used. Moreover, with regard to ERPs, other stimulus characteristics such as stimulus discriminability or memory accessibility (which may nevertheless also be related to the socio-emotional salience) might play a role. Another possibility is that stimulus characteristics of facial stimuli resulted in higher amplitudes in general. Although next to the FRN, feedback P3 amplitudes at electrode site Pz are also higher for faces than for signs, visual inspection at Cz (Fig. 5) seems not to indicate considerable effects on this electrode site for the P3 component, not indicating a general effect on all amplitudes. Visual inspection of ERPs in a study presenting faces compared to images of buildings (Hermann et al., 2002) neither indicates a general increase in amplitudes for faces, at least in the FRN time range.

The relationship between FRN or P3 amplitudes and stimuli differing in the socio-emotional salience might also be addressed with a different experimental design in future studies. Instead of symbolic feedback neutral faces assigned with a specific feedback character may be used as a second or maybe third feedback condition. By applying these stimuli, the impact of emotional salience on the observed results can be investigated. However, this would also be associated with some shortcomings – one focus and strength of the experimental paradigm, the socio-distinction would be eliminated and there probably remain differences in psychological processes depending on the task (e.g. the need to discriminate on the basis of face identity instead of emotions, etc.).

One fundamental psychological question is whether these differences reflect different processing of the feedback stimuli per se or more involvement in facial feedback situations. Hajcak et al. (2006) found the FRN to be magnitude-independent when using monetary outcomes and consider it to reflect a binary classification in good and bad outcomes. The block design applied confounds stimuli processing and task (block) involvement. A randomized presentation of facial and symbolic feedback stimuli could help to elucidate this matter, as participants would not be systematically more involved in one type of stimulus processing due to the block design. However, we decided to implement a block design to avoid additional cognitive processes (e.g. expectations about the nature of the next stimulus).

There are also some limitations concerning the personality factors investigated. Although the PPI-R is theoretically linked to the PCL-R there remain some differences. However, dimensions reflecting primary or secondary psychopathy show considerable overlap in these instruments. Moreover, the self-description instruments like the PPI-R are more applicable for non-clinical, non-offender populations.

In addition, it was shown that very broad personality concepts like negative affect influence error monitoring (Luu et al., 2000). Some studies included measures of negative affect to partial effects out in order to detect unique contributions of other personality factors of interest (Larson et al., 2010). Therefore, future studies might apply psychometric instruments measuring negative affect or other broad personality constructs. Moreover, social anxiety and primary psychopathy might share common variance accounting for feedback processing effects found, which could be addressed in more detail in future research.

Another limitation was the moderate sample size. Larger samples for investigating between-subject effects would be desirable and even more important for investigating interaction effects between personality and differences in the socio-emotional salience of feedback stimuli. Nevertheless, statistically significant effects, some even with large effect sizes were found and general patterns of feedback processing could be elucidated.

As far as detection of underlying neural sources is concerned, possible ACC activation needs to be further explored using other neuroimaging techniques (e.g., fMRI) than rather limited EEG source localization techniques such as sLORETA, as the latter did not show expected differences in activation of the ACC in the FRN time range. Technical limitations are probably due to the EEG inverse problem or insufficient sample size.

A final remark needs to be made for sample characteristics. To avoid any gender influence we included only female participants in the present study. Regarding personality factors, women tend to show lower levels of psychopathy in the self-descriptive questionnaire of psychopathy applied (Alpers & Eisenbarth, 2008), Nevertheless, natural variation in levels of psychopathy is considerable and reported effects may be even more interesting, as women have been studied to a lesser extent compared to men as far as psychopathy is concerned. However, replication studies consisting of male participants or mixed gender are desirable in order to secure generalizability.

13. Conclusion

Summarizing, feedback valence and probably differences in socio-emotional salience of feedback stimuli affect the FRN and feedback P3. Negative feedback was associated with higher FRN amplitudes, positive feedback with higher feedback P3 amplitudes. Emotional faces elicited higher amplitudes in feedback-related potentials than symbols.

Moreover, several socio-emotional personality factors were shown to modulate these components in distinct ways. Results extend the body of evidence that primary and secondary variants of psychopathy are associated with different neurophysiological processes. Social anxiety, body-related emotional experience and emotional regulation also modulate feedback processing in specific ways.

