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The involvement of the FRN and the P300 brain potential in the neural processing of empathy

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1. Theoretical Part

1.1 Introduction

The word “feedback” is a term that has its origin in systems theory and cybernetics, where it is widely used to describe a signal that feeds back the information about the current state of a system, after that system has changed its initial state (Häcker & Stapf, 2004). Thus, feedback conveys information about the change in system properties that help to regulate and to monitor system operations. In this sense feedbacks are crucial for the functioning of automated machines as well as for biological systems (for example, consider feedback-loops in the hippocampus that are required for learning mechanisms; cf. Wehner & Gehring, 2007). In a similar way, feedbacks also serve their function in social communication situations, with the difference that a given feedback is transferred from one system to another (from person to person), instead of being signaled between the subunits within one system alone. An information exchange in form of a feedback during interpersonal communication does not necessarily require the recipient to change his or her behavior or attitude according to the information, as opposed to technical or biological systems. Still, feedbacks are very important for social interactions and even social survival in a world where human beings have to collaborate with each other on a daily basis. The interpersonal feedback has been investigated thoroughly in the field of social psychology. Recently, feedback processing became also a topic of neuroscientific research, after social issues have emerged there in the early 90’s of the 20th century, which led to the interdisciplinary field of social neuroscience (e.g. see Cacioppo & Berntson, 1992).

1.2 The feedback- and error-related negativity and their common origin in the anterior cingulate cortex.

In neuroscience, feedback processing has been mainly examined using EEG and fMRI techniques. An event-related potential (ERP), measured with EEG, that showed a negative deflection in the ongoing wave after subjects received a negative feedback, was termed “feedback-related negativity” (FRN). The FRN was found in many studies and is, at the moment, besides the ERN, the most prominent ERP in the research of feedback processing. The FRN has first been discovered and described in detail by Miltner, Braun and Coles (1997) who carried out an EEG experiment using a time-estimation task. In their design, subjects were required to estimate the duration of one second after presentation of a cue by pressing a button. They received a performance feedback 600 ms after the button press, indicating whether the estimation had been accurate or not. In trials with a negative feedback (inaccurate estimation) the ERP-wave became more negative (in comparison to the trials with a positive feedback) and peaked 200 – 300 ms after feedback onset. Miltner and his colleagues proposed that there is a relationship between the FRN and the error-related negativity (ERN). The ERN occurs earlier (with a peak approximately 80 – 120 ms after stimulus onset) and is elicited by an error that is self-evident for the subject performing the task, whereas the FRN only occurs when the outcome of an event has to be mentioned explicitly in form of a feedback (Heldmann, Rüsseler & Münte, 2008). In other words: a feedback after a self-evident error would be redundant and therefore not necessary for an ERN, but essential for the FRN to occur, because without it, there would be no information about the outcome of an event. Miltner et al. (1997) regarded both ERPs as parts of a generic error-detection system, because they both respond to negative outcomes, only differing in the way that error information is obtained. Figure 1 shows the waveforms of the ERN and the FRN with their respective latency.

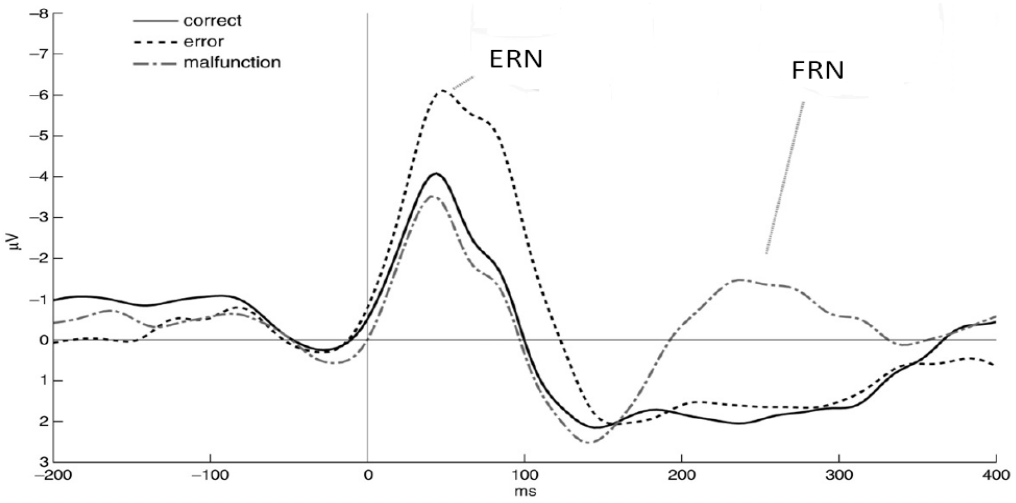

Figure 1: An example showing that ERN and FRN have different latencies and are evoked by different sources of information (error = internal; malfunction-feedback = external). Adapted from Gentsch, Ullsperger and Ullsperger (2009).

The terminology of ERPs that are concerned with error and feedback processing can be confusing, because different terms and abbreviations are used in the literature to describe the same brain potentials. “Ne”, for example, is sometimes used as an abbreviation for the error-related negativity. Another example comes from a study from Gehring and Willoughby (2002) in which they postulated a new event-related potential that occurs when subjects experience a loss in a gambling task. They called it “medial-frontal negativity” (MFN), assuming that this ERP has its source in the medial-frontal area of the brain. The study design included a gambling task with two choices that could either reveal a win or a loss in each separate trial. It has been shown, that the MFN was sensitive to monetary losses, disregarding the relative amount of the monetary outcome. Losing 5 cents in a single trial, even though the other choice would have been a loss of 25 cents, created the same negative deflection in the EEG waveform that occurred when the other choice would have been a monetary gain and vice versa. In the first example the MFN was elicited despite the fact that a loss of 5 cents was clearly the better choice, compared to a loss of 25 cents. Therefore the authors suggested that this brain potential is not responsible for error detection but rather for the registration if an outcome can be regarded as negative or positive in general. Since the MFN and FRN have the exact same shape and latency with both of them being recorded from frontal electrode sites, both ERP terms can be regarded as

interchangeable. Some researchers used the term MFN when they investigated outcome evaluation in monetary gambling tasks (e.g. Fukushima & Hiraki, 2006; 2009), whereas others used the term FRN for these experiments (e.g. Yu & Zhou, 2006; Itagaki & Katayama, 2008). Overall, the notion that the FRN and the MFN are basically the same is fairly widespread within the scientific community.

One theoretical explanation for the ERN/FRN, which has received much credit within the scientific community, is the reinforcement learning theory of the ERN, first introduced by Holroyd and Coles in 2002. They suggested that the ERN marks a reward prediction error that occurs when ongoing events are worse than expected. The detection of an error entails a signal that is mediated by the mesencephalic dopamine system and conveyed to the anterior cingulated cortex (ACC), which in turn generates an error signal. According to the theory, this error signal is used to induce a reinforcement learning process that guides action selection based on the experiences of earlier events. Further explanation how the ERN/FRN and the ACC are related will be given later.

That the ERN and the FRN denote a reward prediction error (Holroyd and Coles, 2002), rather than a mere evaluation of good and bad outcomes, has gained support from several studies. Holroyd, Niewenhuis, Yeung and Cohen (2003) found that the FRN was larger for losses in trials where wins were more likely (win-probability: 75 %; loss-probability: 25 %). Consequently, losses in the condition where they occurred more frequently (win-probability: 25 %; loss-probability: 75 %) led to a smaller FRN. According to Holroyd et al. (2003) the brain makes predictions about future outcomes and because it learned in the latter condition that losses where more likely to occur, a perceived loss was consistent with the brains expectations which led to a smaller FRN. A similar study from Holroyd, Larsen and Cohen (2004a) replicated the findings from Holroyd et al. (2003). Holroyd et al. (2004a) came to the conclusion: “An outcome is judged to be good or bad relative to the expectation, rather than in terms of its objective value” (p.250). Nevertheless, the findings have been mixed, with a later study concluding in favor of the hypothesis that the FRN only reflects the evaluation of good vs. bad outcomes (Hajcak, Moser, Holroyd & Simons, 2006). To circumvent problems with

the measurement of the FRN in different conditions Holroyd and Krigolson (2007) calculated difference-waves with the FRN amplitudes from a time-estimation task (with the design from Miltner et al., 1997). There was a hard condition (small time window for correct answers) and an easy condition (wider time window for correct answers). The authors compared unexpected outcomes (errors in easy trials and correct responses in hard trials) with expected outcomes (errors in hard trials and correct responses in easy trials) and found that the FRN again was larger for unexpected outcomes.

Gehring and Willoughby (2002) proposed that the MFN/FRN does not respond to error-feedback information but rather reflects the motivational impact of an outcome event. They based this assumption on the finding that the riskier a choice was, the larger the MFN became after a loss trial. In line with this assumption, Yeung, Holroyd and Cohen (2005) found that the FRN was smaller in a monetary gambling task when subjects made no active choices or carried out no overt actions, compared to a task where the outcomes were contingent upon the subjects' response choices. In addition there was also a correlation between the FRN amplitudes and subjects' ratings on how much they felt to be involved in the task (with larger FRN amplitudes corresponding to higher involvement-ratings). Like in the study of Gehring and Willoughby, other studies also support the notion that valence and magnitude of preceding outcomes influence the FRN in subsequent trials, indicating that motivational factors also modulate this brain potential (Masaki, Takeuchi, Gehring, Takasawa & Yamasaki, 2006; Goyer, Woldorff & Huettel, 2008).

The assumption by Miltner et al. (1997) that the FRN and ERN are phenomena of the same neural processes, as well as the notion that both ERPs share the same neural source, is backed-up by several studies. Holroyd, Nieuwenhuis, Yeung, Nystrom, Mars, Coles et al., (2004b) conducted a fMRI study were subjects had to perform a probabilistic learning task. They received a financial reward for pressing the right button after stimulus presentation and a financial punishment for pressing the wrong button. The study design included trials where subjects realized themselves, if they made a wrong response (internal information) and trials where

subjects had to get a feedback for outcome evaluation (external information). Holroyd et al. (2004b) found that the dorsal anterior cingulate cortex (dACC) was more activated in trials with errors signaled from both information sources.

Another study that provides evidence that FRN and ERN share a common source comes from Gentsch, P. Ullsperger and M. Ullsperger (2009). They used a flanker task to trigger an ERN when an error occurred by the subject, or a FRN when a malfunction signal indicated that an error occurred that was caused by the computer. The malfunctions signals presented a form of unpredictable external interference with goal achievement. Via independent component analysis (ICA) Gentsch et al. revealed that externally generated failures are processed by a neural network that is, in large part, also responsible for the processing of self induced errors. The finding suggests that both ERPs share a common neural source and represent a complementary monitoring mechanism for internal and external generated error signals.

Besides fMRI studies, there exists at least one positron emission tomography (PET) study where the emergence of the FRN could be traced back to activity in the ACC. During a stochastic decision-making task simultaneous recordings of EEG-ERPs and PET were carried out on subjects. An activation of the ACC was found in both, the contingent reward and the random reward condition. The investigators also found a correlation between the activation of the ACC and the amplitudes of the ERP components FRN and FRP (which, due to its height and latency, looks actually like a P3) (Hideki et al., 2010). Considering the possibility that both FRN and ERN are responsible for similar outcome evaluation processes and taking into account that several studies found an association of the FRN with the ACC, it is likely that error-related brain activity will also be located in the ACC. This was shown in studies using dipole analysis for source localization (Ruchsow et al., 2002) and in fMRI studies (e.g. Carter, Braver, Barch, Botvinick, Noll & Cohen, 1998; Kiehl, Liddle & Hopfinger, 2000; Menon, Adleman, White, Glover & Reiss, 2001). Additionally, recordings of intracranial, local field potentials from non-human primates also revealed activation of the ACC after an error was committed, in studies using Macaques (Gemba, Sasaki & Brooks, 1986; Emeric, Brown, Stuphorn, Leslie, Pouget & Schall., 2008).

However, it should be noted, that not all research findings are consistent. Some scientists cast doubt upon the notion that the ACC is involved in error processing and therefore gives rise to the ERN and FRN. Gehring and Willoughby (2004) argued that the different scalp distributions of the ERN and FRN respectively do not confirm the widespread idea that both ERPs reflect the same underlying neural generator. Van Veen, Holroyd, Cohen, Sterngerd & Cartere (2004) as well as Nieuwenhuis, Slagter, Alting von Geusau, Helsenfeld & Holroyd (2005b) were both unable to find an error-feedback-related activation in the ACC. It is interesting to mention that the main author of the first study - van Veen - reported two years beforehand that he and his colleague have found that the ACC was responsible for eliciting the ERN (van Veen & Cameron, 2002). The same accounts for two authors from the second study – Nieuwenhuis and Holroyd – who also reported one year before that internal and external error signals activated the dACC (Holroyd et al., 2004). Thus, even the results from the same researchers regarding a specific question, can sometimes vary between different studies.

1.3 Feedback- and error-processing in self-induced and observed errors

Thinking about a neural signal that reflects the processing of an error or a negative feedback one question immediately arises: would this signal also be sensitive to observed errors and observed negative feedbacks, or would it be restricted to negative outcomes that only concerned the observer himself? The information, acquired by observation, that the behavior of others leads, for example, to an error can be important to oneself, if one wants to avoid committing errors in similar situations. Furthermore, the observation of negative outcomes obtained by others could elicit an emotional response, especially when the observed person is a close friend or relative.

With respect to the FRN, the following studies seem to confirm these thoughts. That an ERN was elicited when subjects failed to execute a task, and an FRN when errors induced by others were observed, was interpreted as an important mechanism for observation-learning (van Schie, Mars, Coles & Bekkering, 2004)

and as a mirror-system of error-monitoring that helps to empathize with the misfortune of others (Miltner, Brauer, Hecht, Trippe & Coles, 2003). Van Shie et al. and Miltner et al. both used a flanker task with a self-execution and an observation-condition. While subjects in the experiment from van Schie et al. directly observed the task performance of another player who sat in front of them, subjects in the design form Miltner et al. observed the performance of a simulated player on their computer screen (but they thought they would actually observe the performance of another person in another room). The FRN in the observation condition of both studies was smaller than the ERN in the self-execution condition, but the FRN was larger when observing incorrect performances, compared to correct ones.

One way of exploring whether the observation of an unfavorable feedback that is being received by others leads to a FRN in the observer, is to use gambling tasks in an experimental design. In EEG experiments this approach has been applied very frequently. The emergence of an ERP that was described as “FRN-like” was observed when subjects monitored others experiencing a monetary loss (Yu & Zhou, 2006). In the design, adopted by Gehring and Willoughby (2002), subjects consecutively either performed the task, or observed the performance of another person on their computer screen. The amplitude of the FRN was largest in the condition where the subjects experienced their own losses and significantly smaller for the observed losses. This indicates that negative outcomes of others are somehow relevant for us, but not as much as our own losses.

