Diplomarbeit

Titel der Arbeit

"WHAT COULD HAVE BEEN, IF ONLY…?"

LIFE IN COUNTERFACTUALS

REGRET AND ITS RELATION TO THE FEEBACK – RELATED NEGATIVITY:

AN INVESTIGATIVE EEG/ERP STUDY INCLUDING THE P3

Verfasser

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Für meine Familie, insbesondere für Luka.

Non! Rien de rien ...
Non! Je ne regrette rien ...
Car ma vie, car mes joies
Aujourd'hui, ça commence avec toi!

Edith Piaf , «Non, je ne regrette rien » (1961)

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1 EARLY ECONOMIC MODELS OF CHOICE BEHAVIOUR

People make decisions every day, ranging from small daily choices up to decisions that can or respectively will alter and influence the rest of their lives. Some of the decisions are made easily, some take days, weeks or months of weighing probabilities. People sometimes take chances in life, at other times they might let them pass (Gilovich & Medvec, 1995). From time to time after having made a choice or set the path for a certain way of life a feeling stays, preying on one's mind to not have chosen the best option or having let go of opportunities, varying from short-term to long-term regrets (Gilovich & Medvec, 1995), some easy to undo, some chances passed for good.

Webster's Dictionary describes regret as "1. Sorrow aroused by circumstances beyond one's control or power to repair. Grief or pain tinged with disappointment, dissatisfaction, longing, remorse, or comparable emotion. 2.a) an expression of sorrow, disappointment, or other distressing emotion." Relief as its opposite is defined as "removal or lightening of something oppressive, burdensome, painful, dangerous, or distressing." Another expression used in the present work is rejoice, which can be seen as: "to feel joy, or great delight; experience gladness or pleasurable satisfaction" (Merriam-Webster, 1981) Rejoice used in the present work is not to be confused with "joy" defined as: "a state of happiness or felicity" (Merriam-Webster, 1981)

The present study will focus on that feeling of regret and its relation to the feedback-related negativity (FRN), an event-related brain potential in the EEG elicited about 200 – 300msec after a received negative feedback about a choice made (Holroyd & Coles, 2002).

For the start it seems important to take a closer look on how early economic models of choice behaviour have tried to tie the process of decision making down in describing it in mathematical formulas. Beginning with the expected utility theory by von Neumann und Morgenstern, who propose a totally rational process of decision making, without even alluding to the term of regret, the line will be drawn further to Loomes and Sugden (1982), as well as Bell (1982) who started out with the expected utility theory, developed it further and incorporated regret into their models of utility, finally leading to more theoretical grounding of this cognitive emotion (Zeelenberg & Pieters, 2007) expressed through counterfactual thinking (Kahnemann & Miller, 1986; Summerville & Roese, 2008). Or as Zeelenberg and Pieters (2007) put it: " (…) regret is a functional emotion that influences decision-making in ways that are relevant to our goals and concerns, (…) to maximize our short term and long term outcomes." The neural basis of regret is adduced, by presenting results of an fMRI study by Coricelli et al.(2005). Finally this will lead to the aim of the present study, which will be presented in chapter 5, by first of all presenting the theoretical grounding of the FRN. Moreover the P3 will be analysed as well. The P3 is positive event – related potential peaking around 350msec after the presentation of feedback. The theory behind the FRN, along with the results from the present experiment will be discussed regarding their relation to regret.

1.1 Expected utility theory

Early economic models of choice behaviour, as stated by von Neumann and Morgenstern (1947), suggest a rational process of decision-making under uncertainty, in which the final goal, reached by defined behavioural principles, is maximizing the expected utility of the final result.

The notion of "utility" means any satisfaction the individual desires, be that of monetary kind or not, described in terms of behaviour in games, which refers to social and economic environments as well. They furthermore state that an individual who finally gained a desired maximum outcome, behaves rational, although von Neumann und Morgenstern admit, at the time publishing their writing, "(…) there exists, at present, no satisfactory treatment of the question of rational behaviour" (von Neumann & Morgenstern, 1947) and that the ways to reach the optimum differ for various individuals, with respect to the possibilities open for them, and considering other individuals striving for the same maximization, all taking place in a social world. Nevertheless they do "(…) wish to find the mathematically complete principles which define "rational behaviour" for the participants in a social economy, and to derive from them the general characteristics of that behaviour." (von Neumann & Morgenstern, 1947)

Von Neumann and Morgenstern (1944) imply that the individual is able to state a probability to a future, visualized event. With the restriction that all events take place in the same period of time in the future, for they are aware of the problem of assigning preferences to events in different time frames. They present axioms upon which their theory is build, deriving from them solutions for rational behaviour under uncertainty in various set of games, beginning with the "simplest game", described in terms that "nobody does anything and that nothing happens" (von Neumann & Morgenstern, 1947). Moreover they define a set of variables for each participant of the game, each set containing the actions, the will of the individual which is further referred to as a "set of elements". They presume that this participant, the player, can clearly state a preference between two choices or events, as well as between a set of combined alternatives with denoted probabilities and compare them to each other rationally. This is referred to as "completeness in the system of individual preferences" and state "transitivity" and "continuity" of preferences to be important axioms of their theory. Transitivity of preference shows this pattern: $x > y > z$, from which it follows that: $x > z$. "Continuity" means that every x that's preferable to y will stay more desirable even considering only a small probability ("1-α") of x alternately to y occurring. This allows the individual to state a preference in terms of n being more desirable than y. Furthermore if x > y, and a z occurs, in itself being very desirable, it's up to the individual to minimize its influence by addressing it the smallest chance of occurring, so it will not affect the preferability of z.

Nevertheless they do acknowledge the problem of intransitivity of preferences, which is most obvious when groups of individuals create what they call "cyclical dominations": e.g.: y > x, z > y. They take this factor into consideration and build their theory on postulates which they furthermore call "standards of behaviour". „The postulates are as follows: A set S of elements (imputations) is a solution when it possesses these two properties: (1) No y contained in S is dominated by an x contained in S. (2) Every y not contained in S is dominated by some x contained in S." Combined these two postulates add up to: „The elements of S are precisely those elements which are undominated by elements of S." (von Neumann & Morgenstern, 1947)

For von Neumann and Morgenstern (1944) games serve an equal function for a social and economic environment as mathematical models for natural science. They postulate rules for the game, under which rationality of behaviour becomes possible, meaning also various rules which apply to a real environment. They act on the assumption of "complete information", meaning that the individual in a social environment, as well as in economy, knows about all the properties, probabilities, and characteristics of the present situation. (Nonetheless they do state examples of games and also give models for situations in which the individual is not fully informed, and address these issues of special cases in separate sections of their book.) The subject starts the game with a plan, a "strategy", which will be updated in every stage of the game with all necessary and available information. They also include the notion that irrational behaviour on the behalf of other individuals involved in the game is to be accounted for in the rules applied. Taking all assumptions together von Neumann und Morgenstern (1947) propose that the subject, with its inherent characteristics and possibilities, will be able "to determine the maximum utility which can be obtained in this situation." and they present solutions for every shape a game can assume. „Paradoxes" (Bell, 1982) are described as situations in which the axioms of this behavioural principles are violated through irrational decisions not leading to the highest expected utility.

1.2 Alternative theories to the expected utility model

Loomes and Sugden (1982), as well as Bell (1982), suggest an alternative theory of decision-making under uncertainty, for Loomes and Sugden (1982) state that „(…) expected utility theory (…) represents an unnecessarily restrictive notion of rationality.". Hence Loomes and Sugden (1982) and Bell (1982) introduce regret as a key-component in their theories of choice behaviour under uncertainty, where they incorporate regret in the process of deciding.

1.2.1 Regret Theory (Loomes & Sugden, 1982)

Loomes and Sugden (1982) argue that people experience regret, anticipate that feeling and let it influence further actions. For them expected utility theory simply overlooks the important impact regret and also rejoice have on further decisions. Including regret and rejoice in their theory they introduce a modified utility function.

$$m_{ij}^{k} = M(c_{ij}, c_{kj}).$$

***Figure 1.1*: Modified utility function (Loomes & Sugden, 1982)**

Let us imagine one would prefer A_i to A_k, and „*j*th the state of the world occurs" (Loomes & Sugden, 1982), with the outcome x_{ij}, instead of x_{kj}, if the individual chose the alternative. The subject now realizes the modified utility m^k_{ij}, where c_{ij} stands for, the chosen alternative of *C* (x_{ij}), respectively c_{kj}, for the rejected one. They speak of *M (.)* being a "real-value index to every pair of "choiceless utility". The difference of m^k_{ij} to c_{ij} stands for increasing, respectively decreasing of utility dependent on the amount of regret or rejoice experienced. They use what they call the „choiceless utility" for the calculation, meaning that there are no other characteristics of the different states of "what is" in comparison to "what might have been" accounted for in the calculation.

They propose that an individual chooses one particular alternative, uncertain about the consequences, but they agree with von Neumann and Morgenstern (1947) that probabilities are given and that the individual either knows about the probabilities of a certain "state of the world" (Loomes & Sugden, 1982) occurring by choosing (objective probabilities), or assigns a subjective probability to it according to the subject's estimation of its appearance. If now this outcome turns out to be less desirable than the simultaneously rejected alternative regret will occur. Respectively if, through comparison, the choice turns out to be better than the opposed consequence, rejoice will be experienced. Accordingly no regret or rejoice will be felt if the outcome turns out to be as predicted, and conversely, consistent to how much better or worse the attained output emerges, subsequently more or less regret, or rejoice, will be experienced.

They state that individuals seek to enhance their performance in choices under uncertainty by taking regret and also rejoice into account, and define the expected modified utility *E* of one decision respectively to the alternative with a probability of *j* occurring when opting for the modified utility $m^k_{ij.}$

$$E_i^k = \sum_{j=1}^{n} p_j m_{ij}^k.$$

Figure 1.2: **Expected modified utility (Loomes & Sugden, 1982)**

They go on by further incorporating regret and rejoice in the expected modified utility function and present the regret-rejoice function, where they propose that the degree of regret or rejoice depends on the difference between "what is" and "what might have been, would I have chosen differently", using these terms as the "choiceless utility", for modifying *M (.)* to the regret-rejoice function *R (.)* with an assigned "real-value index" to every increase or decrease of "choiceless utility", meaning the utility every alternative has for itself despite the value of the choice for c_{ij} itself.

$$m_{ij}^k = c_{ij} + R(c_{ij} - c_{kj}).$$

Figure 1.3: **Regret - rejoice function (Loomes & Sugden, 1982)**

Loomes and Sugden (1982) propose that individuals strive for the maximum expected modified utility and they argue that comprising the anticipation of regret and rejoice in their theory doesn't necessarily make the theory of expected modified utility irrational.

1.2.2 Regret in decision making under uncertainty (Bell, 1982)

A paradoxical behaviour, as mentioned earlier, is described as violations of the axioms of the expected utility model as stated by von Neumann und Morgenstern (1947). In their theory every individual will, at every stage of a "game", or real life situation, aim for rational behaviour to maximize utility. Irrational behaviour is paradox, because it does not lead to highest expected utility. Bell (1982) explains the seemingly paradoxical behaviour with the urge to avoid future regret after decisions and regulate behaviour, because after having made a choice an individual may experience that the rejected alternative would have been more desirable. Seemingly paradoxical refers to the fact that individuals, as can be observed in real life, as well as in economics, do not always orient their decisions on the maximum expected utility, so therefore this behaviour is not really paradoxical, but simply human. Loomes and Sugden (1982) as well do not see their theory as irrational, just because they incorporated regret and rejoice into their modified utility function.

The utility function of *u (x, y)* of choosing *x*, with the value *v (x)* over the alternative *y* with the value *v (y)* and *f(v (x) – v (y))* being the function for regret, when the individual decides in favour of the value of one alternative *v(x)* and rejects, respectively looses, the value of *v (y).* Bell (1982) also mentions that the degree of regret will vary with respect to how much the individual thought about deciding in favour of the chosen, now appearing less preferable, alternative, and on the proximity of almost having chosen the rejected.

$$u(x, y) = v(x) + f(v(x) - v(y))$$

Figure 1.4: **Bell´s utility function (Bell, 1982)**

2 REGRET: BASIC PRINCIPLES

Regret is experienced after choosing in favour of one alternative, simultaneously, of course, rejecting the other. Two important notions of regret are: First the feeling of being personally responsible for the performance (Byrne, 2002), and second realizing that deciding differently would have ended in a more desirable outcome, may it be real or imagined (Summerville & Roese, 2008).

Distinctions need to be made between anticipated and experienced regret. As Mellers et al. (1999) put it: „Experienced emotions affect many levels of cognitive processing. (…) Anticipated emotions prepare us for the future.“ (Mellers, Schwartz, & Ritov, 1999) Zeelenberg and Pieters (2007) also use the terms prospective and retrospective regret. Anticipated, as well as prospective regret is experienced about important future decisions and induces, by the anticipation of probable future regret, a certain kind of disposition to alter strategies in behaviour in advance and therefore resembles a process of learning that is emotionally motivated (Coricelli, Dolan, & Sirigu, 2007; Ritov, 1996; Zeelenberg, Beattie, vanderPligt, & deVries, 1996). Retrospective regret on the other hand focuses on past choices. Experienced regret will be laid out in more detail in the following and can be experienced in long- as well as in short – term runs (Gilovich & Medvec, 1995).

Regret can be defined in terms of an emotion that is cognitively based because it is an emotion that is rather complex, regarding the fact that it "both stems from and produces higher order cognitive processes." (van Dijk & Zeelenberg, 2005) It is not expressed through a distinctive facial expression (Ekman, 1971) consistent over different cultures. It is, like envy or disappointment, more complex than basic emotions, such as happiness and sadness because it enhances a cognitively based comparison process, requiring the ability to imagine different outcomes and performances, different states of the world than the present one. (Zeelenberg & Pieters, 2007) The already made decision, which led to the specific outcome, has to be reflected, moreover the individual has to have the ability to think about what could have been, if a different choice had been made. As will be laid out in more detail in chapter 2.2, these are the important points in regarding regret as a cognitively based emotion, more specifically, a counterfactual emotion (Kahnemann & Miller, 1986; van Dijk & Zeelenberg, 2005), that derives from a process of comparing the outcome of a decision to not chosen alternatives. This is what highlights regret as being cognitively based, because it is the nature of regret to compare. This comparison process using counterfactuals can be elicited through action or inaction equally.

The Cobuild English Dictionary defines regret as: "(…) caused by something that has happened or something that you have done or not done." (Collins & Sons, 1995) and this already highlights the fact that regret can occur due to action, as originally stated by Kahnemann and Tversky (1982), as well as being caused by inaction (Gilovich & Medvec, 1995; Zeelenberg, van den Bos, van Dijk, & Pieters, 2002). Ritov and Baron (1995) found that depending on the amount of knowledge available to the individual about the consequences of their decision the omission bias (refraining to act and prefering inaction to avoid future regret) will be greater, since being well aware of possible worse outcomes will enhance anticipated regret and result in omitting actions. They agree with Gilovich and Medvec (1995), who also found that for recently made decision regret will be enhanced for actions taken, and less for omission, but they found a "temporal pattern" for regret for inaction, meaning that over the course of life people's regret grow greatest for omitting actions, not striking a new path, or not making any changes, when they had the chance to. Zeelenberg et al. (2002), on the other hand, showed that regret for inaction can also elicit a stronger feeling of regret in the short –term, when the majority of people, respectively the norm, would opt for action in the very situation, instead for inaction. The history of previous events and outcomes is important to account for either action or inaction to be the decision of the norm. If, with respect to prior performances, the norm would call for a need for action, but, due to various reasons, the individual decides for inaction, regret will be experienced more strongly, because the decision will be less justifiable (Zeelenberg & Pieters, 2007).

But the major element of regret, whether its cause was an action taken or omitted is "agency": being self – responsible for the decision, which is underlined by results from an fMRI study by Coricelli et al. (2005).

2.1 Agency, its neural underpinnings and the "reward prediction error"

The "agency-effect" (Byrne, 2002) becomes evident as the feeling of responsibility for the decision: selecting one and rejecting the other alternative. The individual is acting as the agent, responsible for actions taken and omitted. Loomes and Sugden (1982) even find a formulation in their regret theory to highlight regret as a reaction to "(…) the result of an act of choice" and Zeelenberg and Pieters (2007) bring it to the point as "(…) regret is experienced as an aversive state that focuses our attention on one's own role in the occurrence of a regretted outcome." This furthermore accentuates regret as being a cognitive emotion.

In the regret gambling task conducted by Coricelli et al. (2005 and in the present study (chapter 6.3) regret for action was elicited. Agency was thereby operationalized using alternating forced -, and free choice trials. Regret was only elicited only in the free choice condition, because the individuals felt responsible for the decision. As found by Coricelli et al. (2005) agency did not only become apparent in the participant's cognitive commitment to the task, but also became evident in physiological parameters. The subjects´ heart rate turned out to be significantly higher in the “choose” conditions, which indicated responsibility for choice, compared to “follow” trials. In the “choose” condition a greater activity in the ventral striatum was found, which was deactivated during “follow” trials. This highlights this region as being sensitive to the processing of rewards, more specifically Coricelli et al. (2005) propose that this area signals mismatches between expected and actual outcomes. Better outcomes than expected elicit an activation, whereas results for “worse than expected” show a relative deactivation. The deactivation during forced choice trials resembles the fact that it simply was not necessary to predict rewards during these trials. Coricelli (2005) linked this finding to the “reward prediction error” (Schultz, 1997). Schultz (1997) found a phasic decrease of dopaminergic neurons, when a predicted reward fails to appear. Holroyd and Coles (2002) propose this prediction error to give rise to the FRN, which will be laid out further in chapter 4.1. Dopamine neurons can distinguish between reward and non-reward (Tobler, Fiorillo, & Schultz, 2005), due to the fact that they make associations between environmental stimuli and reward, and they also identify a mismatch between actual performance and expectations. If an outcome is unexpected and undesirable dopamine neurons are deactivated and active when something turns out to be better than expected (Schultz, 2002).

The personal engagement and involvement of the individual in the task, acting as the agent, plays the crucial role in the experience of regret and is also one element which differentiates regret and disappointment.

2.1.1 Disappointment

For the feeling of disappointment the individual doesn’t necessarily feel responsible for the outcome (Coricelli et al., 2005). This might be the reason why regret seems to be more intensely experienced than disappointment, experiencing a greater desire to undo the decision (Chua et al., 2009).

Furthermore in the regret gambling task conducted by Coricelli et al. (2005) the distinction between a complete and a partial feedback condition allowed differentiating between disappointment and regret. Coricelli et al. (2007) state that, disappointment arises when there is a deviance between the expected and the actual outcome, becoming greater as the difference between the expected and the obtained alternative increases. To elicit disappointment complete feedback is not necessarily needed. Whereas on the other hand, regret, as mentioned above, is experienced when the actual outcome is compared to the rejected alternative that turns out to be preferable. Thus regret is observed only in complete feedback conditions, and is not experienced due to partial feedback, because the individual needs to be able to compare an obtained to a rejected outcome just as Smallman and Roese (2009) propose that counterfactual thoughts drive regret.

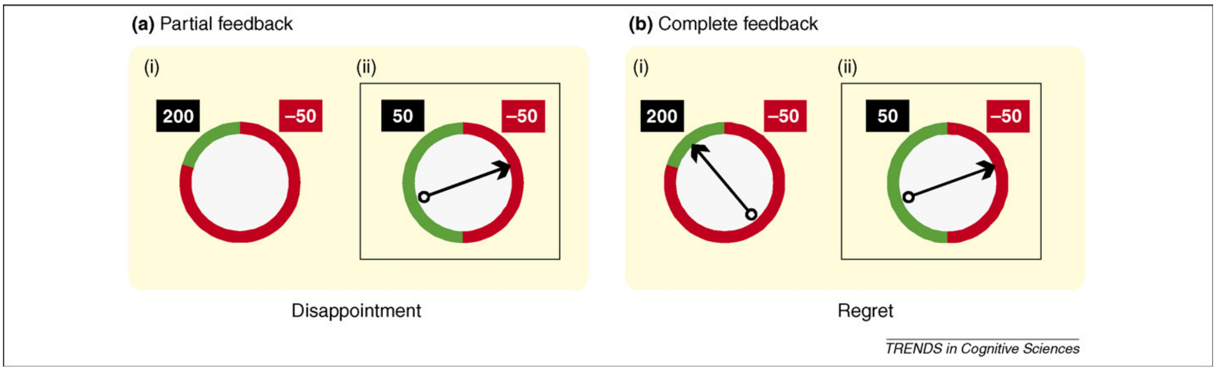

Figure 2.1: **The regret gambling task (Coricelli, et al., 2007)**

An illustration is shown in Figure 2.1:

Imagine a subject deciding in favour of the, seemingly, secure alternative, and choosing the gamble with a 50-50% chance for winning or loosing 50, instead as going for the riskier alternative with a high chance of loosing 50, and a fairly slight chance of winning 200.

In the partial feedback condition the expectation of winning 50, through weighing the probabilities or learning from past experience, is violated. Nevertheless no information is gained about the rejected gamble. The comparison is made between the expected and the unobtained outcome of the chosen gamble, and hence disappointment arises.

On the other hand, when deciding in favour of the "safer" gamble, with the higher probability of winning at all, and finally loosing, but additionally being aware of what the unselected gamble would have brought about, regret arises. Even more in comparing a lost 50 to a rejected win of 200, the experienced regret will become more intense. This comparison can be expressed using counterfactuals, which constitute the cognitive element of the emotion of regret.

2.2 Regret expressed through counterfactual thoughts

Regret is, as already stated by Kahneman and Miller (1986), an evaluative process, an emotion that cognitively compares the performance/decision with a norm, which is acting as a point of reference, but which can also be generated by the construction of counterfactuals. It is inherent in the feeling of regret that it is driven by a comparison between the obtained and the unobtained, lost outcome that turns out to be more desirable. Counterfactual thoughts give the individual the opportunity to compare the present performance with a fictive one

(Sommer, Peters, Glascher, & Buchel, 2009), that turns out to be more advantageous, be that real or simply imagined (Summerville & Roese, 2008).

Counterfactuals are thoughts that mentally simulate the alternative. They are often expressed by using "what might have been" (Loomes & Sugden, 1982) and "if-then" propositions, in the sense of "If I had chosen differently, then…". The "if" takes in account the individual action, or inaction, for example: "If I hadn't dropped out of school", and the "then" regards the desired goal, e.g.: "then I could have gone to university." (Smallman & Roese, 2009), for Smallman and Roese (2009) propose that counterfactual thoughts are goal-directed, in the sense of Moskowitz et al (2004) who stated that "(…) goals are knowledge structures that can be situationally activated, most often when a discrepancy is noted between the current state and the goal state.". For Zeelenberg and Pieters (2007), regret "heavily relies on comparison processes" (Zeelenberg & Pieters, 2007) but they don't support the idea of equating counterfactuals with regret per se, because they are also often used for the expression of other cognitive emotions, for example disappointment or envy, and are moreover often used without even expressing any emotion in daily life.

Epstude and Roese (2008) differentiate between upward (better alternatives) and downward (worse alternatives) counterfactuals. Upward counterfactuals that derive from personal action, or respectively inaction, are called regret, and are very useful for the adoption and regulation of behaviour to acquire better strategies, or actions to reach a desired goal. Downward counterfactuals, on the other hand, can act as an indicator for preservation of the actual behaviour.

2.2.1 Excursus: Content-neutral and -specific and the opportunity principle

Counterfactuals are present on several diverse stages, from a correction in behaviour that is only temporally, implicit, or raises intentions that lead to behaviour automatically up to consciously aware big life-regrets (Smallman & Roese, 2009). Nevertheless the same behaviour-regulation mechanisms apply, may that be for anticipated or experienced regret in a regret-gambling task (Coricelli, 2005) or for the 6 main regrets in life, as elicited by Roese and Summerville (2005): education, career, romance, parenting, the self, and leisure.

Epstude and Roese (2008) present a functional top-down process of counterfactual thinking as an element serving for behaviour regulation to achieve a desired goal. This is in line with a study by Coricelli et al. (2005), who also propose a top-down modulation of emotions.

Epstude and Roese (2008) distinguish between a content-specific and a content-neutral pathway which both drive counterfactuals to actions, to reach a goal. On the content-specific pathway intentions ("I will study harder for the next exam") are formed to implement behaviour ("I am studying harder to pass the exam"). The starting-point is a divergence of a certain norm (Kahnemann & Miller, 1986) as the rejection of a seemingly more favourable alternative, an occurring problem or another negative experience deriving from goal-deviation, or a deficient progress in goal-achievement, all accompanied by negative emotions. In a nutshell, the two determining factors for counterfactual thinking in the content-specific pathway are the identification of problem, accompanied by negative emotions. Furthermore these counterfactuals lead to behavioural intentions which end in adapting behaviour.

The content-neutral pathway does not include specific information about the performance, but activates more general motivational, attentional, or cognitive process that lead to regulation of behaviour. The two pathways can interact, and so produce a higher conjunction between counterfactuals and a change in behaviour.

Epstude and Roese (2008) propose that, as long as there are opportunities available for action and “the chances for corrective action are clearest” (Roese & Summerville, 2005), regret will persist, respectively the individual strives, on every stage on which regret can occur, to “initiate corrective action”, as long as the subject believes actions will be of potential success (Roese & Summerville, 2005). Situations in which opportunities are closed or limited through outside constraints gives rise to cognitive dissonance (Festinger, 1964), affect regulation, rationalization, or reconstrual to diminish the feeling of regret, or abandon it (Roese & Summerville, 2005). They pin, what they furthermore call the opportunity principle, down to three stages, on which possible regret can occur. These are: the action, outcome, and recall stage.

At the stage of action the individual acts in favour of accomplishing a certain goal. Regret will be solely felt when the individual could freely opt for an action during the action stage. If the individual feels to have been driven by outside constraints, external attributions will be generated, and neither regret, nor dissonance (Festinger, 1964) will be felt (Summerville & Roese, 2008). Corricelli et al. (2005), as well as the present study, operationalized this idea of agency through a distinction between free – and forced – choice trials. High opportunities will enhance the feeling of regret, low chances will activate a process of cognitive dissonance reduction, but as opportunity closes, there will be no cognitive dissonance or regret felt. (Roese & Summerville, 2005)

At the outcome stage, the individual experiences either goal-achievement or failure. Roese and Summerville (2008) propose that at this stage the opportunity principle becomes most relevant, as alternative outcomes come to mind which would have been better, accompanied by thoughts about different actions and behaviour that would have led to a more successful outcome.

