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I DEDICATE THIS WORK

TO MY GRANDMOTHER

GERDA MORGENSTERN

WHO HAS SO MUCH BELIEVED IN ME

AND ALWAYS REMEMBERED MY CHILDHOOD DREAM

OF PROCESSING TO THE GUERICKE MEMORIAL

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Chapter I

1 Motivation

The research field of experimental economics applies choice situations in a controlled environment in order to investigate the validity of economic theories and market mechanisms. The application of experimental methods basically comprises lab experiments in which participants are confronted with economic decisions. In this context, theories of individual decision making are particularly focused on experimental economics and behavioral data from experiments provide inferences on the verification of theoretical assumptions. But inferences toward a theoretical model of individual decision making can only be provided, if the experiment is designed according to the constraints of the investigated model. Otherwise theoretical conclusions might be misleading. In this respect, the methodology of experiments has to attract interest since the experimental background is supposed to influence the decision making behavior of individuals in an experiment, as for instance the instructional framing, the amount of choice task or monetary incentives.

In general, theoretical models of individual decision making describe single choice problems which are independently considered from other decisions. As a consequence, such an assumption constrains experimental procedures with multiple choice tasks, which therefore have to ensure that each choice task is evaluated independently by a subject. This can be achieved by implementing a distinct incentive structure such that participants of an experiment are disposed to evaluate a choice task independently from others. In this context, incentive structures represent an important methodological aspect in experimental economics. The role of incentives as a methodological constraint was discussed by Smith (1976) who enunciated the Induced Value Theory. The Induced Value Theory is considered as a fundamental paradigm for lab experiments in economics and proposes a direct conjunction between experimental choice tasks and financial rewards of participants. Incentive structures are usually reflected by monetary reward functions which induce an economic environment and further motivate the subjects to respond seriously according to their underlying monetary preferences. Monetary reward functions can be implemented as incentive compatible with reference to a distinct theory of individual decision making in a way that an individual gains most, if he or she decides according to the rationale of the underlying theory. In this respect, a theoretical independence of each choice task in multiple choice task experiments can be achieved.

Basically, monetary reward functions in multiple choice task experiments can be designed in relation to a realization of a certain amount of choice tasks. Three general possibilities of choice task realization can be distinguished: (1) no choice task is realized; (2) one randomly chosen choice task is realized; (3) all choice tasks are realized. The suitability of these different characteristics of monetary reward functions depends on the research question of the experiment and its underlying theoretical assumptions. In general, a monetary reward function has to provide incentive compatibility in relation to an underlying decision model. Such a requirement ensures the theoretical suitability of the monetary reward function. Moreover, a theoretical suitability may further be achieved by different types of reward functions which are supposed to result in the same behavior of a decision maker who decides according to the rationale of the underlying decision model. However, theoretical suitability does not warrant coherent behavior. Therefore, an empirical suitability of incentive structures has to be taken into account when analyzing the impact of incentives on the individual decision making behavior.

In this respect, a methodological debate on the suitability of monetary reward functions has been started in the research field of experimental economics. Payoff mechanisms, which reflect monetary reward functions in experiments, have to be examined in relation to individual decision making behavior in multiple choice task experiments. According to Smith (1976, 1982), economic experiments have to provide a salient reward structure and therefore have to be related to the experimental choice task. Since then, the concept of incentive compatibility has been a fundamental part of experimental economic research. Incentivizing subjects in economic experiments has been widely discussed (see Smith and Walker, 1993; Jenkins et al., 1998; Camerer and Hogarth, 1999; Bonner et al., 2000) and there is a general consensus that experiments addressing an economic question have to be incentivized. Thus far, the discussion has been focused on a general application of financial incentives with respect to an incentive compatible reward structure. Payoff mechanisms had to comply with a theoretical suitability for a given experimental design.

More recently, this debate has been reflated by a study of Cox et al. (2011) in which different payoff mechanisms applied in multiple choice task experiments were investigated with reference to a single choice task experiment. Aside from a theoretical suitability of payoff mechanisms, this study investigated behavioral differences evoked by different payoff mechanisms from an empirical perspective. Cox et al. (2011) considered a single choice task experiment as a baseline for independent decision making. Several payoff mechanisms, which are usually applied in multiple choice task experiments, were analyzed in their behavioral differences according to the single choice task experiment. As a consequence, differences could be ascribed to the characteristic of the underlying payoff mechanism. Hence, the suitability of a payoff mechanism is referred to descriptive evidence, indicating distorting influences of an underlying incentive structure.

The present work contributes to the methodological debate on the suitability of payoff mechanisms in multiple choice task experiments by approaching this topic from a neuroscientific perspective. The general research question of this work aims for identifying neural differences in the evaluation process of decision making induced by different incentive structures. In this context, neuroimaging techniques can provide implications for the source of behavioral effects related to an applied incentive structure. This work uses the electroencephalography (EEG) as a neuroimaging method for investigating event-related brain potentials during decision making. The intention of this work is to provide neural inferences on the applicability of payoff mechanisms and explanations for potential behavioral biases between different payoff mechanisms. For this purpose, the present work focuses on the neurological construct of cognitive control and its related processing which can be assumed to be involved during decision making. In this respect, a model of conflict monitoring (Botvinick et al., 2001) is applied to establish a relationship between the cognitive process of decision making and the observed EEG data. In particular, the level of conflict, indicated by the appearance of event-related brain potentials, toward a distinct choice task situation is used as an indicator for the characteristic of the decision evaluation process and its underlying goal system.

The current work investigates three basic payoff mechanisms that are commonly used in experimental economics. A first comparison analyzes the flat-rate payoff mechanism and the random payoff mechanism with reference to the influence of monetary incentives on individual choice behavior. The flat-rate payoff mechanism rewards subjects solely for participating in the experiment. For that reason, no choice task is realized for the participants and all decision consequences are hypothetical. In contrast, the random payoff mechanism rewards subjects according to one randomly chosen decision and decision consequences are for real. Potential differences in the individual choice behavior between both payoff procedures are labeled as the hypothetical bias. This behavioral effect is investigated in an EEG paradigm with reference to the aforementioned level of conflict in the evaluation process of the choice task.

A second comparison of payoff mechanisms follows up the first EEG study and analyzes the random payoff mechanisms in contrast to the averaged payoff mechanism. The averaged payoff mechanism rewards subjects according to the average outcome of all decisions in an experiment. Hence, the averaged payoff mechanism realizes every decision of a multiple choice task experiment. Behavioral differences in the individual choice behavior between these two payoff procedures refer to a potential formation of portfolio choices when all decisions are realized. This behavioral effect is named as the portfolio effect. Consequently, the portfolio effect arises from a non-independent evaluation of a choice task. Therefore, neural processes of conflict monitoring are investigated in a second EEG study with reference to the independence of decision making.

The analysis of both EEG studies concerning conflict monitoring provides additional implications for a general suitability of these payoff mechanisms since the level of conflict indicates the characteristic of the evaluated choice task as well as the impact of a distinct incentive structure on the decision making process. For example, neural evidence for a non-independent evaluation of choice tasks would imply that such a payoff mechanism cannot be used for experiments on individual choice behavior.

Besides the main focus on processes of conflict monitoring, the present work considers further analyses that are of interest for a general review of the decision making process. The two EEG studies are additionally analyzed regarding an attentional resource allocation process for categorizing stimulus events of the experimental choice tasks. In this respect, the characteristic of a stimulus categorization process is described in relation to specific stimulus attributes of distinct choice alternatives. The analysis provides further clarifications on the neural processing of individual decision making behavior under risk.

In addition, the processing of risk is focused in more detail on another EEG study that addresses the perception of risk in utility assessment methods. In that study, a utility assessment method with risky decisions is compared to a utility assessment method without risky decisions. The study follows up an EEG study of Heldmann et al. (2009) and discusses the presence of risk in relation to its influence on neural processes of response conflicts.

Moreover, the characteristics of EEG experiments generally entail the methodical constraint that a serious amount of repeated stimulus trials have to be presented to the subjects in order to reveal the tiny electrophysiological signals of the event-related brain potentials. As a consequence, every EEG study provides a huge amount of decisions, which allows for a detailed revision of the individual choice behavior regarding its consistency. According to Butler and Loomes (1988), individuals in experiments on risky decision making tend to have a range of imprecise choices for which they are unsure about their preferred choice behavior. These intervals of imprecision are typically arranged around a switching point, or indifference point respectively, for which the subject changes his or her preference from one choice alternative to another. As a result of the concentrated data of choice behavior, the behavioral results of an EEG experiment are used for analyzing ranges of indifference in risky decision making. Hence, in addition to the neuroeconomic analysis of the EEG studies, this work further provides an analysis of behavioral data with reference to indifference intervals.