In the study of Yu and Zhou’s (2006) the subjects presumably regarded the observed losses as similarly negative as their own. But the way in which the outcomes of others are evaluated clearly depends on the relevance that these outcomes have for the respective observer. The misfortune of one person could mean an advantage for another if they were in a competitive situation. This finding was obtained by Itagaki2008). In a gambling situation subjects had either to cooperate with one another (cooperative condition) or play against each other (antagonistic condition). If one player lost in the cooperative condition it was a loss for both players. Consequently, the observation of the partner’s loss elicited an FRN in the other player. On the other hand, in the antagonistic condition, the gain

of player A meant a loss for player B, and vice versa. In this situation the observation of the gain of player A also elicited an FRN in player B. In conclusion, the evaluation of an observed outcome determines if it is perceived as positive or negative for oneself and therefore if a FRN is elicited or not.

Considering the many studies which found evidence that the ERN and FRN are generated in the ACC, it can most probably be concluded that if those signals are present in the observation of errors of negative outcomes from others, they would also be located in the ACC. At least one study exists, which shows that perceived errors committed by others are also accompanied by activation in the dACC (Shane, Stevens, Harenski & Kiehl, 2008). While subjects where lying in a fMRI-scanner, they performed a go/no-go task themselves and also watched a video of another person performing on the same task. An error that would evoke an ERN if the same task had been used in an EEG-study activated the dACC in both the self-performance and observing condition. This result again strengthens the hypothesis that this brain region is involved in error processing.

Recently, in order to explain why ERPs that process unfavorable outcomes are also found when observing others, some scientists have related this phenomenon to empathy. Beside the hypothesis that the observational-ERN and FRN reflect a mechanism of observational learning (e.g. van Schie et. al., 2004), empathetic concern for the mishap of others is the most frequently used explanation within the scientific community (e.g. Miltner et al., 2003; Larson, Fair, Good & Baldwin, 2010).

If one is trying to define empathy, the problem arises that there are almost as many definitions for empathy as there are researchers who investigate this psychological construct (Singer & Lamm, 2009). Although this accounts for the variability in the description of the term, there seem to be three core components of the construct that most scientists agree on: 1. an affective response towards another person; 2. a process of perspective-taking; and 3. a monitoring mechanisms that enables us to differentiate between feelings that originated in

ourselves and feelings that were induced by the observation of others (Lamm, Batson & Decety, 2007). It has also been argued that two mechanisms constitute empathy: a bottom up process that is the automatic emotional response towards another person and a top down process which involves cognitive appraisal of a specific situation to modulate an emotional experience (Decety & Lamm, 2006). Human empathy is a rather complex and multidimensional phenomenon that urges deeper exploration, but is, due to its versatile nature, difficult to approach with well-controlled experimental designs (Singer & Lamm, 2009). Nevertheless, acquiring at least some knowledge about the neural correlates of empathy would provide an "objective" approach to a psychological construct that has been studied, up to recently, merely phenomenologically.

In two studies, Fukushima and Hiraki (Fukushima & Hiraki, 2006; 2009) linked the MFN to empathy. The design of Gehring and Willoughby (2002) was again used to show that this feedback-related ERP was equally evoked in self-experienced and observed monetary losses. In their earlier study the authors investigated the question whether female and male subjects differed in their affective and electrophysiological response to monetary losses in an antagonistic gaming situation, where the gain of one player resulted in the loss of the other and vice versa (like in the design of Itagaki & Katayama, 2008). Additionally to the EEG recordings, subjects also had to fill out questionnaires about, amongst others, their affective states towards their own and the other player's outcomes. While males showed a MFN when they lost money, as well as when they noticed that the other player won money, females didn't show the same effect. Within the female group the gain of the other player did not elicit a MFN, even though they were well aware that this meant a loss for them. Correspondingly, the females also showed a more positive affect for the outcome of the opponent compared to the males (meaning that females rated the gain of the opponent as less negative compared to males). This gender effect was explained by the authors with the reference to the higher level of empathy within women. The study of Fukushima and Hiraki (2009) incorporated three conditions in their gambling-task design: one's own wins and losses; the wins and losses of a befriended player; and the wins and losses of a PC program. In contrast to their study from 2006 each subject played independently. As expected, the losses in the first and second condition elicited a

MFN in the subjects. Interestingly, when monetary losses by the PC player in the third condition were observed, the MFN was absent. This signifies that subjects experienced an emotional reaction when recognizing that their friend was losing money, whereas the loss of the PC player was not a matter of emotional concern. This conclusion is also supported by the positive correlations between the amplitude of the other-MFN and the self-ratings in empathy questionnaires.

A correlation between the ERN and the ratings in an empathy questionnaire, similar to the one shown before, has also been reported in an article from Santesso and Segalowitz (2009).

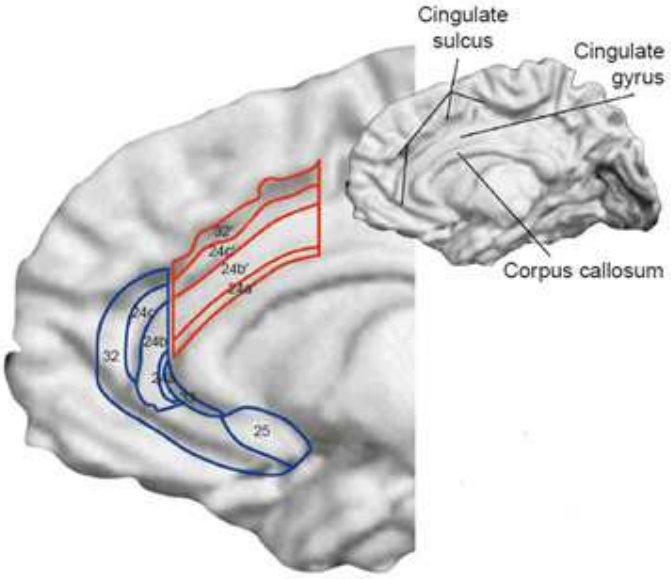

Figure 2: The ACC on the medial surface of the right hemisphere. Marked in blue is the rostral part of the ACC and in red the dorsal part, with the numbers displaying the respective Brodmann areas (adapted from: Bush, Luu & Posner, 2000)

Moreover, the link between error- and feedback-processing and empathy has also been invigorated by studies that suggested that the activation of the ACC (which is proposed to be the generator of the ERN and FRN) gives rise to feelings of empathy (Newman-Norlund, Ganesh, van Schie, Bruijin & Bekkering, 2008), especially considering empathy for pain and stress observed in others (Morrison, Lloyd, di Pellegrino & Roberts , 2004; Singer, O'Doherty, Kaube, Dolan & Frith,

2004; Jackson, Brunet, Meltzoff & Decety, 2006; Lamm et al., 2007). Interestingly Singer et al. found that the activation of the rostral ACC (rACC) showed a significant positive covariation with subject's results in two empathy questionnaires, indicating that high-empathetic people had a higher activation of the rACC during observation of pain in others. On the other hand Newman-Norlund et al. came to opposite results: activation of the ventral ACC (vACC) while observing errors induced by others covaried negatively with the results of an empathy questionnaire. They explained this discrepancy with the hypothesis that high empathetic subjects are better in down-regulating negative affect and that conditions which allow to select a regulatory strategy (like in their study), would lead to less ACC-activation in empathetic subjects, whereas a lack of control of emotional regulation (like in the study of Singer et al, 2004) would induce a stronger activation of the ACC in empathetic subjects. Figure 2 depicts the rostral and dorsal parts of the ACC.

1.4 The P300

The P300, also referred to as P3, is an endogenous event-related potential that peaks around 250 – 500 ms (it owes its large range to the fact that its latency varies significantly across different stimulus conditions) and can be subdivided into two parts: the P3a and the P3b. Whereas the P3a is recorded from more frontal electrode sites and reflects stimulus-driven attentional mechanisms, the P3b originates from parietal activity and is associated with attention to task relevant stimuli (Polich, 2007). As an endogenous ERP it depends much on the processing of stimulus context and the levels of attention and arousal and increases with lower probability and higher discriminability of targets (Linden, 2005). Figure 3 shows a typical P300 wave that is sensitive to infrequent stimuli. A widely accepted explanation for the P300 is provided by the context updating theory. According to the theory, the mental model of the context of a stimulus is maintained if no change in stimulus attribute is detected. But if a new stimulus emerges, attentional processes govern an "update" of stimulus representation which is accompanied by a P300 peak (Donchin & Coles, 1988).

When researchers write about the P300, in the abundance of cases, they are referring to the P3b (Luck, 2005). Although the P300 was discovered more than 40 years ago (Polich, 2007) and there exists a multitude of studies about that ERP, it is still a matter of debate what precise cognitive processes the wave may reflect (Luck, 2005).

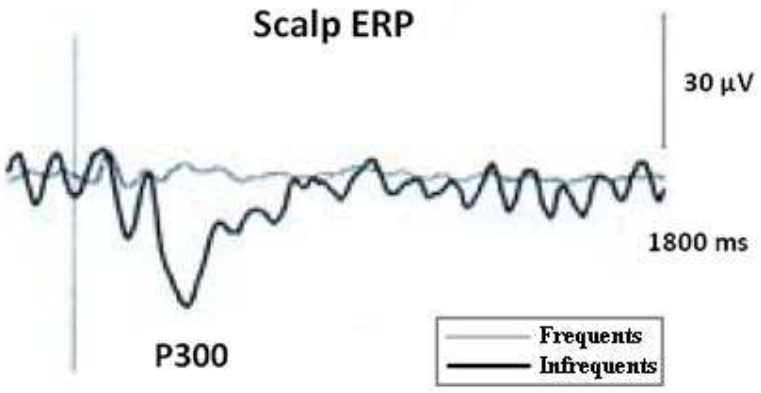

Figure 3: A typical P300 wave responding to infrequent stimuli, whereas the line in light-gray (frequent stimulus) shows no apparent positive deflection (adapted from Linden, 2005).

1.4.1 The modulation of the P300 in gambling tasks: reward magnitude and reward valence

In a similar way as the FRN has been elicited via gambling tasks, the P300 was also investigated using these tasks to elucidate which effects different outcomes have on the P300. With a simple gambling task, Yeung and Sanfey (2004) found out that there is a double dissociation between the FRN and the P300. The task required to choose one of two cards, presented with different colors. First the valence and magnitude of the chosen option (e.g. +7) was shown, then, after the number vanished, the valence and magnitude of the alternative option (e.g. -36) was presented. The results revealed that the P300 was sensitive to reward magnitude but not to reward valence, while the FRN was sensitive to reward valence but not to reward magnitude. The authors found another dissociative pattern regarding the electrophysiological response to the unchosen, alternative option. Here the P300 was sensitive to the magnitude of the alternative option (a larger magnitude evoked a larger P300) whereas the FRN was unaffected by the

valence of the alternative outcome. These findings provide evidence that reward magnitude and reward valence are separately processed in the brain.

Shortly thereafter in a study that was mainly concerned with the question if the FRN reflects mere outcome evaluation or an action-learning process that helps to attain desired outcomes, Yeung et al. (2005) also found that the P300 was modulated in two experimental monetary gambling tasks. In both experiments, subjects had either to do a choice task (selecting a button to win money) or a no-choice task (pressing a button that started a roulette-like game). The second experiment additionally provided a no-response task (similar to the no-choice task with the difference that the roulette began spinning without pressing a button). The P300 amplitude was significantly larger in the choice task of both experiments alike, suggesting that this ERP is sensitive to the level of involvement in the task. Again, the valence of the feedback stimulus (wins or losses) did not significantly influence the amplitude of the P300.

Seemingly the P300 is not (significantly) affected by the valence of rewards according to those two last cited studies. Other investigators, however, couldn't replicate these findings. In two experiments from Hajcak, Holroyd, Moser and Simons (2005) where people had to perform on a guessing task, the P300 was sensitive to feedback valence being larger for positive feedback than for negative feedback. A study with children (average age: 8 years) who played a game where they could win or lose apples to feed a hungry donkey, also revealed a significant effect for outcome valence, but in an opposite direction (Carlson, Zayas & Guthormsen, 2009). Here punishments (losses) elicited a larger P300 compared to rewards (wins). Another study examined, amongst others, the modulation of the P300 to false and veridical feedbacks, while subjects carried out correct actions in both conditions (Balconi & Crivelli, 2010). The results showed that false feedback led to a larger P300 than the veridical feedback.

Because the outcomes in the experimental tasks of these studies were not explicitly money-related, it could be hypothesized that the P300 is only insensitive to monetary rewards alone. Yet, results indicating that the monetary reward valence affected the amplitude of the P300 in gambling tasks have also been

obtained. Wu and Zhou (2009) reported that monetary wins led to larger P300 responses than losses, but only in the condition where the outcomes were expected. Nevertheless reward valence was also a modulating factor of the P300 in recently conducted experiments were outcome expectancy did not come into play (Leng & Zhou, 2010; Rigoni, Polezzi, Ruminati, Guarino & Sartori, 2010; with both experiments showing a larger P300 for monetary gains than losses). Due to the few studies that had been carried out, it is still a matter of debate if the P300 is actually influenced by reward valence, whereas it seems that reward magnitude is a more reliable modulator of this brain potential.

1.4.2 The modulation of the P300 by interpersonal relationship and empathy

So far the research regarding the question if and how the P300 is being influenced by interpersonal relationship and whether this supposed relation could be an indicator for empathy, similar to the possible role of the FRN on that matter, is rather scarce. Only one article directly accessed this question. The study was looking for the effects that playing for different agents in a gambling task had on the amplitudes of the FRN and the P300 (Leng & Zhou, 2010). In three conditions subjects either played for themselves, for a friend or for a stranger. Doing the gambling task, subjects received at the onset of every trial information for whom they were playing. After they received a feedback about the monetary outcome of the trial, subjects had to allocate that outcome to the agent in question. A significant effect for agency was detected concerning the P300, showing the largest amplitude in the self-execution condition and the second largest amplitude in the friend-observation condition. The differential P300 responses caused by interpersonal relationship may be mediated by empathy for the experience of others. What makes this claim viable is the distinction between friend and stranger by the P300, which is in line with the assumption that people care more about their friends than they care about strangers.

The P300 is also assumed to reflect attention allocation (Polich, 2007) and it is possible that subjects are motivated to engage their attentional resources towards themselves and their friends, but not as much towards strangers. Bradley (2009) stated that the P300 is sensitive to stimuli of “motivational relevance”. Other researchers suggested that the P300 is concerned with the “significance” of stimuli

(Donchin, 1981) and the “meaning” of stimuli (Johnson, 1986). All these properties of the P300 could explain why this brain potential is sensitive to stimuli that evoke feelings of empathy for the misfortune of others, but very little is known so far, how the P300 and empathy are related.