As for the recall effect, post hoc framing effects operate, marking the preceding outcome as a lost high or low opportunity. Framing it as a high chance will modify regret experience at this later point in time, bringing along a more considerable reporting of the experienced regret.

Summing it up, the authors conclude that this recall of past feelings of regret, center the proposed opportunity principle as being first and foremost outcome-evoked, serving for behaviour regulation and corrective action as long as opportunities seem open, and taking an action is considered to be feasible and effective.

Regret serving primarily for optimization of behaviour is underlined by the findings by Coricelli et al. (2005) who conducted a fMRI study to get insight in the neural structures responsible for the experience of regret.

3 NEURAL UNDERPINNINGS OF REGRET

According to their findings Coricelli et al. (2007) propose a two – level reward processing comprising the mesencephalic dopamine system (MDS) as the first level, and the orbitofrontal cortex (OFC), the anterior cingulate cortex (ACC), and the amygdala (O'Doherty, 2004) being the second – level. Coricelli et al. (2005) found these neural structures to be very important to the generation of regret. The ACC, along with the MDS is also specifically crucial for the generation of the FRN (chapter 4.1). The underlying neural structures for regret (except the amygdala and the hippocampus as they are not of special importance to the aim of the present study) will be laid out in detail in the following. The OFC will be described more detailed as its involvement in the emotion of regret highlights this emotion as being cognitively based and crucial for the optimization of behaviour. The MDS as well as the ACC are described in detail as they are the generators of the FRN (see chapter 4.1) which is investigated concerning its relation to regret.

3.1 The orbitofrontal cortex

The OFC includes the Brodmann areas 10, 11, 12, 13, 14 (which covers most of the gyrus rectus) and 47. The gyrus rectus controls social consequences, of one's own or observed behaviour. Areas 47 and 11 are hypothesized for being able to learn from social feedback. Nonobservance of negative feedback would enhance impulsiveness and enhanced self-confidence (Bösel, 2006), as, as reported by Camille (2004) and previously described, OFC-lesion patients do not show regret-aversion. The OFC is also interconnected with the amygdala to guide behaviour (Murray, 2007), which processes the emotional value of rewards, positive and negative, as well as its` relative valence. The amygdala is also important for the updating of value in a changing environment and therefore essential for the consideration of value in the OFC (and the nucleus accumbens) (Morrison & Salzman, 2010).

The results by Coricelli et al. (2005) showed that regret was reflected in enhanced activity in the medial OFC, the anterior hippocampus, and the dorsal anterior cingulate cortex (ACC), which sum up to be the three most relevant structures for experiencing regret. The involvement of the hippocampus highlights the connection to the declarative memory responsible for memorizing facts and modulation of knowledge through learning in order to regulate behaviour. Disappointment, which was measured in the "partial choose" condition on the other hand, elicited enhanced activity in the middle temporal gyrus, and the dorsal brainstem. Anticipated regret elicited greater activation in the medial OFC, the right somatomotor, inferior parietal lobe and left amygdala. The anticipation of regret was found to be increased depending on experienced regret on previous trials throughout the study only in the "complete choose" condition, which highlights the importance of past experience of regret on decisions.

An enhanced response was found in the medial OFC and the amygdala for regret-aversion. It became obvious that anticipating regret influences further decisions as participants became more regret-aversive, and they tried to avoid choices bearing a chance for regret, either because they learned through experience or weighed the probabilities, which resembles a reinforcement learning signal. In both the anticipation of regret, when making the decision in expectation of future outcomes in the light of accumulated past regret, as well as the experience of regret at outcome evaluation, even for regret-aversion, the activation and involvement of the medial OFC became apparent. Furthermore activity in the OFC was not only related to the information available about possible future, or presented alternatives, but also to the level of agency, as it was only observed on “choose” trials. (Coricelli, et al., 2005)

3.1.1 Regulation of behaviour versus regret regulation

Coricelli et al. (2007) propose that the OFC conjoins cognitive and emotional processes, and can therefore advance the adaption of behaviour. After outcome evaluation, and experiencing regret augmented activity was found in the right dorsolateral prefrontal cortex, the right lateral OFC and the inferior parietal lobe, which accounts for activation of cognitive control, after having evaluated negative consequences. Especially the involvement of the lateral OFC may contribute to this change in behaviour. As discussed earlier, greater lateral OFC activity showed when subjects desired to change a decision (Chua et al., 2009), or avoided choosing the same option as before after having experienced regret (Coricelli et al., 2005). Sommer et al. (2009) therefore argue that lateral OFC activation might account for the effect of consequences on choice behaviour, instead of underlying the preceding counterfactual thinking when evaluating the valence of the difference between chosen and unchosen option, activating the medial OFC. Coricelli et al. (2005) propose that it is the “counterfactual process” elicited by complete feedback in the losing conditionthat results in greater bilateral activation of medial OFC regions.

This is in accordance with the view presented by Zeelenberg and Pieters (2007), that regret represents a cognitive based emotion. But unlike Coricelli et al. (2007), and Roese et al., (2007) Zeelenberg and Pieters (2007) do not support the idea that regret serves for regulating behaviour. Zeelenberg and Pieters (2007) presented a theory of regret regulation 1.0 which brings together several views about regret and integrate them into their theory. The key element of the theory of regret regulation is that individuals attempt to regulate upcoming regret, for they are regret averse. They state that regret “…is a backward looking emotion signaling an unfavourable evaluation of a decision. (…) coupled with a clear sense of self-blame concerning its causes and the strong wish to undo the current situation.” (Zeelenberg & Pieters, 2007) Carmon, Wertenbroch, and Zeelenberg (2003) propose, that choosing one alternative over another alone evokes “a sense of immediate postdecisional regret”, that enhances the attractiveness of the rejected option. They link this finding for regret to reactance theory (J.W. Brehm, 1966) and describe it as a result to the feeling of restricted freedom produced by mere choosing.

A number of researchers on the other hand have proposed regret being first and foremost directed towards the optimization of a goal. (Coricelli, et al., 2005; Epstude & Roese, 2008; Smallman & Roese, 2009) Merriam – Webster's Dictionary defines goal in this very sense as: "the end toward which effort or ambition is directed; aim, purpose; a condition or state to be brought about through a course of action" (Merriam-Webster, 1981) Zeelenberg and Pieters (2007) see the role of regret in adapting behaviour goal - directedly, but see it's function in generating behaviour to specifically prevent regret and propose strategies for regret regulation. They do acknowledge regret as being "(…) a functional emotion that influences decision-making in ways that are relevant to our goals and concerns, (…) to maximize our short term and long term outcomes." (Zeelenberg & Pieters, 2007) and mention in their regret regulation theory 1.1 (Pieters & Zeelenberg, 2007), that regret serves for relevant implications in behaviour, but not primarily for optimization of behaviour. For them the focus is on regulating the emotion, as for emotions are information about the performance or the goal-directed progress. Consequentially these emotions are regulated to achieve a goal " (…) and emit behaviours to increase, decrease, or maintain these emotions as information about goal outcomes and progress." (Pieters & Zeelenberg, 2007)

Roese, Summerville and Fessel (2007) agree that people regulate their regrets, but they criticize the primary role of regret regulation as mentioned by Zeelenberg and Pieters (2007). They state a fundamental role of regret in the regulation of behaviour, where regret regulation is simply not more than a side-product. They highlight that regulating and adapting behaviour is crucial for managing behaviour on a daily basis and regret serves as "a regulatory signal" (Roese, et al., 2007). Epstude and Roese (2008) acknowledge in their opportunity principle that as possibilities for action closes, affect regulation mechanisms start to work, but furthermore they propose that regret exerts a top-down modulation, which is also in accordance with Coricelli et al. (2005), using the cognitive based emotion regret to regulate behaviour goal-directed. Top-down regulation, in contrast to bottom-up which processes information from sensory perception, refers to strategic processing of information, that is often consciously controlled (Bösel, 2006). Counterfactuals represent the cognitive component of the emotion regret in changing behaviour and gaining new behavioural strategies (Epstude & Roese, 2008). Thus the OFC can regulate regret through using mechanisms like counterfactual thinking, acting as an interface between cognition and emotion (Camille et al., 2004). Camille et al. (2004) underline the key-role of the OFC for regret in conducting a study with OFC lesioned patients using a regret gambling task. They conclude that the patients, in comparison to healthy control subjects, did not experience or anticipate regret, although the affective ratings revealed an emotional responsiveness to monetary wins and losses. Nevertheless they succeeded in choosing the option with the highest possible outcome, which of course also produced maximum regret, and was, for that reason, avoided by the healthy subjects. Camille et al. (2004) state that the decisions of patients with lesions in the OFC are seemingly not influenced by agency, the feeling of being responsible for a negative outcome. So to speak they behave as proposed by von Morgenstern and Neumann (1947), completely "rational", solely interested in maximizing their gains, not including experienced or anticipated regret. Three further control subjects participated with lesions in other parts of the frontal lobes, but an intact OFC, and showed the same behaviour when conducting the regret gambling task as the healthy controls and the same amount of regret.

The reasons for the proposed primary role of regret for behaviour regulation regarding the findings by Coricelli et al. (2005) and the OFC serving as the cognitive element of the emotion of regret have been laid out. The further step will be laying ground for connecting the FRN in its relation to regret by first of all presenting the underlying generators of this event – related negativity: the anterior cingulate cortex and the mesencephalic dopamine system.

3.2 The anterior cingulate cortex (ACC)

The gyrus cinguli consists of the Brodmann Areas 24, 32, 23, and 30, with the areas 24, 32, and 33 describing the anterior cingulate cortex (BA 24 dorsal ACC), which is included in the medial frontal cortex. (Bösel, 2006) Furthermore the ACC detects (Carter & van Veen, 2007) and monitors (Botvinick, Braver, Barch, Carter, & Cohen, 2001) conflict, mainly on response-related levels or even after the response has been made (van Veen, Cohen, Botvinick, Stenger, & Carter, 2001), alerting systems that are involved in controlling top-down processes to resolve the conflict (Botvinick, et al., 2001; van Veen & Carter, 2002) and engages representations about the context in the dorsolateral prefrontal cortex, which leads to enhanced cognitive control (Carter & van Veen, 2007).

The ACC is also highly involved in ascribing salience to past decisions, and this valence is used to predict outcomes in the future, for the ACC even makes it possible to assess and estimate the volatility in a changing environment to adapt choice behaviour in accordance to get to the reward. This holds that the ACC has an important role in decision-making and learning subsequently of past choices. (Behrens, Woolrich, Walton, & Rushworth, 2007) Furthermore the ACC ascribes value to an action prior to decision-making, taking into account subsequent losses or gains, as well as it is considering future decisions in advance by coding to which degree this information should influence a future decision-processes (Rushworth & Behrens, 2008). So to say the ACC is central for selection of action (Rushworth, Behrens, Rudebeck, & Walton, 2007). Yeung, Holroyd, and Cohen (2005) also emphasize the role of the ACC in the processing of the value of rewards and underline the “role (of the ACC) in integrating cognitive and affective information in the control of action” (Yeung et al., 2005), as proposed by Botvinick et al. (2001). The ACC seems to hold a crucial role in bringing together and integrating information about reinforcing stimuli, but Kennerley et al. (2006) question the ACC´s previously described role in conflict monitoring between expected and received outcomes, and subsequently adapting choice behaviour (Botvinick, et al., 2001; Carter & van Veen, 2007; Kennerley, et al., 2006). They propose, in line with Behrens et al. (2007), the ACC to have its function in observating and incorporating values in a changing world, past and expected rewards, actions and risk and so computing the value of options. Thus the ACC has a sensitive role to learning, especially considering which action to make, considering the context. Choices and decision that ought to be made therefore do not only depend on errors committed and on conflict, but do highly rely as well on reward and positive outcomes, as for the ACC uses this information to select the appropriate action (Kennerley, et al., 2006). The ACC is sensitive to decisions with an exploratory component to it which are not constraint by instruction, and the feedback is due to a decision after having explored the environment (Walton, Bannerman, Alterescu, & Rushworth, 2003). The ACC explores values in the environment, acquires and updates information and in that manner establishes its salience, always also taking into account the costs this choice, respectively the action that needs to be made, entails, and weighing if the reward is worth the effort (Rushworth, et al., 2007).

The ACC and the OFC are, as described above, both involved in the process of decision-making. They do share anatomical connections, but still they are distinct in others, which allow them to incorporate a wider range of information in order to guide performance in an optimal way. They are interconnected, of course with each other, the ventral striatum, and the amygdala. Their connections are distinct as it comes to the OFC being highly connected with high-level sensory processing, which grants access to various kinds of stimuli as visual information (Rushworth, et al., 2007) , but is also able to provide insight about the nature of the presented reward, in means of taste, texture, temperature, odor, and respectively the visual appearance (Verhagen, Rolls, & Kadohisa, 2003), and, most important to guide behaviour through a social world, the OFC codes facial expressions and facial identity (Rolls, Critchley, Browning, & Inoue, 2006; Rolls & Grabenhorst, 2008), and represents preferences (Rushworth, et al., 2007).

The ACC, on the other hand, shares strong connections with motor areas. So as for the OFC encodes the rewarding stimuli it is not engaged in action towards the target, for this is assigned to the ACC, which is interconnected with premotor, as well as motor areas and the ventral horn of the spinal cord and is so involved in the major selection for action (Rushworth, et al., 2007). Nevertheless even the ACC plays a very important role in social behaviour, as it is active in the prisoner's dilemma tasks, when subjects are bound to make cooperative decisions. The increased activity in the rostral ACC seems to reflect emotional components in decision making in a social environment. Besides that activation in the anteroventral striatum and the OFC could be found, the OFC being the only component which was also active when cooperating with a computer, the other two being sensitive to social cues in cooperation, but all three reacting equally only to monetary rewards in the social condition (Rilling et al., 2002).

It becomes obvious that the OFC and the ACC, highly interconnected, are in a crucial role for decision making, as for together they decide what choices are to be made and what actions need to be taken (Rushworth, et al., 2007). It is the contribution of the MDS to assign value to stimuli (Schultz, 1998), and the amygdala assigns emotion to the stimuli and contributes to associative learning (Bösel, 2006) which closes the circle in the combination of first- and second – level reward processing (Coricelli, et al., 2007), a circuit of bottom – up and top – down processes, each of the areas relying on each other in the process of decision – making. This is very important and underlines the importance of these neural structures for the experience of regret.

Very important to the present study is that the ACC seems to be the generator of the feedback – related negativity (FRN), as also highlighted by several studies using source localization (Crowley, Wu, Bailey, & Mayes, 2009; Gehring & Willoughby, 2002; Taylor, Stern, & Gehring, 2007; van Veen & Carter, 2002). A phasic decrease in the mesencephalic dopamine system disinhibits apical dendrites in the ACC, giving rise to this specific event – related brain potential (Holroyd & Coles, 2002). It stands to reason that since the ACC represents the underlying generator of the FRN and also shows regret related activity (Coricelli, et al., 2005) to investigate the relation between this specific ERP and regret. But first of all the mesencephalic dopamine system will be described, as it elicits the FRN in the ACC.

3.3 The mesencephalic dopamine system

The mesencephalic dopamine system (MDS) consists of the nigrostriatal and the mesocorticolimbic system. The first arises in the substantia nigra, more precisely in the zona compacta, and ends in the dorsal part of the corpus striatum, which consist of the nucleus caudatum, the nucleus accumbens, and the putamen, with the strongest projections to the caudate putamen. This part of the MDS is strongly associated with motor control. Afferences of the substantia nigra anterior mostly come from the medial and polar prefrontalcortex (BA 9, 10, 11, 12), whereas afferences to the posterior part arise in the precentralcortex (BA 4 and 6). It is due to these connections that intentions from higher information processing can result in motor activity. Efferences project mainly to the nucleus accumbens, where movement is initiated. Dysfunction in the nigrostriatal system leads to Parkinson's disease (Birbaumer & Schmidt, 2003; Bösel, 2006; Coricelli, et al., 2007; Kolb & Wishaw, 2003; Wise, 2004).

The mesocorticolimbic pathway has its` origin in nuclei tegmentales anterior (ventral tegmental area (VTA)) and project mainly over the medial forebrain bundle (MFB), acting as the central communication system of the medial forebrain (septum, hippocampus, amygdala, hypothalamus) with the midbrain (Birbaumer & Schmidt, 2003), to the ventral striatum, in particular the nucleus accumbens, the amygdala, and the prefrontal cortex (Bösel, 2006). More specifically, the mesolimbic dopamine system projects primarily to the nucleus accumbens and the olfactory tubercule and secondary to the septum, the hippocampus, and the amygdala. The connection to the amygdala is also important to the nucleus accumbens as it updates changing values.

The mesocortical pathway innervates the cingulate, the perirhinal, and the prefrontal cortex from the medial VTA. Due to an extensive overlap of these two systems, they are often referred to as the mesocorticolimbic dopamine system (Wise, 2004). It has its main-function in motivational aspects of behaviour and constitutes the core area of the dopaminergic reinforcement system, meaning that their arousal reinforces behaviour, augments the probability for the appearance of a specific behavioural pattern, and plays a central part in learning from success and incentive motivation (Birbaumer & Schmidt, 2003; Bösel, 2006; Coricelli, et al., 2007; Kolb & Wishaw, 2003; Wise, 2004).

The dopaminergic signal can provide reward information in advance to the actual behaviour, make predictions of rewards due to environmental stimuli, learn associations of a certain stimuli leading to reward, and therefore plays an important part in learning, as it is able to assign an appetitive significance to stimuli, and detect rewards, which trigger behavioural approach, as for many of them have a high motivational value for the individual (Schultz, 1998). A reward resembles a goal or individual desires for the dopamine system. As mentioned earlier (chapter 2.1) the involvement of the MDS could be seen in the major element of regret: agency in the study conducted by Coricelli et al. (2005). They referred to it as "reward prediction error" (Schultz, 1998) – the phasic decrease of dopaminergic neurons in the ACC which gives rise to the FRN (chapter 4.1).

Since the important roles of the mediating neural structures for regret have been laid out the FRN will now be presented in detail. Furthermore the line will be drawn to the adaptive critic model (Holroyd & Coles, 2002) to conjoin the information about regret, its underlying neural structures and the FRN which will underline the very interesting question of investigating their relationship.

4 TAKING A CLOSER LOOK ON THE FRN AND THE P3

Event-related brain potentials (ERP), measured in the EEG, are positive and negative deflections indicating ongoing information-processing in their spatial and temporal pattern, and are specific to a certain context and the area of derivation. (Bösel, 2006) They can be described and differ from each other according to the dimensions: amplitude, latency and scalp distribution. (Soltani & Knight, 2000) The aim of the present study is to examine, first and foremost, the feedback – related negativity (FRN) and their relationship to regret, operationalized through the variables "agency" and feedback tested in the experiment (as will be laid out in more detail in 6.3). Secondly the event – related positivity, P3 (P3a, and P3b) will be regarded as well.

4.1 The feedback – related negativity (FRN)

The feedback-related negativity is elicited through feedback, especially linked to negative outcomes, when something is worse than expected. It peaks around 200-300ms after feedback has been received and reaches its maximum at fronto-central locations at the scalp (Fz, Cz, FCz). (Holroyd & Coles, 2002; Miltner, Braun, & Coles, 1997; Yeung, Holroyd, & Cohen, 2005a) Source localization, which is used to depict the underlying neural generators of ERPs by utilizing the topographic characteristics of the electric scalp potentials, revealed its generation in the anterior cingulate cortex (ACC, Brodmann Areas 24 and 32) (Crowley, et al., 2009; Gehring & Willoughby, 2002; Taylor, et al., 2007; van Veen & Carter, 2002)

Holroyd and Coles (2002) propose that the ERN, the response (peaking 100ms after the response has been made), as well as the feedback-related negativity, both depict a negative reinforcement learning signal, a phasic decrease in the mesencephalic dopamine system (MDS) sent to the frontal cortex where it disinhibits the apical dendrites of motor neurons in the ACC, which leads to the generation of this negative deflection in the EEG. In reinforcement learning the learner is referred to as the agent, with the goal to improve behavioural performance to such an extent that the possible maximum of reward will be accomplished (Montague, Hyman, & Cohen, 2004). This resembles a reward prediction error, as described by Schultz (1997) and explained in 3.3.

In the latter the ERN will be referred to as the "response ERN" peaking after 100 ms after responding erroneously, whereas the FRN is specifically elicited through feedback and not the response alone (Bellebaum & Daum, 2008). The caudal-dorsal ACC seems to play an important part in the processing of reward and feedback, resembling a very fast evaluation, as the FRN peaks 200-300ms after receiving feedback (Yeung et al., 2005).

Holroyd et al. (2003) found the FRN to be elicited in conditions with unfavourable outcomes, when the subject's expectations were violated and concluded with the notion that the FRN probably serves for evaluating the emotional significance of the received outcome.

Bellebaum and Daum (2008) highlighted that the degree to which subjects expect reward modulates the amplitude of the FRN. They conducted an experiment in which participants had the chance to derive the probability of the reward through learning a rule underlying the task. They found that the FRN amplitude was larger the more unexpected negative outcomes appeared to the individuals, and referred to it as a "negative prediction error" (Holroyd, Nieuwenhuis, Yeung, & Cohen, 2003). Bellebaum and Daum (2008) therefore propose that the FRN also represents the extent to which the received and the expected outcome differ, and does not only resemble the negative, unexpected outcome alone.

Hajcak et al. (2007) carried out a similar experiment, also interested in bringing light into the contribution of the individual's expectations to the FRN. They stated that not only the expected probability of reward influences the amplitude of the FRN, but that it's very important that an action is actually linked to it. Moreover they had their subjects make predictions about the outcome before they made their choice in a gambling task (Study 1), and after having decided, right before feedback was given (Study 2). Very interestingly Hajcak et al. (2007) found the FRN to be sensitive to predictions only when they were inquired after having decided. They note that the FRN seems to respond more sensitive to expectations that are closely linked to a particular "action-outcome pair" (Hajcak, et al., 2007) to maximize the utility of the outcome. Therefore they suggest a "top-down" process involved in evaluating and choosing a particular action, always in consideration of the expected outcome.

Holroyd et al. (2009) conducted three experiments regarding discrepancies concerning the FRN, which were found in various experiments, as in Hajcak et al. (2005). Their findings break down to that the FRN is sensitive to tasks where the actual outcome can be tied to causal behaviour and contingencies in the action taken and outcome received are apparent. In these trials subjects were able to learn stimulus-reward contingencies, but still there was a probability of being unsuccessful. Holroyd et al. (2009) conclude that "(…) variance in fERN amplitude as a function of reward probability depends on the degree to which outcomes are perceived to be elicited by causal behaviour." (Holroyd, et al., 2009), still they acknowledge it to be one of several diverse factors influencing the amplitude of the FRN, as in the study by Yeung et al. (2005a) the subjects´ interest in the outcome, the motivational significance ascribed to it, turned out to be correlated with the amplitude.

Nieuwenhuis et al. (2002) and Frank et al. (2005) agree in their conclusions for the FRN to be correlated with learning from feedback. Frank et al. (2005) even propose that the FRN is sensitive to error-correction as well, as to the often pronounced error-detection (Holroyd & Coles, 2002; Holroyd, et al., 2003). They also suggest that enhanced activity in the ACC increases the individual sensitivity in realizing the commitment of a mistake and its further avoidance. This, once more, holds for the notion of the FRN reflecting a signal of learning for further improvement of behaviour (Holroyd & Coles, 2002; Holroyd, et al., 2003; Yeung, et al., 2005a).

Crowley et al. (2009) mention that the feedback-negativity resembles a signal for escaping an unfortunate outcome or avoiding a negative performance, as well expecting desirable ones, and consider it an indicator for the processes entangled in feedback-based learning to improve performance.

Even more interesting in this context is a study by Moser and Simons (2009) in which they conclude with the notion that "(…) the FRN reflects a context-sensitive signal that integrates information about current and past actions, thoughts, and emotions" (Moser & Simons, 2009), because they link the feedback-negativity to making a decision and the regret elicited by it, which is a very important statement for it closes the circle with the connection of the feedback-negativity and regret, which was the aim of the present study, described in detail in chapter 6.3. Moser and Simons (2009) interpreted their results to that effect that the FRN was largest when subjects experienced regret, and draw the conclusion that the underlying activity in the ACC serves to optimize the choice behaviour. This is in accordance with the findings of the increased activity in as well the ACC, and the OFC when feeling regret, as presented by Coricelli et al. (2005). Therefore it can be concluded that the FRN is best suited to further examine regret and the relation between experiencing this emotion and the FRN, with special regard to the major element when experiencing regret: agency. The assembled findings and characteristics of the FRN, its sensitivity to an outcome worse than expected compared to a more desirable alternative, and the neuroimaging data (Coricelli, et al., 2005) yielding the same neuronal underlying structures for regret as were found for the FRN support this conclusion. By presenting the adaptive critic model the hypothesized relation between the FRN and regret can even be supported more strongly.

4.1.1 The adaptive critic model and the FRN and regret

Holroyd and Coles (2002) present an "adaptive critic model". They propose that the nervous system of humans is partly compound of motor controllers working in parallel and semi – independently to influence the motor system over the anterior cingulate cortex. These motor controllers are, for example, the amygdala, the dorsolateral prefrontal cortex, or the orbitofrontal cortex (OFC). Their job is to solve problems of high – level motor control, each in its own specific way. The anterior cingulate cortex is thought of as the control filter. The control filter decides which motor controller with its specific characteristics is best suited to solve the specific problem and enables one of them to take control of the motor system. They assume that the ACC gets a reinforcement learning signal, the temporal difference error (TD error), conveyed on the mesencephalic dopamine system to recognize the best suited controller. The basal ganglia hold the role of the adaptive critic which computes values and the change in values of events. If something turns out worse than expected a phasic decrease in dopaminergic activity sent out by the basal ganglia and the mesencephalic dopmine system gives rise to the ERN. This “predictive error signal”(Holroyd & Coles, 2002), or reinforcement learning signal, as the ERN is referred to by Holroyd and Coles (2002) is used to train the ACC to “optimize performance on the task at hand” (Holroyd & Coles, 2002) and to select the controller best suited for the task.