The aforementioned topics will be discussed separately in the subsequent chapters of this work. Each of these topics will be processed in a paper style format comprising a particular introduction, the material and methods, the results, and a corresponding discussion. Before that, a general introduction to the economic and neurological background will be provided in the preceding chapters. These foregoing chapters aim at affording the basic knowledge that is necessary for understanding the applied methods, concepts and terms in the subsequent studies. In particular, the proceeding of this work is structured as follows:

The subsequent chapters 2 and 3 will describe the economic background of this work. Chapter 2 will introduce the theoretical principles of modeling individual decision making behavior under risk as well as the methodology of experiments addressing the measurement of risk attitudes. The theoretical principles will provide a basis for chapter 3 in which the concept of incentive compatibility and its relation to payoff procedures in experimental economics will be motivated. Chapter 3 will clarify the influence of incentive structures on the risk behavior of individuals and will discuss behavioral implications for the application of different payoff procedures.

In chapter 4, an introduction to the EEG technique will be provided. This chapter will describe the experimental methodology of EEG experiments that was applied in the subsequent studies of this work. Chapter 5 will introduce the construct of cognitive control with reference to conflict monitoring. Neural processes in relation to conflict monitoring will be addressed in the research questions of the EEG studies.

The subsequent chapters 6 and 7 will comprise the two EEG studies with reference to the different application of payoff mechanisms. Chapter 6 will focus on the behavioral effect of the hypothetical bias, comparing a hypothetical and a real lottery choice paradigm. Chapter 7 will address the portfolio effect in payoff procedures between a randomly selected realization of one choice and an averaged realization of all choices.

In chapter 8, a further analysis of an EEG study concerning the perception of risk in riskless and risky utility assessment methods will be provided. This chapter will focus on response conflicts in risky choice task experiments which allows for an analysis of the subjective relevance of risk. Chapter 9 will discuss an additional analysis of the behavioral data concerning the hypothetical bias with reference to indifference intervals. Finally, the findings of this work will be summarized and concluded in chapter 10.

Chapter II

2 Theoretical and methodological principles

The methodology of experiments in economics basically serves as a tool for investigating theoretical assumptions according to a predefined model of individual decision making. The present chapter introduces the basic theories for modeling individual decision making behavior under risk and describes the methodological approach for investigating individual decision making under risk in experimental economics. In particular, this chapter defines the concepts and terms that are necessary for understanding the research approach in this work. With regard to a verification of incentive structures in experiments, a review of individual decision making behavior is basically related to a theoretical assumption. In this context, the supposition that a distinct incentive structure induces an incentive related behavior usually refers to a theoretical conception of how decision making is processed by an individual. For that reason, two basic theories of individual decision making are introduced in this section: Expected Utility Theory as a normative decision making model and Prospect Theory as a descriptive decision making model. The theoretical assumptions of both models will be revisited in the subsequent discussion on incentive structures. This chapter will also provide an introduction to the experimental paradigm that is applied in this work for analyzing individual decision making behavior under risk.

2.1 Modeling individual decision making behavior

In everyday life, people are frequently confronted with situations where a decision is needed. Making the best decision for oneself is probably one of the most challenging disputes in life. Decision making basically concerns every human and has therefore been investigated in many different fields of research, as for instance in philosophy, social science, psychology, and particularly, in economics as well.

Researchers attempt to explain the process of how humans reach a decision and which determinants are relevant for a distinct choice. The process of decision making can be described as a cognitive ability of evaluating predetermined choice options and their related consequences, which finally results in a decision for a particular option. In this process, it can be assumed that the resulting choice reflects the most favored decision for the decision maker. Furthermore, if a particular choice is not arbitrary, then the decision process can be ascribed to a specific heuristic in the value system of an individual. Identifying the value system with its heuristics for decision making and estimating behavioral outcomes of decision making is focused in decision theory. The field of decision theory comprehends normative and descriptive approaches, which enable an analytic comparison of choice situations with regard to an optimal prediction of choices and choice behavior. In particular, choice situations that are reflected by uncertain consequences are of basic interest in decision theory. In this context, individual decision making is relevant in economic choice situations which are frequently reflected by uncertain outcome consequences. Several models of decision making have been developed for describing individual decision making behavior in economics. The overall foundation of basically all decision theory models with respect to economic decisions is the construct of maximizing the utility of an individual for a given decision situation. This deductive construct can be ascribed to the presumption that a final decision reflects the most favored choice alternative in a predefined value system of an individual. According to the construct of maximizing utility outcomes, individual decision making behavior could be estimated if a decision maker obeys a rationale with regard to his or her value system. Based on the utility concept, the most prominent model of decision making was developed, the Expected Utility Theory.

2.2 Expected Utility Theory

The preceding foundation of Expected Utility Theory (EUT) relies on the general decision criterion of evaluating uncertain decision alternatives according to their expected values. Expected value of a decision results from an accumulation of decision outcomes weighted in proportion to their probability of occurrence. The expected value criterion indicates that a decision maker has to choose the alternative with the highest expected value. This decision criterion provides an objective choice for the best alternative. However, in 1713 the mathematician Nicolas Bernoulli articulated a paradox which falsified the logic of this decision rule. He formulated a lottery with an infinite expected value and showed that people were not willing to pay an infinite price for participating in this lottery. This is known as the St. Petersburg Paradox. An explanation of this paradox is even today still ambiguous and not completely solved (see Neugebauer, 2010).

With reference to the St. Petersburg Paradox, Daniel Bernoulli (1738) expanded the expected value criterion concerning a mathematical function which converts values of decision outcomes into utility for the decision maker. By the use of utility functions, a first description of the term 'risk aversion' was performed which signifies that the utility of a risky alternative is smaller than the utility of a riskless alternative even though the expected values of both alternatives are equal. Risk aversion assumes that an individual has a preference for avoiding risky outcomes, seeking instead for a certainness in his or her decision. As a result, a decision maker decides on the best alternative according to the expected value in utility and the utility of risky outcomes is reflected by risk aversion.

In this respect, the utility function further integrates several essential conceptions concerning the valuation of goods. For positive outcomes, the utility function is monotonically increasing, which reflects the view that receiving more of a good yields higher utility for an individual than receiving less. Moreover, the utility function has a diminishing marginal utility which reflects the view that an increase in utility for receiving an additional unit of a good diminishes in relation to its quantity. Consequently, the utility function according to these conceptions has a concave shape. This concavity of the utility function further reflects the concept of risk aversion since a comparison of a risky choice alternative and a riskless choice alternative with equal expected values would result in a smaller expected utility for the risky choice alternative due to the concave functional form. Hence, risk aversion can be modeled through the shape of the utility function, and different degrees of risk aversion are captured by in the curvature of the utility function.

The preceding description of expected utility was revisited and enhanced by John von Neumann and Oskar Morgenstern (1944/1947). They enunciated the Expected Utility Theory for decision making under risk and implemented the expected utility concept on an axiomatic basis. The Expected Utility Theory is based on four axioms which define a rational decision maker: completeness, transitivity, independence and continuity.

Completeness postulates that an individual has predefined preferences according to a given set of choice alternatives and can specify between any two alternatives A and B whether he prefers alternative A to alternative B ($A \succ B$) or alternative B to A ($A \prec B$) or whether he is indifferent between A and B ($A \sim B$).

Transitivity postulates that an individual is consistent in his or her decision, which denotes that for any of the alternatives A, B and C, for which the individual has the preferences $A \succ B$ and $B \succ C$, the individual must also prefer A to C ($A \succ C$).

Independence postulates that the order of preferences of two alternatives A and B persists even though a third alternative C is combined with A and B. Hence, if $A \succ B$ then $t \cdot A + (1-t) \cdot C \succ t \cdot B + (1-t) \cdot C$ with $t \in (0,1]$.

Continuity postulates that for any of the three alternatives A, B and C with the preference order $A \succ B$ and $B \succ C$ there must be a combination of A and C which yields to indifference with B. Thus, there exists a probability $p \in (0,1]$ such that $B \sim p \cdot A + (1-p) \cdot C$.

If an individual complies with these four axioms, then he reflects a rational decision maker. The rational decision maker will choose an alternative that yields the highest expected utility with reference to his or her utility function. Thus, a risky alternative A is evaluated according to its utility $u(x_i)$ of the decision consequence x_i and the corresponding probabilities p_i as $E\big(u(A)\big) = \sum_{i=1}^{N} p_i \cdot u(x_i)$.

The Expected Utility Theory describes a normative approach for defining individual behavior in risky decision making and still serves as the normative benchmark. However, the descriptive validity of EUT has widely been reviewed through the methodology of experimental economics. Experiments on the axioms of EUT have revealed several inconsistencies. The paradox of Allais (1952) was one of the earliest evidences that provided a distortion of the independence axiom of EUT and is known as the common consequence effect. Allais has shown that preferences of people for a given two gamble choice set can change by integrating a third alternative which reflects a violation of the independence axiom. Further violations of EUT, for example the Ellsberg paradox (Ellsberg, 1961) or the preference reversal phenomenon (Lichtenstein and Slovic, 1971), were detected over the next decades.