The notion that a larger P300 potentially reflects a process of empathy is supported by other researchers as well. Fan and Han (2008) for instance, report a larger P300 for people who watched images with pain-related content, compared to the P300 that was evoked when they observed neutral images. Han, Fan and Mao (2008) replicated these findings using the same image material and additionally found a gender difference with females producing a larger P300 for painful stimuli than men. Another difference in brain potentials was observed between controls and physicians when they were viewing painful stimuli (image of needle stitching a body part) and non-painful stimuli (image of Q-tip touching a body part) (Decety, Yang & Cheng, 2010). The controls showed significantly larger P300 for the painful stimuli than for the neutral stimuli, whereas physicians did not differ in their electrophysiological response to both kinds of stimuli. Decety et al. (2010) suggested that this could be interpreted by a down-regulation of empathy for pain in a group of people that is repeatedly exposed to the suffering of others.

1.5 Own research outline

The study presented in this work tries to integrate many aspects of some of the experiments described here earlier. One major aim of this endeavor is to render evidence for the notion that the FRN and the P300 are epiphenomena of a neural mechanism for empathy. Some investigators purported the idea that the FRN/ERN may play a role in the processing of empathy (e.g. Miltner et al., 2003; Fukushima & Hiraki, 2006; 2009) and a few others attempted to link the P300 to empathy (e.g. Fan & Han, 2008; Decety et al., 2010). Up to now no one has reported an agency effect for both ERPs in one single experiment in order to indicate neural responses to this emotional process. Whether this is due to the fact that only one of those brain potentials is actually involved in empathy-processing or whether empathy is

generated in the brain in a too complex way that it could be determined by the occurrence of a single ERP alone, still bears explanation.

With the intent to replicate previous findings regarding the FRN and P300 responses in monetary gambling tasks, the study design from Itagaki and Katayama (2008) was adapted and slightly modified. This design allowed testing, if monetary losses, compared to monetary wins, would elicit a larger FRN that should peak approximately between 200 – 300 ms after feedback-stimulus onset. Since the first discovery of the FRN by Miltner et al. (1997) this negative feedback-related signal was found in several studies, therefore it is expected to also occur in the new study. Itagaki and Katayama's (2008) design also incorporated playing for other agents. This feature was used to examine if the observed monetary losses of affiliated people would evoke an FRN, but not the losses of an institution. In line with other studies that investigated losses observed from others, the FRN should be evoked by losses of affiliated others but with a smaller amplitude than the own losses of the subject that performs on the task. On the other hand, the FRN should not be sensitive to the losses of an institution (the Austrian National Bank). This institution has been chosen as a quasi-neutral agent. The underlying hypothesis was that people cared for their own losses and for the losses of friends but not for the (small) losses of the Austrian National Bank in a gambling task (comparable to the results obtained by Fukushima & Hiraki, 2009). After prior research showed that the FRN for losses of others was not seen for the observation of strangers and computer agents, it was assumed that the FRN would also be absent even if the agent was an existing institution that everyone knew.

In addition, a similar modulating effect that outcome valence (wins or losses) and agency ("self", "affiliated person" and "institution") has on the FRN is also expected for the P300. Hence the P300 should be larger for wins than for losses (Wu & Zhou, 2009; Leng & Zhou, 2010; Rigoni et al, 2010) and reveal the largest amplitude for the self-condition and the second largest for affiliated person-observation-condition (Leng & Zhou, 2010). The P300 should differentiate between oneself and the two other agents by allocating more attentional resources to self-relevant stimuli. This attentional focus should be largest for the subjects'

own outcomes (because they probably regard their own outcomes as more relevant than the outcomes of others), smaller for close others and smallest for the Austrian National Bank (because the outcomes of close others should still matter to the subjects, whereas the outcomes of the OeNB should not).

In respect of the previous research the gambling task of the new study differs in two ways. First, when subjects view the outcomes of an affiliated person, they don't sit next to them (e.g. Fukushima & Hiraki, 2006; 2009) or get informed about their outcomes via a computer network; instead they play for the affiliated person by proxy. Second, the third agent in the gambling task (beside "self" and "affiliated person") is neither a stranger (e.g. Leng & Zhou, 2010) nor a computer agent (e.g. Fukushima & Hiraki, 2006, 2009) but a well-known Austrian institution: the Austrian National Bank.

To further corroborate the hypothesis that empathy for the losses of affiliated others is responsible for the different ERP amplitudes in different task conditions two empathy questionnaires and one psychopathy questionnaire will be handed out to the subjects. According to expectations, higher empathy scores from both empathy questionnaires should go along with larger FRNs for losses and larger P300s for wins in the affiliated-person-condition and higher scores in the cold-heartedness scale of the psychopathy questionnaire should go along with smaller FRNs for losses and smaller P300s for wins in the affiliated-person-condition. Finally, it is assumed that the neural generator of the FRN would be found in the ACC and that the ACC is more strongly activated in the self-condition than in the affiliated-person-condition.

2. Empirical Part

2.1 Methods

2.1.1 Subjects

Twenty-four right-handed male and female subjects took part in the experiment. Four of them had to be excluded from further data analysis due to excessive electroocular- and electromyogram-artifacts in their EEG recordings. The twenty remaining subjects (6 males and 14 females) ranged in age between 20 to 30 years, with a mean age of 24.95 (SD = 2.4). They participated on a voluntary basis, and didn't receive any monetary compensation. Handedness was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971). All subjects had normal or corrected-to-normal vision. None of them had reported any history of psychiatric or neurological disorders. Prior to the experiment, written informed consent was obtained from the subjects.

2.1.2 Task and procedure

Subjects sat comfortably in front of a 19'' CRT (Sony GDM-F520) screen with a viewing distance of approximately 80 cm in a dimly lit and sound-attenuated room. Visual stimuli were presented using E-prime 2.0 (Psychology Software Tool, Inc.) Subjects either played for themselves, or played by proxy for one of two agents: an "affiliated person" – a well-known person which the subject values very much, or the National Bank of Austria (abbreviated with "OeNB" for the German expression "Oesterreichische Nationalbank"). Thus, there were three main conditions:

1) The *self*-condition:
2) The *person*-condition (short for "affiliated-person")
3) The *bank*-condition (called "The OeNB" in the gambling task)

The stimuli and sequence were based on the gambling task design of Itagaki and Katayama (2008) which was slightly modified. The trial procedure started with the presentation of a fixation cross in the middle of the screen that remained there for the whole duration of the EEG recording. It only vanished during the breaks and reappeared thereafter. At the beginning of each trial a headline was presented, informing the subjects for which agent they were playing. The headline kept its position till the end of the trial. Underneath the headline, two white cards, also centered in the middle of the screen, appeared at trial-onset; one at the right-hand side and the other at the left hand side of the fixation cross. Each card had the size of 6.7 x 6.7 cm and was presented in front of a white background. Subjects were required to select one of the cards by pressing a keyboard button with the index finger of their right hand. After the button-press, the respective card was framed to accentuate the selected option, for the duration of 1000 ms. Subsequently the card was either highlighted in green displaying “+100” in white font, indicating a (virtual) win of 100 Euros, or in red displaying “-100” in white font, which showed that 100 Euros had been (virtually) lost. The sequence within one trial is displayed in Figure 4. Because subjects did not actually receive their cumulated outcomes after the experiment had ended, the wins and losses from the gambling task were merely hypothetical.

Subjects were instructed to imagine that the wins and losses they perceive were wins and losses of the agents of the respective conditions. Names of the affiliated persons had to be given in advance from the subjects, and were inserted into the set of the presented stimuli. As a further part of the instructions, subjects were called upon to try to maximize their gain (as well as the gains of the other agents) and were informed that they are allowed to use any strategy they might find helpful to accomplish this goal. Effectively there was no such strategy that could have been applied, because the probability of wins and losses was equally 50%, appearing in a random order to control the frequency of the feedback stimuli. The implication of the instruction that during the gambling task strategies may be applied to maximize the gains should make sure that subjects remained motivated. A similar instruction was used by Gehring & Willoughby (2002) to facilitate motivation in a monetary gambling task. The trials also occurred in a random order to exclude order effects.

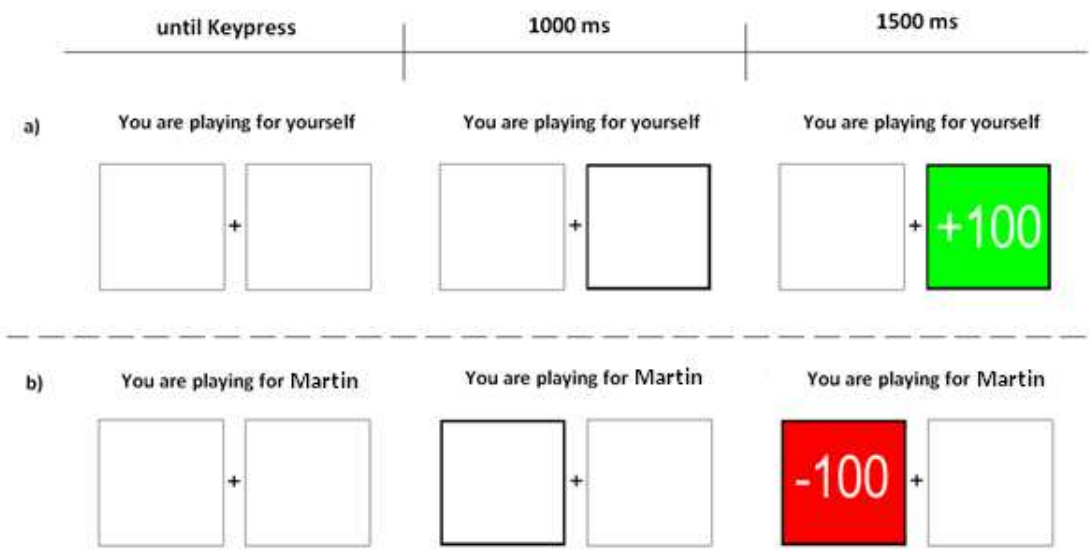

Figure 4: Timeline of two example trials. a) win-trial of the self-condition b) loss-trial of the affiliated-person-condition, who in this case goes by the name Martin.

After every 100 trials, subjects received a false feedback about the relative gains of each agent. These feedbacks were presented for the duration of 10 seconds, prior to each one of the breaks in the EEG recording and consisted of three sentences. A typical feedback, for example, was:

You won more than the OeNB; Martin won more than you.

Martin won more than the OeNB and you.

The OeNB won the least amount of money

Here, Martin is an example of a name of the affiliated person. The information in the feedbacks was counterbalanced within one experiment, so that the subjects thought that the amount of money that each agent won or lost differed between trial blocks. Those feedbacks did not reflect the actual gains in each condition. This was to prevent that subjects recognized too easily that wins and losses occurred with an equal probability if a feedback had given them the correct accounts of wins and losses. The whole experiment consisted of 600 trials with five breaks after every 100 trials and lasted approximately 60 minutes.

2.1.3 Apparatus and EEG recordings

Electroencephalogram (EEG) was recorded using a 64-channel low-input impedance amplifier (Ing. Kurt Zickler GmbH, Pfaffstätten, Austria). The 59 Ag/AgCl electrodes were imbedded in an elastic electrode cap (EASYCAP GmbH, Germany) equidistantly positioned to each other (montage M10). The individual 3D electrode coordinates on the cap of every subject were measured with a photogrammetric head digitizer (3D PHD; Bauer, Lamm, Holzreiter, Holländer, Leodolter & Leodolter, 2000). To this end, light markers were attached to electrode sockets of 17 pre-defined positions on the cap, prior to the EEG recording procedure. Twelve calibrated cameras simultaneously took pictures of the subject's head from different angles. The 17 light-marked positions were captured and the remaining electrode positions were reconstructed via interpolation. Afterwards, to record the potential produced by vertical eye movements, two electrooculogram (EOG) electrodes were placed above and underneath the left eye, with both centers being in line with the subject's pupil if he or she looked straight forward. To control for horizontal eye movements, two EOG electrodes were additionally placed at the outer canthi of each eye. The ground electrode was placed onto the forehead. To make sure that any potential that was not caused by electro-cortical activity was subtracted from the scalp electrodes, a reference was used consisting of an electrode placed on the sternal end of the right clavicle and another electrode placed on the "vertebra prominens", the 7^{th} cervical vertebrae. The impedances of all electrodes in use were kept below 3 kΩ by slightly scratching the skin at each electrode position and filling the ring-electrodes with an air-vacuumed electrode-gel (Electrode-Cap International, Inc., Eaton/Ohio; USA). Recorded EEG signals were within a frequency range of 0.1 – 125 Hz and were digitized at a sampling rate of 250 Hz.

2.1.4 Questionnaires

Batson-Scale

Directly after the EEG recording procedure three personality questionnaires were handed out to the subjects. The first questionnaire was the German version of the Batson-Scale (original English version: Batson, Fultz & Schoenrade, 1987) and was given to the subjects while they were still sitting in the EEG recording room. The Batson-Scale comprises several adjectives from which six belong to the "empathetic concern scale" (e.g. the German words for: sympathetic, moved, compassionate) another eight make up the "personal distress scale" (e. g. the German words for: alarmed, grieved, upset) and the remaining items are filler items. On the questionnaire subjects were requested to describe the emotions they felt when a monetary loss on the gambling task was being observed. For that, they had to make a cross on a scale, next to each adjective, ranging from 1 ("not a bit") to 7 ("extremely"). The Batson-Scale came in three versions, one for each main condition (*self, person* and *bank*).

Interpersonal Reactivity Index (IRI)

The German version of the Interpersonal Reactivity Index (original English version: Davis, 1996) was presented outside the recording room and was filled out during the detaching of the cap and the external electrodes. This empathy questionnaire consists of 28 items in form of statements that have to be agreed or disagreed with on a scale from 1 ("does not describe me well") to 5 ("describes me very well"). The four scales of the IRI are labeled "empathetic concern scale", "perspective-taking scale", "fantasy scale" and "personal distress scale" and they consist of seven items each.

Psychopathic Personality Inventory – Revised (PPI-R)

The last questionnaire was the German translation of the Psychopathic Personality Inventory – Revised (Alpers & Eisenbarth, 2008). In contrast to the other two, which are empathy questionnaires, the PPI-R contains eight psychopathy-relevant scales and one validity scale. Only the "cold-heartedness scale" was used for further analysis, because cold-heartedness is thought to be the opposite of

empathy (Alpers & Eisenbarth, 2008). Still, subjects were required to fill out the whole questionnaire to exclude item-order effects. The cold-heartedness scale consists of 15 items of self-describing statements, on which subjects had to rate on a scale from 1 (false) to 4 (true) whether the statement was an accurate description of their personality or not.