Holroyd et al. (2006) modified the version of the adaptive critic model to that respect that the TD error is the product from “a cognitive preprocessing system” evaluating goal-achievement, and not only the value of the reward, which is then sent out as a temporal difference error from the adaptive critic.

The adaptive critic model therefore presents a framework which enables to conjoin the previously described neural systems and the FRN in the experience of regret. It can be proposed and is hypothesized that when a negative outcome, something worse than expected is encountered the mesencephalic dopamine system gives rise to the FRN in the ACC which furthermore, in the case of regret, selects the OFC which is, as described earlier, involved in decision-making and weighing valence of alternatives (Bechara, Damasio, & Damasio, 2000) to guide behaviour goal – directed (Coricelli, et al., 2005; Holroyd & Coles, 2002). This hypothesis will be further examined in the present study.

The P3 will be explored as well and will therefore be described in detail in the following.

4.2 The P3

The main focus of the present study is the FRN and regret, nevertheless the P300 will be regarded as well as it is a prominent event – related brain potential and the results will also be included in the subsequent interpretation of the results (chapters 8 and 9). Therefore the theoretical basis of the P300, or P3, will be laid out as well.

The P300 is a large positive, more than 10µV, broad event – related brain potential peaking around 300msec (from 300 up to 900msec) after presentation of any sensory stimuli, specifically after stimulus evaluation, and is usually investigated in “oddball paradigms”. (Kok, 2001; Linden, 2005; Soltani & Knight, 2000) It resembles a network of processes in the brain, which are responsible for attention to stimuli, working memory and further transition to memory storage, where accurate responses to new stimuli are acquired. (Nieuwenhuis, Aston-Jones,

& Cohen, 2005; Polich, 2007) Moreover it is specifically sensitive to the subjective probability of events (Donchin & Coles, 1988b) meaning that the amplitude is greater the smaller the probability of the appearance of the eliciting stimulus. More specifically research has found that it is a matter of probability of appearance of a certain class to which the stimulus belongs to, rather than the probability of the individual appearing of the stimulus. (Johnson & Donchin, 1980) Kok (2001) referrs to it as “event categorization”, meaning a process that is concerned with the comparison and decision to whether a new stimulus, or one with a high salience, or a low probability of occurring, matches the established stimulus category. Its amplitude is also shown to vary due to the discriminability of stimuli. (Linden, 2005) The P3 is furthermore very sensitive to the motivational significance of stimuli (Nieuwenhuis, et al., 2005), and depends on the amount of attention that is captured by the stimulus (Johnson, 1993). It seems to play a crucial role in the processing of outcome evaluation, reward valence, as well as its magnitude, and furthermore expectancies towards reward magnitude, and the attention directed to the stimuli. (Wu & Zhou, 2009) Yeung and Sanfey (2004) proposed that the P3 does not seem to be particularly responsive to the actual outcome’s valence, but to the valence of the alternative. They define valence as “high – level affective evaluations, for example, reflecting regret or disappointment”(Yeung & Sanfey, 2004), instead of the P3 being sensitive to valence in terms of the value of the reward. Other studies, on the other hand, did find the P3 as being sensitive to reward valence and magnitude, in the conventional definition, with greater positive amplitude due to a positive outcome, instead of a negative feedback. (Hajcak, et al., 2005; Holroyd, et al., 2006; Wu & Zhou, 2009; Yeung, et al., 2005a) Hajcak et al. (2005) also found that the P300 is affected by the probability of feedback occurrence, as it shows a more positive amplitude to unexpected outcomes.

Nevertheless the P3 cannot be seen as one single ERP with only one specific scalp distribution. A very important and interesting distinction needs to be made between the P3a and the P3b, two functionally distinguished P3 subcomponents, with distinct neuronal generators. (Soltani & Knight, 2000) Furthermore these two parts of one comprehensive event – related positivity, the P300, seem to represent two parts of the memory and attention mechanisms engaged in information processing. (Polich, 2007)

The P3a is called the novelty P3, and is specifically elicited when stimuli are new and irrelevant to the specific task. Nevertheless the P3a was also reported to appear on trials with rare, but relevant stimuli (Spencer, Dien, & Donchin, 2001). The peak of the P3a is approximately 60 – 80msec prior to the P3b, has a frontocentral (Fz, FCz, Cz) distribution, and seems to be associated with frontal dopaminergic pathways. It diminishes with habituation to the stimulus, as it is proposed to resemble the orienting response (Linden, 2005; Nieuwenhuis, et al., 2005; Polich, 2007; Soltani & Knight, 2000).

The P3b is elicited by task – relevant, but infrequent stimuli (Friedman, Cycowicz, & Gaeta, 2001) and is evoked during the processing of target stimuli. The P3b reaches its maximum over centroparietal electrodes, and is supposed to be evoked through norepinephrine action. Both its amplitude and latency vary due to "stimulus probability, subjective probability, stimulus meaning, and task relevance" (Soltani & Knight, 2000). One major theory holds that the P3b represents cognitive processing in corticolimbic structures by updating working memory and during attention, when unexpected outcomes are compared to predictions. (Polich, 2007; Soltani & Knight, 2000)

Various theories have proposed a framework underlying the generation of the P300. One of them is the context updating theory, with the underlying thought that mental representations underlie a revision whenever new stimuli are incoming and attention is driven to it which resembles the process of updating that gives rise to specific brain activations, which become visible in the EEG in the P3. Specifically this theory seems to hold for the generation of the P3a, since, as mentioned before, the P3a is specifically sensitive to habituation. As the novelty of the stimulus diminishes the P3b emerges to enable the maintenance of the context using mnemonic operations. So when a stimulus requires attentional processing and changes in the working memory, frontal activation would elicit a P3a, concluding with temporoparietal activation giving rise to the P3b. The P3b resembles the updating and storage of memory, or as stated by Nieuwenhuis (2005), the organization of response for goal – directed behaviour and "coding the motivational significance of reward" (Wu & Zhou, 2009), that the P3 serves " to differentiate good from bad outcomes of decision making and to potentiate and optimize further actions." (Wu & Zhou, 2009) This underlines the assumption of the connection between the P3a and the P3b indicating a pathway from frontal to temporoparietal scalp sites. Furthermore this view underlines that the frontal dopaminergic activity accounts for the P3a, whereas the P3b correlates with norepinephrenic activity in the locus – coeruleus. (Donchin, 1981; Donchin & Coles, 1988a; Linden, 2005; Nieuwenhuis, et al., 2005; Polich, 2007; Soltani & Knight, 2000)

Polich (Linden, 2005; 2007) propose a hypothesis after which the P3 with its underlying generators could represent neural inhibition to alleviate information processing due to the task and the presented stimulus, from frontal P3a to temporo – parietal P3b sites. As also stated by Soltani & Knight (2000), the P3a could resemble a signal to enhance the current attention during the detection of the stimuli, in relation "to the contents of working memory" (Polich, 2007) Hence the inhibition of processing irrelevant stimuli would facilitate the transition from frontal working memory, as expressed by the P3a, through a neural circuit to the areas responsible for the P3b and subsequent storage of memory. The underlying assumption of the responsible neuronal circuit suggests that the information about the stimulus is first of all retained in the frontal lobe, the working memory, especially monitored by the ACC. If now a novel stimulus appears, that captures the attention of the individual because of its` distinct nature to other stimuli, or even motivation significance, the P3a could be generated by the ACC and related neuronal structures. Furthermore, as described above, transmission is started to convey the signal to temporoparietal sites, where operations are started to store the new information in memory and the P3b is elicited. (Linden, 2005; Polich, 2007)

The amplitudes and latencies of the P3a and the P3b vary due to the eliciting stimuli and task. The amplitude, as well as the latency of the P3 is sensitive to the amount of attention needed for a specific task, as the amplitude is found to be smaller and the peak latency longer the more attention is needed. Moreover smaller amplitudes of the P3 can be seen when only passive processing of stimuli is required. Evidence from ”single – stimulus” paradigms suggests, that the important determinant for the amplitude of the P3 is not a variation in the probability of the target stimulus, but the time between its occurrence, as it becomes bigger the longer the intervals. The latency of the P3 component changes proportional to the time needed for stimulus evaluation. Both the latency and the amplitude vary across the scalp, as the amplitude becomes bigger, while the latency grows longer, moving from frontal (P3a) to parietal (P3b) sites and even more also changes due to individual cognitive capability. (Mertens & Polich, 1997; Polich, 2007)

The P3 seems to be generated in multiple brain areas, still researchers have not yet agreed on its generators as it can also be recorded in several areas, such as medial temporal and subcortical structures, as the amygdala. Nevertheless evidence holds that apparently the temporal – parietal junction (TPJ), as it is referred to the area of the supramarginal gyrus and caudal parts of the superior temporal gyrus, seems to be very important to the generation of the P3a and P3b, as well as the medial temporal cortex, and the lateral prefrontal cortex (Halgren et al., 1995; Linden, 2005; Nieuwenhuis, et al., 2005; Soltani & Knight, 2000),whereas parts of the lateral prefrontal cortex contribute specifically to the generation of the P3a (Linden, 2005). Auditory tasks elicited a modality specific activation in the superior temporal gyrus, and visual tasks in the occipital cortex. (Soltani & Knight, 2000) Pineda et al. (1989), on the other hand, argued that, since the P3 shows homogenous latency across all the neural sites where it can be recorded, it seems plausible that the P3 wave resembles the activity of a neural system that has an impact on several, distinct brain areas, and propose that the locus coeuruleus – norepinephrine system (LC – NE) would hold all functional, anatomical, and physiological properties for such a generator and that specifically the phasic activation of the locus coeuruleus, which releases NE at axon terminals resembles the electrophysiological measure of the P3. (Aston-Jones, Rajkowski, Kubiak, & Alexinsky, 1994) This phasic activitiy of the LC seems to be tightly locked to the motivational significance of a stimuli (Berridge & Waterhouse, 2003) and the guidance of behaviour into task -, or goal - relevant direction. (Nieuwenhuis, et al., 2005)

5 AIM OF THE STUDY AND HYPOTHESES

The aim of the study is to examine the relationship between the FRN and regret, since this ERP and this emotion share similarities about their occurrence: The FRN prominently occurs whenever an outcome is worse than expected and regret as counterfactual emotion perceives an outcome as worse than expected along with the notion "If I had only chosen differently, then I could have won/lost less money". Therefore examining their specific relation to each other is a very interesting topic. More specifically the present study aims to explore the hypotheses that the FRN electrophysiologically resembles regret and moreover that the amplitude of the FRN resembles the extent of regret felt. The FRN is generated in the ACC (Crowley, et al., 2009; Gehring & Willoughby, 2002; Taylor, et al., 2007; van Veen & Carter, 2002) and this neural structure is also prominently involved in the feeling of regret (Coricelli, et al., 2005) which suggest the exploration of these hypotheses. The design of the present regret gambling task allows, through the distinction between free – choice "choose" and forced – choice "follow" blocks, to differentiate between "agency", the core element of regret, as the degree to which oneself is personally responsible for the outcome of the made decision (Byrne, 2002; Coricelli, et al., 2005; Loomes & Sugden, 1982; Zeelenberg & Pieters, 2007), in contrast to forced – choice runs with forced choice, and hence no feeling of responsibility. Therefore a further hypothesis to test in the present study will be that the main effect of agency will become visible in the FRN, as it is supposed to be elicited on free – choice "choose" trials whereas no or a smaller FRN should be elicited by the forced – choice condition. Furthermore the gradual distinction of the amount of regret felt due to the specific feedback types should be resembled in different mean amplitudes of the FRN. Regret is proposed to be highest in the "loss/alternative win" condition, since the alternative to which it is compared to would have been a win. Consecutively the interaction effect is therefore supposed to show the highest mean amplitude of the FRN in the free – choice ("loss/alternative win" condition. Hence it follows that a smaller FRN along with less regret, is expected in the free – choice "smaller loss/alternative larger loss" which could be expressed in a counterfactual: "Unfortunately I lost, but if I had chosen the other option I would have lost even more!" and an even smaller amplitude of the FRN in the free – choice "partial feedback loss" condition. (Coricelli, et al., 2005) where the chosen gamble is a loss, the alternative remains hidden, but still the thought of "what could have possibly been, if I had chosen differently? Maybe I would have won!" arises. Accordingly no FRN is supposed to show in the free – choice "win" condition where a P3 is expected. The P3, especially the subcomponents P3a and P3b are hypothesized to show the greatest amplitude in the free choice – win condition. Since no pattern can be derived due to the random delivery of win/lose feedback no habituation effect is expected. The detailed hypotheses will be laid out in the following.

5.1 Hypotheses Ratings

5.1.1 Kolmogorov – Smirnov and Shapiro – Wilk test

There exists a significant deviation from a normal distribution in the data.

5.1.2 Friedman's ANOVA

There is a significant difference between the ten distinct conditions (each feedback condition in free – and forced – choice). Therefore post hoc tests will be carried out to test for specific hypotheses regarding agency and the feedback types.

5.1.3 Agency and feedback

There exists a significant main effect in the ratings of feedback types. According to the theory of regret, after which "agency" as being self-responsible for the decision is the core element of regret, the ratings will be significantly different in the free choice condition relative to the forced choice condition, due to the personal engagement in the task. The ratings of the free choice condition will be smaller for the loss – conditions and greater for the win – condition compared to the forced choice condition.

The ratings of the feedback types in the free choice condition differ significantly from the mean ratings in the forced choice condition. The feedbacks indicating a loss in the free – choice condition will be rated significantly lower than in the forced – choice condition. The mean ratings of the free – choice "win" - condition will be significantly higher than those of the forced – choice "win" - condition.

The mean ratings of the free – choice loss – conditions will be significantly lower than the mean ratings of the free – choice "win" – condition.

There is significant difference in the mean ratings of the free - choice loss – conditions, as, due to the high salience of the alternative in "loss/alternative win" it will be rated as being worse compared to "larger loss/alternative smaller loss" where the alternative was also bearing a loss, followed by "smaller loss/alternative larger loss", with the alternate choice showing an even greater loss, and "partial feedback loss" in which the alternative remained unknown.

There are significant differences in the ratings of the feedback types in the free – choice condition, to that extent that the ratings of the conditions with losses are significantly lower than the ratings for the win condition.

5.2 Hypotheses FRN and P3a at FCz

The FRN will be specifically expected 200 – 300msec after feedback presentation, as can be seen in the plot and was stated by various researchers (Holroyd & Coles, 2002; Miltner, et al., 1997; Yeung, et al., 2005a). The P3a is supposed to peak around approximately 350msec after feedback, but could possibly have a longer latency, and will therefore be explored in the consecutive timeframes. Due to the proposed theories (chapters 4.1 and 4.2) the FRN is expected to be elicited in the free – choice “choose” blocks with a gradual distinction due to the different loss – trials (“loss/alternative win”, “smaller loss/alternative larger loss”, “partial feedback loss”), or show at least the greater mean amplitude than in the forced – choice trials. In the free – choice – win condition (“win/alternative loss”) a greater mean amplitude of the P3a is expected at FCz than in the forced - choice conditions. If a P3a is elicited in the loss – conditions also, it is supposed to be a lot smaller in its mean amplitude compared to the win - condition. The P3b is explored at Pz. The exploration at FCz due to the timeframes will be: 0 – 100msec and 100 – 200msec after feedback: exploration of the data, 200 – 300msec: exploration of FRN and possible onset of P3a, 300 – 400msec, and 400 – 500msec: exploration of P3a. The hypotheses will furthermore be presented in detail split up due to the explored main effects of agency (free- versus forced – choice), the main effect of feedback and the interaction effect (agency x feedback).

5.2.1 Agency

There exists a significant main “agency effect” in both the FRN and the P3a. The average amplitude of the FRN and the P3a is significantly larger in the free – choice than in the “forced – choice conditions or neither of the ERPs are elicited at all in the forced – choice condition.

5.2.2 Feedback type

There is a significant difference in the average amplitude of the FRN expected due to the distinct feedback types as it will be larger in the “loss/alternative win” condition, where the alternative choice would have been a win, smaller in the “smaller loss/alternative larger loss” condition, where both options were losses, and even smaller in the “partial feedback loss” condition. No FRN is expected to appear in the win – condition.

Due to the high salience of the chosen outcome bearing a win and its low probability of occurring the win – condition will elicit a P3a. The mean amplitude of this P3a will be significantly different from the loss – conditions, which elicit a FRN in the timeframe 200 – 300, as it will be significantly more positive. In the following timeframes the mean amplitude of the P3a will be significantly largest in the win – condition with no or a significantly smaller P3a in the loss – conditions.

5.2.3 Interaction effect: agency x feedback

There exists a significant interaction effect in the mean amplitude of the FRN between agency and the given feedback. The mean amplitude of the FRN is highest in the free – choice “loss/alternative win” condition, smaller in the free – choice “choose – smaller loss/larger loss” and even smaller in the “partial feedback loss” condition compared to the corresponding forced – choice “follow” conditions in which no FRN or a significantly smaller one is elicited.

The interaction effect (agency x feedback) shows significant results. The mean amplitude of the P3a is significantly greatest in the free choice – win condition, relative to the forced choice conditions and compared to the free choice – lose conditions. The mean amplitude of the observed P3a will be significantly more positive than in the free – choice – loss conditions, as they will elicit a FRN in the timeframe 200 – 300msec and either no or a significantly smaller mean amplitude of the P3a in the consecutive timeframes (300 – 400msec, 400 – 500msec), as compared to the forced - choice trials in which nor a P3a, nor a FRN, or at least significantly smaller mean amplitudes of these ERPs can be detected.

5.3 Hypotheses P3b at Pz

5.3.1 Agency

There exists a significant main effect for agency. The mean amplitude of the P3b is significantly greater in the free choice conditions “choose” than in the forced choice conditions “follow”.

5.3.2 Feedback types

The main effect for the feedback types shows significant results, in that direction that the mean amplitude of the P3b is significantly more positive in the win – condition than in the conditions indicating a loss if they even elicit a P3b.

5.3.3 Interaction effect: agency x feedback

The interaction effect (agency x feedback) shows significant results. The mean amplitude of the P3b is significantly greatest in the free choice – win condition, relative to the forced choice conditions and compared to the free choice – lose conditions, as the mean amplitude of the P3b is either significantly smaller or does not even deviate from the baseline.

5.4 Hypotheses for source localization (sLORETA)

According to the aim of the study which is to explore the relationship between the FRN and regret source localization will be carried out in the timeframe in which the FRN is to be expected, which is 200 – 300msec after feedback presentation.

According to the previous findings on locating the generator of the FRN in the ACC (Crowley, et al., 2009; Gehring & Willoughby, 2002; Taylor, et al., 2007; van Veen & Carter, 2002), and the activation in the ACC found by Coricelli et al. (2005) due to regret, there is a significant activation in the ACC to be found in all the free - choice loss – conditions compared to their corresponding forced – choice conditions, as they give rise to regret and the FRN. In accordance with agency being the core element to regret the activation of the ACC is, along with the FRN, only expected in the free – choice "choose" condition.

6 METHODS

In this chapter the procedure, as well as the regret gambling task and the study design are laid out. The methods used for collecting and exploring the data are also described in detail starting with the theoretical ground about the EEG and source localization followed by describing the procedure for EEG data processing to explore the data in the ERP – plots, with the repeated measures analyses, and sLORETA.

6.1 Procedure

A total of 24 right-handed subjects, mostly undergraduates of the University of Vienna participated in the experiment (15 female, 9 male). The data of one female had to be excluded due to too many artifacts and another female could not complete the experiment due to technical problems. The remaining total of 22 participants (13 female and 9 male) were aged between 19 and 36 ($M = 24.82$). Every participant signed a standardized written consent from in which they were informed in detail about all steps of the experiment, as well as of the application of the electrodes including the skin scratching of the scalp. The participant had no neurological or other diseases. The handedness was verified using the “Edinburgh handedness inventory” (Oldfield, 1971).

6.2 The regret gambling task

Regret has been induced in various ways by different researchers in neuroimaging studies. In the present work the attention will focus on the fMRI study conducted by Coricelli et al. (2005), using a regret gambling task (Camille, et al., 2004; Mellers, et al., 1999) to gain insight in the neural basics of anticipated and experienced regret with alternating forced and free choice trials to create a feeling of agency: personal involvement and engagement in the task, which will be used in a modified version for the present EEG study.

Chua et al. (2009) also used a modified version of the regret gambling task to elicit disappointment and regret, with the possibility for the subjects to rate, after each trial, their wish to alter the decision. Liu et al. (2007) presented the alternatives to put money on the bank or on a dice game. Regret was induced by tossing the dice even when the subjects chose the bank, so they experienced what would have happened had they opted for the gamble. Chandrasekhar et al. (2008) had their participants decide between three doors, behind which electric shocks were hidden. The participants were provided with information about the amount of electric shocks on each trial. Regret was supposed to be greatest when the information was given that a shock was hidden behind only one of the doors and the participant subsequently chose the wrong one.

The regret gambling task, as used by Coricelli et al. (2005) consisted of two gambles, resembling a wheel of fortune, which depicted the probabilities to win through the relative size of coloured circles. The participants indicated choice by pressing the right or left button. The chosen gamble was then highlighted by square, followed by a rotating arrow appearing and stopping after 4 seconds at the outcome, indicating a financial gain or loss.

Half of the trials were conducted as “choose” trials, allowing the individual to freely choose an option. The other half of the trials were designed as “follow” trials, where the computer picked a gamble and which served as the control-condition, because no responsibility for the choice could be taken by the subject, hence they suggested that no agency, and respectively no regret would be felt, which was the case.

Both the “choose”, as well as the “follow” trials were divided into a “complete” and a “partial” feedback condition. The complete feedback trials provided the participants with both information about the chosen and the rejected alternative, and were so informed about the financial consequences and what they lost, whereas in the partial feedback condition only the outcome of the chosen gamble was shown.

This regret gambling task is the model after which the present study was designed. The regret gambling task holds various properties that make it perfectly suited to test the relation between the FRN and regret. There are parallels in the occurrence of the FRN and regret. The FRN is elicited whenever an outcome is worse than expected (Holroyd & Coles, 2002). Regret is an emotion that appears whenever an individual cognitively compares a undesired outcome to “what might or could have been, would I have chosen differently” (Summerville & Roese, 2008), which is expressed by using an upward counterfactual comparison, meaning that the unchosen alternative would have been preferable, aiming for a change in behaviour to reach a desired goal (Epstude & Roese, 2008). The regret gambling task allows operationalizing agency by presenting alternating free- and forced – choice trials, and moreover the feedback providing losses and/or gains can be varied. The specific hypotheses regarding the relation between the FRN and regret will be presented in chapter 5.

6.3 Study design

The participants were seated in a dim light, soundproofed room in front of a 18 – inch computer screen (Samsung SyncMaster 181T) in a distance of about 70cm. Furthermore they were instructed to place their right hand comfortably on the table in front of the response box.

To avoid artifacts the participants were instructed to sit still, keep their eyes in the middle of the screen, have their hand resting comfortably on the desk in front of the response box and that there will be breaks in between the blocks for them to relax. All instructions were given on the screen (in german). The instruction for the rating of the various feedback types to collect behavioural data which was conducted at the beginning of the experiment said: “Please rate on a scale from 1 – 6 how you rate the result.1 means the result was “very bad”, 6 means “very good”. Use the corresponding keys for your judgment.” After the rating was completed, the instructions for the experiment appeared on the screen. The subjects were instructed to place their index and their middle finger of the right hand on the numbers ”3” and “4” in the middle of the response box in front of them, which were also marked with a sticker, to indicate their choice of the left or the right square appearing on the screen. The experiment consisted of four blocks subdivided into forced- and free – choice conditions to collect data regarding the agency effect. In the free – choice condition this was the instruction: “The experiment starts whenever you press the key „1“. You can freely decide which one of the two cards you want to choose. Your starting capital is 45€.” In the forced – condition the instruction was as follows: “The experiment starts whenever you press the key „1“. Please choose the card the arrow is pointing to. Your starting capital is 45€.“ If they pressed the wrong button, a message appeared saying: “You hit the wrong key, please try again.” The five different types of feedback (see Figure 6.2) with each four possible sets of combinations of wins and losses finally added up to a total of 100 trials per block, after each 20 trials the participants were told their current balance. After each completed block an instruction appeared saying: “You have now completed the first block of the experiment. Your current balance is …. Euro. Please take a short break and start the next block by pressing the key „1“. In the following block you will not be able to decide freely which card to use. Instead please pick the card with the arrow pointing to It follows that a similar instruction was of course displayed when changing from the forced – to free – choice block with the obvious distinction that the participants were told that they could choose freely again. Unknown to the participants everyone ended up with a total amount of 17€, which were subsequently paid out after the experiment and every subjects also signed a confirmation of receiving the money. Money was provided the by Brain Research Lab at the Faculty of Psychology.

Before the actual experiment behavioural data was collected. After the rating had been completed the actual experiment began, as depicted in Figure 6.1. Each trial was started by showing a white fixation cross for 1500msec in the center of the screen. This was followed by item presentation, consisting of two empty squares (width: 5.15cm, height: 3.9cm, diagonal: 6.4cm; the space between the two squares was 0.65cm). The participants were instructed to choose one of the two squares, either freely or forced, as mentioned above. By pressing the left button they indicated to choose the left square, by pressing the right one, the right square was chosen. The chosen square was subsequently highlighted by a black framing, which appeared on the screen for one second. The presentation of the feedback followed for two seconds, indicating one of the 5 possible result types (see Figure 6.2), with the chosen alternative still highlighted through a thick black frame wins coloured in red, losses in green, since Gehring and Willoughby (2002) showed that the colour of the squares bearing a win or a loss, does not modulate the FRN. The inter stimulus interval was poisson distributed in an interval from 500 – 2000msec.

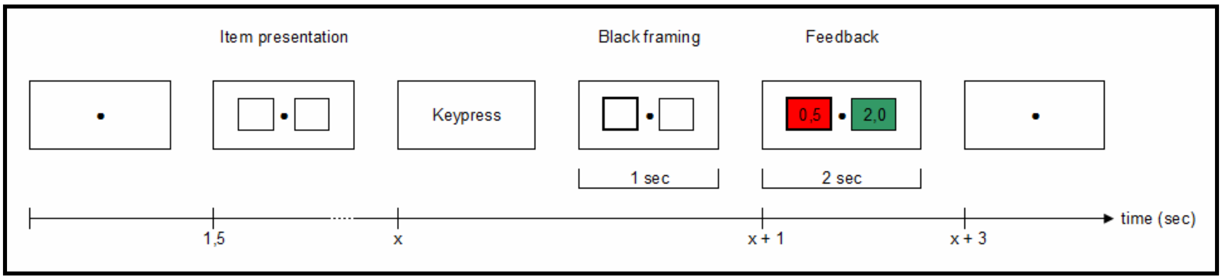

***Figure 6.1:* Study design ("*x*" refers to time of keypress)**

The design of the study resembled a regret gambling task as described above and used by Coricelli et al. (2005) (Camille, et al., 2004; 2005; Mellers, et al., 1999). Regret was induced by two variables agency and feedback.