Hence, the Expected Utility Theory could not perfectly describe the behavior of individual decision making for specific choice situations. For that reason, several adjustments (e.g. Rank-dependent Expected Utility by Quiggin [1982, 1993]) and alternative 'non-EU' theories (e.g. Prospect Theory by Kahneman and Tversky [1979]) were developed. Most notably, the Prospect Theory (Kahneman and Tversky, 1979) provided a reasonable approach for explaining several inconsistencies of EUT and the enhancement to Cumulative Prospect Theory (Tversky and Kahneman, 1992) constitutes the most established alternative to EUT.

2.3 Prospect Theory

In contrast to the normative approach of EUT, Prospect Theory (Kahneman and Tversky, 1979) represents a descriptive model based on empirical findings. Prospect Theory intends to describe real behavior in individual decision making rather than determining the 'optimal' solution of a rational decision making as proposed in EUT. Basically, both models rely on the concept of expected utility but, Prospect Theory additionally integrates biasing psychological aspects into the decision making process. Kahneman and Tversky (1979) separate the decision making process into an editing phase and an evaluation phase. The editing phase represents a first stage in the decision making process. In the editing phase a decision is prepared according to specific heuristics. This preceding process reduces complexity for the decision maker and allows for an isolated comparison of the prospect. Furthermore, outcomes are defined as potential gains or losses relative to an individual reference point which corresponds to a present asset situation of the decision maker. Subsequently, the evaluation phase determines the expected utility of a current prospect through a transformation of outcomes into a utility value and a transformation of probabilities into a probability weight. Contrary to EUT, Prospect Theory relies on two functional transformations, a value function $v(x)$ that determines a utility value similar to EUT and, additionally, a probability weighting function $w(p)$. Hence, a risky prospect A is evaluated according to its utility value $v(x_i)$ of the decision consequence x_i and the corresponding probability weight $w(p_i)$ of the probability p_i as $E\big(u(A)\big) = \sum_{i=1}^{N} w(p_i) \cdot v(x_i)$.

The value function $v(x)$ has a similar concave functional form as the utility function $u(x)$ in EUT but solely for the region of potential gains. Hence, potential gains in Prospect Theory are also reflected by risk aversion. In contrast, potential losses are presumed to be reflected by risk seeking behavior, indicating an avoidance of realizing a certain loss. Consequently, the value function in the region of potential losses has a convex functional form. A value function according to Kahneman and Tversky (1979) is presented in Figure 1. The reversion of risk attitudes in relation to the reference point is mentioned as the reflection effect. But again, the shape of the utility function indicates a distinct risk attitude of an individual toward a risky decision. In addition, Prospect Theory values the absolute amount in utility for a loss as higher than for a gain. This represents the psychological conception that losses loom larger than gains and is described as loss aversion. As a consequence, the value function in the region of losses has a steeper functional form than in the region of gains.

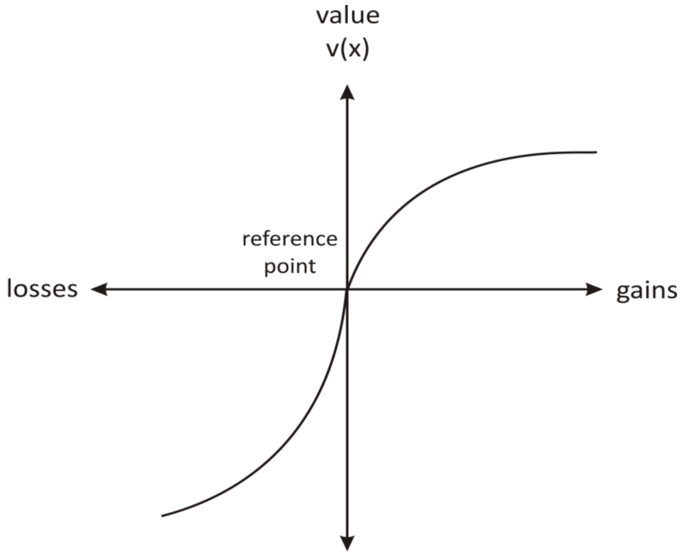

Figure 1: Value function in Prospect Theory (cp. Kahneman and Tversky, 1979)

The probability weighting function $w(p)$ relies on the behavioral observation that small probabilities are apparently overweight by individuals while moderate as well as large probabilities are underweight. Such a non-linear transformation of probabilities influences the decision of an individual differently and yields different evaluations of risky outcomes as compared to those derived from EUT. The enhancement of Prospect Theory to Cumulative Prospect Theory (Tversky and Kahneman, 1992) proposed a probability weighting function with an inverse S-shaped functional form (see Figure 2).

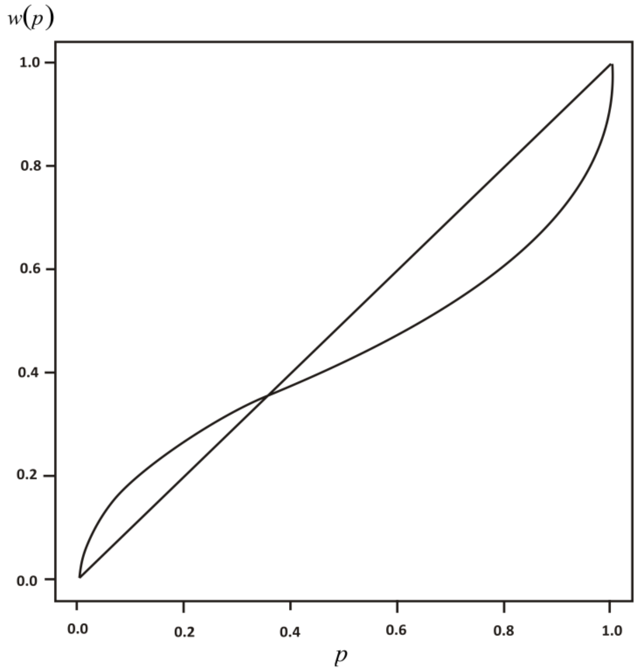

Figure 2: Functional form of probability weighting (cp. Tversky and Kahneman, 1992)

Cumulative Prospect Theory was developed to eliminate some inconsistencies of Prospect Theory with reference to prospects with more than two outcome consequences. However, it relates to the same basic principle. Prospect Theory and Cumulative Prospect Theory have been applied to explain several violations of EUT, for example the Allais Paradox. Both are assumed to describe a better prediction of individual decision making behavior. However, even Cumulative Prospect Theory has its shortcomings and cannot provide a stable approximation of individual decision making behavior.

2.4 Measuring risk attitudes

According to the previously introduced theories of decision making under risk, the attitude to risk is supposed to have an essential influence on the decision making process. Risk attitudes, or risk preferences respectively, of individuals about the presence of risk are an integrated part of these theories and are determined by the characteristics of utility functions. Apart from theoretical differences in those models concerning the process of decision making, the concept of risk attitudes is a fundamental similarity. Hence, determining risk attitudes through experimental and empirical investigations reflects a basic principle for understanding individual decision making behavior and further enables a deductive estimation of utility functions. In this context, experiments on risk attitudes reflect a reference method in experimental economics and are used in the present work as a tool for analyzing incentive mechanisms with regard to their applicability. Therefore, this section will provide an overview of the methodological approach for measuring risk attitudes of individuals.

2.4.1 Characteristics of risk attitudes

In economic decision making situations, decision consequences are commonly not certain. The decision maker is faced with a situation in which potential consequences are uncertain events. Thus, the decision maker is confronted with a discrete type of uncertainty in his or her decision. The type of uncertainty regarding decision consequences can be distinguished between an a priori known probability of occurrence and an unknown probability. Frank H. Knight (1921) was the first who differentiated the uncertainty of consequences concerning an a priori probability of occurrence. He defined the term 'risk' for a measurable uncertainty (probability is known) and the term 'uncertainty' for an immeasurable uncertainty (probability is unknown). With respect to this differentiation, risk attitudes are commonly determined for decisions with predefined probabilities and can therefore be ascribed to decision making under risk.

In general, risk attitudes are differentiated with regard to an objective reflection of the decision situation and its riskiness. An objective reflection of the decision situation is apparently the expected value criterion which reflects the mean outcome of a choice alternative. Furthermore, the riskiness of a choice alternative can be characterized by its variance. A higher variance reflects a higher degree of risk related to the expected value of a choice alternative and can therefore be ascribed as 'more risky' compared to a 'less risky' choice alternative with a smaller variance. According to these attributes of a risky choice alternative, risk attitudes are basically categorized as risk averse, risk neutral and risk seeking attitudes. Individuals who prefer a less risky choice alternative over a more risky choice alternative, although the more risky alternative has a higher expected value, are labeled as *risk averse*. In contrast, individuals who prefer a more risky alternative over a less risky alternative, although the more risky alternative has a lower expected value, are labeled as *risk seeking*. Individuals who have no distinct preference toward a comparison of risk in choice alternatives are labeled as *risk neutral*. Risk neutral individuals are supposed to decide solely according to the expected value of the decision alternatives. Hence, for risk neutral decision makers, the expected utility converges to the expected value.