2.1.5 Data analysis

EOG movement and blink correction

The EOG electrodes record the electrical potential produced by eye movements that also disperses into other scalp channels thus creating artifacts. Therefore these EOG artifacts were removed by successive subtraction of the weights of the vertical and horizontal EOG's. Prior to the experiment, a vertical and a horizontal eye-movement task were used to calculate those weights as the ratio of the covariance between each EEG channel and the EOG (Fretska, Bauer, Leodolter, M. & Leodolter, 1999). Thus, the algorithm reads as follows:

$$c = \frac{\mathrm{Cov}\ (\mathrm{EEGk},\ \ \mathrm{EOG})}{\mathrm{Var}\ (\mathrm{EOG})}$$

Here, **c** denotes the calculated correction factor, **Cov** marks the covariance between the EEG signal at channel **k** and the **EOG** and **Var** stands for the variance within both EOG channels.

Eye-blinks occur frequently during EEG recordings and create another source of EOG artifacts that need to be corrected. To this end, the time windows that contained blinks were identified using a template matching procedure. Blink correction coefficients were calculated for each EEG channel using the previously identified time windows by means of linear regression. The time windows containing blinks were then corrected based on the blink correction coefficients (Lamm, Fischmeister & Bauer, 2005)

EEG analysis

EEG data were imported into EEGLAB 6.03b (Delorme & Makeig, 2004), a toolbox imbedded in Matlab 7.5.0 (The MathWorks, Inc.). A finite impulse response (FIR) low-pass filter with a cut-off frequency of 30Hz was applied to get rid of mains hum and other high-frequency electrical noise. To exclude artifactual trials, a semi-automated artifact-rejection procedure using the combination of three algorithms to assist visual inspection was applied. If the trials met at least one of the following criteria they were marked and removed after visual inspection: a voltage exceeding the threshold of +/- 75 µV, a linear voltage drift with a slope exceeding the threshold of 50 µV and if the probability for the occurrence of a single channel or a whole trial was low based on a standard deviation of 5. Additional criteria for the removal of trials that contained artifacts, but were not detected by the algorithms, were noise or drifts in the baseline, as well as artifacts caused by muscular and eye-blink activity, within the first 700 ms after feedback onset. Those additional criteria were checked via visual inspection of the data and trials that met the criteria were removed. As a result of this procedure, four subjects had to be excluded from further analysis due to excessive artifacts.

ERP analysis

Before filtering the data and artifact-rejection, the ongoing signals were epoched, extracting the time domain from 200 ms before feedback-onset, which constituted the baseline, and 1300 ms thereafter.

Because there were three main conditions (*self*-condition, *person*-condition and *bank*-condition) and two outcome possibilities (win or loss), six conditions, by combination of the two factors, have been created:

1) self-loss
2) self-win
3) person-loss
4) person-win

5) bank-loss

6) bank-win

Artifact-corrected trials were first averaged for each of the six conditions (self-loss, self-win etc.) per subject (averages) and then for all subjects per condition (grand means). Prior to peak-detection, all averages were visually inspected to find the respective time domains of the FRN and the P300 using a peak-detection tool implemented in EEGLAB that enabled to examine ERP averages of single channels. Using this tool the FRN was found within 184 – 332 ms after feedback-onset and was assessed at electrode Fz. This electrode channel was used because the FRN was most strongly pronounced at Fz, judging from the grand mean waveforms. Instead of merely using the highest negative peak of the FRN, it was quantified as the base-to-peak difference between the FRN and the average amplitude of the immediately preceding and following positive peak according to the following formula (Yeung & Sanfey, 2004):

$$\frac{1.\,\text{positive peak} + \text{P300 peak}}{2} - \text{FRN}$$

The P300, assessed at electrode location Pz using the same peak-detection tool, was found by means of visual inspection within 268 – 496 ms. The electrode was chosen because the P300 was most strongly pronounced at Pz.

Statistical analysis

Visual inspection of the simultaneously plotted grand means from all six conditions provided first insight which conditions showed apparent differences in regard of their ERP peak amplitudes and therefore helped to narrow down the choice of the statistical procedures that should be applied. The grand means clearly demonstrated that a significant effect on the FRN could not be expected since the peak voltages of all conditions were located too close to each other. Hence the FRN was not further analyzed and statistical calculations that were carried out, only concerned the P300 at electrode location Pz.

Three mixed design 3x2x2 ANOVA's were calculated, all of them having the same within-subject factors: agency (*self*, *person* and *bank*) and outcome (win, loss). For the between-subject factors, results of different scales from the personality questionnaires were taken to divide subjects into two groups for each scale respectively. Based on the empathetic concern scale of the IRI and the Batson-Scale (in the affiliated-person version) subjects were split-up, according to the median of the scores, into a high-empathy group (above median) and a low-empathy group (below median). The cold-heartedness score of the PPI-R was used in the same manner to create a cold-hearted (above median) and a warm-hearted (below median) group. Thus, the between-group factors were: empathy IRI, empathy Batson-Scale and cold-heartedness. Additionally simple contrasts were computed to indicate the direction of significant main- and interaction-effects. To test if the assumptions for a repeated measurement ANOVA with a between-subject factor were met, Mauchly's test for the assumption of sphericity and Levene's test for the assumption of homogeneity of variances were calculated. Because Levene's test was significant for two of the three between-subject factors, the raw data of the dependent variable have been log-transformed and all ANOVAS plus the tests for the assumptions have been calculated again.

Standardized low resolution brain electromagnetic tomography (sLORETA)

The sLORETA software was used for the localization of neural activity (Pascual-Marqui, 2002). In short, sLORETA attempts to solve the inverse problem of locating the current density distribution that arises from post-synaptic activity (initial state), based only on the measurement of electrical potentials from scalp electrodes (final state). Although there is no unique solution to inverse problems in brain imaging, Pascual-Marqui (2002) claims that sLORETA has zero localization error. sLORETA solutions are restricted to cortical grey matter and hippocampus. Calculations resulted in a spherical head model registered to the Talairach human brain atlas (Talairach & Tournoux, 1988), available as digitized MRI from the Brain Imaging Centre, Montreal Neurological Institute (MNI). Images of brain activity thus created contain 6430 voxels at 5 mm spatial resolution (Pascual-Marqui, 2002).

In order to view the maximal neural activation for all six conditions, grand means for sLORETA were computed, averaging the time domain of 1 to 1300 ms after feedback-onset into 13 timeframes of 100 ms each. For all sLORETA data files a signal-to-noise ratio of 1 to 100, as a regulatory parameter, was selected.

Statistical non-parametric Mapping (SnPM)

The SnPM tool (Holmes, Blair, Watson & Ford, 1996) is integrated into the sLORETA software and offers a way of calculating the difference between two sets of tomographic data, without having to meet the assumptions required for a t-test. Hence SnPM is also referred to as a "pseudo t-test". It uses a voxel by voxel nonparametric randomization procedure (carrying out 5000 permutations) to test the null-hypothesis if e.g. two conditions are the same.

After the statistical analysis of ERP peak amplitudes and questionnaire results the following conditions were compared in separate pairwise SnPM-tests: high-empathy vs. low-empathy (according to the median split of empathetic concern scale results from the IRI), *self* vs. *person* and *person* vs. *bank*. These comparisons have been chosen after the ANOVAS revealed significant differences between the high- and low-empathy group (between-subject factor: empathy IRI) and a significant main-effect for agency with significant differences between *self* vs. *person* and *person* vs. *bank*. For all of these comparisons averages were created, merging together all the conditions per person for the first comparison and merging the win and loss conditions for the second and third comparison.

2.2 Results

2.2.1 ERP data and between subject factors

By means of visual inspection of the ERPs from all six conditions (*self*-loss, *self*-win, *person*-loss, *person*-win, *bank*-loss and *bank*-win) a FRN peak of every condition, occurring approximately between 200 – 300 ms, is evident in Figure 5. It is also obvious that these FRN peaks, located at channel Fz, don't differ very much across all conditions. In contrast, the gaps between the peaks of the P300 in some conditions are much bigger. Figure 6 displays these ERPs at channel location Pz where the P300 peaks had been detected.

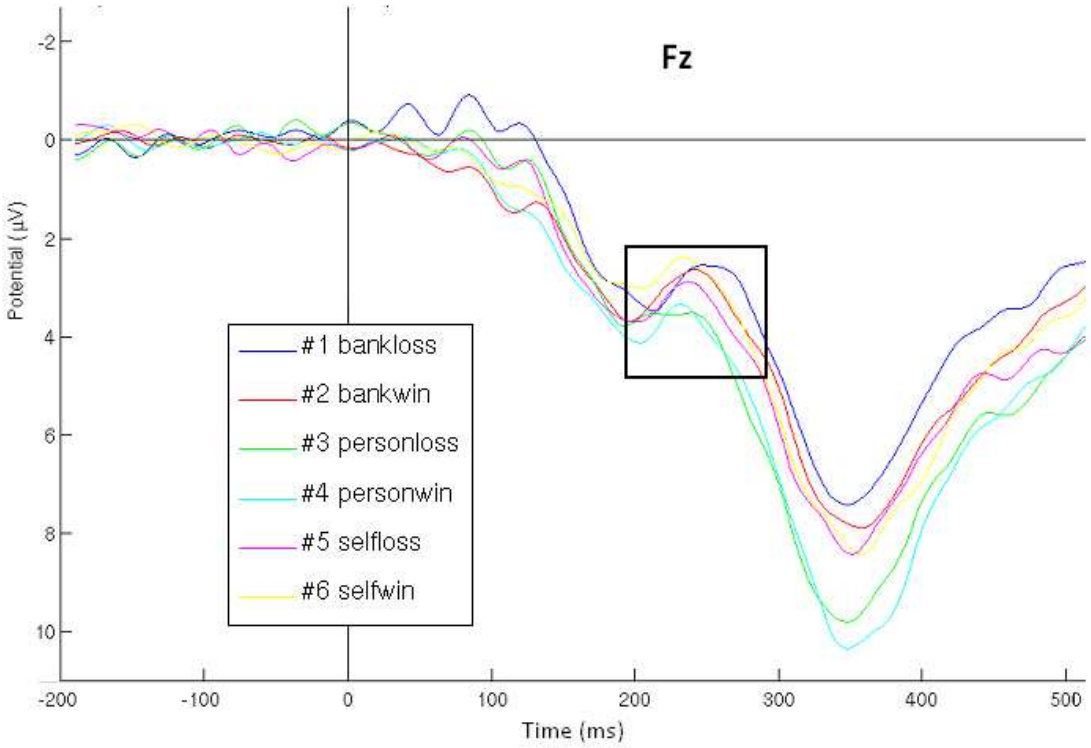

Figure 5: Grand means of all conditions at electrode location Fz, between -200 to 600 ms are depicted. Feedback onset started at time-point 0. The legend in the left corner shows which color belongs to which condition and the black frame superimposed upon the waves show the FRN peaks.

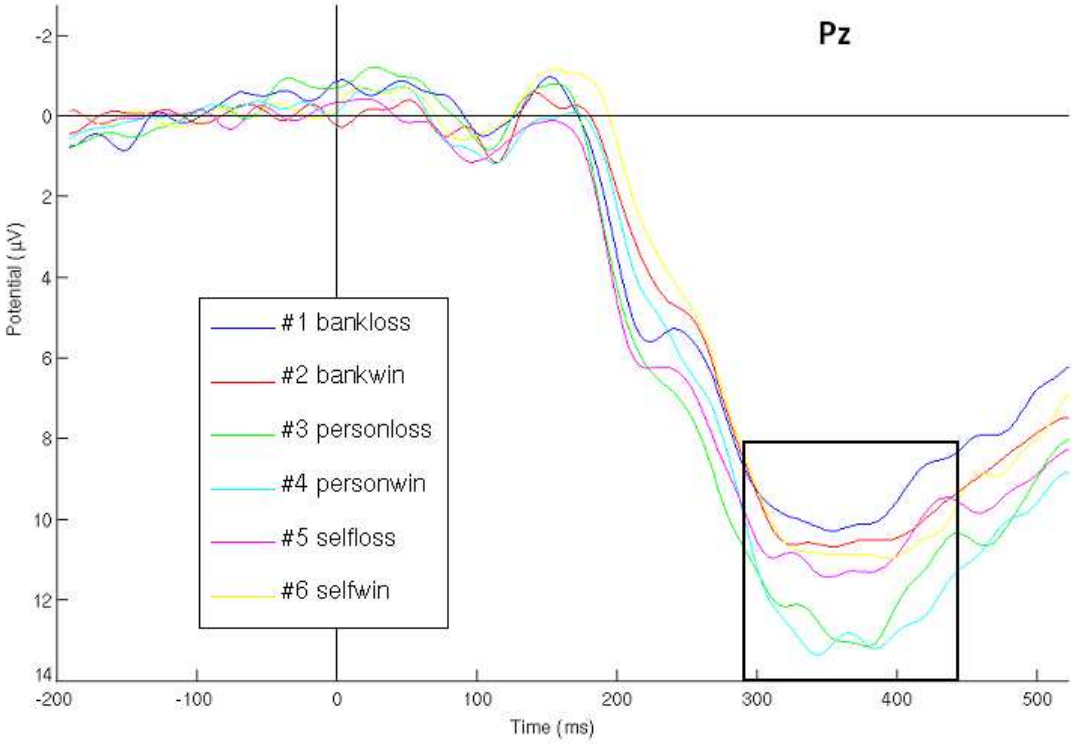

Figure 6: Grand means of all conditions at channel Pz. The P300 peaks within the black frame are easily visually discernable, indicating a significant difference between some conditions.

The three ANOVAs showed that the P300 peaks differed significantly between conditions. Results from the ANOVAs will now be presented separately:

ANOVA with between-subject factor: empathy IRI

The first ANOVA revealed a highly significant effect for the within-subject factor agency (*self*, *person*, *bank*) ($F_{2,36}$ = 10.192, p < .001). The means for the agency levels are separately shown in Figure 7. *Person* had the highest mean (= 1.10, SD = .36), followed by *self* (= 1.03, SD = .30) and *bank* (.98, SD = .25). Simple contrasts showed that there were significant differences in agency between *self* and *person* ($F_{1,18}$ = 7.73, p = .012) as well as between *bank* and *person* ($F_{1,18}$ = 18.316, p < .001).

The interaction between *agency* × *empathy IRI* also turned out to be significant ($F_{2,36}$ = 3.982, p = .027). Figure 8 shows an interaction graph of both factors.