The five distinct feedback types were presented pseudo - randomly, four of which were indicating losses, which were supposed to elicit regret in the free choice conditions and hence a FRN, and one bearing a win, which was supposed to elicit a P3. The five different feedback types are depicted in Figure 6.2 (currency in Euro). The feedback types are distributed in the free – and the forced – choice blocks and will be explained in detail:

"Loss/alternative win": The chosen option turned out to be a loss, the alternative would have been a win. The participant lost money (0,4; 0,5; 0,6; 0,7) and the alternative was presented as a win (1,9; 2,0; 2,1; 2,2). The win in this option was accordingly always 1,5€ higher than the loss. Each of the 4 yielding possible combination of wins and losses occurred 6 times in each of the 4 blocks.

"Smaller loss/alternative larger loss": Both options were losses. The individual had chosen the alternative with the smaller amount of loss (0,4; 0,5; 0,6; 0,7) in comparison to a possible loss that was respectively always 0,5€ higher (0,6; 1,0; 1,1; 1,2). According to "choose/follow loss/alternative win" every set had an appearance frequency of 6.

"Partial feedback loss": The chosen gamble indicated a loss (0,4; 0,5; 0,6; 0,7) whereas the other option remained unknown and only a white square was to be seen. Also this set of combinations appeared 6 times each.

"Win": This was the only win gamble for the participants. Their choice indicated a win (1,9; 2,0;2,1;2,2) the alternative was a relative loss of 1,5€ (0,4; 0,5; 0,6; 0,7). The frequency totaled 5 of each of the 4 possibilities.

“Larger loss/alternative smaller loss”: This type of result was similar to “Smaller loss/alternative larger loss”. Both options would have meant a loss for the individual, but in this case the subject lost 0,5€ more in the chosen alternative (0,9; 1,0; 1,1; 1,2) relative to the unchosen one (0,4; 0,5; 0,6; 0,7). This set only had a frequency of appearing only 2 times each which, in the further processing of the EEG data, turned out to not have been sufficient to get utilizable data and was therefore not included in the subsequent statistical analyses.

Feedback Type	Feedback		Frequency
Loss/ alternative win	0,5	2,0	6
	0,4	1,9	6
	0,6	2,1	6
	0,7	2,2	6
Smaller loss/ alternative larger loss	0,5	1,0	6
	0,4	0,9	6
	0,6	1,1	6
	0,7	1,2	6
Partial feedback loss	0,5		6
	0,4		6
	0,6		6
	0,7		6

Feedback Type	Feedback		Frequency
Win	2,0	0,5	5
	1,9	0,4	5
	2,1	0,6	5
	2,1	0,7	5
Larger loss/ alternative smaller loss	1,0	0,5	2
	0,9	0,4	2
	1,1	0,6	2
	1,2	0,7	2

Figure 6.2 : **Feedback types**

6.4 The electroencephalogram (EEG)

Electrical impulses account for processing information in the brain by distributing neuro-transmitters. The action potential is a brief voltage spike which lasts approximately a milli-second, conducting information from the cell body along the axon to its terminals where neu-rotransmitters are being released. (Kolb & Wishaw, 2003; Luck, 2005) The neurotransmitters furthermore bind to receptors on the postsynaptic membrane which induces a change in the electrical potential of the cell membrane by bringing ion channels to either close, which is referred to as the inhibitory postsynaptic potential (IPSP) or open which is called the excita-tory postsynaptic potential (EPSP). They last longer than the action potential (ten to hun-dreds of milliseconds). EPSPs originate at the cortical pyramid cell’s apical dendritic tree. (Luck, 2005; Seifert, 2005) These postsynaptic potentials cause a change in voltage on the cortex which is the basis of the EEG: The release of an excitatory neurotransmitter at pre-synaptic terminals leads to a flow of positive ions along the apical dendrite into the postsy-naptic neuron. This creates a small dipole: On the outside of the dendrite, as well as in the nucleus, negative ions are still predominant with an overload of positive ions on the outside of the membrane. This creates a small dipole. The current flow compensating the imbalance between the extra and intra cellular concentration of ions generates measurable electrical potentials on the scalp. At least ten-thousand neurons have to be activated simultaneously, they have to fire synchronously, and they have to be orientated in the same direction, for the electrical potentials to summate and generate an electrical signal that becomes visible in the EEG. Cortical pyramide cells fulfill these requirements, (Birbaumer & Schmidt, 2003; Luck, 2005; Seifert, 2005) because they "are oriented perpendicular to the cortical surface" (Pascual-Marqui, Esslen, Kochi, & Lehmann, 2002a)

Another point that is very important to mention is that "an ERP waveform reflects the difference in activity between two sites, not the activity at a single site" (Luck, 2005) The differences between the electric potentials of two electrodes, an active one, for example the placement of electrodes at frontocentral (FCz), central (Cz), or a frontal (Fz) (Electrode number site of the scalp to record the FRN (Holroyd & Coles, 2002), and a reference electrode at a site with a preferably negligible electrical activity like the mastoid or a sternovertebral reference yield the EEG, respectively the event-related brain potentials (ERP). (Baillet, Mosher, & Leahy, 2001; Luck, 2005; Seifert, 2005)

Event-related brain potentials (ERPs) are subcortical potentials appearing during, after or before anticipation of, reaction or response to a sensory or psychological stimulus, challenge or feedback, like the feedback-related negativity (see chapter 4.1). They are therefore stimulus-induced and vary due to presentation of different tasks and stimuli. Their amplitude (1-30 µV), due to their specific localization dependent on the nature of the initiating stimulus is smaller than the amplitude of the neocortical EEG which superimposes the ERPs as noise. The amplitude of the ERPs will be measured relative to the baseline, which is a pre-stimulus interval of preferably 200ms as it was the case in the present study, as will be laid out in chapter 6.3.

The ERPs are assumed to resemble identical neural activity on each trial with the same stimulus or feedback, whereas the noise is randomly distributed when repeating the trial. By averaging together lots of EEG waveforms elicited by the same time-, and stimulus - locked trial the signal-to-noise ratio improves which means that the consistent waveforms of the ERPs remain, become visible and can be identified as the noise diminishes. The grand-mean can then be computed by averaging together the mean waveforms of each participant in trials requiring the same response, representing the ERPs an average brain would show when confronted with that specific task. (Baillet, et al., 2001; Birbaumer & Schmidt, 2003; Luck, 2005; Seifert, 2005)

The waveforms can be contaminated by various artifacts. These artifacts can, for example, derive from motor activity (e.g. blinking, eye and head movement, breathing, muscle activity such as chewing, facial expressions, talking), from the electrodes (e.g. change in the impedance, material defect, contact fault, which can also be caused by sweating), or from electronic devices (e.g. cell phone). (Seifert, 2005) Problems arise through these artifacts as they are normally fairly large, “and may greatly decrease the S/N ratio of the averaged ERP waveform.” (Luck, 2005), but even more, other than the previously mentioned noise generated by the neocortical EEG that occurs randomly throughout the repetition of trials, some artifacts can appear systematic, which has the consequence that they will, just as the interesting ERPs, not be cancelled in the averaging process, which might lead the investigator to wrong conclusions about the data. Of course first of all every investigator will try to avoid artifacts by, for example, instructing the participant not to blink or chew gum, and controlling the electrodes and instruments. Still artifacts cannot always be completely avoided and must therefore be eliminated after recording. Luck (2005) mentions “two main classes of techniques for eliminating the deleterious effects of artifacts” : artifact rejection and correction. “Artifact correction” (Luck, 2005) uses their estimated influence on the ERPs and cancels them out through a correction procedure, as it is often done with eye artifacts. To register eye movement in order to correct artifacts the electrooculogram (EOG) can be measured by four extra electrodes.

“Artifact rejection” (Luck, 2005) means detecting artifacts by looking over each EEG epoch and excluding them from further analysis. Artifacts can be identified by their specific morphologic and topographic characteristics, as well as by their frequency, which are typically very distinct from “clean” EEG lines.

6.4.1 Data acquisition and processing

An EEG cap with 57 unpolarizable silver/silverchlorid (Ag/AgCl) electrodes from *EASYCAP GmbH (Herrsching, Germany)* was used to record the EEG with equidistant montage. The cap was placed on the head by aligning Cz (number 16 in Figure 6.3) in the middle of the scalp relative to the nasion and the inion.

Eye movement was recorded using an EOG. The vertical EOG (VEOG) was placed in a straight line with the pupil by above and under the left eye. The horizontal EOG (HEOG) was placed next to the left and right outside canthi. The EOG is used to correct artifacts deriving from eye movement offline, and is included in the baseline calculation online.

Furthermore a sternovertebral reference was applied, which made it also possible to filter the EKG out of the EEG. 64 channels were recorded using a DC-amplifier by *Ing. Zickler GmbH (Pfaffstätten, Austria).*

The scalp underneath the electrodes was scratched with a sterile injection needle and filled with electrode paste *(Electro-Gel, ElectrodeCap International Inc., Eaton/OH, USA)* to reduce the impedance of the electrodes, which was measured and less than 2 kΩ.

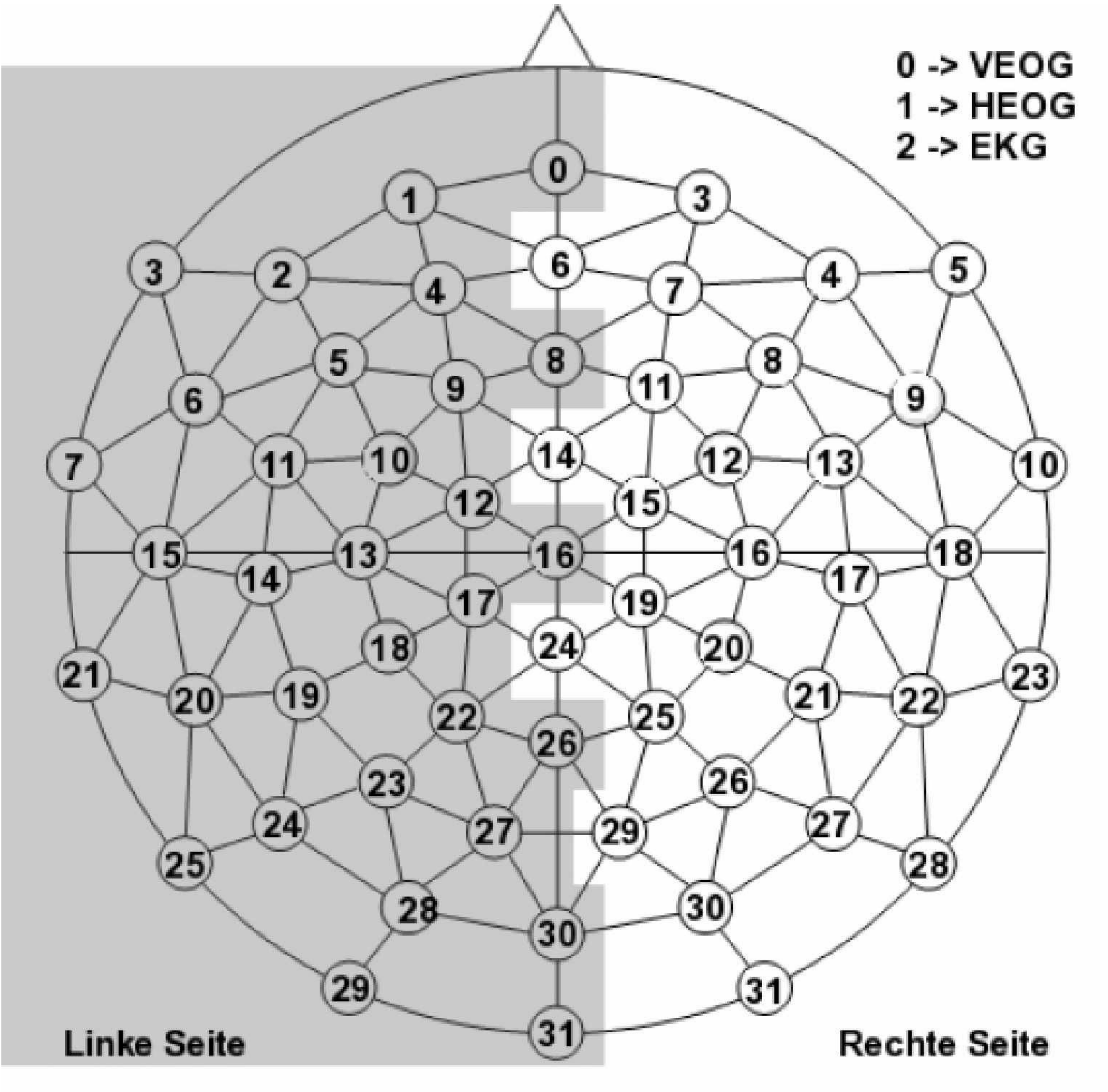

Figure 6.3: **Alignment of electrodes using easy cap by EASYCAP GmbH**

The collected EEG data was furthermore pre – processed with an EEG pre-processing script. This allocates each separate trial to the condition to which it belongs to, sets the baseline and filters the EEG data with 30Hz. The baseline was defined as the last 200ms of the high-lighting of the chosen square with black framing in the study design before the feedback presentation ((200 – (x+1); (x+1) referring to the presentation of the feedback (see Figure 6.1)) and was furthermore used as the baseline for EEG data evaluation. Moreover a time-frame of 1sec starting with the baseline, and the starting point of “0” referring to the presentation of the feedback was extracted for further processing. Artifact correction was also applied in this process: the correction of the EOG, the EKG measured with the sternovertebral reference, as well as the "Blink" – correction, which excluded artifacts deriving from eye – blinks. Furthermore the remaining artifacts were manually excluded from further analysis. The EEG data of one participant had to be removed completely because of too many artifacts. In a further step the data was averaged for every subject for every EEG – channel in the all the conditions with *EEGLAB (Swartz center for computational neuroscience, San Diego/CA USA)*. The interesting timeframe defined through the pre-processing procedure was used for averaging. A grand – mean across all subjects was computed for all the conditions and also plotted for the electrodes of interest: Fz, FCz and Pz in this timeframe. The plots revealed the same amplitude for the FRN and the P3a at Fz and FCz. According to Holroyd et al. (2003) and Yeung and Sanfey (2004) the FCz was furthermore chosen to explore the FRN and the P3a. The averaged data for FCz and Pz for each participant was further processed by computing the mean amplitude of the EKPs in each timeframe of interest for statistical analyses with SPSS *(Statistical Package for the Social Sciences)*. The mean amplitude of the EKPs was analysed with SPSS in these timeframes of interest: 0 – 100msec, 100 – 200msec, 200 – 300msec (timeframe of interest for FRN at FCz), 300 – 400msec, and 400 – 500msec after the presentation of feedback (last two timeframes are of interest for P3a at FCz) (for the P3b at Pz all timeframes were explored). The averaged EEG data was also further processed with *EEGLAB* for source localization in sLORETA *(The KEY Institut for Brain-Mind Research, University Hospital of Psychiatry, Zurich, Switzerland)* in the timeframe of interest for the FRN ranging from 200 – 300msec after feedback presentation.

6.5 Source localization

The ERPs display ongoing "cerebral processing" (Kolb & Wishaw, 2003) associated with a stimulus or reaction to a task "in real time" (Luck, 2005), but they don't provide the extent of spatial resolution as does functional magnetic resonance (fMRI). Nevertheless investigators have been working out solutions for source localization using ERPs, on the basis of the bit of spatial information they do provide.

Predicting the distribution of voltage on a surface caused by one single dipole in a conductor, is referred to as the "forward problem" and can be solved by using simple equations. This proceeding can be fairly easy compared to finding a solution to the "inverse problem" (for a review see: (Pascual-Marqui, 1999)) when an inference wants be drawn from a known distribution of voltage across the scalp to the orientations and positions of the underlying dipoles. The problem is that there is no unique solution to this problem, because "for any given scalp distribution, there is an infinite number of possible sets of dipoles that could produce that scalp distribution" (Helmholtz, 1853; Luck, 2005; Plonsey, 1963) Ways to solve this problem can be summarized into the “equivalent current dipole category of source localization methods”, and the “distributed source approach”(Luck, 2005).

The second category is of special interest to the present study and will therefore be laid out more detailed. Generally the idea is to subdivide the brain into voxels. “At each voxel there is a point source, which may be a vector with three unknown components (i.e., three dipole moments), or a scalar (unknown dipole amplitude, known orientation)” (Pascual-Marqui, 2002) The “nonuniqueness problem” therefore arises because there are simply too many dipoles that could have produced the specific distribution across the scalp. One solution to the nonuniqueness problem is called the “minimum norm solution” as first reported by Hämäläinen and Ilmoneimi (1984), which comprises the observed scalp distributions and uses the “minimum overall source magnitudes” (Luck, 2005). This solution has its constraints when it comes to accounting for deep sources contributing to the scalp distribution and generates a 2D solution (Pascual-Marqui, 1999, 2002). Pascual-Marqui, Michel and Lehmann (1994) presented the low-resolution electromagnetic tomography (LORETA) which yields a 3D localization solution to the inverse problem using the Talairach brain atlas (Brain Imaging Center, Montreal Neurological Institute). LORETA uses the current density in the brain and can localize the center of activation correct between adjacent populations of neurons (voxels) that show a maximum synchronous and simultaneous activation. (Luck, 2005; Pascual-Marqui, et al., 2002a; Pascual-Marqui, et al., 1994) It furthermore detects “the smoothest 3 dimensional current distributions” (Pascual-Marqui, et al., 1994) and so yields images of source localization of the electrical potential recorded in the EEG.

Pascual-Marquis (2002; Pascual-Marqui, et al., 2002a) introduced a new imaging method, sLORETA (standardized low resolution brain electromagnetic tomography), which was used in the present study, and which provides “images of standardized current density with zero localization error” (Pascual-Marqui, 2002; Pascual-Marqui, et al., 2002a) in the cortical grey matter, which is determined by the Talairach brain altlas (Brain Imaging Center, Montreal Neurological Institute) by using a realistic head model (MNI152 template), which allows to map the current density in each voxel of the cortical grey matter. eLORETA is a further improvement to sLORETA with exact localization of the neuronal source. Despite the high localization, in the case of sLORETA, standardized, current density comes at the price of low spatial resolution in sLORETA/eLORETA which will entail a high correlation of close-by neuronal structures. sLORETA/eLORETA is an improvement to LORETA and was used in the present study for source localization. (Pascual-Marqui, 2002, 2007; Pascual-Marqui, et al., 2002a)

6.5.1 Data processing

EEG data was processed for the timeframe 200 – 300msec after feedback presentation in *EEGLAB*. Channel – locations were applied using a mean head and transferred to sLORETA where the EEG data was converted into an inverse solution to enable source localization of the underlying neural generators of the FRN peaking in this specific timeframe.

It is possible to compute comparisons of current density of two conditions with sLORETA/eLORETA "Statistical non – parametric Mapping" (SnPM) by conducting T – tests. They were carried out to compare each free choice condition to its corresponding forced choice condition to reveal the maximum activation difference for every comparison at a significance level of *$p < 0.05$ (two - tailed)*. Furthermore the grand – mean of every free – choice condition was computed to gain insight of the grand – average maximum activation in each specific free choice condition.

6.6 Statistical analyses for the behavioural data

A Kolmorogov – Smirnov and Shapiro - Wilk test was carried out to test for normal distribution of the ratings. Furthermore Friedman's ANOVA was carried out, which is an alternative to the repeated measures design for data violating the assumption of normal distribution for a repeated measures ANOVA. It was used to test whether the ratings of the ten different conditions (free – and forced – choice conditions) differed significantly from each other.

Furthermore post hoc tests for Friedman's ANOVA were computed using the Wilcoxon signed rank test with corrected significance levels. The *Bonferroni correction* was applied to the *α – level* of the post hoc tests. To test for the agency and feedback the feedback types in the free – choice condition were compared to their corresponding forced – choice conditions. The significance level using the exact statistics *Monte Carlo method* was corrected to *α (0.05)/5* because of the resulting five comparisons that were carried out, which yielded a significance level of *$\alpha = 0.01$ (confidence level of 99%)* at which all the results will be reported.

The relation between all the ratings for the feedback types in the free – choice condition were compared to each other, as well as the ratings for the feedback types in the forced – choice conditions to reveal whether the distinct feedback types were rated significantly different from each other in the particular agency condition. The corrected significance value (*Monte Carlo method*) was *α (0.05)/4*, because of the resulting four comparisons and was *$\alpha = 0.0125$ (confidence level of 98.75%).*All the results will be reported at the corrected significance level.

6.7 Statistical analyses for the EEG data

In the present study EEG/ERP data was collected to explore the FRN and the P3 regarding two independent variables: 1. the personal responsibility for the choice, referred to as “agency”, 2. the type of feedback given to the participants (5 distinct result types). (Field, 2005)

Data for the FRN was extracted from FCz (electrode number 14 in Figure 6.3) (Holroyd, et al., 2003; Yeung & Sanfey, 2004), and, as reported in 4.1, the timeframe for the FRN will presumably be elicited 200-300ms after feedback presentation (Holroyd & Coles, 2002; Miltner, et al., 1997; Wu & Zhou, 2009; Yeung, et al., 2005a), which, accordingly, will be the timeframe of interest to explore the hypotheses regarding the FRN. As reported by Yeung and Sanfey (2004) a P3 could be expected at FCz, which, because of its frontocentral distribution will be referred to as the P3a, as laid out in 4.2 (Linden, 2005; Nieuwenhuis, et al., 2005; Polich, 2007; Soltani & Knight, 2000). The FCz was chosen in accordance with studies by Holroyd et al. (2003) and Yeung and Sanfey (2004), because the amplitudes of the FRN and the P3a were the same in Fz as they were in FCz. As reported by Yeung and Sanfey (2004) a P3 could be expected at FCz, which, because of its frontocentral distribution will be referred to as the P3a, as laid out in 4.2 (Linden, 2005; Nieuwenhuis, et al., 2005; Polich, 2007; Soltani & Knight, 2000). Moreover the P3b was explored parietal at the Pz (electrode number 58; which is number 26 in the grey shaded part of Figure 6.3) (Polich, 2007; Soltani & Knight, 2000; Yeung & Sanfey, 2004).

For detailed exploration the data was split up into time-divisions of 100ms, starting from feedback-onset in 5 timeframes (0 – 100msec, 100 – 200msec, 200 - 300msec, 300 – 400msec, 400 – 500msec after feedback presentation). The EEG/ERP data was furthermore computed using the repeated measures design. It was explored regarding the main effect of agency, measured by comparing the mean amplitude of the FRN, respectively the P3, in the free – choice condition “choose” to the forced – choice condition “follow”. Moreover the main effect of feedback was examined to find out whether the various feedback types had a different effect on the mean amplitude of the ERPs. The third variable that has been explored was the interaction effect of agency x feedback to find out if the agency conditions interacted with the distinct feedback types. Put differently: to examine whether the feedback types had a different effect on the mean amplitude of both the FRN and the P3 depending on in which agency condition (“choose” or “follow”) they were measured. The Greenhouse – Geisser correction was furthermore applied to the degrees of freedom and the results reported. (Field, 2005)

To further test the hypotheses standard planned contrasts were carried out to test the specific hypothesized relations between the various free choice conditions relative to the corresponding forced choice conditions. Simple contrast starting with the first condition as the reference category give an insight into the relation of each of the conditions to this reference category, which in this case, is free choice "loss/alternative win" condition relative to the forced choice conditions. Simple contrasts can also be used to compare the last of the conditions to all the other conditions, which was also carried out in the present study to compare the effect of each condition to the free choice win conditions also relative to the forced choice conditions. Repeated contrasts allow to compare each condition with the previous one, except the first one (free – choice "loss/alternative win"), which provides additional results concerning the relation of the two free choice conditions "smaller loss/alternative larger loss" the "partial feedback loss" condition relative to its corresponding forced choice conditions.

7 RESULTS

7.1 Behavioural data: Ratings

Behavioural data had been collected before the actual experiment in both conditions with different levels ofagency: the free choice “choose” condition where participants were free to decide which option to choose and were hence responsible for the win or the loss and the “follow” condition which represented forced choice released the individual of the responsibility for the outcome. Feedback type “larger loss/alternative smaller loss” was excluded from EEG data exploration, because there were not enough trials collected to get clear data. Still the behavioural results will include the ratings for “larger loss/alternative smaller loss” as well to depict whether general differences between the feedback types are significant, and for possible future use of the same feedback types, including “larger loss/alternative smaller loss”.

Figure 7.1 and Figure 7.2 depict the frequencies of the ratings (1-6) per feedback condition split up according to “agency”. Figure 7.3 shows the mean ratings per feedback type by comparing free choice “choose” to forced choice “follow” trials.