The differentiation of risk attitudes is an essential variable in all models concerning decision making under risk. On an individual level, a prediction of choice behavior cannot be made without knowing the risk attitude of the decision maker. For this reason, the measurement of risk attitudes through behavioral experiments provides significant knowledge for modeling decision making behavior. Therefore, different approaches for measuring risk attitudes have been emerged in experimental economics

2.4.2 The gamble choice approach for eliciting risk attitudes

Approaches for eliciting risk attitudes typically involve gamble choices between alternatives which differ in terms of their probability of occurrence and their level of outcome. Farquhar (1984) introduced several gambling choice paradigms for eliciting risk attitudes and assessing utility functions in particular. According to Farquhar (1984), a gamble choice (lottery) can be defined as follows:

Every possible decision consequence can be assigned to a level x in an attribute set X, which represents a subset of real numbers for the occurrence of possible levels of a single attribute. Moreover, decisions are considered as lotteries, or gambles respectively, over finite sets of outcomes, that is decision consequences, from the subset X. A decision alternative is defined as a lottery L which assigns probabilities $p_1, p_2, \dots, p_m$, at which $0 \leq p_i \leq 1$ and $\sum_{i=1}^{m} p_i = 1$, to outcomes $x_1, x_2, \dots, x_m$ in the attribute set X resulting in a set $\{x_i : p_i\}_{i=1}^{m}$. The collection of all lotteries over X is denoted as $\mathcal{L}$.

Most elicitation methods use a binary lottery choice paradigm for which a lottery has at most two outcomes in X. For a lottery L with two outcomes $x, y \in X$ and a given probability p, the outcome x is realized with the probability p and the outcome y with the probability $1 - p$. Such a binary lottery can be denoted by $[x, p, y]$. Additionally, a lottery choice with only one outcome consequence $s \in X$, hence $p = 1$, reflects a sure outcome and is denoted simply as outcome s without indicating a probability.

Furthermore, lotteries in $\mathcal{L}$ are compared by an individual decision maker through a preference relation R which has $\succ$ (is preferred over), $\sim$ (is indifferent to), or $\prec$ (is not preferred over) as relations. Hence, a comparison of a binary lottery with the outcomes $x, y \in X$ and the probability p and a second binary lottery with the outcomes $w, z \in X$ and the probability q can be expressed as $[x, p, y]R[w, q, z]$.

Determining the preference relation for two lotteries provides information about the risk attitude of a subject. The determined preference relation allows for a comparison of the decision concerning the level of risk, that is the variance, and the expected outcome. Hence, it is possible to determine whether the choice reflects risk averse, risk neutral or risk seeking behavior. Furthermore, applying a sequence of lottery choices to a subject in which one parameter is varied among an otherwise constant gamble choice set enables an observation of a potential change in the preference for a choice alternative.

For example, a decision problem with a binary lottery $[100, .5, 0]$ as choice alternative A and a sure choice s as choice alternative B is presented to a subject. The sure outcome s is varied within the two outcomes of the binary lottery. Now, assuming that the subject has a preference for the binary lottery in case of $s = 5$ and a preference for the sure outcome in case of $s = 95$. Here, a determination of risk attitudes according to these two observations is not possible. But given these observations, there has to be a value of s within 5 and 95 for which the preference changes from one alternative to the other. Thus, there is a point at which the preference relation between both alternatives is ‘indifferent’ ($\sim$). This indifference point in relation to the expected value directly indicates the risk attitude of a subject for the given decision problem. Alternative A reflects a risky decision for the subject since the outcome of A is unsure. Alternative B reflects a less risky, in this case ‘riskless’, decision since its outcome is known for sure. Comparing the expected outcomes of both alternatives, a decision for alternative B with an amount of s smaller than the expected outcome of the binary lottery reflects risk averse behavior. In contrast, a decision for alternative A with an amount of s higher than the expected outcome of the binary lottery would reflect risk seeking behavior. In this respect, the determination of the indifference point further specifies the intensity of the underlying risk attitude. A greater difference between the indifference point of an individual compared to the expected value of the risky alternative indicates a higher degree of risk averse or risk seeking behavior. This allows for a comparison of risk preferences of different individuals. Thus, determining the point at which a subject is indifferent between two lotteries is an essential objective of methods for eliciting risk attitudes.

According to the concept of expected utility (Bernoulli, 1738/1954), the indifference point would indicate that both alternatives have obviously the same utility for the decision maker. A preference relation for one of the two alternatives would therefore indicate that such a preferred alternative has a higher utility for the decision maker. Thus, the measurement of risk attitudes and preferences for particular alternatives can directly be related to the utility concept. In this context, outcome consequences are converted into utility through a utility function $u(x)$. On the basis of the axioms of von Neumann and Morgenstern (1944/1947), risk attitudes in Expected Utility Theory are expressed by the shape of the utility function $u(x)$, while choice alternatives are evaluated through the expected utility $E\big(u(x)\big)$ of a given prospect. Hence, risk averse behavior is described by a concave utility function, risk seeking behavior by a convex utility function and risk neutral behavior by a linear utility function. Consequently, methods for eliciting risk attitudes are particularly utilized for determining utility functions.

The approach of a single comparison of two gambles as a decision problem is the basic similarity in the majority of the methods for measuring risk attitudes. Differences refer to the parameters that are manipulated (variation of outcomes or probabilities) and whether two binary lotteries are compared, labeled as paired gamble methods, or one binary lottery is compared to a sure outcome, labeled as standard gamble methods (cp. Farquhar, 1984). Standard gamble methods provide a baseline comparison of risk attitudes toward a sure choice, whereas paired gamble methods allow for a direct comparison of different levels of risk.

2.4.3 The certainty equivalent method

A paradigm for a standard gamble method is the *certainty equivalent method* (CE method) which has already been introduced in the example before. The CE method determines a point of indifference between a binary lottery $[x, p, y]$ and a sure outcome s, resulting in $[x, p, y] \sim s$. The binary lottery is predefined and kept constant, whereas the sure outcome s is the parameter which has to be determined. Moreover, the determined value of a sure outcome at which the subject has an indifferent preference relation is labeled as 'certainty equivalent'

(CE). The determination of the certainty equivalent in comparison with the expected value (EV) of the lottery defines the risk attitude. A subject is deemed to be (1) risk averse if $CE < EV$, (2) risk neutral if $CE = EV$ or (3) risk seeking if $CE > EV$. A common sequence procedure is to present monotonically increasing amounts of s so that a subject can account for a switching point from a choice for the lottery to a choice for the sure outcome.

2.4.4 The Holt-Laury procedure

A paradigm for a paired gamble method is the *Holt-Laury procedure* enunciated by Holt and Laury (2002). At present, this method is widely applied in experimental economics for measuring risk attitudes among two risky gambles. The Holt-Laury procedure comprises a list of 10 lottery choice sets with two binary lotteries each. The lottery outcomes are kept constant and the probability of occurrence is varied across the choice sets. The two lotteries in each choice set are characterized by a less risky lottery $[x, p, y]$ (option A) and a more risky lottery $[w, q, z]$ (option B), specified by $x < w$, $y > z$ and $p = q$. For each lottery choice set a preference relation is indicated by the subject, $[x, p, y]R[w, q, z]$ respectively. In the first choice set, the probability p is 0.1 and increases to 1 within the subsequent choice sets with a step size of 0.1 (see Figure 3). Hence, a subject should prefer option A in the first choice set and should definitely prefer option B in the last choice set since both lotteries involve sure events and the outcome of option B is higher ($x < w$). The number of choices for the less risky alternative, or the switching point from one alternative to another respectively, classifies the risk attitudes of subjects. As a consequence, it can be implied that the more choices for the less risky lottery are indicated by a subject the more risk averse the behavior of the subject is.