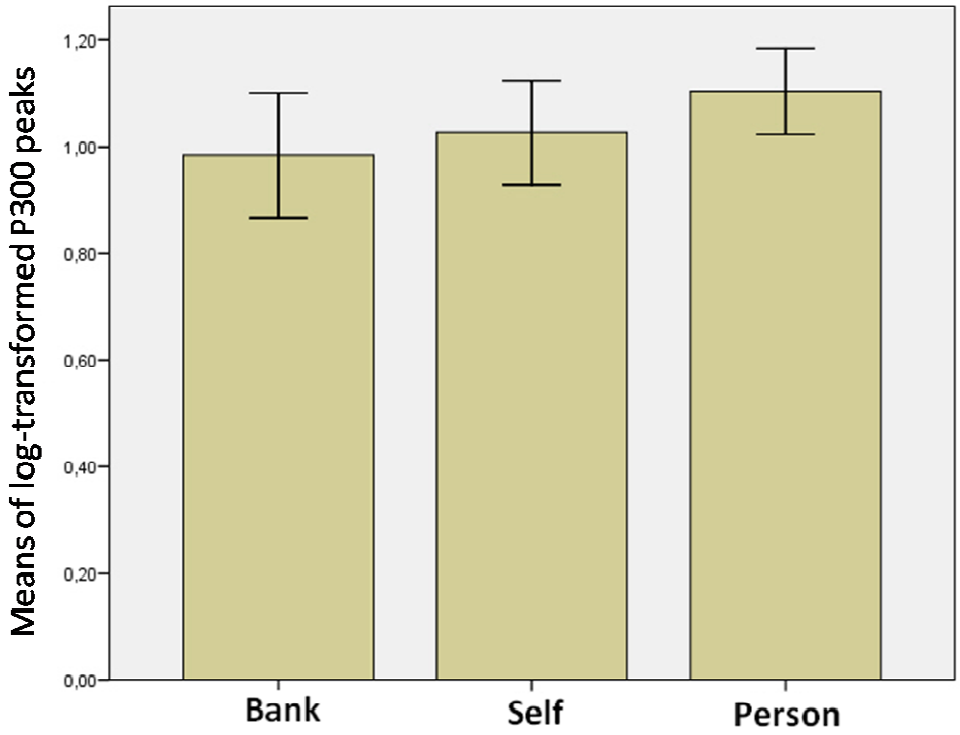

Figure 7: The means of the log-transformed P300 peak amplitudes of the agency levels *bank*, *self* and *person*.

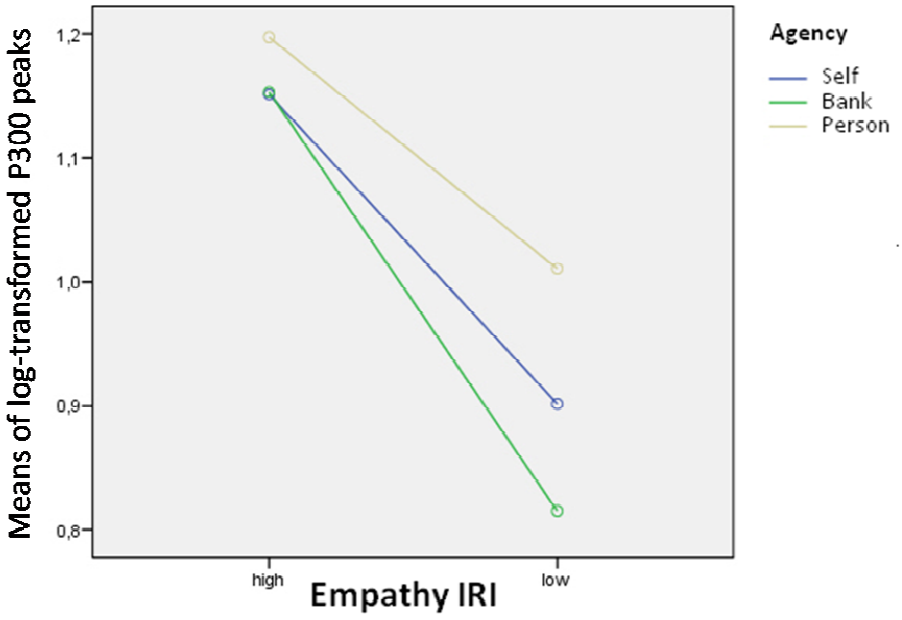

Figure 8: A graph displaying the interaction between the within-subject factor agency (self, bank and person) and the between-subject factor empathy IRI (high-empathy, low-empathy)

The between subject factor empathy IRI also reached significance ($F_{1,18}$ = 4.845, p = .041) with high results in the empathetic concern scale of the IRI leading to larger P300 peaks, as can be seen in Figure 9. No other effects or interactions were significant.

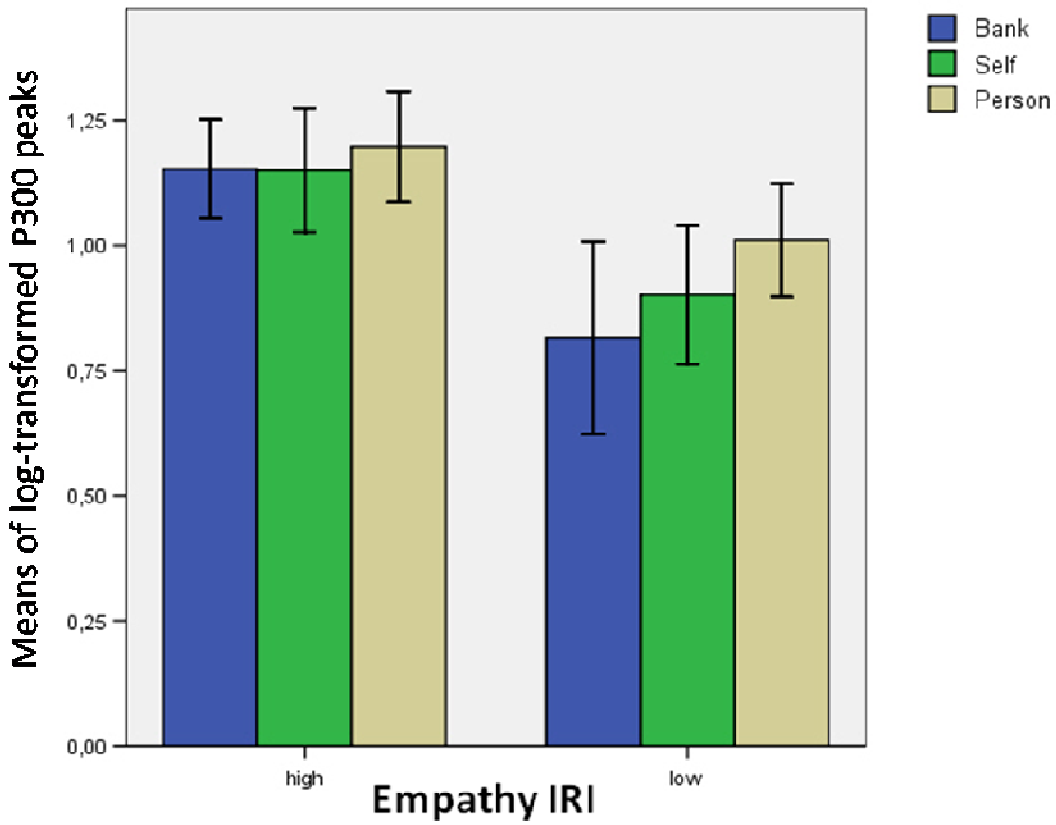

Figure 9: Differences in log-transformed P300 mean peak amplitude for the factor agency, after splitting up subjects into a high empathy and a low empathy group according to the median of the results of the empathetic concern scale of the IRI. Error bars indicate the 95% confidence interval (CI).

ANOVA with between-subject factor: empathy Batson-Scale

In this ANOVA the factor agency was significant ($F_{2,36}$ = 8.716, p = .001), whereas the other factors including their interaction were not. As has already been shown in the last ANOVA results, *person* had the largest P300 amplitude followed by *self* and *bank*. Comparisons for the levels of agency were accomplished using simple

contrasts. Results indicated a difference between *self* and *person* ($F_{1,18}$ = 7.293, p = .015) and between *bank* and *person* ($F_{1,18}$ = 13.953, p = .002).

Empathy Batson-Scale as the between-subject factor showed that subjects with high empathy scores had a larger P300 amplitude than subjects with low empathy scores ($F_{1,18}$ = 6.404, p = .021). Levene's test was significant for the two conditions: *self-loss* ($F_{1,18}$ = 6.244, p = .022) and *person-win* ($F_{1,18}$ = 5.235, p = .034) indicating that the assumption of homogeneity of variances was not met. But because both groups of the empathy Batson-scale factor were of the same size the between-subjects comparison should be relatively robust against the violation of homogeneity of variances. Figure 10 displays the means of the P300 amplitudes of both groups.

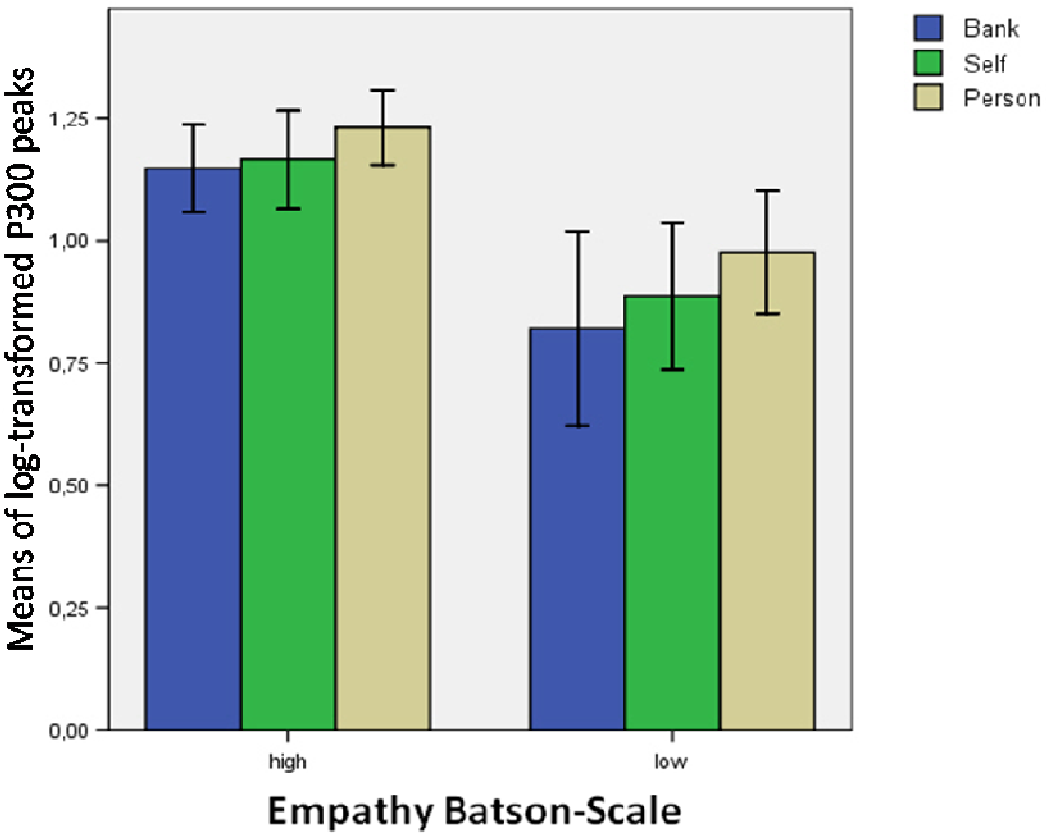

Figure 10: Subjects with higher scores in the empathetic concern scale of the Batson-Scale showed higher P300 peaks in comparison with subjects who had lower scores. Error bars indicate 95% CI.

ANOVA with between-subject factor: cold-heartedness

Finally the last ANOVA replicated again the result that the factor agency was significant ($F_{2,36}$ = 8.866, p = .001), with the factor-level *person* having the highest P300 amplitude, followed by *self* and *bank*. The simple contrast comparisons uncovered once more that the difference between self and person was significant ($F_{1,18}$ = 7.262, p = .015) as well as the difference between bank and person ($F_{1,18}$ = 16.748, p = .002).

The between-subject factor cold-heartedness did not reach significance; hence subjects did not differ in their P300 peaks in regard to that factor. All remaining effects and interactions were also not significant.

2.2.2 sLORETA: source analysis

The neural activation patterns of the grand means from all six conditions were inspected across three time frames (in sum: 200 – 500 ms after feedback-onset). This time domain was chosen to examine the activation during the occurrence of both, the FRN and the P300. Overall, the tomographic images of the neural activations looked quite similar for all conditions within the observed time frames. No activity in the ACC was found within the time frame of interest (200 – 300 ms). Table 1 presents the strongest activated region within those three time frames for all conditions.

2.2.3 SnPM: activation differences

To examine if the differences in P300 peak amplitudes between high and low empathetic persons would also be reflected in differences of their current density, two groups (high empathy IRI and low empathy IRI) were compared in a pairwise SnPM test. Because the P300 occurred within a rather wide latency range (268 – 496 ms) the time frames 4 (300 – 400 ms) and 5 (400 – 500 ms) were inspected. The reason why time frame 3 (200 – 300 ms) was omitted from inspection was that only one subject had a P300 peak that occurred before 300 ms after stimulus onset. However, the comparison did not reach significance for those two time frames.

Permutation tests for the comparison of the agency-levels self and person also turned out to be non- significant in the relevant time frames.

Condition	TF's in ms	Most activated anatomical region	MNI coordinates
self-loss	200 - 300	Superior Frontal Gyrus (BA 6)	X=5, Y=30, Z=60
	300 - 400	Superior Frontal Gyrus (BA 6)	X=5, Y=20, Z=65
	400 - 500	Postcentral Gyrus (BA 3)	X=45, Y=-20, Z=65
self-win	200 - 300	Superior Frontal Gyrus (BA 6)	X=10, Y=30, Z=60
	300 - 400	Superior Frontal Gyrus (BA 6)	X=5, Y=5, Z=70
	400 - 500	Postcentral Gyrus (BA 1)	X=55, Y=-20, Z=60
person-loss	200 - 300	Superior Frontal Gyrus (BA 6)	X=5, Y=30, Z=60
	300 - 400	Middle Frontal Gyrus (BA 6)	X=55, Y=5, Z=45
	400 - 500	Postcentral Gyrus (BA 3)	X=45, Y=-20, Z=65
person-win	200 - 300	Medial Frontal Gyrus (BA 9)	X=-5, Y=55, Z=40
	300 - 400	Superior Frontal Gyrus (BA 6)	X=5, Y=5, Z=70
	400 - 500	Postcentral Gyrus (BA 1)	X=55, Y=-20, Z=55
bank-loss	200 - 300	Superior Frontal Gyrus (BA 8)	X=15, Y=30, Z=60
	300 - 400	Superior Frontal Gyrus (BA 6)	X=10, Y=10, Z=70
	400 - 500	Postcentral Gyrus (BA 1)	X=55, Y=-20, Z=55
bank-win	200 - 300	Superior Frontal Gyrus (BA 8)	X=5, Y=30, Z=60
	300 - 400	Superior Frontal Gyrus (BA 6)	X=10, Y=10, Z=70
	400 - 500	Postcentral Gyrus (BA 1)	X=55, Y=-20, Z=55

Table 1: The neural areas are shown that were most strongly activated within the time domain of the occurrence of the FRN and P300 with the associated Brodmann area in parenthesis. TF is short for "time frame" and show the respective time frames in milliseconds (ms). Coordinates stem from the Montreal Neurological Institute.