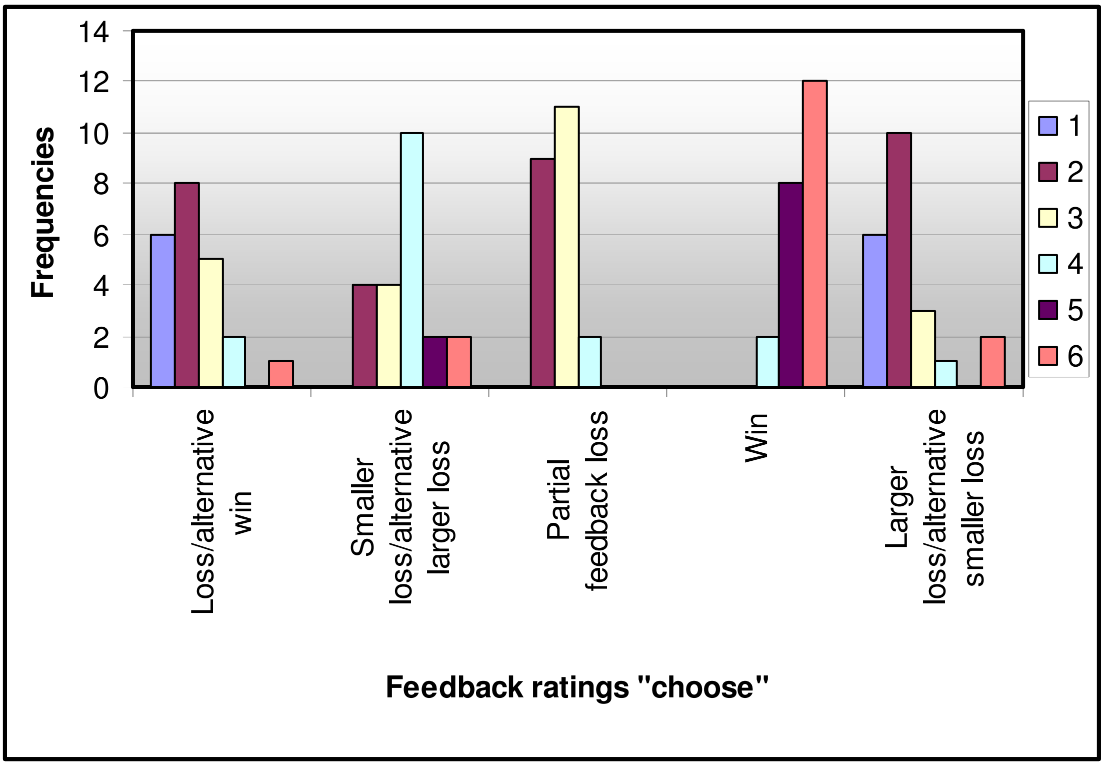

Figure 7.1: **Frequencies of ratings due to different feedback types in the free – choice conditions (Legend displays the ratings)**

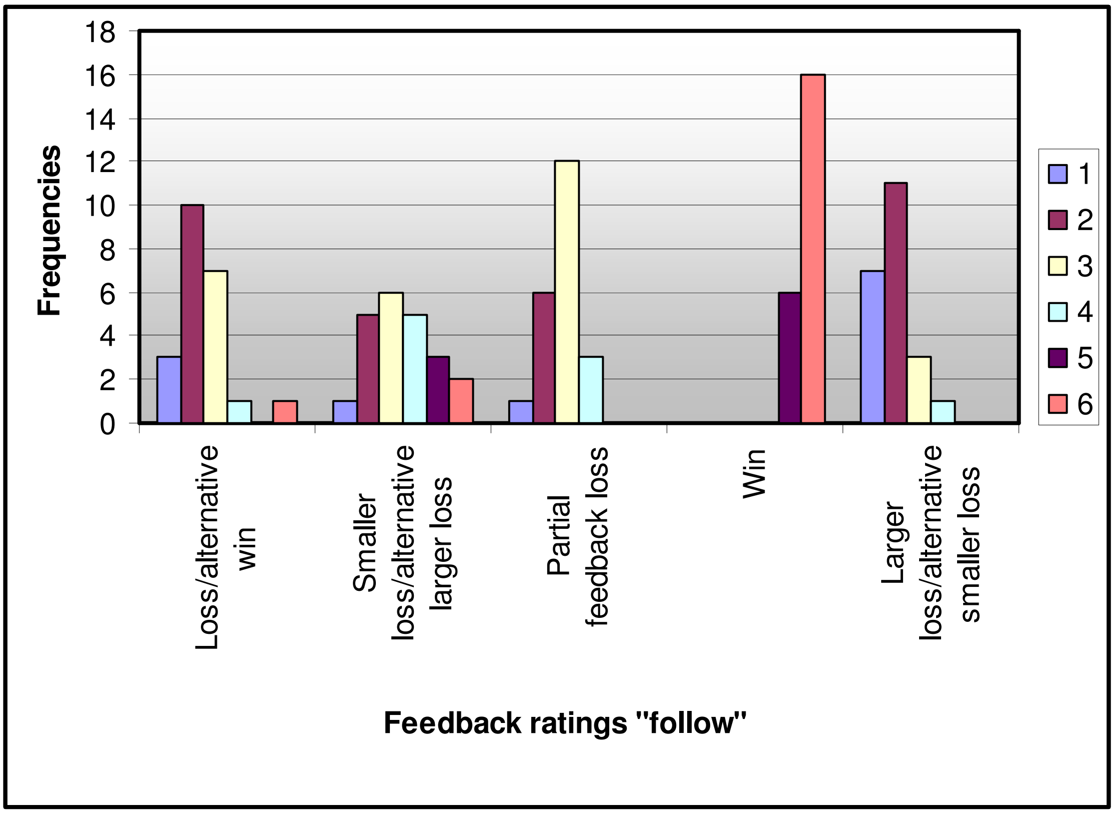

Figure 7.2: **Frequencies of ratings due to different feedback types in forced choice conditions (Legend displays the ratings)**

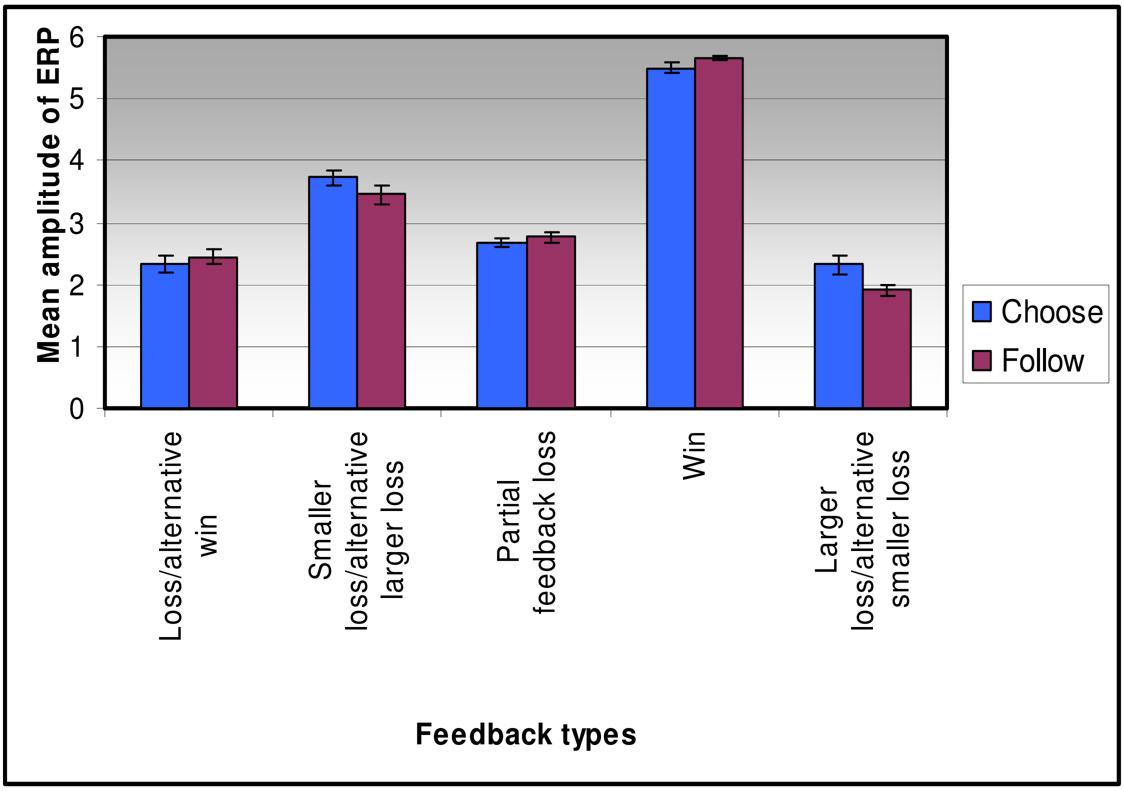

Figure 7.3: **Mean ratings of different feedback types in free – and forced – choice (Error bars displaying *standard error (SEM)*)**

The Kolmogorov – Smirnov and the Shapiro – Wilk test confirm significant deviations of the data from a normal distribution except for the forced – choice "smaller loss/alternative larger loss" condition which showed a non significant result which indicated that this specific condition is normally distributed. ($p < 0.05$, *two - tailed*).

Friedman`s ANOVA showed that the ratings of the ten distinct conditions differed significantly from each other ($\chi^2(9) = 133.126$, $p < 0.05$, *two - tailed)*

7.1.1 Agency and feedback

No significant differences in the ratings between the two agency conditions were determinable ($p < 0.01$, *two - tailed*). Subjects did not rate the feedback given in the free choice condition "choose", where they were responsible for the outcome, significantly different than in the forced choice condition "follow".

The feedback in the free – choice condition "loss/alternative win" showed significant differences in the ratings to free – choice "smaller loss/alternative larger loss" ($T = 12$), and also to the free – choice "win" condition ($T = 0$). As can be seen in Figure 7.3 the free choice "loss/alternative win" is rated significantly lower than the other two free choice feedback conditions. The free choice "smaller loss/alternative larger loss" was rated significantly distinct from all the other feedback categories. By looking at Figure 7.3 it can be concluded that the free – choice "partial feedback loss" condition was rated significantly lower (*T* = 0), as was free - choice "larger loss/alternative smaller loss" (*T* = 37.50), whereas the "win" - condition was rated significantly higher (*T* = 0). Furthermore the "win" – condition was rated significantly higher than all the free – choice loss – conditions also to the "larger loss/alternative smaller loss" (*T* = 2). As previously reported the feedback free – choice "larger loss/alternative smaller loss" showed significantly distinct ratings to the free choice conditions "smaller loss/alternative larger loss" and "win" as they were all rated higher. It follows from these results that no significant differences in the free choice condition could be found regarding the "partial feedback loss" and "larger loss/alternative smaller loss" to "loss/alternative win". Neither did the free – choice "partial feedback loss" condition differ significantly from "larger loss/alternative smaller loss". (all results at $p < 0.0125$*, two – tailed*)

Regarding the forced choice conditions "follow" significant differences for "loss/alternative win" and "smaller loss/alternative larger loss" (*T* = 9) and the "win" condition (*T* = 0) as both were rated significantly higher. Forced – choice "smaller loss/alternative larger loss" was furthermore rated significantly different to the "larger loss/alternative smaller loss" (*T* = 0) and was rated higher. The "partial feedback loss" condition in forced choice was also rated significantly different to the "win" condition (*T* = 0) and to "larger loss/alternative smaller loss" (*T* = 0). The "win" condition was rated significantly better than all the loss – conditions, also better than "larger loss/alternative smaller loss" (*T* = 0). Slightly insignificant differences in the ratings of "partial feedback loss" and "smaller loss/larger loss" can be reported by testing at $p < 0.0125$*, two – tailed.* The difference in the ratings between "loss/alternative win" and "the partial feedback loss", as well as to "larger loss/smaller loss" can be reported as not significant. (all results at $p < 0.0125$*, two – tailed*)

7.2 Results for the mean amplitude of the FRN (FCz)

The FRN will be specifically explored in the timeframe of 200 – 300msec after the presentation of the feedback. The timeframes 0 – 100msec and 100 – 200msec after presentation of feedback are used for data exploration.

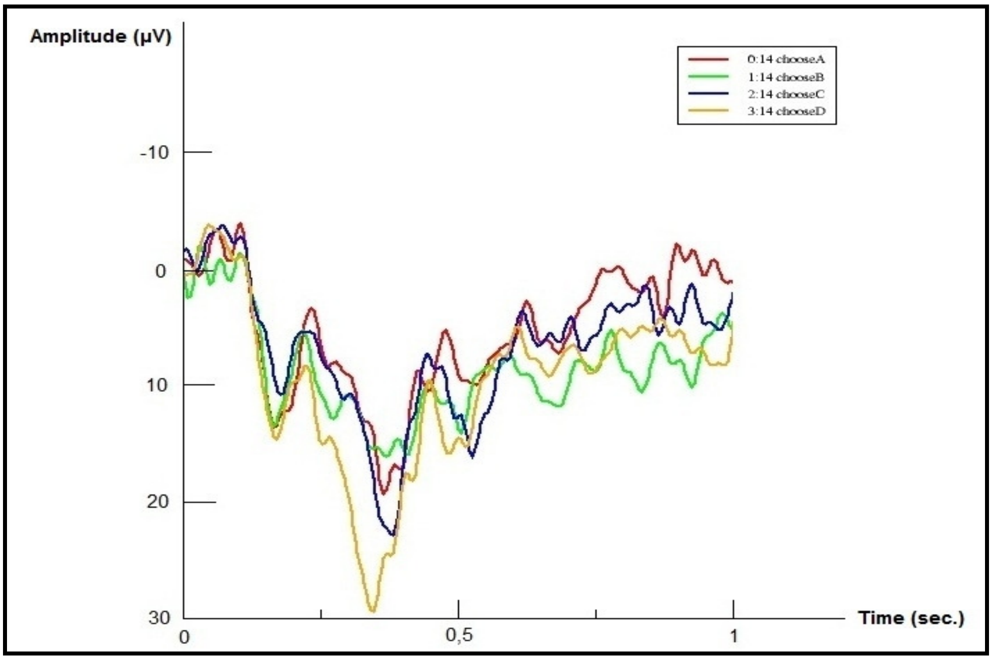

Figure 7.4: **Plotted ERP lines recorded at FCz for the different feedback types in the free – choice condition*. Note: "A" refers to "loss/alternative win", "B" to "smaller loss/alternative larger loss", "C" to "partial feedback loss", "D" to the "win" condition***

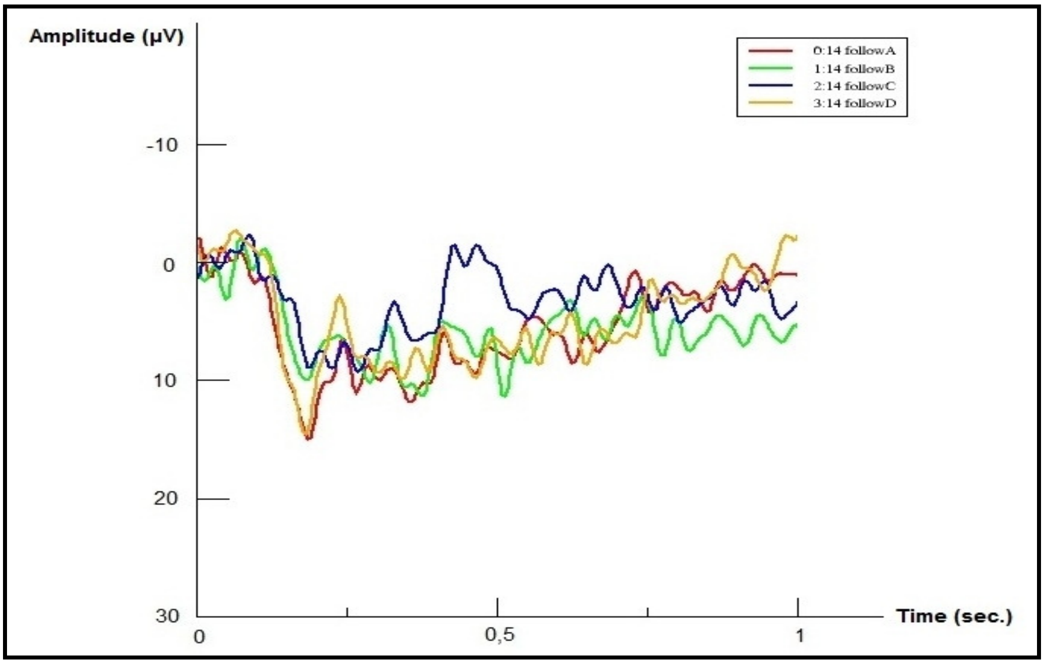

Figure 7.5: **Plotted ERP lines recorded at FCz for the different feedback types in the forced – choice condition. *Note: "A" refers to "loss/alternative win", "B" to "smaller loss/alternative larger loss", "C" to "partial feedback loss", "D" to the "win" condition"***

7.2.1 0 – 100msec after feedback

Neither the main effect of "agency" and of the result types, nor the interaction effect was significant at $p < 0.05$ in the first timeframe.

7.2.2 100 – 200msec after feedback

There was a significant main effect for "agency" $F(1,21) = 6.61$, $p < 0.05$, to that extent that the mean amplitude of the FRN was significantly more positive in the free choice conditions $M = 3.35$ (*SEM* = .62, *CI* [2.06, 4.64]), than in forced choice trials $M = 2.13$ (*SEM* = .41, *CI* [1.27, 2.99]), as can be seen in the plot.

A significant main effect can also be reported for the feedback types (abcd) $F(2.4, 42.85) = 14.35$, $p < 0.05$. The mean amplitude of the ERP differed significantly across the feedback conditions. A conducted repeated contrast revealed in which direction and which feedback types specifically differed from each other in their mean amplitude: condition "smaller loss/larger loss" $F(1, 21) = 9.2$, $M = 2.36$ (*SEM* = .52, *CI* [1.28, 3.43]) differed with a smaller ERP amplitude significantly from "loss/alternative win" $M = 3.4$ (*SEM* = .53, *CI* [2.3, 4.5]), the mean amplitude of the "partial feedback loss" condition $F(1, 21) = 9.53$, $M = 1.46$ (*SEM* = .41, *CI* [.61, 2.3]) was significantly different from the "smaller loss/alternative larger loss" conditions, as it showed a smaller mean amplitude, and this was the same case with the "win" – condition $F(1, 21) = 24.59$, $M = 3.76$ (*SEM* = .63, *CI* [2.42, 5.05]) differing significantly from the "partial feedback loss" condition, as it showed a greater mean amplitude. In every condition, except "loss/alternative win", the mean amplitude differed significantly from the "win" – condition in which the most positive ERP could be found: "smaller loss/alternative larger loss" $F(1, 21) = 2.82$, "partial feedback loss" $F(1, 21) = 0.56$, in which the mean amplitude of the FRN also was significantly distinct from "loss/alternative win" $F(1, 21) = 42.28$, as the resulting ERP was significantly smaller (all results reported at $p < 0.05$).

No significant interaction effect (agency x feedback) could be reported for the timeframe 100-200msec after feedback at $p < 0.05$.

7.2.3 200 – 300msec after feedback presentation: the FRN

There exists a significant main effect for "agency" $F(1, 21) = 15.5$, $p < 0.05$ in that direction that the mean amplitude of the FRN is significantly more positive in the free – choice, $M = 11.35$ (*SEM* = 0.91, *CI* [9.46, 13.24]) than in the forced – choice condition, $M = 9.01$ (*SEM* = .78, *CI* [7.39, 10.63]). An agency – effect could be found. The assumption can be made, that this positive result derives from the onset of the P3a which can, as seen in the plot, be found in all the conditions and overlays the visible FRN.

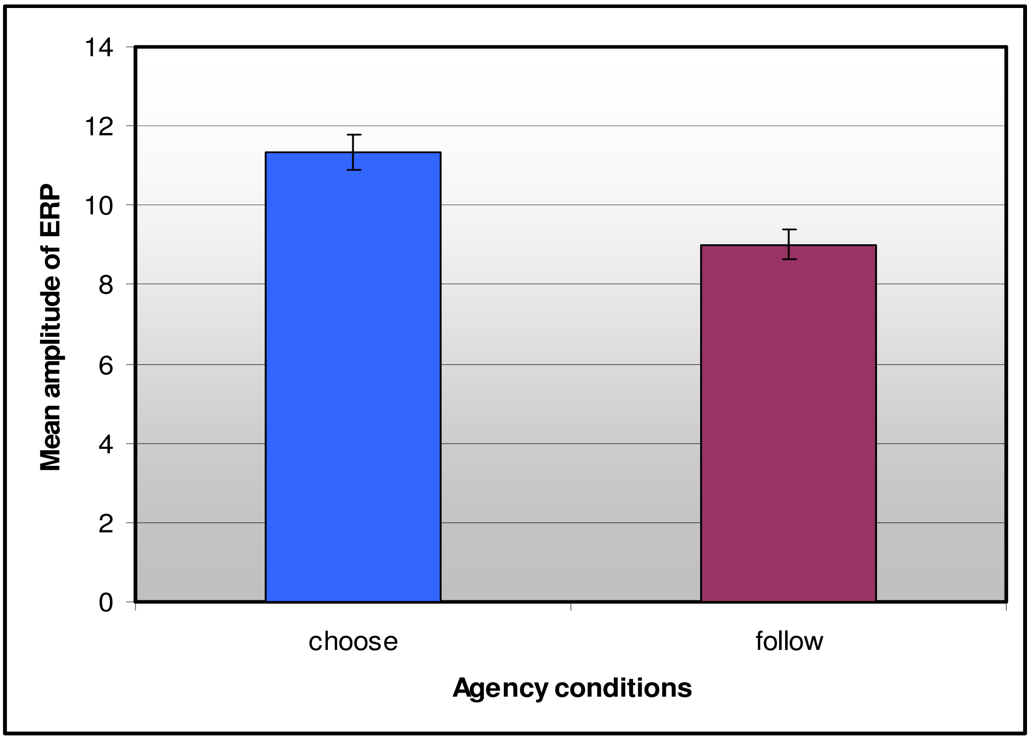

Figure 7.6: **Mean amplitude of ERPs in the timeframe 200 – 300msec (FCz) after feedback presentation for main effect of agency (Error bars displaying *standard error (SEM)*)**

There is also a significant main effect for "feedback" *F*(3, 63) = 15.39, $p < 0.05$. Contrasts showed that the lose-feedback types "loss/alternative win" *F*(1,21) = 15.31, "smaller loss/alternative larger loss" *F*(1, 21) = 25, and the "partial feedback loss" *F*(1,21) = 39.82 differed significantly from the win-feedback condition *M* = 12.05 (*SEM* = .88, *CI* [10.23, 13.88]), as its mean amplitude was significantly most positive. The mean amplitude of the FRN was significantly more positive "win" than in the lose conditions. Repeated contrasts further revealed no significant differences. (Significance level $p < 0.05$, *two - tailed*) The mean amplitudes for the "lose" conditions showed the values: "loss/alternative win" *M* = 10.01 (*SEM* = .84, *CI* [8.26, 11.76]), "smaller loss/alternative larger loss" *M* = 9.67 (*SEM* = .8, *CI* [8, 11.34]), "partial feedback loss" *M* = 8.99 (*SEM* = .86, *CI* [7.21, 10.77]). The FRN shows no significant differences between the "loss" – conditions. The mean amplitude of the onset of the P3a is significantly larger in the "win" – condition.

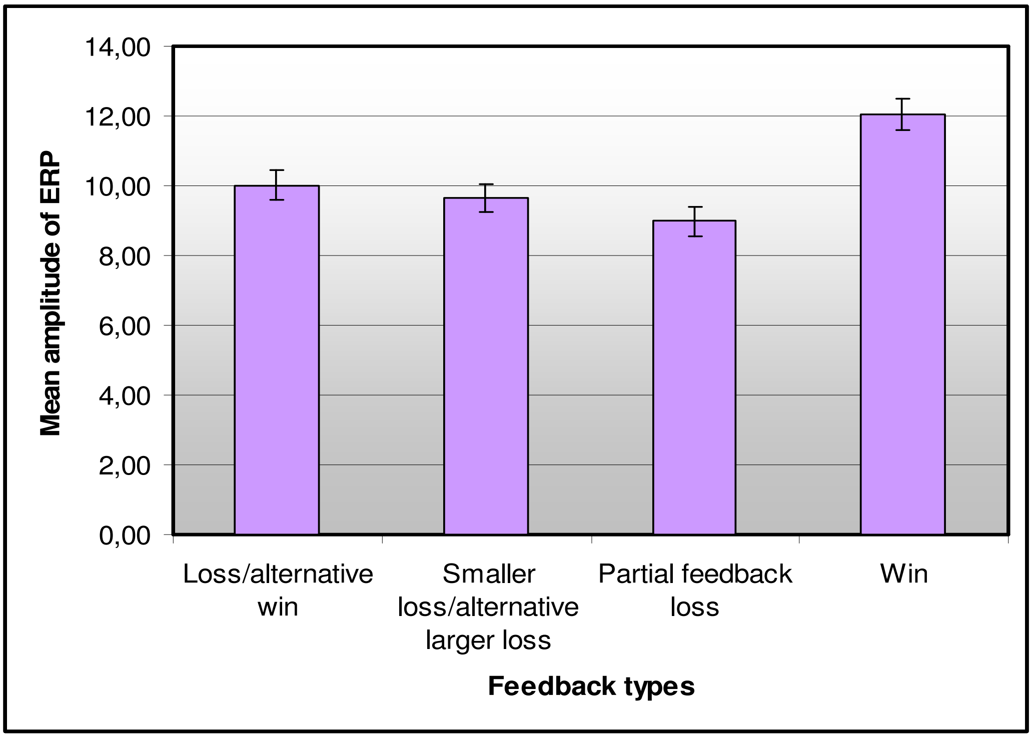

Figure 7.7: **Mean amplitude of ERPs in the timeframe 200 – 300msec (FCz) after feedback presentation for main effect of feedback (Error bars displaying *standard error (SEM)*)**

The interaction effect (agency x feedback) was significant $F(3, 63) = 7.07$ *(p = 0.05)*, indicating that whether participants were acting as agents or not had a different effect on the mean amplitude of the FRN depending on the feedback types. Conducted contrasts revealed the specific distinctions: Planned simple contrasts revealed that the feedback types indicating a loss when subjects were responsible for the decision free – choice “loss/alternative win” $F(1,21) = 8.76$, free – choice “smaller loss/alternative larger loss” $F(1,21) = 18.45$, free – choice “partial feedback loss” $F(1,21) = 12.6$, as compared to forced-choice trials (“follow”), significantly differed from the free choice win-feedback condition, as it showed the most positive amplitude. Repeated contrast revealed no further significant differences between the mean amplitude of the FRN regarding the trials in which subjects lost money neither did simple contrast using the free – choice “loss/alternative win” as reference category. The different lose – conditions do not differ significantly in their mean amplitude. The free choice win – condition elicits a small FRN as well, but due to the onset of a very large P3a this conditions differs significantly from the “loss” - conditions as it shows the most positive mean amplitude. An FRN becomes visible in all the free – choice conditions, as well as the onset of the P3a in this particular timeframe (see plot in Figure 7.4)

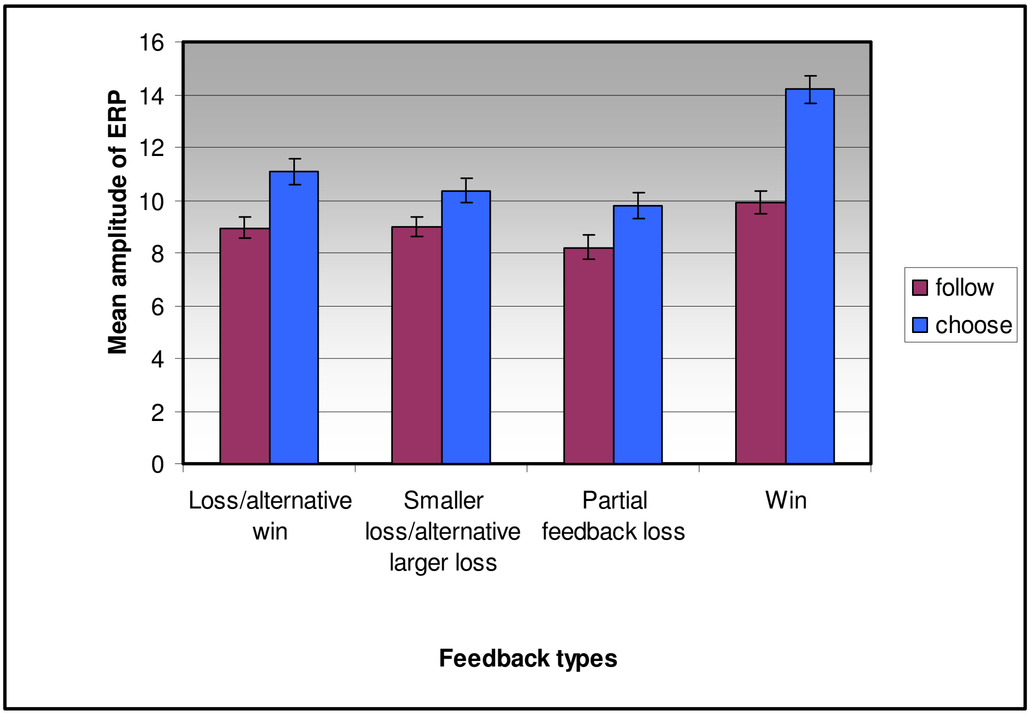

Figure 7.8: **Mean amplitude of ERPs in the timeframe 200 – 300msec (FCz) after feedback presentation for interaction effect (agency x feedback) (Error bars displaying *standard error (SEM)*)**

It becomes also evident by taking a look at the plotted ERP lines that this is the timeframe where the FRN becomes apparent.