Option A	Option B	Expected payoff difference
1/10 of \$2.00, 9/10 of \$1.60	1/10 of \$3.85, 9/10 of \$0.10	\$1.17
2/10 of \$2.00, 8/10 of \$1.60	2/10 of \$3.85, 8/10 of \$0.10	\$0.83
3/10 of \$2.00, 7/10 of \$1.60	3/10 of \$3.85, 7/10 of \$0.10	\$0.50
4/10 of \$2.00, 6/10 of \$1.60	4/10 of \$3.85, 6/10 of \$0.10	\$0.16
5/10 of \$2.00, 5/10 of \$1.60	5/10 of \$3.85, 5/10 of \$0.10	−\$0.18
6/10 of \$2.00, 4/10 of \$1.60	6/10 of \$3.85, 4/10 of \$0.10	−\$0.51
7/10 of \$2.00, 3/10 of \$1.60	7/10 of \$3.85, 3/10 of \$0.10	−\$0.85
8/10 of \$2.00, 2/10 of \$1.60	8/10 of \$3.85, 2/10 of \$0.10	−\$1.18
9/10 of \$2.00, 1/10 of \$1.60	9/10 of \$3.85, 1/10 of \$0.10	−\$1.52
10/10 of \$2.00, 0/10 of \$1.60	10/10 of \$3.85, 0/10 of \$0.10	−\$1.85

Figure 3: Multiple lottery choice list according to Holt and Laury (2002, p. 1645, Table 1)

Chapter III

3 Incentive structures in experimental economics

In this chapter, an introduction to the methods of experimental economics will be presented. The focus is put on the reliability and validation of experimental payoff procedures which are the methodical backbone of experimental economics. Payoff mechanisms incentivize subjects in an experiment for a given experimental task and are supposed to have a significant impact on the results of experimental studies. For that reason, in experiments with reference to a revision of theoretical assumptions, an application of a distinct payoff mechanism has to be reviewed with regard to its validity for the underlying theoretical model. Hence, in experimental economics it is necessary that a payoff mechanism is incentive compatible for a distinct theory. But aside from the theoretical necessity of incentive compatibility, payoff mechanisms should further provide an incentive for a truthful response of subjects. Behavioral results of an experiment could still be valid, although incentive compatibility is not provided by an applied payoff mechanism. In this comparison, a methodological question about the applicability of payoff mechanisms arises, which will be discussed in the subsequent sections.

As for now, this chapter starts by reviewing the general motivation structure of subjects in experiments and its potential impact on task performance. Next, the concept of incentive compatibility will be introduced with reference to an application in economic experiments. In this context, it will be discussed whether incentive structures ensure truthful responses, and what would more likely provoke a truthful response in experiments. Especially the need for independent responses in experiments with a multiple choice task design yields several uncertainties as regards the reliability of the subjects' responses. These uncertainties will be discussed with reference to the design of payoff mechanisms. Therefore, an introduction to payoff mechanisms used in multiple choice task experiments will be provided followed by a general discussion about the applicability of these payoff mechanisms.

3.1 The impact of intrinsic and extrinsic motivation on task performance

In general, behavioral experiments with individuals in a laboratory are accompanied by the fact that the subjects have to perform a certain task which requires them to make either physical or cognitive efforts. In order to ensure that subjects are willing to make an appropriate effort for a given task, the experimenter must think about the motivational structure of subjects (cp. Lee, 2007). When subjects are participating in an experiment, they should generally have an intrinsic motivation for performing an experimental task (see Deci, 1975), which means that subjects are self-motivated without extrinsic incentives. However, most subjects do also expect a compensation for participating in an experiment. Subjects are willing to be rewarded for their effort, which reflects an extrinsic motivation. The question emerges whether the effort is influenced by extrinsic motivation which, as a consequence, would result in a different task performance. Task performance is the behavioral outcome of a subject in an experiment and can rely on the accuracy of a judgment, the rate of success or the closeness to an optimal solution but also on the elicitation of truthful responses in a choice task. Concerning a truthful response, there is no obvious inducement for lying when subjects are not motivated by an extrinsic incentive. According to Kahneman and Tversky (1979), subjects seem to have no specific reason for concealing their true preferences in experiments. However, a purely intrinsic motivation might not be a reliable basis for verifying experimental results, and the influence of extrinsic motivation on task performance, like financial incentives, has to be taken into account.

Financial incentives as an extrinsic motivation are broadly applied in experimental economics and have therefore been investigated with reference to task performance. In this comparison, an improvement of task performance is not always achieved and depends on the type of a task, the task complexity, and the payoff mechanism. However, the variance in behavior is supposed to be reduced by financial incentives (see for example Smith and Walker, 1993; Jenkins et al., 1998; Camerer and Hogarth, 1999; Bonner et al., 2000). Furthermore, it is presumed that subjects expand their mental effort on the task in contrast to hypothetical task situations (Smith and Walker, 1993; Wilcox, 1993; Camerer and Hogarth, 1999). In this context, Camerer and Hogarth (1999) described a 'capital-labor-production' framework which suggests that the performance of a subject is a function of cognitive abilities and cognitive effort. Financial incentives are presumed to induce more cognitive effort for performing a task, which could improve the performance. In contrast, a critique against extrinsic incentives is remarked by some psychologists who argue that extrinsic motivation can also induce a conflict for subjects, resulting in different performance outcomes since extrinsic motivation could remain in contrast to an intrinsic motivation (Lepper et al., 1973; Deci and Ryan, 1987).

However, providing extrinsic incentives for subjects in economic experiments is not only a question of motivation but rather a methodical aspect since an economic decision is usually affected by financial consequences. A financial incentive structure coinciding with the task performance is therefore more than an adequate extension for rewarding subjects for their participation. Such a conjunction ensures the reliability of experimental results, as it enables the experimenter to emulate an economic environment. In this respect, the concept of incentive compatibility is applied to financial incentives in economic experiments.

3.2 Financial incentives and incentive compatibility

The concept of incentive compatibility formally introduced by Leonid Hurwicz (1972) is a constraint in the theory of economic systems. Incentive compatibility is reflected by mechanisms applied to individuals in an economic system. Such incentive compatible mechanisms are designed to constrain individual self-interested behavior in order to achieve a desirable outcome. In economic systems, incentive compatibility induces individual behavior, which is consistent with a normative prediction or performance criterion (e.g. Nash equilibrium, Pareto-efficiency). Hence, incentive compatibility is constantly related to a specific theoretical prediction and has to be considered coherently to the underlying theory. In this context, applying incentive compatible mechanisms in experiments allows for a revision of behavioral assumption in decision theory.

In experimental economics, Vernon L. Smith (1982) has enunciated conditions for microeconomic experiments. Amongst others, he composed a condition of 'saliency' which is based on incentive compatibility. The 'salience condition' suggests a monetary reward function depending on the responses of a subject. Aside from a general motivational relevance, monetary rewards are characterized by a monotonic utility for an individual and are concerned to have a neutral value for a subject (Smith, 1976). In addition, such a reward function has to provide a significant relevance on the utility of the subject, which is articulated by Smith (1982) as the precept of dominance. It implies that the rewards have to be sufficiently large regarding the effort that has to be put on the task and the time that has to be spent in the experiment. If these two criterions are implemented, then a monetary reward function reflects an appropriate procedure for applying an incentive compatible mechanism in an economic experiment.

Furthermore, the specification of monetary reward functions is expressed in the type of a payoff mechanism applied to the participants in an experiment. A payoff mechanism defines the outcome for a subject by determining the relevance set of decisions and the exchange rate of decision consequences. With respect to this procedure, a payoff mechanism is labeled as ‘incentive compatible’, if the payoff mechanism ensures that the ‘best-response’ of a subject leads to a previously predicted behavior of a distinct theory. Therefore, incentive compatibility with regard to a theoretical assumption enables researchers to investigate the suitability of theoretical models.

In experimental practice, most researchers use the term ‘incentive compatible’ with reference to the Expected Utility Theory, which is the most prominent and most applied normative decision theory. Behavioral experiments on EUT and its axioms are often the baseline for analyzing a behavioral effect. Most payoff mechanisms are designed to be incentive compatible in relation to EUT. An additional basic purpose of incentive compatible payoff mechanisms is to elicit truthful responses according to the individual risk attitudes of subjects. But a verification of truthful responses cannot directly be provided by incentive compatibility. A general evidence that the behavior of a subject in a distinct payoff mechanism environment is driven by the given incentive structure is not possible. However, payoff mechanisms should be incentive compatible in order to preclude biasing effects due to an absence of a standardized incentive structure, but incentive compatibility does not warrant true behavioral responses.

A recent study by Cox et al. (2011) investigated several payoff mechanisms according to theoretical predictions, behavioral biases and mutual comparability. The authors raise two types of questions concerning the evaluation of payoff mechanisms: “(a) Are any of the mechanisms behaviorally unbiased under conditions in which they are theoretically incentive compatible? (b) Do they provide usable data under conditions in which they are not theoretically incentive compatible?” (Cox et al., 2011, p. 31) Both questions contribute to the discussion of incentive compatible payoff mechanisms from two points of view: (1) an incentive compatible payoff mechanism does not warrant unbiased behavior and (2) a non-incentive compatible payoff mechanism can also be appropriate for eliciting true behavior. The key question is: What are truthful responses in a lab experiment?