The last non-parametric test yielded a significant difference for the agency-levels *person* and *bank* within the time intervals of 200 – 300 ms, 300 – 400 ms and 400 – 500 ms. Because the current density differences in the time domain of the P300 was of interest, only the time domain of 300 – 500 ms was inspected. In the interval of 300 – 400 ms following feedback onset, many voxels were found to be significantly more activated for *person* than for *bank*. A voxel reached significance when he was above the t-value of 6.040 for $p < .05$. Table 2 displays all significant voxels with their number and anatomical region and Figure 11 depicts the corresponding tomographic image of the neural activation pattern. A list with the exact coordinates of all activated regions can be seen in the appendix.

Voxel number	Activated anatomical region
12	Inferior Parietal Lobule (BA 40)
9	Superior Temporal Gyrus (BA 41, BA 42, BA 22)
6	Insula (BA 13)
3	Precuneus (BA 7)
3	Postcentral Gyrus (BA 40)
1	Inferior Temporal Gyrus (BA 20)

Table 2: Comparison between *person* and *bank* in the interval of 300 – 400 ms. The activated anatomical regions are listed together with the number of significant voxels therein.

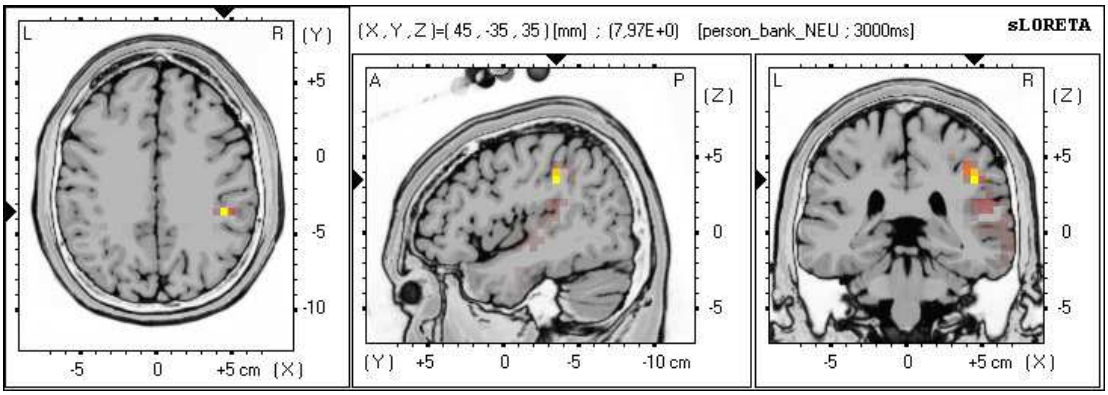

Figure 11: Tomographic image of the activated regions shown in Table 2. Yellow colored voxels mark the points of highest activation differences for *person* compared to *bank.*

In the time interval of 400 – 500 ms activation in the inferior and middle frontal gyrus was higher for *person* than for *bank*. Table 3 and Figure 12 display the significantly more activated regions in the same manner as shown for the time interval of 300 – 400 ms. Again significant voxels were those that had a t-value that was above the threshold of 6.040 for $p > .05$.

Voxel quantity	Activated anatomical region
10	Inferior Frontal Gyrus (BA 47, BA 10)
10	Middle Frontal Gyrus (BA 11, BA 47)

Table 3: Comparison between *person* and *bank* in the interval of 400- 500 ms.

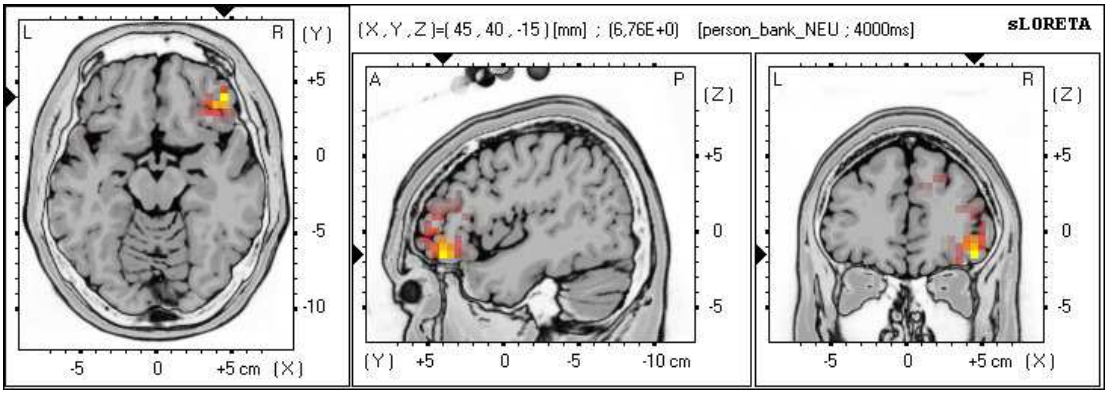

Figure 12: Tomographic image of the activated regions listed in Table 3.

3. Discussion

The main hypotheses of this diploma study were that own losses in a monetary gambling task would lead to a larger FRN than own wins, and that a similar FRN-effect, even though with a smaller amplitude, would also be apparent if losses from close others were observed, whereas this effect should be non-existent if subjects observed losses from an institution. In the study design subjects did not directly observe the outcomes of other players, but instead played for them by proxy. Furthermore it was expected that the P300 would be larger for own wins, compared to own losses and larger for the observed wins of close others, compared to observed losses of close others, again with the absence of this observation P300-effect when observing the outcomes of an institution. Personality questionnaires were used to test the assumption that both ERP-effects were related to empathy. Finally, it was expected that the ACC would be activated in the time interval where the FRN occurred with a higher activation for losses than for wins.

3.1 FRN

Although numerous studies showed that the FRN was more pronounced for monetary losses than for monetary gains (e.g. Miltner et al, 1997; Gehring & Willoughby, 2002; Yeung & Sanfey, 2004) and some found that FRN peak amplitude was larger for self-referred losses than for observed losses from others (e.g. Fukushima & Hiraki, 2006, 2009; Yu & Zhou, 2006), the results of the study presented here weren't able to support either of those findings. That the FRN was not larger for monetary losses in the self-execution condition seemed to be particularly surprising at first sight. Despite the variation in results attained from monetary gambling tasks, losses constantly led to larger FRNs compared to gains. All prior studies, however, used monetary compensation for participation in the experiment and often additionally incorporated payment depending on performance on the task. In the present study subjects didn't receive any money and there was no strategy to apply to increase the gains, which might have lowered the subjects' motivation. This thought is in line with the circumstance that

many subjects reported post-experimentally that they had felt as if no such strategy existed. The notion that the FRN/MFN is influenced by motivational factors in the way that less motivated people have significantly decreased FRN/MFN amplitudes has found support in recent studies (Masaki et al., 2006; Goyer, et al., 2008). For the ERN the same motivational effect has been put forward (Gehring, Goss, Coles, Meyer & Donchin 1993; Luu, Collins & Tucker, 2000; Taylor et al., 2006). Finally, it was also suggested that the proposed generator of both, ERN and FRN – the ACC, is influenced by affect and motivation (Bush et al., 2000). Thus a lack of motivation and a disinterest in the task (as was mentioned from some participants as well) could explain why feedback valence (gain/loss) had no influence on FRN peak amplitude. What speaks against that conclusion is the fact that the FRN was apparent in all conditions, thus it could be argued that the subjects actually were motivated and that there was merely no difference in motivation between the conditions. Another explanation for the absence of a feedback valence effect would be that because there was no strategy to apply, subjects did neither expect losses nor wins. That feedback-expectancy influences the amplitude of the FRN was demonstrated in prior studies (e.g. Holroyd & Krigolson, 2007).

Concerning the question why the FRN did not differ for conditions where subjects observed their own outcomes and where they observed the outcomes of others in a gambling task, only one study from Leng and Zhou (2010) has come to similar results. Leng and Zhou could not find a difference between the FRN responses to the losses of friends and strangers, even though the subjects' own losses were significantly larger than their own wins. The authors try to explain this finding by proposing that the FRN, as an early component that reflects outcome evaluation, is incapable of distinguishing between friend and stranger and only manages to differentiate between self and others. Backed up by studies that showed that the observational-FRN was only elicited because the losses of others had a direct impact on one's own gains (Fukushima & Hiraki, 2006; Itagaki & Katayama, 2008) and by referring to theories that differentiate between automatic and controlled processing (for example described by Fazio, 2001), their explanation sounds rather tempting. However, this explanation disregards cases in which an observational-FRN was apparent in studies where the outcomes of other agents

were not associated with the subjects own benefits (Fukushima & Hiraki, 2009). Further studies are needed to shed light on this finding from Leng and Zhou (2010).

In order to explain why there was no agency-effect in the present study, one should keep in mind that this was the first experiment ever conducted where subjects clearly knew that they were not observing the performances of others, but merely played by proxy for the two non-self agents instead. One question, amongst others, was to find out if to imagine a friend or a relative was already sufficient enough to evoke a larger FRN after a monetary loss has been "observed". The results present in this study would suggest that this is not the case, although a lack of an agency-effect could in turn be explained by a lack of motivation during task-execution. If not even own losses in the game were relevant to the subjects than it is not surprising that subjects were also indifferent to the losses of others.

3.2 P300

Like in the studies from Yeung and Sanfey (Yeung & Sanfey, 2004, 2005) the P300 was also insensitive to reward valence in the present study. In contrast to the study of Yeung and Sanfey (2004), reward magnitude was not a factor in the presented study, due to gains and losses being of equal amount (+100/-100) in the trials. The results from Yeung and Sanfey (2004; 2005) and from the study presented here seem to stand alone because other scientists consistently reported the P300 to be affected by feedback valence (see the following examples). In regard to that matter, it is noteworthy, that the findings how the P300 responds to feedback valence diverge among different studies. Ito, Larsen, Smith and Cacioppo (1998) argued in favor of a negativity bias of the brain resulting in a larger P300 for negative visual stimuli. Hajcak et al. (2005) reported an increase of the P300 caused by positive feedback, irrespective of feedback expectancy, whereas a larger P300-response to false feedback after correct task-performance was found by Balconi and Crivelli (2010). In monetary gambling games, however, gains have, so far, consistently led to a more positive going P300 (Leng & Zhou,

2010; Rigoni, et al., 2010). Yeung and Sanfey (2004) initially proposed separate processing mechanisms for reward magnitude and reward valence, but it is difficult to give credence to this idea in light of the fact that contradicting evidence from different sources exists.

How do these findings fit together with the fact that the P300 was significantly more pronounced when subjects played for close others than when they played for themselves or for the Austrian National Bank? The P300 is thought to reflect mechanisms of attentional allocation (Linden, 2005), with a larger response to motivationally significant events (Nieuwenhuis, et al., 2005a). Recall memory for words has also been linked to the P300 in a study where larger P300 amplitudes were associated with subjects' attention to words that have been learned beforehand (Curran, 2004). Perhaps subjects were emotionally involved when they viewed the labels of different agents on the screen. Gray, Ambady, Lowenthal and Deldin (2004) found out that autobiographical self-relevant stimuli, such as one's own name, elicited a much larger P300 than other names. In their study words of different categories were presented to the subjects sequentially. There was always one self-relevant word sharing the same physical properties (word length and color) with most of the non self-relevant words. Some of these non self-relevant words were in red font and the subjects were instructed explicitly to draw their attention only to those red target-words. Notwithstanding this instruction the self-relevant words in black font elicited a larger P300 than non self-relevant words in black font. Moreover, Gray et al. (2004) predicted that stimuli with autobiographical information about close others (e.g. romantic partners) would elicit a larger P300 as well. This finding is compatible with results for the P300 in the present study. The circumstance that subjects showed the highest P300 peak when observing the names of the close person may be caused by the fact that the name of this person was explicitly presented on the screen, whereas the name of the subject who was playing was not (instead they were informed: "You are playing for yourself").

Another result of this study was that subjects who were more empathetic had larger P300 peaks. It may be the case that this ERP reflects a mechanism of

empathy processing, but in earlier research, scientists only came to that conclusion when the P300 was susceptible to the observation of gains of close others, but not to the gains of strangers (Leng & Zhou, 2010) or to the viewing of pain-related stimuli (e.g. Decety et al., 2010). Leng and Zhou's study differs from the present study in regard to the observation of the outcomes from the agents: whereas Leng and Zhou's subjects viewed the gains and losses of actual co-players on the screen, subjects in the present study had to play by proxy for the other agents. The process of imagining that observed outcomes were those of the respective agents probably did not suffice to create an emotional response that would be reflected in the P300. Decety et al., like in the present study also used questionnaires (e.g. the Interpersonal Reactivity Index –IRI) to examine if larger P300 responses from the control group go along with higher empathy scores. Unlike in the present study, subjects with higher P300 amplitudes (control group) did not differ from subjects with lower P300 amplitudes (physicians) in regard to their empathy scores. Both groups only differed in the evaluation of how they perceived the pain intensity and how unpleasant they felt when observing pain-related images. Thus, the P300 in Decety et al.'s study may reflect only differences in empathy that were restricted to pain-related stimuli. In contrast, the higher P300 amplitudes in the present study are related to higher scores in empathy questionnaires and therefore probably indicate a more general empathetic response. However, larger P300 peaks were not associated with the observation of positive or negative events of others in any kind in the present study. It is therefore assumed that the P300 which was larger in empathetic people across all conditions is explained by the fact that these people paid more attention to the monetary gambling task in general.

Contrary to the results of many earlier studies, the ACC was not found to be more activated in the time domain of the FRN. In the interval of the P300 (300 – 500 ms) the following regions were activated across all conditions in 300 – 400 ms: superior frontal gyrus (BA 6) and middle frontal gyrus (BA 6); and in 400 – 500 ms the highest activations were found in the postcentral gyrus (BA 3 and BA 1). The neural areas that generate the P3b are roughly defined as the temporal-parietal regions (Polich, 2007). Brodmann Area 3 and 1 are part of the parietal cortex and

an activation of those regions in the time window of the P300 matches the findings that the P300/P3b has its source there.