7.3 Results for the mean amplitude of the P3a (FCz)

The P3a is reported at FCz as it shows a frontal activation in contrast to the P3b which is explored parietal at Pz.

7.3.1 300 – 400msec after feedback

The main effect of "agency" could be reported as significant with $F(1, 21) = 126.28$ at $p < 0.05$, in that direction that the mean amplitude of the P3a was significantly more positive in the free – choice "choose", $M = 18.68$ ($SEM = 1.52$, CI [15.51, 21,84]), condition where participants were responsible for their decision and hence their loss or win, in contrast to the forced – choice "follow" trials $M = 9.09$ ($SEM = 1.32$, CI [6.35, 11.38]). The mean amplitude of the P3a is significantly largest in the free – choice conditions. The P3a shows a significant agency effect.

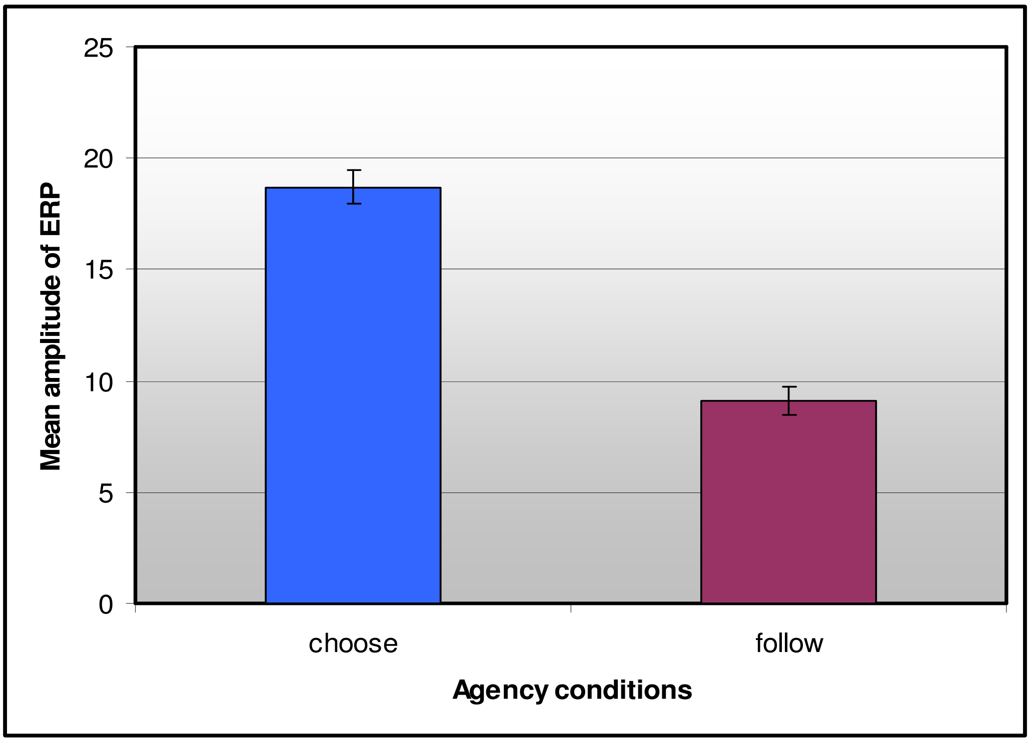

Figure 7.9: **Mean amplitude of ERPs in the timeframe 300 – 400msec (FCz) after feedback presentation for main effect of agency**

A significant main effect in the mean amplitude in "feedback" F(3, 63) = 17.25, $p < 0.05$ could also be found. Simple contrast, with "loss/alternative win" being the reference category showed that all feedback types "smaller loss/alternative larger loss" $F(1, 21) = 9.11$, "partial feedback loss" $F(1, 21) = 15.11$,"D" $F(1, 21) = 9.36$ all at $p < 0.05$ differed significantly from condition "loss/alternative win". Taking a closer look at the means discovered that the "win" condition holds the most positive mean amplitude followed by "loss/alternative win" ,"smaller loss/alternative larger loss", and finally "partial feedback loss". A conducted simple contrast using the "win" – condition as reference category revealed that all three lose - conditions differed significantly from it ("loss/alternative win" $F(1, 21) = 9.39$, "smaller loss/alternative larger loss" $F(1, 21) = 21.11$, "partial feedback loss" $F(1, 21) = 42.3$ with $p < 0.05$). Repeated contrast showed no further significant distinctions. The mean amplitudes for the feedback conditions were as follows: "loss/alternative win" *M* = 14.87 (*SEM* = 1.48, *CI* [11.8, 17.94]), "smaller loss/alternative larger loss" *M* = 12.33 (*SEM* = 1.27, *CI* [9.68, 14.98]), "partial feedback loss" *M* = 11.82 (*SEM* = 1.37, *CI* [8.97, 14.68]), "win" *M* = 16.51 (*SEM* = 1.59, *CI* [13.21, 19.82]) The interesting notion about this result is that all mean amplitudes of the P3a differ also significantly from "loss/alternative win". The mean amplitude of the P3a is significantly largest in the "win" – conditions, as hypothesized.

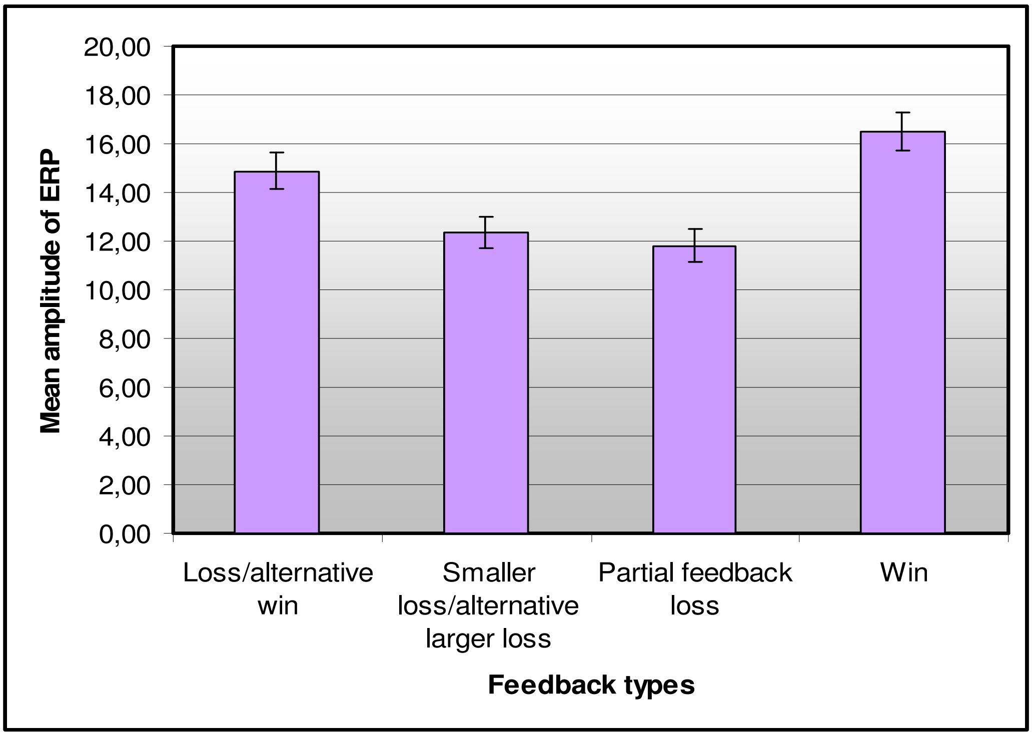

Figure 7.10: **Mean amplitude of ERPs in the timeframe 300 – 400msec (FCz) after feedback presentation for main effect of feedback**

The interaction effect agency x feedback can be reported as significant $F(3, 63) = 7.71$, $p < 0.05$. Contrasts were conducted to get insight in the nature of the interaction. A simple contrast with the free – choice condition "loss/alternative win" as the reference category revealed significant interaction effects relative to the forced choice conditions, when compared to free – choice "smaller loss/alternative larger loss" $F(1, 21) = 8.36$, free – choice "partial feedback loss" $F(1, 21) = 4.42$, but not significant in comparison to the free choice "win" condition. Calculating a simple contrast with the free – choice "win" condition as the reference category showed a significant difference, relative to the forced choice trials "follow", in the mean amplitude of the P3a in free – choice "smaller loss/alternative larger loss" $F(1, 21) = 14.71$, and free – choice "partial feedback loss" " $F(1, 21) = 11.29$, and according to the previously reported contrast, no significant interaction with "loss/alternative win" in the free – choice condition. Interestingly the mean amplitude of the P3a did not differ significantly comparing the free choice conditions "loss/alternative win" and "win".

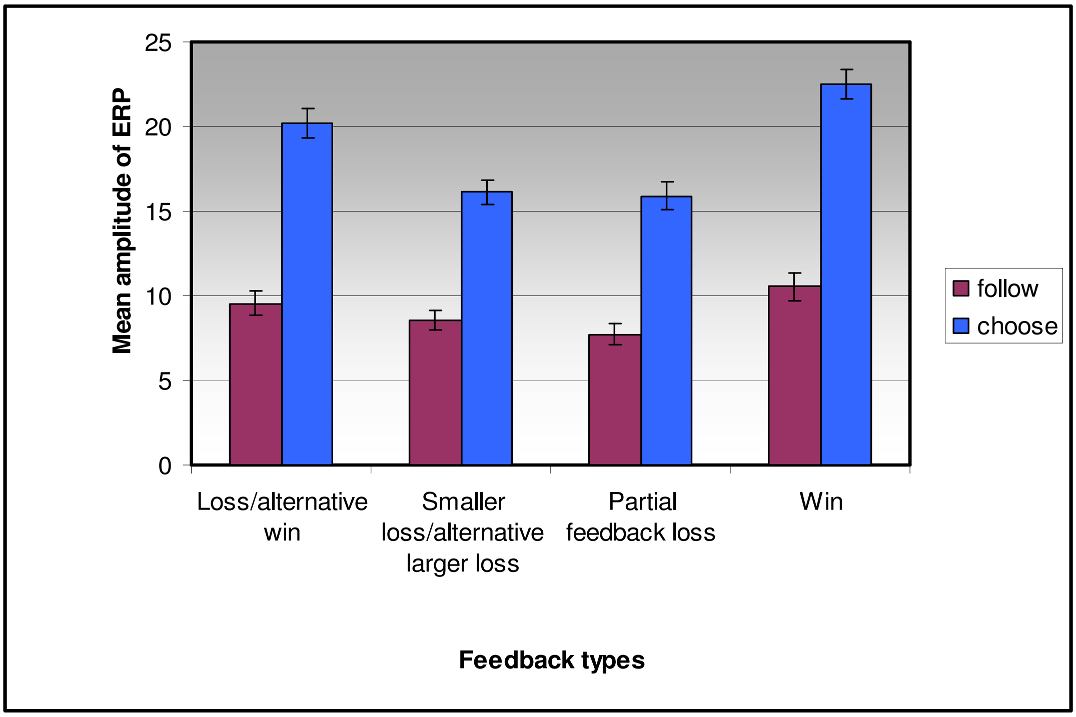

Figure 7.11: **Mean amplitude of ERPs in the timeframe 300 – 400msec (FCz) after feedback presentation for interaction effect (agency x feedback)**

7.3.2 400 – 500msec after feedback

The main effect of "agency", referring to the degree of experienced responsibility for the choice, showed a significant result with $F(1, 21) = 78.32$ with $p < 0.05$. That means that the mean amplitude of the P3a was significantly more positive in the free – choice "choose" condition $M = 16.19$ ($SEM = 1.21$, CI [13.68, 18.79]), compared to forced – choice "follow" $M = 9.17$ ($SEM = 1.18$, CI [6.72, 11.62]). The P3a shows a significant agency effect.

The main effect of feedback was also significant with $F(2.12, 44.53) = 13.08$ at $p < 0.05$. Simple contrast comparing the mean amplitude of the "win" – condition with $M = 14.53$ ($SEM = 1.23$, CI [11.98, 17.08]) to the "lose"- conditions showed that "smaller loss/alternative larger loss" $F(1, 21) = 40.5$ ($M = 11.97$ ($SEM = 1.16$ CI [9.56, 14.37])) and "partial feedback loss" $F(1, 21) = 40$ ($M = 10.8$ ($SEM = 1$, CI [8.717, 12.88])) differed significantly, as the "smaller loss/alternative larger loss" condition showed a more positive result. The conditions "smaller loss/alternative larger loss" $F(1, 21) = 6.21$ and "partial feedback loss" $F(1, 21) = 9.58$ were significantly distinct from "loss/alternative win" when comparing their mean amplitudes of the P3a, as "loss/alternative win" held a significantly more positive P3a ($M = 13.43$ ($SEM = 1,36$, CI [10.611, 16.256]). ($p < 0.05$, *two-tailed*).

The interaction effect turned out not-significant.

7.4 Results for the mean amplitude of the P3b (Pz)

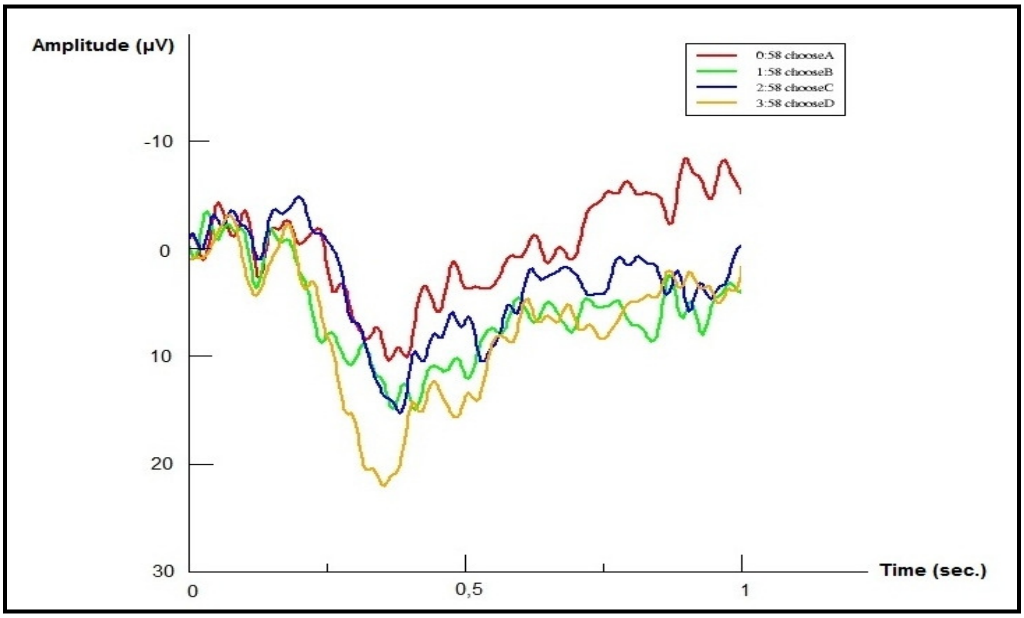

Figure 7.12: **Plotted ERP lines recorded at Pz for the different feedback types in the free – choice condition. *Note: "A" refers to "loss/alternative win", "B" to "smaller loss/alternative larger loss", "C" to "partial feedback loss", "D" to the "win" condition***

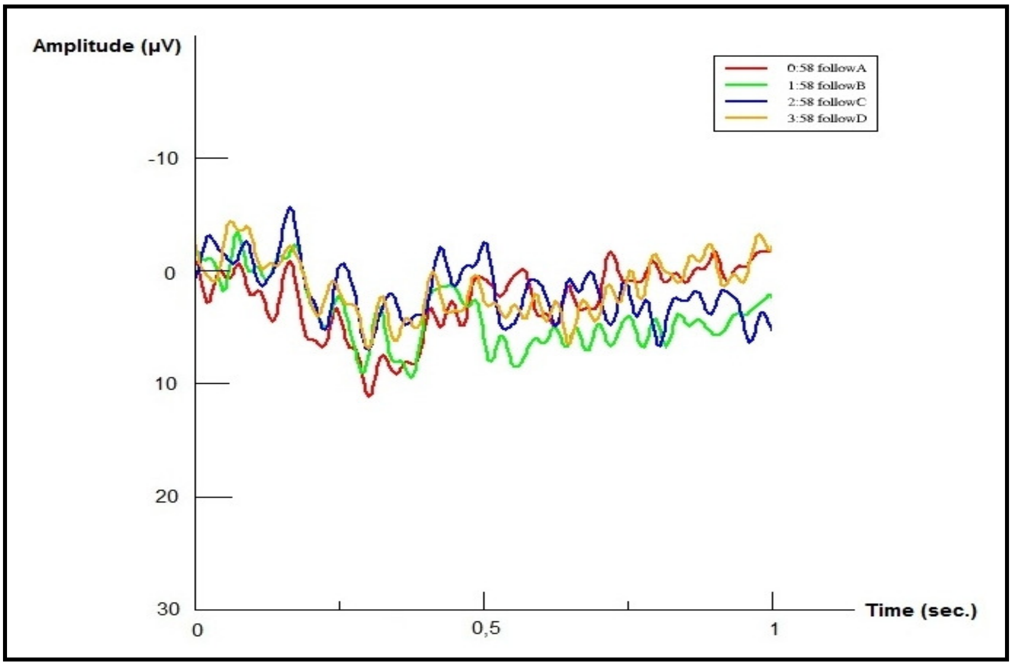

Figure 7.13: **Plotted ERP lines recorded at Pz for the different feedback types in the free – choice condition *Note: "A" refers to "loss/alternative win", "B" to "smaller loss/alternative larger loss", "C" to "partial feedback loss", "D" to the "win" condition***

7.4.1 0 – 100msec after feedback

The main effect of “agency” was non significant, as well as the main effect for feedback, and the interaction effect. ($p < 0.05$)

7.4.2 100 – 200msec after feedback

The main effect of “agency” showed no significant result ($p < 0.05$).

The main effect of feedback turned out significant $F(3, 63)= 2.98$ at $p < 0.05$. A simple contrast was conducted using the mean amplitude of the “win” – condition *M* = 1.12 (*SEM* = .63, *CI* [- .19, 2.43]) as the reference category, showing that both loss – conditions “smaller loss/alternative larger loss” = - .02 (*SEM* = .54, *CI* [-1.13, 1.1]) and “partial feedback loss” *M* = .16 (*SEM* = .44, *CI* [- .75, 1.07]) *M* differed significantly from it, but not the “loss/alternative win” condition *M* = .67 (*SEM* = .56, *CI* [- .5, 1.84]).

The interaction effect turned out not significant at $p < 0.05$.

7.4.3 200 – 300msec after feedback

The main effect of “agency” $F(1, 21)= 7.38$ at $p < 0.05$ showed a significant result in this timeframe of 200 – 300 msec after the presentation of the feedback. The mean amplitude of the P3b in the forced choice condition “follow” *M* = 6.9 (*SEM* = .67, *CI* [5.5, 8.31]) was significantly smaller than the mean in the free – choice condition *M* = 8.51 (*SEM* = .94 *CI* [6.58, 10.47]).

The main effect of feedback $F(3, 63) = 30.1$ at $p < 0.05$ was also significant. Repeated contrast revealed a significant difference in the mean amplitude of the P3b between “smaller loss/alternative larger loss” $F(1, 21)= 4.81$, *M* = 7.9 (*SEM* = .8, *CI* [6.23, 9.56]) and “partial feedback loss” $F(1, 21)= 9.9$ with *M* = 6.78 (*SEM* = .76, *CI* [5.2, 8.35]) and the win – condition with *M* = 8.75 (*SEM* = .84, *CI* [7, 10.5]). Simple contrast with the “win” - condition as the reference category also showed a significant difference between the mean amplitudes of the “win” – condition and “loss/alternative win” $F(1, 21)= 5$, with *M* = 7.43 (*SEM* = .93, *CI* [5.5, 9.36]). (All results at $p < 0.05$). The P3b showed the significantly greatest mean amplitude in the “win” – condition, as hypothesized.

The interaction effect remained insignificant at $p < 0.05$.

7.4.4 300 – 400msec after feedback

The main effect of “agency” turned out significant, $F(1, 21) = 79.03$ at $p < 0.05$. The mean amplitude of the FRN was greater in the free – choice “choose” condition *M* = 18.67 (*SEM* =

1.62, *CI* [15.3, 22.04]) than in the “follow´” condition *M* = 10.48 (*SEM* = 1.24, *CI* [7.91, 13.06]). The P3b showed a significant agency – effect.

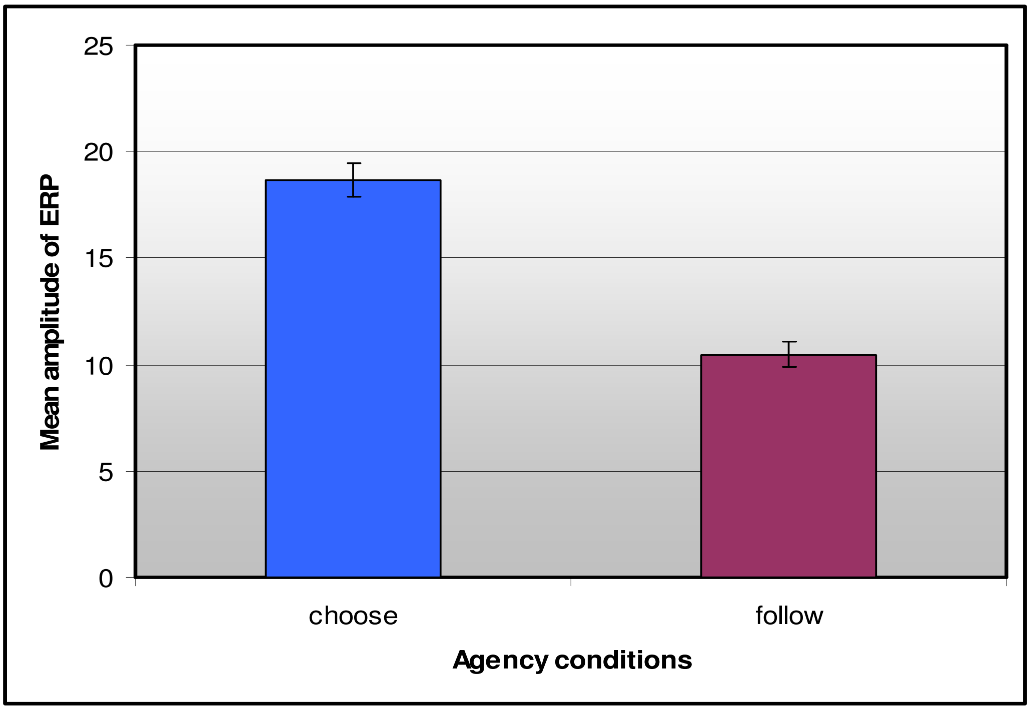

Figure 7.14: **Mean amplitude of ERPs in the timeframe 300 – 400msec (Pz) after feedback presentation for main effect of agency**

The main effect of “feedback” also became significant, $F(2.11, 44.38) = 14.74$ at $p < 0.05$. Simple contrast using the “win” – condition as reference category revealed that the mean amplitude of the P3b was significantly distinct in all the lose-conditions compared to the “win” - condition with *M* = 17.12 (*SEM* = 1.63, *CI* [13.73, 20.49]): “loss/alternative win” $F(1, 21)$= 11.8 with *M* = 15.33 (*SEM* = 1.52, *CI* [12.16, 18.49]) , “smaller loss/alternative larger loss” $F(1, 21)$= 27.02 with the mean amplitude of *M* = 13.21 (*SEM* = 1.3, *CI* [10.5, 15.92]), “partial feedback loss”, $F(1, 21)$= 23.2 with *M* = 12.66 (*SEM* = 1.29, *CI* [9.98, 15.34]). Additionally a simple contrast using the lose – condition “loss/alternative win” was furthermore carried out which showed that the mean P3b differed also significantly in all the other conditions relative to “loss/alternative win”: “smaller loss/alternative larger loss” $F(1, 21)$= 8.42, and “partial feedback loss” $F(1, 21)$= 9.9. (Significance level $p < 0.05$). The mean amplitude of the P3b is significantly different comparing all the feedback types to the “loss/alternative win” condition, and also when compared to the “win” – condition.