3.3 Inferences on truthful responses in lab experiments

First of all, behavioral observations in lab experiments should finally be valid to real world behavior. Such an implication is probably the most important conclusion that has to be drawn from experimental results, but it is also the weakest one. Lab experiments are characterized by an artificially designed and controlled environment, attended by limitations, constraints, and a simplification of economic situations. Hence, the observed behavior is limited to the experimental setting and a deduction to real world behavior has to be drawn with care. For this reason, a new research area in experimental economics has emerged over the last decades, namely field experiments (see Harrison and List, 2004; List, 2007; Levitt and List, 2009).

However, lab experiments can inform researchers about general characteristics of individual decision making behavior and are therefore appropriate indicators for real behavior. Furthermore, lab experiments can provide evidence against or implications for a theory since an observation in an experiment is nonetheless an outcome of individual decision making. According to theoretical models of individual decision making, experiments are typically focusing on distinct assumptions which are isolated from other potential influences. In this context, one purpose of incentive compatible payoff mechanisms is to ensure an independence of choices among a series of different choice settings because individual decision making theories are usually modeling single choice situations. As a consequence, the experimental baseline of modeling individual choice behavior is a single choice task decision for which a truthful response according to a realization of the decision consequences can be assumed.

Hence, an inference from single choice task experiments to real behavior is probably the most reasonable one. The behavioral results of incentivized one task experiments are therefore a reference for all kind of payoff mechanisms. But single choice experiments are limited in their expressiveness since only between-subjects analyses are possible. Furthermore, it is rather common practice in experimental economics to conduct experiments with more than one choice task for a subject. For this reason, it is worthwhile to establish payoff mechanisms for multiple choice task experiments which evoke an equivalent behavior according to an independent decision making of a single choice task.

Relating to the study of Cox et al. (2011), a comparison of multiple choice task payoff mechanisms with a single choice task experiment revealed several differences in choice behavior, which the authors attribute to different kinds of cross task contamination effects. The study of Cox et al. (2011) illustrates that a general review on methodical aspects of payoff mechanisms even for well established incentive compatible payoff mechanisms has to be further investigated. The findings of this study will subsequently be revisited and further discussed in more detail. But before that an introduction to payoff mechanisms in multiple choice task experiments as used in this work has to be considered.

3.4 Payoff mechanisms

As mentioned before, payoff mechanisms reflect the implementation of an extrinsic incentive structure for performing an experimental task. Payoff mechanisms reward a subject for participating in an experiment and, moreover, are supposed to ensure a significant effort on task performance by the subject. The design of a payoff mechanism is often related to the purpose of the experimental study and the necessity for an appropriate incentive structure. In single choice task experiments, the design alternatives for a payoff mechanism are straightforward. Here, the experimenter has the possibility to reward the subjects directly related to their decisions or to pay a predetermined amount that is independent from the decision. The first option would obviously induce real consequences for the subject, whereas the latter would not. If there is no apparent reason against a direct reward, the payoff mechanism should depend on the decision since incentive compatibility is provided for all kinds of decision theory models (cp. Cox et al., 2011). Apparent reasons against a direct reward could be unaffordable outcomes, consequences of moral conflicts (e.g. choices related to health economics) or losses.

However, single choice task experiments are not a general application in experimental economics. The majority of experimental studies comprise multiple choice tasks. According to methods for eliciting risk preferences, sequences of gamble choices are part of the methodological approach. Furthermore, multiple choice task experiments are appropriate for testing the consistency of choices and allows for a broader data analysis of individual decision making. But the application of multiple choice tasks raises the problem of repeated decisions that might influence each other. In view of repetition, the subject is not faced with a single decision and the perception of a single decision problem could be changing in the presence of further decision problems. This would violate the desirable result of independent decision making. Aside from a potential non-independent evaluation of the given choice tasks, further influences may also emerge. For example, repetition could accustom a subject to the decision environment, resulting in a kind of learning even in case of absent feedback or resulting in an appearance of boredom to the decision task (see Lee, 2007).

Thus, financial incentives in multiple choice task experiments may play a more crucial role since a considerable amount of potential influence can distort the behavioral results in these experiments. In the next section, a brief introduction to the most widely applied payoff mechanisms in multiple choice task experiments will be presented. The payoff mechanisms are considered with reference to an independent evaluation of a single choice task in a multiple choice task environment and its consequences on risk attitudes.

3.4.1 The flat-rate payoff mechanism

The flat-rate payoff mechanism rewards a subject by paying out a predetermined amount of money which is not related to the performance in the experiment. The payoff is independent from all performed decisions of the experiment and solely represents a compensation for participation. This implies that all decisions are hypothetical. The flat-rate payoff mechanism is not incentive compatible for any theoretical assumption based on the utility concept, as the outcome consequences have no influence on the utility of a subject. According to Smith (1982), the salience condition for a reward structure is not satisfied, which allows for influences of other variables. However, there is a lack of evidence that influences of other variables are identifiable and assignable to the choice task, and subjects have no obvious motive for disguising their real choice preference (Kahneman and Tversky, 1979). As a consequence, if subjects are aware of their true risk preferences in an individual choice situation and if they have no motivation for lying, then the flat-rate payoff mechanism could provide behavioral results similar to a single choice task experiment, although this mechanism is not incentive compatible.

3.4.2 The random payoff mechanism

The random payoff mechanism is probably the most frequently applied payoff mechanism in multiple choice task experiments when analyzing individual decision making behavior. At the end of an experiment, one out of all decisions a subject has performed is selected randomly. Subsequently, the randomly selected decision is realized according to its consequences, thereby determining the final reward for the subject. The procedure ensures a direct relationship between the reward and the choice task for the subject. Hence, the salience condition (Smith, 1982) is satisfied and the outcome consequences influence the utility of a subject. Furthermore, the random payoff mechanism is incentive compatible under EUT, if the independence axiom is satisfied by the decision maker. Moreover, the random payoff mechanism is also incentive compatible for non-EU theories (e.g. Cumulative Prospect Theory by Tversky and Kahneman [1992]) if the isolation hypothesis (Kahneman and Tversky, 1979) holds for a decision maker (cp. Cox et al., 2011). Thus, a subject to whom the random payoff mechanism is applied has theoretically no incentives to deviate from his or her true preference. A deviation from a truthful response would cause losses in utility. As long as a subject follows conditional rationality, the 'best-response' is an independent response from other choices in every choice task. As a result, the random payoff mechanism is supposed to induce independent choice behavior and should therefore be comparable to choice behavior of a single choice task experiment.

3.4.3 The averaged payoff mechanism

In contrast to the random payoff mechanism, the averaged payoff mechanism includes all decisions of a subject such that every realized decision outcome contributes proportionately to the final reward. At the end of an experiment, all decisions are realized independently and the averaged outcome value determines the final reward. The averaged payoff mechanism refers to several approaches for realizing all decisions in an experiment. For example, in market experiments, it is common to realize every decision in accumulation. Furthermore, approaches for realizing all decisions could also differ in the time of realization or in their independence of occurrence. In this context, there exist approaches that realize every decision sequentially after a completed choice task and also that realize all decision corresponding to one random outcome state (cp. Cox et al., 2011).

The averaged payoff mechanism satisfies the salience condition according to Smith (1982) and results in an influence on the subjects' utility. However, the averaged payoff mechanism has its shortcoming when providing incentive compatibility. Assuming that the independence axiom of EUT holds, the averaged payoff mechanism is only incentive compatible in case of risk neutrality as a result of a reduction of risk across all choices. This is mentioned as the portfolio effect, indicating that a portfolio of risky choices reduces the variance. Thus, the certainty equivalent of a risk averse and a risk seeking expected utility maximizer would be shifted toward the expected value of the risky outcomes, if choice portfolios are composed. Furthermore, the averaged payoff mechanism is only incentive compatible for non-EU theories, if the isolation hypothesis is satisfied (cp. Cox et al., 2011). As a consequence, if the assumption holds that subjects are isolating each decision, then the averaged payoff mechanism is applicable for revealing choice behavior according to a single choice task experiment.