The comparison between close others vs. the Austrian National Bank revealed consistently more activation for the former in the interval of 300 – 400 ms mostly in temporal-parietal regions (inferior parietal lobule (BA 40) superior temporal gyrus (BA 41, BA 42, and BA 22), precuneus (BA 7) and postcentral gyrus (BA 40)). Because the P300 was larger when playing for close others, this finding could further strengthen the notion that temporal-parietal regions can be considered as the source of this brain potential. The Brodmann area 40 is a part of the temporoparietal junction - a region of the brain that was (amongst other regions) found to be commonly activated in a non-verbal task (viewing comic strips) that triggered Theory of Mind- and empathy processes (Völlm, Taylor, Richardson, Corcoran, Stirling, McKie et al., 2006). In the interval of 400 – 500 ms, where the observation of the outcomes of close others again led to more activation, areas of activation were found in prefrontal regions (inferior frontal gyrus (BA 47, BA 10) and middle frontal gyrus (BA 11, BA 47)) but not in parietal-temporal ones. The orbitofrontal cortex (BA 10, BA 11, BA 47) is considered to be an important structure for sensory integration, emotional processing, hedonic experience and decision making that has many reciprocal projections to the ACC and the amygdala (Kringelbach, 2004). Evidence exists, that the orbitofrontal gyrus (BA 11, BA 47) and precuneus (BA 7) were activated when making empathy judgments after reading social scenarios (Farrow, Zheng, Wilkinson, Spence, Deakin, Tarrier et al., 2001). Considering the findings of the present study it seems as if higher neural activations during the observation of outcomes of close others compared to the observation of the outcomes of the Austrian National Bank would indicate that subjects were more empathetic in the former condition. But because the tasks in both studies from Völlm et al. (2006) (viewing comic strips) and Farrow et al. (2001) (reading social scenarios and making empathy judgments) were very different from the monetary gambling task in the present study, the results are to be interpreted with caution.

This is the first study that attempted to access the question whether the observation of losses of close persons would elicit similar FRN and P300

amplitudes as self-referred losses, in a playing-by-proxy paradigm. As a consequence it emphasizes the importance of strategies to keep subjects motivated throughout the entire experimental process and suggests that future studies with the same aim should either incorporate real co-players or make the subjects believe that such real co-players exist. It is further suggested that future studies should try to make wins and losses more salient for the subjects in order to receive stronger electrophysiological responses. A way of achieving this goal could be, for example, giving monetary incentives that are dependent on subjects' performances. This would also require that subjects had the possibility to apply useful strategies to raise their gains. If outcomes were – at least to some degree – controllable, wins perhaps would be more rewarding and losses more adverse. To avoid that self-relevant autobiographical information (e.g. the name of a romantic partner) only influences the P300 when observing the outcomes of others it is suggested, that future experiments include the name of the player as well. Thereby the effect of self-relevant information on the P300 should be approximately the same for self-executed and observed outcomes. Finally, in order to facilitate the process of perspective-taking, images of people for whom subjects are playing by proxy could be placed next to their names in the gambling task.

4. Appendix

Abstract

Recent work revealed that the FRN, a negative event related brain potential occurring between 200 – 300 ms after feedback-onset, was not only elicited when people received a negative feedback, but also when they observed others receiving a negative feedback. Monetary gambling tasks have frequently been used to investigate the observational-FRN (an FRN that is evoked by the observation of losses from others), whereas a monetary loss served as a negative feedback. In order to explain why an FRN is also elicited when observing the losses of others, some scientists have referred to the construct of human empathy, hypothesizing that people regarded the misfortune of others as similarly negative as their own. The P300, a positive going wave peaking between 300 – 500 ms, has also been shown to be modulated by different conditions in gambling tasks as well as by the empathetic concern of people. Prior studies required subjects to perform a gambling task alongside other players (or playing with others via network) and consecutively observing their own and the other player's outcome. In contrast subjects in the present study had to play for themselves and for two other agents (a close person and the Austrian National Bank) by proxy. Electroencephalogram (EEG) was recorded while subjects played a gambling task where they could either win or lose 100 virtual Euros per trial, for themselves or for the respective agents. Additionally, empathy questionnaires were handed out to the subjects post-experimentally to examine if larger FRN and P300 peak amplitudes would be found in subjects who rated themselves as highly empathetic.

Neither outcome valence nor playing for the different agents had a significant effect on FRN peak amplitude. The P300, on the other hand, was modulated by playing for close others, but outcome valence again had no impact on this brain potential. Subjects with higher empathy scores in two questionnaires had significantly larger P300 amplitudes compared to subjects with lower empathy scores. The conclusion was drawn that these results were caused by the fact that due to the absence of a strategy to raise the gains in the task, subjects neither

expected losses nor wins and that the P300-effect for close others could be explained by an emotional reaction while reading their names on the screen.

Zusammenfassung auf Deutsch

Jüngste Studien haben gezeigt dass die FRN, ein ereigniskorreliertes Potenzial das einen negativen Wellenverlauf aufweist, nicht nur evoziert wurde, wenn Personen selbst eine negative Rückmeldung erhielten, sondern auch, wenn sie eine solche Rückmeldung bei anderen beobachteten. Die am häufigsten angewandte Methode, um die sogenannte Beobachtungs-FRN (eine FRN die auftritt wenn beobachtet wird das andere eine negative Rückmeldung erhalten) zu erforschen, stellen Glückspielaufgaben dar, bei denen finanzielle Verluste als negative Rückmeldung verwendet werden. Die Beobachtungs-FRN wurde von einigen Forschern dadurch erklärt, dass Personen empathisch auf den beobachteten finanziellen Verlust von anderen reagieren. Die P300, eine positive Welle die zwischen 300 – 500 ms maximal ist, wurde in Glücksspielaufgaben ebenfalls durch unterschiedliche Aufgabenbedingungen moduliert. Gleichfalls hat sich gezeigt, dass die P300 auf Stimuli reagiert, von denen vermutet wird, dass sie empathische Reaktionen auslösen. Vorangehende Studien haben die Beobachtungs-FRN untersucht, indem sie ein Design benutzten bei dem zwei Spieler sich entweder gegenseitig beobachten konnten, und jeder die Spielergebnisse des anderen Spielers sah, oder bei dem eine Versuchsperson die Ergebnisse des 2. Spielers am eigenen Bildschirm mit verfolgte. In der vorliegenden Studie hingegen spielten die Versuchspersonen für sich selbst und, in Stellvertretung, für zwei weitere Parteien (eine nahestehende Person und die Österreichische Nationalbank). EEG Signale wurden abgeleitet, während Versuchspersonen in einer Glückspielaufgabe 100 virtuelle Euro (pro Runde) für sich selbst bzw. für eine der beiden Parteien gewannen oder verloren. Zusätzlich wurden Empathie-Fragebögen vorgegeben, um zu untersuchen, ob sich hoch-empathische von niedrig-empathischen Personen in ihren Gehirnpotenzialen unterscheiden. Die FRN unterschied sich weder in der Gewinn- bzw. Verlustbedingung, noch hatte das Spielen für eine der drei Parteien einen signifikanten Einfluss auf ihre Amplitude. Für welche Partei gespielt wurde, hatte allerdings einen Einfluss auf die P300, die sich ebenfalls nicht durch die Valenz

des Spielausgangs modulieren ließ. Die P300 war am größten wenn für die nahestehende Person gespielt wurde, unabhängig von beobachteten Gewinnen oder Verlusten. Am zweithöchsten war die ereigniskorrelierte Komponente wenn Versuchspersonen für sich selbst spielen und am dritthöchsten wenn sie für die Österreichische Nationalbank spielten. Zusätzlich wiesen hoch-empathische Personen eine höhere P300 auf als niedrig-empathische Personen. Die Ergebnisse wurden dahingehend interpretiert, dass aufgrund des Fehlens einer Strategie um die Gewinne zu erhöhen Versuchspersonen sowohl Verluste als auch Gewinne für unerwartet hielten. Die P300 Effekte können dadurch erklärt werden, dass Versuchspersonen emotional auf den Namen der nahestehenden Person reagiert haben.

SnPM comparison of person versus bank: time frame 4 (TF4)

Activated anatomical region	Voxel value	MNI coordinates
Inferior Parietal Lobule (BA 40)	7.96897E+0000	X = 45, Y= -35, Z = 35
Inferior Parietal Lobule (BA 40)	7.80264E+0000	X = 45, Y = -35, Z = 40
Inferior Parietal Lobule (BA 40)	7.50188E+0000	X = 40, Y = -40, Z = 40
Inferior Parietal Lobule (BA 40)	7.35694E+0000	X = 40, Y = -35, Z = 40
Inferior Parietal Lobule (BA 40)	7.24669E+0000	X = 40, Y = -35, Z = 45
Inferior Parietal Lobule (BA 40)	7.09306E+0000	X = 40, Y = -40, Z = 45
Precuneus (BA 7)	6.80140E+0000	X = -25, Y = -50, Z = 45
Inferior Parietal Lobule (BA 40)	6.70579E+0000	X = 50, Y = -35, Z = 35
Insula (BA 13)	6.66118E+0000	X = 50, Y = -30, Z = 20
Inferior Parietal Lobule (BA 40)	6.65212E+0000	X = 50, Y = -30, Z = 25
Insula (BA 13)	6.52410E+0000	X = 50, Y = -35, Z = 20
Superior Temporal Gyrus (BA 41)	6.50847E+0000	X = 50, Y = -30, Z = 15

Superior Temporal Gyrus (BA 42)	6.48455E+0000	X = 55, Y = -35, Z = 15
Postcentral Gyrus (BA 40)	6.48238E+0000	X = 55, Y = -30, Z = 20
Superior Temporal Gyrus (BA 42)	6.45928E+0000	X = 55, Y = -30, Z = 15
Insula (BA 13)	6.44626E+0000	X = 55, Y = -35, Z = 20
Superior Temporal Gyrus (BA 41)	6.40890E+0000	X = 50, Y = -35, Z = 15
Inferior Parietal Lobule (BA 40)	6.30990E+0000	X = 55, Y = -30, Z = 25
Insula (BA 13)	6.25810E+0000	X = 45, Y = -35, Z = 20
Superior Parietal Lobule (BA 7)	6.24526E+0000	X = -25, Y = -55, Z = 45
Superior Temporal Gyrus (BA 41)	6.22772E+0000	X = 50, Y = -30, Z = 10
Superior Temporal Gyrus (BA 41)	6.22666E+0000	X = 55, Y = -30, Z = 10
Insula (BA 13)	6.19864E+0000	X = 55, Y = -40, Z = 20
Superior Temporal Gyrus (BA 42)	6.12681E+0000	X = 60, Y = -35, Z = 20
Postcentral Gyrus (BA 40)	6.09332E+0000	X = 55, Y = -25, Z = 15
Superior Temporal Gyrus (BA 22)	6.08834E+0000	X = 65, Y = -40, Z = 15
Superior Temporal Gyrus (BA 42)	6.08742E+0000	X = 60, Y = -30, Z = 15
Inferior Parietal Lobule (BA 40)	6.08161E+0000	X = 40, Y = -45, Z = 45
Inferior Parietal Lobule (BA 40)	6.07655E+0000	X = 55, Y = -35, Z = 25
Precuneus (BA 7)	6.07113E+0000	X = -20, Y =-55, Z = 45
Insula (BA 13)	6.06391E+0000	X = 50, Y = -40, Z = 20
Inferior Parietal Lobule (BA 40)	6.06017E+0000	X = 40, Y = -35, Z = 35
Inferior Temporal Gyrus (BA 20)	6.05101E+0000	X = 60, Y = -25, Z = -25
Postcentral Gyrus (BA 40)	6.04495E+0000	X = 60, Y = -30, Z = 20

Table 4: All the significantly activated voxels with their specific MNI coordinates found in time frame 4 of the comparison between *person* and *bank*. The voxel values are above the threshold value (6.040) for the significance level of .05. Because all values are positive, all significant voxels were stronger activated in the *person*-condition.

SnPM comparison of bank versus person: time frame 5 (TF5)

Activated anatomical region	Voxel value	MNI coordinates
Inferior Frontal Gyrus (BA 47)	6.76065E+0000	X = 45, Y= 40, Z = -15
Middle Frontal Gyrus (BA 47)	6.59481E+0000	X = 45, Y = 40, Z = -10
Middle Frontal Gyrus (BA 11)	6.58800E+0000	X = 40, Y = 35, Z = -10
Middle Frontal Gyrus (BA 11)	6.58064E+0000	X = 40, Y = 35, Z = -15
Inferior Frontal Gyrus (BA 47)	6.54551E+0000	X = 45, Y = 35, Z = -15
Inferior Frontal Gyrus (BA 47)	6.38854E+0000	X = 45, Y = 35, Z = -10
Middle Frontal Gyrus (BA 47)	6.37099E+0000	X = 45, Y = 40, Z = -5
Middle Frontal Gyrus (BA 47)	6.33774E+0000	X = 40, Y = 40, Z = -10
Inferior Frontal Gyrus (BA 47)	6.25935E+0000	X = 35, Y = 30, Z = -5
Middle Frontal Gyrus (BA 47)	6.25607E+0000	X = 40, Y = 40, Z = -5
Middle Frontal Gyrus (BA 11)	6.24034E+0000	X = 35, Y = 35, Z = -10
Middle Frontal Gyrus (BA 11)	6.22416E+0000	X = 45, Y = 45, Z = -10
Inferior Frontal Gyrus (BA 47)	6.20555E+0000	X = 35, Y = 30, Z = -10
Inferior Frontal Gyrus (BA 47)	6.16820E+0000	X = 50, Y = 40, Z = -10
Middle Frontal Gyrus (BA 11)	6.14156E+0000	X = 35, Y = 35, Z = -15
Inferior Frontal Gyrus (BA 47)	6.13204E+0000	X = 50, Y = 45, Z = -10
Inferior Frontal Gyrus (BA 10)	6.10492E+0000	X = 45, Y = 45, Z = 0
Inferior Frontal Gyrus (BA 47)	6.09571E+0000	X = 40, Y = 30, Z = -10
Middle Frontal Gyrus (BA 11)	6.08155E+0000	X = 45, Y = 45, Z = -15
Inferior Frontal Gyrus (BA 47))	6.05371E+0000	X = 40, Y = 30, Z = -5

Table 5: Again, the significantly activated voxels with their specific MNI coordinates, now found in time frame 5 are shown. The voxel values are above the threshold value (6.040) for the significance level of .05. Because all values are positive, all significant voxels were stronger activated in the *person*-condition.

5. References

Alpers, G.W. & Eisenbarth, H. (2008). Psychopathic personality inventory revised. Deutsche Version. Wien: Hogrefe

Balconi, M. & Crivelli, D. (2010). FRN and P300 ERP effect modulation in response to feedback sensitivity: The contribution of punishment-reward system (BIS/BAS) and Behaviour Identification of action. *Neuroscience Research, 66*, 162-172

Batson, C. D., Fultz, J., & Schoenrade, P. A. (1987). Distress and empathy: Two qualitatively distinct vicarious emotions with different motivational consequences. *Journal of Personality, 55*, 19–39

Bauer, H., Lamm, C., Holzreiter, S., Holländer, I., Leodolter, U. & Leodolter, M. (2000). Measurement of 3D electrode coordinates by means of a 3D photogrammetric head digitizer. *NeuroImage 11*, *number 5, part 2*, 461

Bradley, M.M. (2009). Natural selective attention: Orienting and emotion. *Psychophysiology, 46,* 1–11

Bush, G., Luu, P., & Posner, M. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences, Vol. 4, No. 6*, 215-222

Cacioppo, J. T., & Berntson, G. G. (1992). Social psychological contributions to the decade of the brain: Doctrine of multilevel analysis. *American Psychologist*, 47, 1019-1028.