Findings suggest a strong interrelationship between socio-emotional processes and feedback processing.

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Appendix

14. Abstract (English)

Feedback processing is important for adaptively adjusting behavior and electrophysiologically reflected in the so-called feedback-related negativity (FRN) and feedback P3 of the event-related potential (ERP). Applying a time-estimation task, the present study investigated how the socio-emotional salience of the feedback stimuli (emotional faces vs. symbols) modulates the FRN and P3. Moreover, we were particularly interested how socio-emotional personality constructs such as psychopathy and anxiety affect the FRN and P3.

Negative feedback elicited a larger FRN, while positive feedback elicited a larger feedback P3. Faces displaying emotions led to larger FRN and P3 amplitudes than symbols, a finding which might be due to differences in the socio-emotional salience.

Personality showed distinct relationships consistent with literature. Primary psychopathy reflected in the subfactor Social Influence of the Psychopathic Personality Inventory-Revised was associated with lower FRN amplitudes, consistent with reported deficits in error monitoring and passive avoidance learning. Moreover, aspects of social anxiety in the Liebowitz Social Anxiety Scale were associated with increased FRN amplitudes, extending previous anxiety-related ERP findings to social anxiety and FRN. Lower scores in the subscale Body-Related Symbolization of the Emotional Experiences Scale (SEE), possibly reflecting lower interoceptive sensitivity, was associated with reduced P3 amplitudes when processing negative feedback, similar to previous ERP studies. The SEE subscale Emotion Regulation, reflecting self-report of emotional regulation competence, also modulated the P3 component, consistent with previous ERP findings and modal models of emotion processing.

Thus, the findings suggest a strong interrelationship between the salience of feedback stimuli, distinct personality factors, and feedback processing.

15. Abstract (German)

Die Verarbeitung von Feedback hat eine zentrale Bedeutung für adaptive Anpassungen des Verhaltens und wird elektrophysiologisch von der sogenannten feedback-related negativity (FRN) und der feedback P3 im ereigniskorrelierten Potential (EKP) repräsentiert. Die vorliegende Studie untersuchte die Modulation der FRN und P3 durch die sozio-emotionale Salienz von Feedbackreizen (emotionale Gesichter vs. Symbole) und in Bezug auf sozio-emotionale Persönlichkeitskonstrukte in einer Zeitschätzungsaufgabe.

Negatives Feedback ging mit einer höheren FRN einher, während positives Feedback mit einer größeren feedback P3 assoziiert war. Gesichter, die Emotionen ausdrücken, waren von höheren FRN- und P3-Amplituden begleitet. Dieses Ergebnis könnte auf Unterschiede in der sozio-emotionalen Salienz zurückgeführt werden.

Persönlichkeit war in Übereinstimmung mit früheren Studien mit spezifischen Zusammenhängen verbunden. Primäre Psychopathie, welche sich im Subfaktor Sozialer Einfluss des Psychopathic Personality Inventory-Revised (PPI-R) widerspiegelt, ging mit niedrigeren FRN-Amplituden einher, was mit berichteten Defiziten im Fehlermonitoring und im passiven Vermeidungslernen übereinstimmt. Andererseits waren Aspekte sozialer Angst in der Liebowitz Social Anxiety Scale (LSAS) mit erhöhten FRN Amplituden assoziiert, was frühere EKP-Ergebnisse in Studien über Ängstlichkeit auf soziale Ängstlichkeit und die FRN erweitert. Geringere Ausprägungen in der Körper-bezogenen Symbolisierungs-Subskala der Skala Emotionalen Erlebens (SEE), die möglicherweise geringere interozeptive Sensitivität widerspiegeln, gingen mit reduzierten P3 Amplituden bei Verarbeitung negativen Feedbacks einher, ähnlich früherer EKP Studien. Die SEE Subskala Emotionsregulation, ein Selbstbericht von Emotionsregulations-Kompetenzen, modulierte ebenfalls die P3 Komponente, in Übereinstimmung mit früheren EKP Befunden und modalen Modellen der Emotionsverarbeitung.

Die Ergebnisse weisen auf eine starke gegenseitige Beziehung von sozio-emotionalen Prozessen und Feedbackverarbeitung hin.

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