3.4.4 Discussion on the suitability of payoff mechanisms

Comparing the above described types of payoff procedures according to their theoretical application of an independent choice task evaluation, the most appropriate payoff mechanism for providing truthful responses is apparently the random payoff mechanism. Several studies addressing the suitability of the random payoff mechanism (e.g. Starmer and Sugden, 1991; Cubitt et al., 1998; Hey and Lee, 2005) have shown that the random payoff mechanism provides an independent evaluation of choice task in multiple choice task experiments. These findings give strong support for a standard application of the random payoff mechanism in experiments on individual decision making. But more recently, some critique (see Cox et al., 2011; Harrison and Swarthout, 2012) came up on the use of the random payoff mechanism when subjects have non-expected utility preferences. Cox et al. (2011) argue that the random payoff mechanism may fail to be incentive compatible, if subjects behaved according to the reduction of the compound lotteries axiom (Holt, 1986). In this case, different choice tasks are evaluated simultaneously by the subject and the isolation of a single choice task is not given. The results of the study revealed behavioral differences between similar choices of a one task experiment and an experiment which applied the random payoff mechanism. Cox and colleagues attribute this result to a cross task contamination effect which is not directly assignable to a reduction of compound lotteries but violates the isolation hypothesis. Another potential weakness of the random payoff mechanism is the fact that, based on an increase in the number of decision trials, the probability of selecting a particular decision decreases. Thus, the importance of a single choice task is reduced and possibly neglected, if a distinct amount of decision trials is attained. Wilcox (1993) suggested that the probability of a decision being selected needs to be sufficiently large for subjects in order to exert an appropriate effort for performing the given task. Under this assumption, the incentive compatibility might fail inferentially, if the effort on the task performance was dissociated from the incentive structure.

With respect to the averaged payoff mechanism, the assumption concerning incentive compatibility is much more susceptible since this mechanism is theoretically not applicable on expected utility maximizers who are risk averse or risk seeking. However, assuming that a subject’s behavior is liable to the isolation hypothesis, the averaged payoff mechanism yields the same results as the random payoff mechanism. A study by Laury (2006) investigated differences between a random payoff procedure and an accumulated payoff procedure for small payoffs. Laury (2006) could not confirm behavioral differences for small payoffs. Hence, a potential portfolio effect might not be traceable for small payoffs since the degree of risk aversion in small payoff treatments is usually not far from risk neutrality. However, a study by Selten et al. (1999) investigated an accumulated payoff mechanism with reference to an induced risk neutral choice behavior. They did not find that risk neutrality was induced by paying out all decisions. This finding would negate the presence of the portfolio effect in multiple choice task experiments. In contrast, the study of Cox et al. (2011) reported differences between an accumulated payoff procedure and a single choice task treatment, indicating the presence of a portfolio effect. Interestingly, this divergence appears to be similar to the cross task contamination effect revealed for the random payoff mechanism. As a result, both mechanisms do not warrant the isolation hypothesis in this study. But an absence of behavioral differences between both payoff mechanisms could indicate that choice tasks are evaluated similarly.

The flat-rate payoff mechanism does not provide an appropriate incentive structure for examining individual decision making behavior in experimental economics, because the behavioral results are based on hypothetical decisions and cannot be verified concerning a deductive reliability. However, Camerer and Hogarth (1999) reviewed several experimental studies concerning financial incentives and reported that an improvement of performance through financial incentives can be achieved in judgment and routine tasks, but an effect in market experiments and gamble choice tasks remains negligible. Consequently, hypothetical results in experiments on individual decision making do provide implications on real behavior, but researchers have to be aware of a hypothetical bias. Differences between hypothetical and real choice tasks has been confirmed for high payoffs. Holt and Laury (2002) have shown that differences in risk attitudes occur in high-stakes payoff treatments, whereas for low-stakes payoffs there are no differences apparent. Holt and Laury (2002) attributed this deviation in risk attitudes to an incentive effect, because high-stakes payoffs provide higher incentives for a subject than low-stakes payoff. This further implies that the evaluation process of high payoff choices differ between hypothetical and real decisions.

In summary, a theoretical prediction of how payoff mechanisms are affecting the behavior of subjects in gamble choice tasks is essential for verifying experimental results. But, an application of a theoretically appropriate payoff mechanism does not ensure a faultless methodological framework. Researchers in experimental economics have considered theoretical and empirical approaches for identifying the 'true' payoff mechanism, but the evidence is ambiguous and a suitable solution remains absent.

On that account, this work contributes to the topic by investigating the evaluation process itself through a neurological approach. Aside from theoretical assumptions, payoff mechanisms and incentive structures are presumed to induce motivations for exerting mental effort on a given task. If so, different levels of mental effort influence cognitive processes in the brain. In addition to behavioral results, neurological observations can provide further clarifications on the processing of incentive structures. Hence, the suitability of payoff mechanisms is investigated by focusing the decision making process regarding its underlying neural mechanism through the use of the EEG technique.

Chapter IV

4 Introduction to the EEG technique

This chapter is to a great extent based on the book of Steven J. Luck (2005) "An Introduction to the Event-related Potential Technique" and on the book chapter "Event-related Brain Potentials" by Fabiani, Gratton, and Coles in "Handbook of Psychophysiology" edited by Cacioppo, Tassinary, and Berntson (2000). In this chapter, a brief introduction to the EEG technique will be presented in order to call attention to the specific characteristics of EEG experiments and their advantages and disadvantages. The purpose of introducing the general principles of EEG is to provide clarifications on how the EEG technique has to be applied, what kinds of signals are measured and how the EEG data have to be processed in order to be able to draw conclusions.

4.1 The EEG and event-related potentials

The technique of measuring brain activity on the human scalp was first described by Hans Berger (1929), who placed electrodes on the scalp of subjects in a series of experiments. By amplifying the electrical signals and plotting the changes of voltage over time, he found that these signals are related to the activity of the brain. Berger concluded that this activity refers to a huge amount of different activities of neural sources that are mounted up on the surface of the scalp. The electroencephalography (EEG) as a research method was invented.

During the next decades, the findings of Berger (1929) were investigated in more detail. It was found that a distinct pattern of the EEG signals could be obtained, if the waveforms were averaged upon an amount of distinct motor, sensory or cognitive events. The conclusion was drawn that the averaging time locked to similar events extracts a specific neural response-related to the presentation of these events. This characteristic pattern is normally covered from the overall EEG oscillation, reflecting the huge amount of simultaneously activated neural sources. By assuming that the overlaying background EEG oscillation reflects a randomly distributed error term converging to zero, the background noise diminishes by averaging and a specific neural response time locked to a distinct event can be extracted. This resulting signal pattern is mentioned as event-related potential (ERP), a term introduced by Herb Vaughan (1969). Event-related potentials are meant to occur in preparation for or in response to a discrete event. A further clarification of what an ERP is, is specified by Steven J. Luck (2005, p. 59) as "[s]calp-recorded neural activity that is generated in a given neuroanatomical module when a specific computational operation is performed."

Event-related potentials can be defined by three characteristics: (1) the time at which ERPs occur in relation to the event (latency), (2) the type of deflection of the ERP amplitude (polarity), and (3) the maximum position on the scalp (location). Hence, ERPs can be described as a function of voltage, time, and location. On the basis of these three characteristics, the labeling of the most ERP components can be ascribed to these attributes. ERP components denoted with an 'N' are related to a negative peak deflection and a denotation with 'P' refers to a positive peak deflection. The prefix letter is followed by a number that indicates either the position of the peak or the latency of its appearance. For example, an ERP component labeled as 'P300' refers to a positive peak at about 300 milliseconds (ms) after stimulus onset. Interestingly, a component labeled as 'P3' reflects the same P300 component but in this case refers to the third positive peak of the ERP waveform after stimulus onset. In many cases, the number labels reflecting the latency are equal to the number labels reflecting the peak position (e.g. N1 = N100, P1 = P100, N2 = N200, P3 = P300). Due to the fact that the latency of some components varies according to the stimulus type, the labeling with reference to the peak position is used more frequently. Furthermore, some labels directly refer to the occurrence of the ERP component in relation to an experimental condition or response (e.g. ERN = error-related negativity, MMN = mismatch negativity).

Moreover, an event-related potential can be evoked by endogenous and exogenous factors. An exogenously evoked ERP is directly related to a reaction on the character of a stimulus. Thus, the occurrence of the ERP is obligatorily modulated by different shapes of a stimulus (e.g. the intensity of an acoustic tone) and can therefore be ascribed as a stimulus sensor. Such exogenously evoked potentials are typically so called 'early components', occurring within 100 ms after stimulus presentation, and are assumed to represent the sensory processing of an external signal in the brain. Endogenously evoked ERPs are generally related to internal processes, as for example information processing, and can further occur in the absence of an external stimulus. These potentials generally occur after 300 ms and reflect evaluative brain processes that require cognitive capacities. Hence, endogenously evoked potentials are of great interest when examining cognitive functions in the brain. Some ERP components, like several negativities between 100 ms and 300 ms, cannot directly be assigned to such a categorization and are considered as mesogenous.