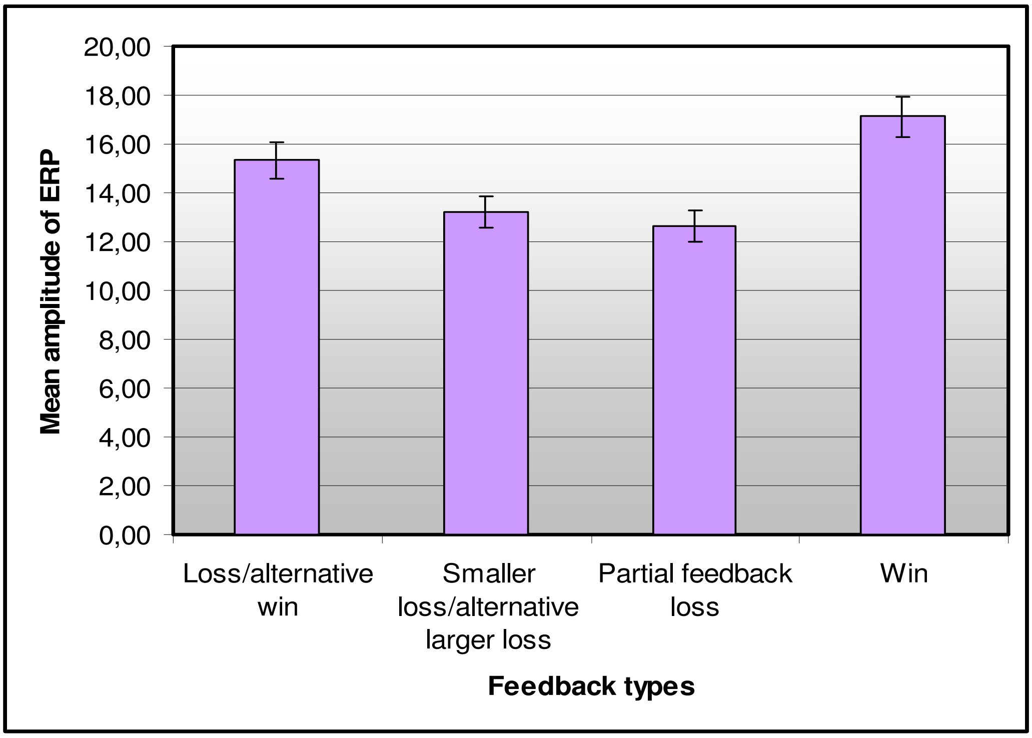

Figure 7.15: **Mean amplitude of ERPs in the timeframe 300 – 400msec (PZ) after feedback presentation for main effect of feedback**

The results for “agency” x “feedback”, $F(3, 63)= 6.02$ at $p < 0.05$ revealed a significant interaction effect. Conducted simple contrast by using the free – choice “win” as the reference category revealed that relative to the forced – choice “follow” condition with the forced choice option, the mean amplitude of the P3b in the free – choice “smaller loss/alternative larger loss”, $F(1, 21)= 13.7$ and the free – choice “partial feedback loss”, $F(1, 21)= 9.74$, conditions differed significantly from the free – choice “win”-condition, as they showed a significantly smaller P3b mean amplitude. The mean amplitude of the P3b in the free – choice “loss/alternative win” condition however did not differ significantly from the free choice “win” – condition. A conducted simple contrast with the free – choice condition “loss/alternative win” being the reference category, relative to the forced – choice conditions, showed significant differences in the mean P3b compared to free – choice “smaller loss/alternative larger loss” condition $F(1, 21)= 4.69$. (All result are reported at $p < 0.05$) The mean amplitude of the P3b does not differ significantly from the free choice “loss/alternative win” condition compared to the free choice “win” condition.

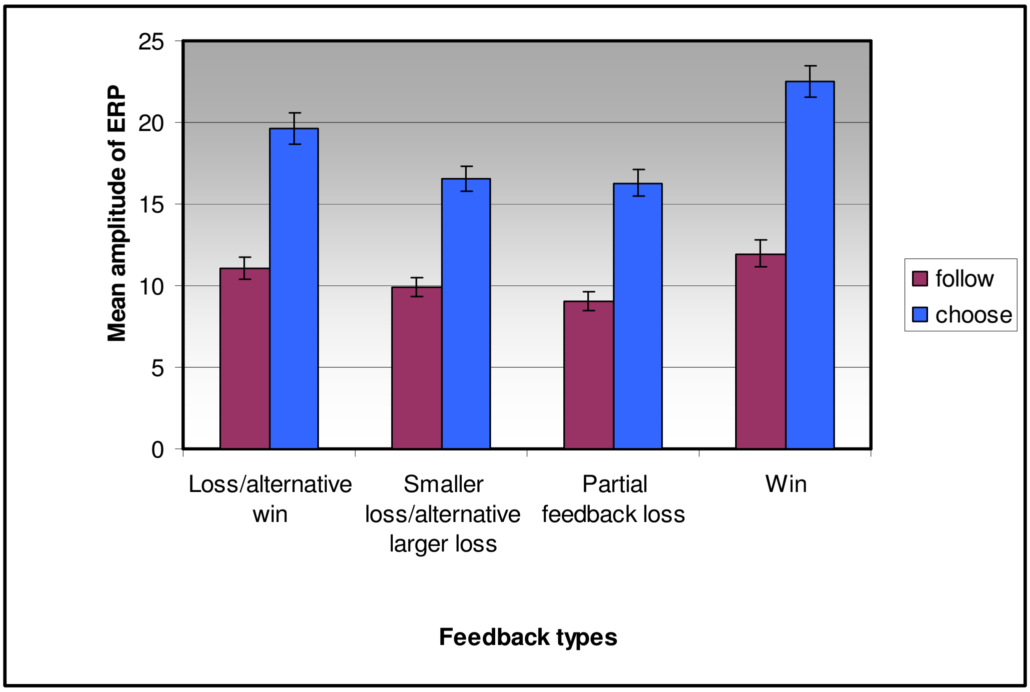

Figure 7.16: **Mean amplitude of ERPs in the timeframe 300 – 400msec (Pz) after feedback presentation for interaction effect (agency x feedback)**

7.4.5 400 – 500msec after feedback

The main effect of "agency", $F(1, 21) = 102.88$ could be reported as significant *($p < 0.05$, two-tailed).*

The main effect of "feedback" $F(3, 63) = 13.4$, $p < 0.05$ also showed significant results, indicating that the mean amplitude of the event-related positivity differed significantly due to the feedback conditions with the mean amplitudes being: for "loss/alternative win" $M = 16.54$ ($SEM = 1.70$, CI [12.99, 20.08]) , for "smaller loss/alternative larger loss" $M = 15.27$ ($SEM = 1.51$, CI [12.12, 18.41]), "partial feedback loss" $M = 13.34$ ($SEM = 1.29$, CI [10.67, 16.01]), "win" $M = 17.79$ ($SEM = 1.62$, CI [14.43, 21.51]). Simple contrasts with the win – condition as reference category revealed significant mean differences between "smaller loss/alternative larger loss" $F(1, 21) = 28.91$ and "partial feedback loss" $F(1, 21) = 29.69$ compared to the "win" condition. Furthermore a simple contrast with the reference category of "loss/alternative win" showed significant mean amplitude differences in "partial feedback loss" $F(1, 21) = 13.1$ and "smaller loss/alternative larger loss" $F(1, 21) = 3.98$ compared to "loss/alternative win", and repeated contrast also indicated a significant difference in the means between "loss/alternative larger loss" and "partial feedback loss" $F(1, 21) = 5.15$ (*$p < 0.05$, two-tailed*). There could be no significant difference found between the mean amplitudes of the P3b in the "win" – condition compared to the "loss/alternative win" condition.

The interaction effect could be reported as not significant at *$p < 0.05$ (two-tailed).*

7.5 Results from source localization (sLORETA/eLORETA)

Source localization using sLORETA/eLORETA yielded to localize specifically the FRN. For that reason data was extracted from a 100msec timeframe 200 – 300msec after feedback presentation, as described above. The statistical analyses using SPSS revealed significant main effects, as well as a significant interaction effect in this timeframe at FCz, where the FRN was recorded. T – tests were carried out to compare each feedback condition in free choice to the corresponding forced choice condition.

Results indicated a non significant difference in the activation comparing the free – choice "loss/alternative win" to the forced – choice "loss/alternative win" condition. The maximal activation difference was found to be insignificant (all results reported *two – tailed, $p < 0.05$*). Nevertheless, very interestingly, the result revealed maximal (insignificant) difference in the activation at the Brodmann – Area (BA) 9, the medial frontal gyrus, as well as the comparison between the free – choice "smaller loss/alternative lager loss" and its corresponding forced – choice condition which also yielded the maximum activation difference in the BA 9, the superior frontal gyrus and the medial frontal gyrus. The grand mean activation of the free – choice loss – conditions for "loss/alternative win" was found at the BA 37, the inferior medial temporal lobe. The free – choice "smaller loss/alternative larger loss", as well as the "partial feedback loss" condition showed a grand average activation in the BA 39, the superior medial temporal gyrus which is located at the lateral conjunction of the temporal, occipital and the parietal lobes. Furthermore the free – choice condition "partial feedback loss" compared to its corresponding forced – choice coniditon revealed no significant results, but showed the maximum activation in the BA 19, in the occipital lobe, the lingual gyrus. A t – statistic comparing with free – choice "win" and forced – choice "win" condition revealed a significant greater result at $t = 4.354$ (*$p < 0.05$, two – tailed)*. The maximum activation difference was found in the BA 7, in the parietal lobe with the superior parietal lobule, the precuneus, and the postcentral gyrus. Further activation was found in the BA 20, the temporal lobe. Even more the free choice "win" condition shows an activation for the grand – mean parietal at the BA 40, the supramarginal gyrus.

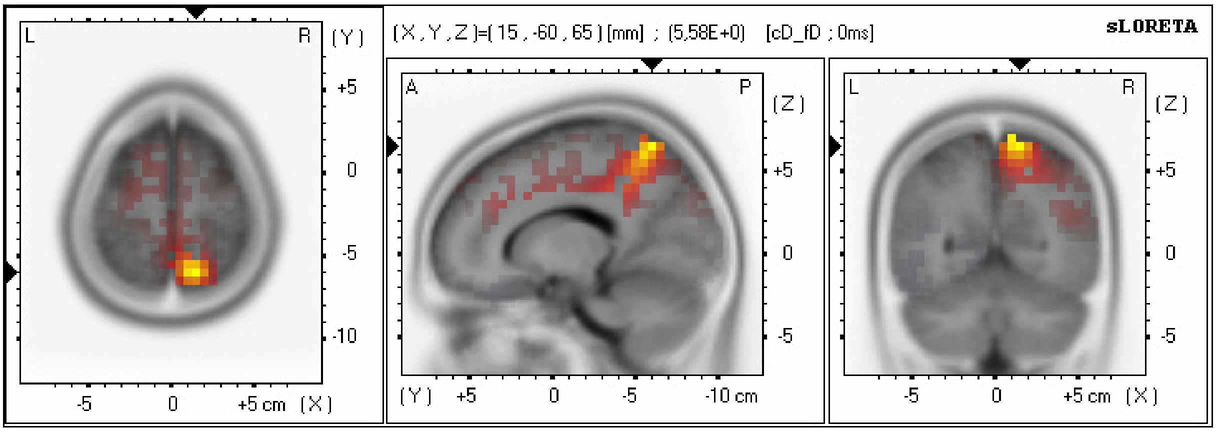

Figure 7.17: **Source localization with sLORETA: a conducted T – test between the free – choice "win" condition and the corresponding forced – choice condition revealed a significant right parietal activation (BA 7)**

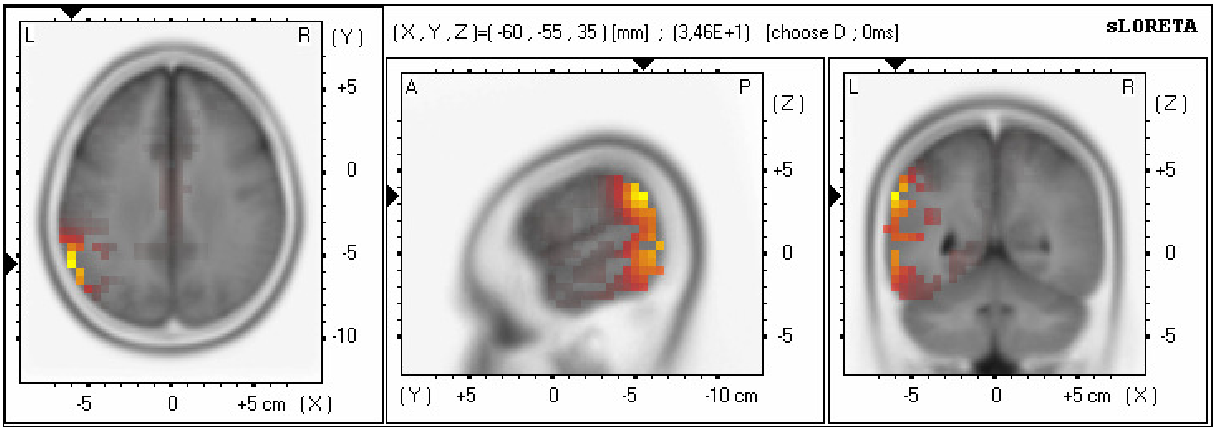

Figure 7.18: **Source localization of the Grand Mean of the free – choice "win"condition showed significant maximum activation in the left supramarginal gyrus (BA 40)**

Table 7.1: **Maximum activation difference using sLORETA for feedback types comparing free – to corresponding forced – choice conditions. Significant results indicated through * with *t* = 4.354 (all results at *p < 0.05, two – tailed)***

Feedback types	Source localization	MNI coordinates (X, Y, Z)
Loss/alternative win	Right medial frontal lobe (BA 9)	5, 45, 35
Smaller loss/alternative larger loss	Right superior frontal gyrus (BA 9) Right medial frontal lobe (BA 9)	5, 50, 35 5, 45,35
Partial feedback loss	Left lingual gyrus (BA 19), Occipital lobe	-15, -65, 0
Win*	Right superior parietal lobule* (BA 7)	15, -60, 65*

Table 7.2: **Maximum grand – mean activation using sLORETA for feedback types in the free – choice condition.**

Feedback types	Source localization	MNI coordinates (X, Y, Z)
Loss/alternative win	Left middle temporal gyrus (BA 37) Middle temporal gyrus (BA 39)	-60, -65, 5 -55, -75, 10
Smaller loss/alternative larger loss	Left middle temporal gyrus (BA 39) Middle temporal gyrus (BA 37)	-55, -75, 10 -60, -65, 5
Partial feedback loss	Left middle temporal gyrus (BA 39)	-55, -75, 10
Win	Supramarginal gyrus (BA 40), Parietal lobe	-60, -55, 35

8 DISCUSSION

The previously described results will be interpreted and discussed in synopsis with the theoretical basic principles regarding regret, the behavioural results, the FRN and the P3 (P3 will refer to the P3a and the P3b as well). Based on the discussion perspectives for further research will be provided in chapter 10.

8.1 Behavioural results

The behavioural results collected before the experiment was carried out, revealed no significant differences between the agency conditions in the subjects´ ratings.

In the free – choice condition the “loss/alternative win” condition was rated significantly lower than “smaller loss/alternative larger loss” and the “win” condition, but not distinct from the “partial feedback loss” or the “larger loss/alternative smaller loss” condition. This admits the conclusion that these three feedback types elicited the same feeling in the individual. Upward counterfactuals could be used when comparing the alternatives to each other in the “loss/alternative win” condition “If I had chosen differently I would have won!” and a similar counterfactual could be used for the “partial feedback loss” condition in the sense of “If I had chosen differently, maybe I would have won!” The rating showed that, compared to “loss/alternative win”, as well as to “larger loss/alternative smaller loss” there was no significant distinction in the ratings to be found. The conclusion can be drawn that contradictory to Coricelli et al. (2005) the free – choice “partial feedback loss” condition did not elicit disappointment but regret as in “loss/alternative win” and “larger loss/alternative smaller loss”. Ritov and Baron (1995) showed that anticipated regret is greater the more knowledge about the possible outcome is available. According to this rating experienced regret is also felt enhanced when the alternative remains unknown, since it could have possibly been a win, and elicited the same amount of regret as knowing the alternative to be a win or a smaller loss. It is rather unfortunate that the feedback condition “larger loss/alternative smaller loss” had to be removed from further analyses due to the low frequency of its occurrence during the experiment, which created no useable ERP data.

The free – choice feedback condition “smaller loss/alternative larger loss”, with both alternatives bearing a loss was rated significantly different from all the other free – choice categories. This result suggest, that despite the loss, the participants felt relieved, in contrast to the other loss – conditions, to book, at least, the smaller loss: “If I had chosen differently, I would have lost even more!” In contrast to the inverted version, the free – choice “larger loss/alternative smaller loss” condition which elicited regret.

Regarding the ratings in the “win” free – choice condition it could be reported that the win – condition was, as presumed, rated significantly better than the loss – conditions. It can be presumed that individuals used downward counterfactuals, when encountering a win: “I won! If I had chosen differently I would have lost.” As mentioned earlier in chapter 2.2 downward counterfactuals aim to preserve behaviour that was successful, and can enhance a feeling of relief (Epstude & Roese, 2008), and even the free – choice “smaller loss/alternative larger loss” seems to elicit at least some kind of relief.

The most interesting notion though about the behavioural results is that no significant effect could be shown regarding the agency. Significant differences between the loss – conditions could be reported in the forced – choice condition as well. As will be discussed later this is very interesting in the synopsis with the diverging results regarding agency provided by the EEG. Conducting a rating at the end of the experiment could have shed more light on the agency factor, since by then the individuals would have been really aware of their feelings towards being responsible for the losses, or not.

8.2 The agency – effect in the ratings and the FRN

The ERPs show a different picture: being responsible for the decision does make a difference. These results can be taken as an indicator that the core element of regret “agency” really does show distinct patterns in the neural activation of the brain and that this element is very important to change behaviour according to the goals as in the forced choice condition nothing can be done to maximise the gain. According to the diverging results from the ratings reactance theory (J.W. Brehm, 1966; Herkner, 2001) comes to mind which holds that every restriction of free choice or action gives rise to reactance which will subsequently lead to the upgrading of the stimulus that is not available, or as in the present study, cannot be chosen freely. As showed by Brehm et al. (1966), typical effects of reactance only show when freedom of choice is expected from the beginning. Since the subjects were aware that they were supposed to participate in a gambling task, their initial assumption about the experiment had been to gamble which is dependent on one’s own choice, luck, or abilities, and not constraint. This could be an explanation why the conscious ratings were as high for the free - choice as for the forced – choice conditions because the subjects upgraded the decision that they could not opt for themselves. After the rating, when the experiment started participants already knew that part of the experiment would be forced choice conditions. Hence they did not expect free choice on all the trials any more, thus no further reactance would have presumably be elicited.

The FRN data recorded during the gamble serves an indicator for the involvement and engagement of the participants in the free choice condition, which underlines the role of responsibility for a decision when experiencing regret. It showed a larger FRN for the free choice condition, in which subjects acted as agents, than in the forced choice condition. When looking at the plot (Figure 7.4 and Figure 7.5) it becomes obvious that in the forced choice condition no FRN is detectable, but a large FRN can be seen in the free choice condition. This is indeed an important finding, because this directly links the appearance of the FRN to the feeling of regret, with agency, being its core element. It shows that, as laid out previously, for the brain the fact of being responsible for the decision makes the important difference of caring for the outcome, of using this experience to further optimize behaviour on the task. Unconsciously the neural networks in the brain identify an action that was taken under free choice according to the abilities, knowledge and skills of the individual and nonetheless led to an unfortunate outcome, and send out a distinct signal in contrast to a decision that was forced upon the individual. The agency effect can nonetheless be observed for the P3 (P3a and P3b) as well (see Figure 7.4 and Figure 7.5 for P3a and Figure 7.12 and Figure 7.13 for P3b). This can also be explained in terms of attribution theory (Herkner, 2001; Weiner, 1985). The forced – choice condition can be attributed by the participants as externally caused, uncontrollable, and variable, which leads individuals to attribute losses, as well as wins, to luck and coincidence. These two variables do not lead to a change in behaviour, because absolutely nothing can be done to predict wins, to raise the gain, or prevent losses. It has often been argued that the P3 codes high salience of a stimulus also in the sense of a low probability of its occurrence and unpredictability (Donchin & Coles, 1988a; Johnson & Donchin, 1980). But it is very interesting to note that, with regard to the present results, this does only apply to situations when the individual is acting as the agent and does not feel constraint. The free choice condition can be attributed as being caused internally, controllable, and stable, which makes the individuals responsible for the outcome, due to their abilities and skills. Summerville and Roese (2008) also propose in their opportunity principle for the action stage that regret and cognitive dissonance (Festinger, 1957) will only be felt as long as free choice is possible during the act of deciding.

8.3 The unexpected FRN – effect and the P3

In this free – choice condition interesting results regarding the FRN and the P3 could be found. Statistical results showed, as mentioned above, that the main amplitude of the FRN in the free - choice "win" situation, measured in the timeframe 200 – 300msec, is significantly different to the loss conditions, as the mean amplitude is significantly more positive, greater. This result comes, as can be seen in the plot, from the very large P3a in "win". This P3a peaks 350msec after feedback presentation and reaches an amplitude maximum of almost 30µV. This very large positive potential creates this very positive result of the free – choice "win" condition, as very interestingly, because unexpected, an FRN can also be detected.

This FRN in a win condition can be explained due to the low probability and frequency of the occurrence of the “win” condition (Bellebaum & Daum, 2008; Cohen, Elger, & Ranganath, 2007; Hajcak, et al., 2007). Oliveira (2007) also showed that the FRN is also elicited by positive feedback when the basic expectancy of the individual is negative feedback. In this context the framing effect as a psychological framework for an explanation also comes to mind. The framing effect is part of decision – heuristics. These heuristics are simple rules which are applied to a problem whenever few information is available about a problem and so make decision easier by orientation to specific characteristics of the situation leading to the construction of a specific frame (Eysenck & Keane, 2003; Herkner, 2001). This effect was first reported by Tversky and Kahneman (Tversky & Kahneman, 1987) and could imply that since, as can be pursued in Figure 6.2, the frequency of the loss – conditions was a lot higher than the appearance of a gain a “loss – frame” (De Martino, Kumaran, Seymour, & Dolan, 2006) was established. The individual with the established loss - frame encountered an unexpected win. The unexpectedness of this win is reflected in the small, but visible FRN. This is in line with findings reported by Wu and Zhou (2009), who propose “that the FRN may reflect the detection of a conflict between expectancy an the actual outcome, irrespective of on what attribute the expectancy is built” (Wu & Zhou, 2009), the only important point is the deviation from the pre-established expectancy. Yeung at al. (2005) also highlight that the motivational significance of an outcome is also correlated with the amplitude of the FRN. Unquestionable it is the free – choice “win” – condition which has the highest motivational significance.

The P3 is also reported to be particularly sensitive to the frequency and probability of the occurring of stimuli (Donchin & Coles, 1988a). Furthermore the framing effect also provides a psychological framework of the low probability of the occurrence of a win as an explanation for the very large P3. The individual has this loss - frame built and the win with its low probability features a very high salience and valence. As also the proposed categorization theory by Kok (2001) holds in which it is suggested that its amplitude reflects low probability and high salience of outcomes, as well as task relevance.

Another psychological framework as explanation for the generation of the large peaking P3 could be the “reference dependence”, as stated by Tversky and Kahneman (1991), representing a reference point to which all the values of gains and losses are relatively defined to. Since the reference point in the conducted regret – gambling – task is obviously “loosing”, the P300 could yield such a high amplitude peak in the win condition, as the gain is completely divergent from the point of reference, and, as mentioned above, therefore of high salience.

To sum it up, first of all the low probability and the low frequency of the occurring win, and the framing – effect (Tversky & Kahneman, 1987), as well as the event – categorization theory (Kok, 2001), and reference dependence (Tversky & Kahneman, 1991) as psychological theoretical framework, all hold that the P3 reflects a deviation from an established expectation which marks high salience with a high amplitude.

8.4 The P3

Statistical analyses revealed a significant main effect for agency for the P3a and the P3b, as their amplitude was significantly greater in the free – choice condition. This highlights that not only the FRN, but also the P3 is sensitive to the experienced responsibility for a decision. As seen for the FRN in the forced choice condition, not being personally responsible also abolished the P3. Furthermore the P3a, as mentioned by Kirino et al. (2000), is sensitive to memory process, even if it is just an arbitrary one. This suggest that in the free – choice condition, since the individual felt responsible for the choice made and consecutively for the outcome the participants wanted to keep track of their gains and losses, which brought about this memory process. Whereas the forced – choice condition, supposedly, did not enhance a memory process, since the participants just followed the instructions and did not care so much about keeping track of the money lost and gained, since they could not alter the result in any direction. This is also in line with the notion that the P3a is specifically sensitive to stimuli which require high attention, as do the feedback types in the free – choice condition. This explanation can be passed on to the general appearance of the P3a and the updating of working memory and the transferring of information to the memory storage, resembled in the P3b for all the free – choice conditions peaking in the timeframe of 300 – 400msec after feedback presentation. Source localization revealed maximum activation for the loss conditions "loss/alternative win" and "smaller loss/alternative larger loss" in the middle frontal gyrus (MFG), although not significant, which corresponds with other findings regarding the P3a source localization, and which overlays the activation of the FRN (Kirino, et al., 2000; Nieuwenhuis, et al., 2005; Wu & Zhou, 2009; Yeung & Sanfey, 2004). Interestingly source localization yielded a maximum difference in the activation comparing the free – and forced choice "partial feedback loss" condition in the occipital lobe which can be linked to the findings of Soltani and Knight (2000) who found an activation for the P3a in the occipital lobe specifically for visual tasks. This is interesting since in the "partial feedback loss" condition the alternative remained hidden, which suggests an enhanced visual exploration of the "partial feedback loss" condition, which did not take place in the other conditions. The maximum grand – mean activation in the "loss/alternative win", the "partial feedback loss", as well as in the "smaller loss/alternative larger loss" conditions in the middle temporal gyrus (BA 37 and 39) furthermore fortify that the large P3 overlaid the FRN activation, as this results are in line with previous reported results of middle temporal gyrus being important to the generation of the P3 (Halgren, et al., 1995; Linden, 2005; Nieuwenhuis, et al., 2005; Soltani & Knight, 2000).