Carlson, S.M., Zayas, V. & Guthormsen, A. (2009). Neural correlates of decision making on a gambling task. *Child Development, vol. 80*, Num. 4, 1076-1096

Carter, C.S., Braver, T.S., Barch, D.M., Botvinick, M.M., Noll, D. & Cohen, J.D. (1998). Anterior cingulated cortex, error detection and the online monitoring of performance. *Science, Vol. 280*, 747-749

Curran, T. (2004). Effects of attention and confidence on the hypothesized ERP correlates of recollection and familiarity. *Neuropsychologia, 42,* 1088–1106

Davis, M. H. (1996). Empathy: A social psychological approach. Madison, WI: Westview Press.

Decety, J. & Lamm, C. (2006). Human empathy through the lense of social neuroscience. *The Scientific World JOURNAL, 6*, 1146–1163

Decety, J. Yang, C.-Y. & Cheng, Y. (2010). Physicians down-regulate their pain empathy response: An event-related brain potential study. *Neuroimage, 50*, 1676-1682

Delorme, A. & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods, 134*, 9-21

Donchin, E. (1981). Surprise!....Surprise? *Psychophysiology,18*, 493–513.

Donchin. E. & Coles, M.G.H. (1998). Is the P300 component a manifestation of context updating? *Behav Brain Sci;11*, 357–74.

Emeric, E.E., Brown, J.W., Leslie, M., Pouget, P., Stuphorn, V., & Schall, J.D. (2008). Performance Monitoring Local Field Potentials in the Medial Frontal Cortex of Primates: Anterior Cingulate Cortex. *J Neurophysiol* 99, 759–772

Fan, Y. & Han, S. (2008). Temporal dynamic of neural mechanisms involved in empathy for pain: An event-related brain potential study. *Neuropsychologia, 46*, 160-173

Farrow, T.F.D., Zheng, Y., Wilkinson, I.D., Spence, S.A., William, D., Tarrier, N., et al. (2001). Investigating the functional anatomy of empathy and forgiveness. *Neuroreport, 12, No. 11*, 2433-2438

Fazio, R.H. (2001). On the automatic activation of associated evaluations: An overview. *Cognition and Emotion, 15 (2),* 115–141

Fretska, E., Bauer, H., Leodolter, M. & Leodolter, U. (1999). Loss of control and negative emotions: a cortical slow potential topography study. *International Journal of Psychophysiology, 33*, 127-141

Fukushima, H. & Hiraki, K. (2006). Perceiving an opponent's loss: gender-related differences in the medial-frontal negativity. *Social cognitive and affective neuroscience*, 149-157

Fukushima, H. & Hiraki, K. (2009). Whose loss is it? Human electrophysiological of non-self reward processing. *Social neuroscience,* 4(3), 261-275

Gehring, W.J., Goss, B., Coles, M.G.H., Meyer, D.E. & Donchin, E. (1993). A neural system for error detection and compensation. *Psychological Science, Vol. 4*, *No. 6*, 385-390

Gehring, W.J. & Willoughby, A.R. (2002). The Medial frontal cortex and the rapid processing of monetary gains and losses. *Science, 295*, 2279-2282

Gemba, H., Sasaki, K., & Brooks, V.B. (1986). Error potentials in limbic cortex (anterior cingulated cortex area 24) of monkeys during motor learning. *15th Annual Meeting of the Society for Neuroscience*,

Gentsch, A., Ullsperger, P., & Ullsperger, M. (2009). Dissociable medial frontal negativities from a common monitoring system for self- and externally caused failure of goal achievement. *Neuroimage,* 47, 2023–2030

Goyer, J.P., Woldorff, M.P. & Huettel, S.A. (2008). Rapid electrophysiological brain responses are influenced by both valence and magnitude of monetary rewards. *Journal of Cognitive Neuroscience, 20:*11, 2058–2069

Gray, H.M., Ambady, N., Lowenthal, W.T. & Deldin, P. (2004). P300 as an index of attention to self-relevant stimuli. *Journal of Experimental Social Psychology, 40*, 216–224

Hajcak, G., Moser, J.S., Holroyd, C.B. & Simons, R.F. (2006). The feedback-related negativity reflects the binary evaluation of good versus bad outcomes. *Biological Psychology, 71,*148–154

Han, S., Fan, J. & Mao, L. (2008). Gender difference in empathy for pain: An electrophysiological investigation. *Brain Research, 1196,* 85-93

Häcker, A.A. & Stapf, K.-H. (ed.). (2004). Dorsch. Psychologisches Wörterbuch. 14. Auflage. Bern: Verlag Hans Huber

Heldmann, M., Rüsseler, J., & Münte, T.F. (2008). Internal and external information in error processing. *BMC Neuroscience*, *9*:33

Hideki, O., Ichikawa, N.I., Nomura, M., Isowa, T., Kimura, K., Kanayama, N., Fukuyama, S., Shinoda, J., & Yamada, J. (2010). Brain and autonomic association accompanying stochastic decision making. *Neuroimage, 49*, 1024-1037

Holmes, A.P., Blair, A.C., Watson, J.D. & Ford, I. (1996). Nonparametric Analysis of Statistic Images from Functional Mapping Experiments. *Journal of Cerebral Blood Flow & Metabolism, 16*, 7–22

Holroyd, C.B., & Coles, M.G. (2002). The neural basis of human error processing: reinforcement learning, dopamine, and the error-related negativity. *Psychological Review*, *109*, 679-709.

Holroyd, C.B., Nieuwenhuis, S., Yeung, N. & Cohen, J.D. (2003). Errors in reward prediction are reflected in the event-related brain potential. *Neuroreport, 14, No. 18,* 2481-2484

Holroyd, C.B., Larsen, J.T. & Coles, J.D. (2004a). Context dependence of the event-related brain potential associated with reward and punishment. *Psychophysiology, 41*, 245–253.

Holroyd, C.B, Nieuwenhuis, S., Yeung, N., Nystrom, L., Mars, R.B., Coles, M.G.H., & Cohen, J.D. (2004b). Dorsal anterior cingulate cortex shows fMRI response to internal and external error signals. *Nature Neuroscience, vol. 7, No. 5*, 497-498

Holroyd, C.B. & Krigolson, O.E. (2007). Reward prediction error signals associated with a modified time estimation task. *Psychophysiology, 44,* 913–917.

Itagaki, S. & Katayama, J. (2008). Self-relevant criteria determine the evaluaton of outcomes induced by others. *Neuroreport, Vol. 19*, *No. 3*, 383-387

Ito, T.A., Larsen, J.T., Smith, K.N. & Cacioppo, J.T. (1998). Negative information weights more heavily on the brain: The negativity bias in evaluative categorizations. *Journal of Personality and Social Psychology, Vol. 75, No. 4*, 887-900

Jackson, P.L., Brunet, E., Meltzoff, A.N. & Decety, J. (2006). Empathy examined through the neural mechanisms involved in imagining how I feel versus how you feel pain. *Neuropsychologia, 44*, 752–761

Johnson, R. (1986). A triarchic model of the P300 amplitude. *Psychophysiology, 23,* 367-384

Kiehl, K.A., Liddle, P.F. & Hopfinger, J.B. (2000). Error processing and the rostral anterior cingulate: An event related fMRI study. *Psychophysiology, 37*, 216-223

Kringelbach, M.L. (2005). The human orbitofrontal cortex: linking reward to hedonic experience. *Nature Reviews. Neuroscience, vol. 6*, 691-702

Lamm, C., Batson, C.D., & Decety, J. (2007). The Neural Substrate of Human Empathy: Effects of Perspective-taking and Cognitive Appraisal. *J. Cogn. Neurosci,. 19:1*, 42-58

Lamm, C., Fischmeister, F.Ph.S. & Bauer, H. (2005). Individual differences in brain activity during visuo-spatial processing assessed by slow cortical potentials and LORETA. *Cognitive Brain Research, 25*, 900–912

Larson, M.J., Fair, J.E., Good, D.A. & Baldwin, S.A. (2010). Empathy and error processing. *Psychophysiology, 47*, 415–424.

Leng, Y. & Zhou, X. (2010). Modulation of the brain activity in outcome evaluation by interpersonal relationship: An ERP study. *Neuropsychologia, 48*, 448-455

Luck, S.J. (2005). An introduction to the event –related potential technique. Cambridge: The MIT Press

Luu, P., Collins, P. & Tucker, D.M. (2000). Mood, personality and self-monitoring: Negative effect and emotionality in relation to frontal lobe mechanisms of error monitoring. *Journal of Experimental Psychology: General, Vol. 129*, No. 1, 43-60

Masaki, H., Takeuchi, S., Gehring, W.J., Takasawa, N. & Yamazaki, K. (2006). Affective-motivational influences on feedback-related ERPs in a gambling task. *Brain Research, 1105*, 110-121

Menon, V., Adleman, N.E., White, C.D., Glover, G.H. & Reiss, A.L. (2001). Error related brain activation during a go/no-go response inhibition task. *Human Brain Mapping, 12*:131-143

Miltner, W.H.R., Braun, C.H. & Coles, M.G.H. (1997). Event-related brain potentials following feedback in a time-estimation task: evidence for a generic neural system of error detection. *J. Cogn. Neurosci.,* 9:6, 788-798

Miltner, W.H.R., Brauner, J., Hecht, H., Trippe, R., & Coles, M.G.H. (2003). Parallel brain activity for self-generated and observed errors. In: Ullsperger, M., Falkenstein, M.,(Hrg). *Errors, conflicts and the brain: current opinions on performance monitoring.* Leipzig: MPI of Cognitive Science, 124-129

Morrison, I., Lloyd, D., di Pellegrino, G., & Roberts, N. (2004). Vicarious responses to pain in anterior cingulated cortex is empathy a multisensory issue? *Cogn. Affect. Behav. Neurosci.* 4, 270–278.

Newman-Norlund, R.D., Ganesh, S., van Schie, H.T., De Brujin, E.R.A., & Bekkering, H. (2008). Self-identification and empathy modulate error-related brain activity during the observationof penalty shots between friend and foe. *Social cognitive and affective neuroscience*, *4(1)*. 10-22

Nieuwenhuis, S., Aston-Jones, G. & Cohen, J. (2005a). Decision Making, the P3, and the Locus Coeruleus–Norepinephrine System. *Psychological Bulletin, Vol. 131, No. 4,* 510–532

Nieuwenhuis, S., Slagter, H.A., Alting von Geusau, N.J., Helsenfeld, D.J. & Holroyd, C.B. (2005b). Knowing good from bad: differential activation of human cortical areas by positive and negative outcomes. *Eur. J. Neurosci,* 21, 3161-3168

Nieuwenhuis, S., Yeung, N., Holroyd, C.B., Schurger, A., & Cohen, D. (2004). Sensitivity of Electrophysiological Activity from Medial Frontal Cortex to Utilitarian and Performance Feedback. *Cerebral Cortex,* 14, 741-747

Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh Inventory. *Neuropsychologia, 9*, 97-113.

Pascual-Marqui, R.D. (2002). Standardized low resolution brain electromagnetic tomography (sLORETA): technical details. *Methods & Findings in Experimental & Clinical Pharmacology, 24D:* 5-12

Rigoni, D., Polezzi, D., Rumiati, R., Guarino, R. & Satorio, G. (2010). Brain *Research Bulletin, 81*, 445-452

Ruchsow, M., Grothe, J., Spitzer, M. & Kiefer M. (2002). Human anterior cingulate cortex is activated by negative feedback: evidence from event-related potentials in a guessing task. *Neuroscience Letters, 325,* 203–206

Santesso, D.L. & Segalowitz, S.J. (2009). The error-related negativity is related to risk taking and empathy in young men. *Psychophysiology, 46*, 143–152.

Shane, M.S., Stevens, M., Harenski, C.L., & Kiehl, K.A. (2008). Neural correlates of the processing of another's mistakes: A possible underpinning for social and observational learning. *NeuroImage,* 42, 450–459

Singer, T. & Lamm, C. (2009). The social Neuroscience of empathy. *Ann. N.Y. Acad. Sci,. 1156*: 81-96

Singer, T., Seymour, B., O'Doherty, J., Kaube, H., Dolan, R.J., & Frith, C.D. (2004). Empathy for pain involves the affective but not the sensory components of pain. *Science, 303*, 1157–1161.

Talairach, J. & Tournoux, P. (1998). Co-planar stereotaxic atlas of the human brain. Stuttgart: Georg Thieme Verlag

Taylor, S.F., Martis, B., Fitzgerald, K.D., Welsh, R.C., Abelson, J.L., Liberzon, I. et al. (2006). Medial frontal cortex activity and loss-related responses to error. *The Journal of Neuroscience, 26(15):*4063– 4070

van Schie, H.T., Mars, R.B., Coles, M.G.H., and Bekkering, H. (2004). Modulation of activity in medial frontal and motor cortices during error observation. *Nature Neuroscience,* vol 7, No. 5, 549-554

van Veen, V. & Carter, C.S. (2002). The timing of action-monitoring processes in the anterior cingulated cortex. *J. Cogn. Neurosci. 14:4*, 593-603

van Veen, V., Holroyd, R.B., Cohen, J.D., Stengerd, V.A., & Cartere, C.S. (2004). Errors without conflict: Implications for performance monitoring theories of anterior cingulate cortex. *Brain and Cognition,* 56, 267–276

Völlm, B.A., Taylor, A.N.W., Richardson, P., Corcoran, R., Stirling, J., McKie, S. et al. (2006). Neuronal correlates of theory of mind and empathy: A functional magnetic resonance imaging study in a nonverbal task. *NeuroImage, 29*, 90–98

Wehner, R. & Gehring, W. (2007). Zoologie. Stuttgart: Georg Thieme Verlag

Wu, Y. & Zhou, X. (2009). The P300 and reward magnitude, valence and expectancy in outcome evaluation. *Brain Research 1286*, 114-122

Yeung, N., Cohen, J.D., & Botvinick, M.M. (2004). The Neural Basis of Error Detection: Conflict Monitoring and the Error-Related Negativity. *Psychological Review, Vol. 111*, No. 4, 931–959

Yeung, N., Holroyd, C.B., & Cohen, J.D. (2005). ERP correlates of feedback and reward processing in the presence and absence of response choice. *Cerebral Cortex, 15*, 535-44.

Yu, R., & Zhou, X. (2006). Brain responses to outcomes of one's own and other's performance in a gambling task. *Neurorepor,t 17*, 1747–1751.

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