A further very interesting result is that as well in the mean amplitude of the P3a as in the P3b no significant difference could be found regarding the "win" – condition and the "loss/alternative win" condition. These results indicate furthermore the proposed sensitivity of the P3 to high salience as "loss/alternative win" was the condition with the highest salient alternative – the win, and the "win" condition of course resembled the highly salient win - outcome. Furthermore the "win" condition, of course showed the lowest frequency, another prominent characteristic of the occurrence of the P3.

The free – choice "win" – condition yielded the largest amplitude peak in the P3a at FCz. The outstanding characteristics of this condition were first of all, of course, the high salience and the high valence of the win, secondly the low probability of its occurrence, respectively the long interval between its occurrence, and, to allude a third point, this can of course also be referred to as the task -, or goal – relevant condition, as the aim of the participant was to win and maximise the gain. The downward counterfactual is: "If I would have chosen differently, I would have lost!" Furthermore the context updating theory is coherent with this finding, as the encountered win, seems new, due to its low probability, and all the attention is driven towards it, to update the loss – context. Since encountering a win stays very low on probability, the novelty of this stimulus doesn't diminish over the course of the experience. Even more, since the free choice conditions and the forced choice conditions alternate, and the P3 is only sensitive to the free – choice condition; these two arguments serve as an explanation why no habituation (Friedman, et al., 2001) set in.

All these factors also account for the very large amplitude recorded at FCz, with source localization yielding a significant maximum activation parietally, in the superior parietal lobule, the precuneus, the postcentral gyrus, and moreover in the temporal lobe, comparing the mean amplitudes of the free – choice "win" condition to forced – choice "win" in the timeframe of 200 – 300msec. The source localization of the win - condition revealed activation of the supramarginal gyrus. As laid out in chapter 4.2 the temporal – parietal junction (TPJ) which describes the area of the supramarginal gyrus and the superior temporal lobe is, along with the medial temporal cortex (for which activation could be found in the grand – mean activation of the free – choice loss – conditions) and the lateral prefrontal cortex, proposed to be of high importance for the generation of the P3 (Halgren, et al., 1995; Linden, 2005; Nieuwenhuis, et al., 2005; Soltani & Knight, 2000).

This leads to the conclusion that the P3a first of all encodes the highly attentional fact of a win and the behaviour leading to that win in working memory, and the P3b transferring it into memory storage, marking its very high valence, salience, and motivational impact along with its low probability. These results are also in accordance with previous findings regarding the P3b which encodes the motivational significance of a stimulus, and highlights the importance for this behaviour for the goal directed process of the stimuli. (Nieuwenhuis, et al., 2005; Wu & Zhou, 2009)

8.5 The FRN and its relation to regret

The FRN also seems to be sensitive to goal – achievement. Statistical analyses of the ratings for the loss – feedback types in the free – choice condition did not reveal significant differences between the conditions “loss/alternative win”, “partial feedback loss”, and “larger loss/alternative smaller loss”, which was excluded from further analyses. Significant differences were found regarding the “smaller loss/alternative larger loss” condition. These results could partly be found in the ERP data as well, with exception to the free – choice “smaller loss/alternative larger loss” condition which also yielded no significant difference in the FRN. The only significant difference showed comparing the free - choice loss – conditions, to the “win” - condition. It can be stated for the conditions of the present experiment that obviously the brain primarily detects self caused losses as one category, but does not care so much about their gradual distinction. The brain encodes that the goal was not achieved; it simply categorizes the outcome as a loss (Hajcak, Moser, Holroyd, & Simons, 2006; Holroyd, et al., 2006; Yeung & Sanfey, 2004), but does so only when the individual is acting as the agent, as this present results imply. Converging evidence holds that the FRN is sensitive to learning in order to serve further behavioural improvement. (Crowley, et al., 2009; Frank, et al., 2005; Holroyd & Coles, 2002; Holroyd, et al., 2003; Nieuwenhuis, et al., 2002; Yeung, Holroyd, & Cohen, 2005b) As the present results imply this is limited to task in which the individual is self – responsible for the outcome.

Regret theory holds that regret is experienced as a cognitive emotion and uses counterfactuals to compare an outcome to a rejected alternative, which is more desirable. In this sense the presented distinct feedback types in the present study should have, as hypothesized, brought about significant different ratings and significant different amplitudes of the FRN, being greatest in the free – choice “loss/alternative win” condition, as Moser and Simons (2009) as well have pointed out that the FRN is linked to regret. This was not the case in the present study which leads to the conclusion that the FRN does not resemble an electrophysiological equivalent to regret. On the other hand it could also be argued as proposed by Smallman and Roese (2009) that counterfactuals are directed towards a goal, as mentioned in chapter 2.2, as they refer to a goal in the sense of Moskowitz et al. (2004) who state that goal resemble “knowledge structures” (Moskowitz, et al., 2004). This is further mentioned (see excursus 2.2.1) by Kahneman and Miller (1986) that regret derives from the deviation of a goal or a inefficient progress in achieving the desired goal. By looking at regret from this side which highlights that a goal was not accomplished instead of highlighting the comparison between an outcome and an alternative as used in the present experiment to elicit regret could shed a different light on the present results. The goal of the experiment was to win money. Oliveira et al. (2007) proposed the FRN and its generator, the ACC to be “part of a more general performance monitoring system that is activated by violations in expectancy” (Oliveira, et al., 2007) and the furthermore state that individuals tend to be overoptimistic in their expectancies, a bias that leads to the commonly observed greater negativity generated by negative outcomes. For the present experiment this “overoptimistic bias” (Oliveira, et al., 2007) could be interpreted in terms of overoptimistic expectancies towards goal – achievement, even when considering the low frequency of the occurring win. So every loss – condition could have elicited the same electrophysiological sign of categorization for a deviant progress in the achievement of the overall goal: the FRN. Roese and Summerville (2008) propose in their opportunity principle (see excursus in chapter 2.2.1) that as long as opportunities are open for changes the individual will persist in taking actions to achieve a desired goal. Accordingly regret will persist which will be expressed using counterfactuals. Epstude and Roese (2008) (see excursus 2.2.1) propose two different pathways on which counterfactuals serve for the regulation of behaviour, one of them is the content – neutral pathway which does not hold specific information about the performance, but activates overall motivational and attentional processes leading to the optimization of behaviour. In the present context the FRN could be seen as an electrophysiological signal resembling unspecific goal – deviation in the sense that it is not significantly gradually distinct in the varying feedback – types, which would have elicited significantly distinct FRN amplitudes and accounted for the FRN being the electrophysiological equivalent to regret. This very first encounter of goal – deviation is resembled in the FRN driven by a mesencephalic decrease of dopaminergic neurons and generated in the ACC. This happens 250msec after the presentation of the feedback. It is argued that travelling on the content – neutral pathway the FRN enables the rise of the cognitive emotion regret. This is very much in line with the proposed circuit of bottom – up and top – down regulation of behaviour as stated by Coricelli et al. (2005) and the adaptive critic model (Holroyd & Coles, 2002; Holroyd, et al., 2006), which assigns through this FRN the OFC to express the cognitive emotion of regret through a “counterfactual process” (Coricelli, et al., 2005) in order to optimize behaviour. The adaptive critic model (see chapter 4.1.1) serves as a perfect framework to explain the relation between the FRN resembling the electrophysiological starting signal or as put by Holroyd et al. (2006) being the product of a “a cognitive preprocessing system" which evaluates the achievement of a goal, generated by the control filter, the ACC which then gives rise to the motor controller best suited to exert control over the motor system to optimize behaviour, which in the case of regret could resemble the OFC in which the cognitive emotion of regret is expressed through counterfactual thoughts giving rise to behaviour regulation.

It is stated that the FRN with its underlying generating mechanisms resembles the electrophysiological ignition, the first – level of encountering goal – deviance, metaphorically speaking the FRN could be imagined as being sent out to tell second – level cognitive processing "Watch out, this outcome is not what we expected! We need to do something about this!" that enables other cognitive structures, in the case of regret the OFC, the ACC and the amygdala to optimize behaviour. Therefore it can be proposed that the FRN and regret both first of all serve for the regulation of behaviour. An interesting question that arises through this argumentation is whether the FRN also serves as this electrophysiological first – level processing for other cognitive emotions, such as envy, which would be a very interesting research question.

Moreover following this line of argument it is stated here that the P3 could resemble the diametrical electrophysiological equivalent to relief, another cognitive emotion that can be expressed by downward counterfactuals in the sense of: "I won! If I had chosen differently I would have lost!" Kok (2001) proposes an event categorization theory for the P3, as laid out in chapter 4.2, as a process of categorization, as also proposed for the FRN, which establishes categories for expected outcomes and yields a large P3 if the internal representation and the external outcome deviate. It is stated that the P3 resembles the first – level of encountering a highly salient win, passing the information onto second – level processing of preserving this goal – achieving behaviour, as it could also be seen in the present experiment that the amplitude of the P3 is sensitive to agency and being responsible for the outcome.

8.5.1 The FRN and regret: Regret regulation versus behaviour regulation

The previously discussed argumentation and various research on regret and the FRN propose them to aim for optimization of behavioural performance (Coricelli, et al., 2005; Epstude & Roese, 2008; Holroyd & Coles, 2002; Smallman & Roese, 2009). This would hold against the theory of Zeelenberg and Pieters (2007), suggesting a regret regulation theory (see chapter 3.1.1). It has been argued in regret – regulation theory that individuals are primarily motivated to regulate their regret, which is perceived as an aversive emotion, even as an emotion of self – blame, to maximize outcomes as well for the short term, as to learn for the future (Pieters & Zeelenberg, 2007; Zeelenberg & Pieters, 2007). The theory of regret regulation and regret as behaviour regulation (Epstude & Roese, 2008; Smallman & Roese, 2009) seem to be contradictory in the detail that for Zeelenberg and Pieters (2007) the cognitive element of regulating this aversive emotion regret is interposed between the identification of the bad outcome and optimizing behaviour. The previously discussed arguments regarding the FRN as electrophysiological initiation of regret along with the findings by Coricelli et al. (2005) (Coricelli, et al., 2005) highlighting regret, and the adaptive critic model (Holroyd & Coles, 2002) the FRN, to aim to optimize behaviour on hand and therefore underline the primary role for regret and the FRN serving to optimize behaviour.

Secondly regret regulation could set in if needed, respectively if the goal and/or optimization of behaviour was not reached aiming to regulate regret and keep the self – worth up if, as Epstude and Roese (2008) argue, opportunity for change closes and strategies to minimize this dissonant state (Festinger, 1957; Herkner, 2001) will be elicited.

9 CONCLUSION

The FRN has been hypothesized to encode motivational significance (Gehring & Willoughby, 2002) and to appear due to unexpected outcomes (Holroyd & Coles, 2002), and this is proposed for the P3 as well (Hajcak, et al., 2007; Nieuwenhuis, et al., 2005), just in the diametrical direction. The categorization theories proposed for both the FRN (Hajcak, et al., 2006; Holroyd, et al., 2006; Yeung & Sanfey, 2004) and the P3 (Kok, 2001), can be interpreted in favour of this proposal, since both have been argued to establish categories of events, and the FRN and the P3 are elicited by outcomes deviating from this internal representations, coding the degree of deviation with their amplitude and latency. It can therefore be further argued, in synopsis of the results, that the FRN and the P3 are part of one system detecting unexpected results of high salience, depending on their above described nature, either worse or better outcomes, aiming to create one complete image in the brain, which aims to avoid and/or code losses, respectively wins, in whatever sense, onto optimizing behaviour towards whatever goals the individual has set, as Loomes and Sugden (1982) already highlighted the important impact of regret and rejoice on decision – making (chapter 1.2.1).

Roese et al. (2007) mention regret serving as “a regulatory signal” (Roese, et al., 2007). It is argued here that relief serves the same function and that the electrophysiological ignitions to this regulatory signal are the FRN for regret and subsequent optimization of behaviour, and the P3 for relief serving for the preservation of goal – achieving behaviour.

It is proposed here that the FRN resembles the electrophysiological ignition, the electrophysiological starting signal, giving rise to the cognitive and emotional processes of regret, with the P3, supposedly serving the equivalent role for relief. Yeung and Sanfey (2004) point out that the P3 is sensitive to valence when it is defined as “high – level affective evaluations” such as regret. It is argued here that the FRN is, as well as the P3, involved in higher – level of stimulus evaluation, but in diametrically opposed directions: the FRN resembling regret at its very core, the initial unconscious comparison process identifying goal - deviation, the signal that gives rise to cognitive expressions of counterfactuals and the feeling of regret, and the P3 doing the same for relief. For the FRN this is in accordance with the two – level reward processing proposed by Coricelli et al. (2007), with the mesencephalic dopamine system presenting the first level, which gives rise to the FRN by a phasic decrease of dopaminergic activity, consecutively giving rise to the second level, that’s associated with the OFC, the ACC and the amygdala (O'Doherty, 2004). But even more the perfect framework for this interpretation is provided by the adaptive critic model (Holroyd & Coles, 2002; Holroyd, et al., 2006) (as already laid out previously in chapter 8.5) in which a “cognitive preprocessing system” (Holroyd, et al., 2006) asses the achievement of a goal, and sends out a temporal difference error – the FRN from the ACC, the adaptive critic, whenever the goal was not reached to assigns the OFC with optimization of behaviour by, in the case of regret, eliciting a “counterfactual process” as brought to the point by Coricelli et al (2005). The adaptive critic model, especially in its modified version (Holroyd, et al., 2006) highlights goal – achievement as a major element and not only the processing of reward value which makes this model such an appealing framework for the relationship between the FRN and regret.

It is stated here that the P3 with its characteristics and its involvement in memory processes serves for preservation of successful behaviour through relief. A downward counterfactual elicited by the electrophysiological starting signal for relief, the P3, could be: “Wow! I did not expect to win, but I did! That’s great! If I would have decided differently I would have lost” This goal achievement, meaning goal in whatever drawn from life meaning, as defined in chapter 1 will lead the brain to aim to preserve this behaviour and store it in the memory. Converging evidence comes from an fMRI study (Fujiwara, Tobler, Taira, Iijima, & Tsutsui, 2009), in which the relative value of reward elicited relief, which yielded a maximum activation in the anterior ventrolateral prefrontal cortex. The lateral prefrontal cortex has also been previously mentioned to be involved in the generation of the P3a (Halgren, et al., 1995; Linden, 2005; Nieuwenhuis, et al., 2005; Soltani & Knight, 2000). Further research will be needed to test the hypotheses of the P3, and by taking into consideration the fMRI results and previous research on the localization of the P3a especially this subcomponent, and its correlation to relief.

The present study was conducted to gain insight in the relation of regret and the FRN. It can be concluded that the FRN serves as the electrophysiological starting signal giving rise to the cognitive emotion of regret expressed through counterfactual thoughts. Both the FRN and regret are stated to serve first and foremost for the regulation of behaviour and directing it towards a goal.

10 PERSPECTIVES

The study design of the present experiment could be improved in a few aspects. First of all the frequency of the appearing wins could have been augmented, as the probability of its occurrence was very low, which, on the other hand, elicited a small FRN even in the win – condition, but furthermore a very large peaking P3. The very high P3a, on the other hand, overlaid the FRN in the statistical analyses. Equal probabilities and frequencies of the feedback types could diminish this effect, as the amplitude of the P3a should become smaller the more frequent the wins occur, which would diminish the confounding of the FRN and the P3a. A second suggestion could be to state the probabilities of the appearance of a loss or a gain, as seen by Corricelli (2005), since due to the declared probabilities the individuals could build more solid expectations of winning or losing which could also lead to a diminished confounding of the two ERPs. The ratings indicate that more frequencies of the feedback type "E" could have also lead to an interesting result. The rating could be placed before and after the experiment to see whether the subjective perception of the feedback types, especially varying due to agency, changed during the course of the experiment. Chua (2009) let their participants even rate their wish to change their choice after every trial.

In chapter 8, the hypothesis was made to conduct further research on the possible connection between regret being first and foremost responsible for the optimization of behaviour (Epstude & Roese, 2008; Summerville & Roese, 2008) and regret regulation theory (Pieters & Zeelenberg, 2007; Zeelenberg & Pieters, 2007) and keep their self – worth up with regard to the FRN. For future research it seems to be very interesting to test this hypothesis by conducting an FRN experiment, with collection of data on how the individuals dealt with the feedback – shortly after and at the time filing out the questionnaire. The regret gambling task, as presented here could also be modified in various ways to gain a better insight in the processing of negative outcomes, such as indicating probabilities or balance the frequencies of win/loss trials to see whether the results change. This would especially be interesting in combination with a personality questionnaire.

Sailer et al. (2010) found the FRN and the P3 to diminish with the learning of a task. It would be very interesting to examine whether the proposed regret regulation strategies even apply to learners, as they have learned the task and do not need to repair their self – worth, because presumably no regret needs to be felt after task accomplishment, and moreover if the non – learners which show no decreased ERPs, use such strategies and if they do, of what kind, to keep their self – worth up.

To further test the relation between FRN and regret decisions drawn from real life could be presented to the participant. This could be the choice between two pictures, such as two cars, two pictures of holiday scenes and to provide texts before the picture, such as: “Imagine you want to buy a car/want to go on holiday. You could decide between the following two options. Which one would you choose?” Known to the participants after their decision they would see if they chose the “right” option, or whether their decision turned out as being worse than expected. For better feasibility this could be indicated through a sad, indicating the regrettable choice, and a smiling face, indicating relief, or a text could appear saying: “This is what you get:” followed by one single picture showing e.g. a dirty, disgusting hotel – room in the holiday condition. This could alternate with a block of forced choice, with two options (pictures) appearing, and a text saying: “This option was chosen for you”. The experimental design using pictures, instead of a gambling task could enhance more personal involvement of the participants because it presents real – life situations. This idea can be expanded to vary the probability of bad and good outcomes, to elicit relief and rejoice, which could assumedly elicit a P3.

According to Schwartz (2002), who found that different personality types experience regret distinctly, it could be very interesting to combine FRN experiments with personality questionnaires, to see whether personality differences enhance, not only a distinct experience of regret, but also yield a different pattern in the FRN.

As proposed in chapter 9 the hypothesis that the P3 might reflect the electrophysiological ignition for relief, as the fMRI results by Fujiwara et al. (2009) and the converging results due to the localization of the P3, especially the P3a (Halgren, et al., 1995; Linden, 2005; Nieuwenhuis, et al., 2005; Soltani & Knight, 2000) underline, should be further examined, especially with respect to the FRN and the P3 encoding the diametrically opposed salience, and motivational significance of unexpected outcomes, representing two electrophysiological codes serving for one higher – level emotional processing leading to the optimization of behaviour. Even more the relation of these two ERPs in relation to other cognitive emotions could serve interesting hypotheses for further research. It could, for example be an interesting question to test the relation between the FRN and envy.

ABSTRACT

Regret is a cognitively based emotion using counterfactual thoughts to compare an outcome with a more desirable alternative. The aim of the present study was to conduct an EEG study to examine the relationship of the feedback – related negativity (FRN) and regret in a regret gambling task. Furthermore the P3a and the P3b were examined. The regret gambling task was used to elicit regret by operationalizing the core element of regret, the agency – effect through free – and forced – choice conditions and inducing regret in the free – choice conditions through distinct feedback types bearing losses, which also elicited a FRN. The free – choice “win” – condition elicited a large peaking P3, as well a P3a with frontal and a P3b with parietal activation. The collected EEG data was explored regarding the hypothesis. Behavioural data was explored using a non – parametric design. Behavioural results did not reveal a significant agency – effect. One significant effect could be found for the distinct loss feedback – types and of course the different loss – feedback types were rated significantly different to the “win” condition. The EEG data showed a significant main effect of agency and feedback, as well as a significant interaction effect (agency x feedback) for the FRN, the P3a and the P3b in the timeframe of interest according to their peaks. Nevertheless no significant gradual distinction in the mean amplitude of the FRN could be found in the free – choice loss – feedback types. This indicates that the FRN does not resemble the electrophysiological equivalent to regret. It could be concluded that the FRN resembles the electrophysiological ignition giving rise to the experience of the cognitive emotion of regret using counterfactuals. It is stated that the FRN as well as regret are both serving for behaviour regulation. This interpretation is linked to the proposed interaction of a bottom – up and top – down two level reward processing by Coricelli et al. (2005) and the adaptive critic model by Holroyd and Coles (2002; Holroyd, et al., 2006). The interpretation was made that the P3, especially the P3a, electrophysiologically resembles the diametrical opposed starting signal for the emotion of relief to preserve goal – achieving behaviour. Further research will be needed to test this hypothesis.

Keywords: regret, counterfactual thoughts, feedback – related negativity (FRN), P3

ZUSAMMENFASSUNG

„Regret“ (wörtlich übersetzt: das Bedauern) ist eine kognitiv basierte Emotion, die mittels kontrafaktischem Denken das Ergebnis einer getroffenen Entscheidung mit einer attraktiver scheinenden Alternative vergleicht. Das Ziel der vorliegenden Studie war in einer EEG/EKP – Studie die Beziehung von „Regret“ und der “feedback – related negativity“ (FRN) in einem „Regret Gambling Task“ zu untersuchen. In weiterer Folge wurde sowohl die P3a, als auch die P3b untersucht. Unter Anwendung eines “Regret Gambling Task” wurde „Regret“ induziert, indem dessen Hauptelement, der “Agency” – Effekt, durch eine freie und erzwungene Wahlbedingung operationalisiert wurde. „Regret“, als auch eine FRN, wurden in der freien Wahlbedingung durch Vorgabe unterschiedlicher Verlustergebnisse hervorgerufen. In der freien Wahlbedingung “Gewinn” wurde eine P3 erzeugt, sowohl eine P3a mit frontaler, als auch eine P3b mit parietaler Aktivierung. Die mittleren Amplituden der ereigniskorrelierten Potentiale (EKP) wurden hinsichtlich der gestellten Hypothesen statistisch analysiert. Die Verhaltensdaten wurden mit nicht – parametrischen Methoden ausgewertet. Diese zeigten keinen signifikanten “Agency” – Effekt. Es konnte ein signifikanter Effekt bezüglich der verschiedenen Verlust – Ergebnisvarianten festgestellt werden. Alle Verlustbedingungen zeigten signifikante Unterschiede zu der Gewinnbedingung. Die mittleren Amplituden der EKP – Daten zeigten einen signifikanten Haupteffekt bezüglich des „Agency“ – Effekts und der verschiedenen Ergebnisvarianten. Weiters einen signifikanten Interaktionseffekt (“Agency” x Ergebnis) für die FRN, die P3a und die P3b in den interessierenden Zeitfenstern. Es konnte keine signifikante graduelle Abstufung in der mittleren Amplitude der FRN zwischen den Verlustergebnissen in der freien Wahlbedingung festgestellt werden. Das weist darauf hin, dass die FRN nicht das elektrophysiologische Äquivalent zu „Regret“ darstellt. Vielmehr könnte die FRN die elektrophysiologische „Zündung“ für das Erleben der kognitiven Emotion von „Regret“ mittels kontrafaktischen Denkens darstellen. Die FRN, als auch „Regret“ dienen damit der Verhaltensregulatio. Die Interaktion einer “Bottom – Up” und “Top – Down” – Zwei – Stufen Verarbeitung von Belohnung von Coricelli et al. (2005), als auch das “Adaptive Critic” Model von Holroyd und Coles (2002; Holroyd, et al., 2006) stellen zwei Bezugsrahmen dar, die diese Schlussfolgerung untermauern. Die P3, besonders die P3a, könnten das diametrisch entgegengesetzte elektrophysiologische Startsignal für die Emotion von „Relief“ (wörtlich übersetzt mit: Erleichterung) darstellen, das dem Erhalt von zielführendem Verhalten dient. Weitere Forschung dazu wäre wünschenswert.

Schlüsselwörter: Regret, kontrafaktisches Denken, feedback – related negativity (FRN), P3

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September 2009	**SMZ Ost** Akutpsychiatrie, Frau Mag. Gold (Klinische Gesprächsführung, Leitung von psychologischen Gruppen und IPT)
April - Juni 2009	**St. Anna Kinderspital** Psychosomatische Ambulanz, Frau Dr. Höfinger (Selbständige Diagnostik)
Juli - Oktober 2007 (6 Wochen Pflichtpraktikum)	**Institut für Klinische, Differentielle und Biologische Psycholgie** Projektmitarbeit an der Abteilung für Biologische Psychologie, Frau Dr. Uta Sailer (Rekrutierung Versuchspersonen, Literaturrecherche, Auswertungen, EEG Ableitungen und Datenerhebung)

Soziales Engagement
Schnupperpraktikum Asylzentrum – Beratungsstelle für Flüchtlinge Mariannengasse 11, 1090 Wien Februar 2006
Leitung Jungschargruppe im Team, Pfarre Eisenstadt Oberberg Mädchen, 6-10 Jahre

Arbeitserfahrung	
Oktober – Dezember 2006 (Nebenbeschäftigung)	**EU-Büro Mag. Othmar Karas, Abgeordneter zum europäschen Parlament, Wien** Büroagenden (Word, Excel, etc.)
Seit 2004	**Geringfügig beschäftigt bei Dr. Josef Rauchbauer**
Frühjahr 2003 (Nebenbeschäftigung)	**Bank Gutmann** Rezeption
2000-2004 (Nebenbeschäftigung)	**Fremdenführungen Schloß Esterhazy, Eisenstadt** Für Kinder und Erwachsene, Englisch und Deutsch

Weitere Kenntnisse und Fähigkeiten

- Englisch (fließend in Wort und Schrift) – 1 Jahr USA Aufenthalt
- Französisch, Italienisch (leicht fortgeschritten)
- Spanisch, Kroatisch (Anfängerniveau)
- Trainerausbildung NLP Trinergy derzeit Master Practicioner

Hobbys und Interessen

Spezielle Interessen

- Reisen
- Jazzgesang: Leadsängerin der Band „Flexible Friends" bis Dezember 2006; diverse Musical-Gesang-, Tanz-, und Schauspielaufritte

Sport

- Yoga, Laufen, Mountainbiken, Schifahren, Bergsteigen, Kajakfahren