Figure 4, adopted from Luck (2005, p. 8, fig. 1.1), briefly demonstrates how event-related potentials are derived from an EEG experiment. The figure depicts the process of extracting event-related potentials for two stimulus types in an EEG experiment. Part A illustrates the experimental setup, indicating a subject in front of a computer screen. Stimuli are presented for the subject on the screen, while brain activity is recorded simultaneously through an electrode placed on the scalp of the subject. Part B of the figure shows the spontaneous EEG waveform recorded at the Pz electrode. The time ranges at which a distinct stimulus type (‘X’ or ‘O’) was presented are marked in the timeline. These time epochs are extracted from the spontaneous EEG (see part C on the left-hand side) and further averaged according to ‘X’ or ‘O’ stimulus trials. The result of the averaging is presented in part C on the right-hand side. According to both stimulus types, two different illustrations of the event-related potentials at the Pz electrode are presented. Here, it is worth mentioning that event-related potentials are commonly displayed upside-down, namely negative deflections are placed upward and positive deflections downward.

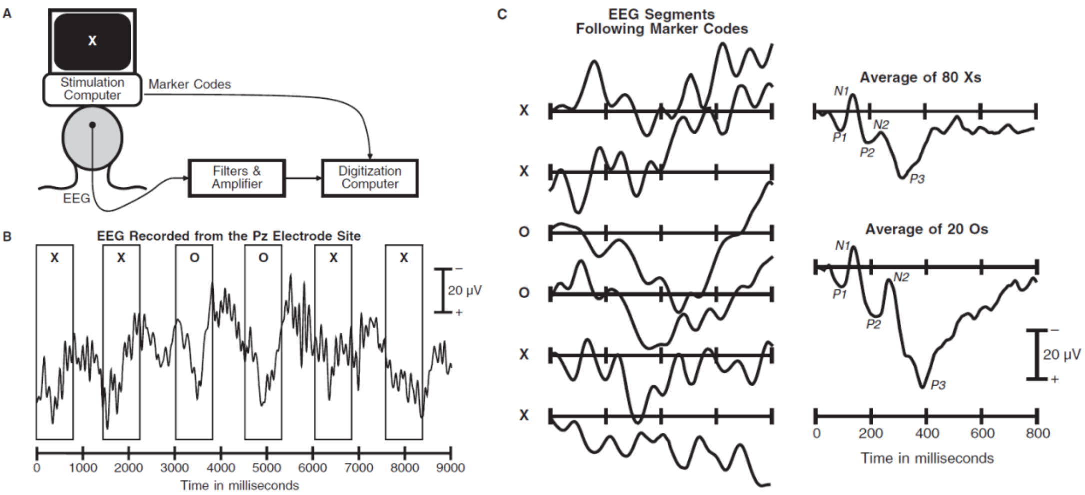

Figure 4: Procedure of ERP extraction (cp. Luck, 2005, p. 8, fig. 1.1)

4.2 The neural source of ERPs

Although the understanding of what ERPs are reflecting is prevalent, the identification of the neural sources remains challenging. ERPs are generally assumed to reflect the cumulative activity of postsynaptic potentials of a large number of neurons which are synchronously activated (see Allison et al., 1986). Since the electrical activity of a single neuron is very small, the EEG recording from the scalp returns an integrated activity of a large number of neurons. Thus, it is only possible to record a subset of the brain activity from the scalp in which single neuron signals are frequently overlaid from other sources. A direct localization of the neural source of an EEG signal is not possible since the recorded activity refers to a potentially indefinite number of neural generators that are activated simultaneously. Furthermore, each neural generator varies in amplitude, orientation of the electric field and the location in the brain. Hence, a source localization through an inverse deduction of the recorded activity from each electrode lacks in providing a unique solution. Nonetheless, researchers have tried to localize ERP components in the brain through invasive and noninvasive approaches. The invasive approach tries to deduce the source of an ERP either by placing electrodes directly into the brain of humans or animals or by analyzing lesion data. Noninvasive approaches usually draw conclusions by performing specific source analysis algorithms or combine ERP results with other neuroimaging techniques which have a higher spatial resolution (e.g. functional magnetic resonance imaging).

4.3 Advantages and disadvantages of the EEG technique

As mentioned before, EEG recordings can provide detailed information about the change of voltage distribution on the scalp over a certain time period. Eliciting event-related potentials in relation to an experimental paradigm allows for an observation of differences in brain activity over time. This is potentially the most powerful advantage of the EEG technique. Furthermore, ERPs can additionally provide information about stimulus processing in the absence of a behavioral response. The EEG technique is able to discover processes which are not observable in behavioral data.

With respect to other neuroimaging techniques, EEG with its very high temporal resolution is therefore suitable for a temporal analysis of information processing in the brain. Functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) have a considerably smaller temporal resolution, which limits conclusions concerning the temporal relationship of brain functions. In contrast, the EEG technique performs quite poorly in locating the source of a neural process. As discussed before, source localization through EEG information is only possible by approximation algorithms. In this comparison, fMRI and PET outperforms EEGs, because of the very high spatial resolution. These techniques are therefore suitable for locating neural sources.

A general disadvantage of all neuroimaging techniques is the lack of interpretation. With reference to the EEG technique, the knowledge of an ERP component and its functional relationship to brain processes has been derived from a huge amount of EEG studies addressing detailed questions on stimulus processing or information processing. Thus, all further findings and conclusions are based on previous deductions. Consequently, a direct functional significance is not that explicit as behavioral evidence would draw. Furthermore, in every EEG experiment, a large number of stimulus trials are necessary in order to reveal the very small signal occurrence of an ERP. As a consequence, in relation to experiments addressing economic questions, only multiple choice task experiments are possible.

4.4 ERP analysis

In this part, a short overview regarding the procedure of the ERP analysis will be presented. Here, the main purpose is to provide a basic understanding of EEG data analysis. Subsequently, different steps of deriving event-related potentials and main issues of processing EEG data are discussed.

4.4.1 EEG recording

The brain activity on the scalp of humans is usually recorded with an electrode cap, containing a number of electrodes placed according to a standardized, conventional normalization. This normalization ensures that standardized electrode positions are recording the same scalp area over different experiments. As a result, a standardized electrode placement allows for a comparability of experimental results. One standardized electrode position convention is the International 10-20 system (Jasper, 1958) in which 29 electrode positions are placed according to a relative distance to each other. This system has also several expanded versions (see Nuwer, 1987) for which one example is the 10-10 system with 61 electrode positions introduced by Chatrian et al. (1985). According to the standardized electrode positions, single electrodes are further labeled based on unified denotations. The denotation follows across the basic labeling of scalp areas which are in general frontal, central, parietal, occipital, and temporal electrode sites. Such a general fragmentation of the scalp area is presented in Figure 5 for an electrode cap with 61 electrode positions.

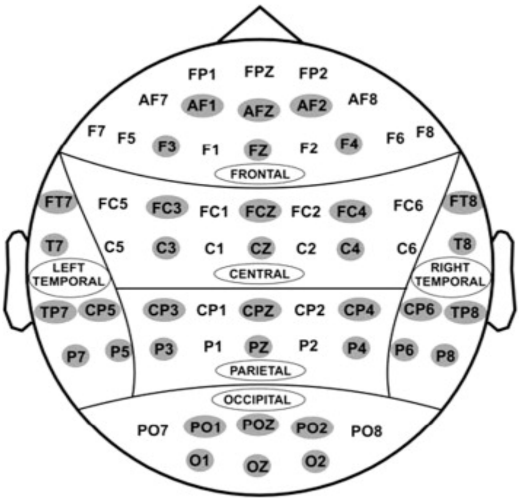

Figure 5: Example of an electrode placement with 61 electrode positions adopted from Kamarajan et al. (2010, p. 579, fig. 8)

During the EEG recording, the analog EEG signals are passed to an amplifying and filtering system and subsequently converted to digital signals by sampling them at a high frequency of at least 100 Hz. The EEG recordings in this work are sampled on a frequency of 250 Hz.

4.4.2 Artifacts and artifact rejection

Artifacts are one of the main error sources in the analysis of ERPs. The electrical signals recorded at the electrodes are influenced by sources that are not located in the brain. Eye movements, eye blinks, activity from muscles in the head or neck as well as heart beats, or the pulse respectively, are sources of electrical activity that can interfere with the small EEG activity. For that reason, it is important to apply measures for avoiding artifact-based biases in the data. First of all, a careful experimental setup accompanied by an instruction of the subject for a clean data recording is probably the most important issue in this context. Subsequently, in the procedure of data analysis, the EEG data have to be checked for samples with artifacts. Artifacts can either be discarded from the sample or filtered from the data. Furthermore, several EEG data correction algorithms exist (see Gratton et al., 1998; Joyce et al., 2004) which can be applied in order to adjust artifacts.

4.4.3 Averaging and filtering

As mentioned in the preceding section, deriving ERP components from the background EEG is achieved by averaging an amount of samples time-locked to repeating events. The small ERP signals are uncovered from the background EEG by reducing the signal-to-noise ratio. The background EEG noise is assumed to be randomly distributed among each sample so that the error term of the noise converges to zero by averaging a high amount of samples. The signal-to-noise ratio will increase by the square root of the number of included trials for averaging. In order to achieve an appropriate signal-to-noise ratio, it is common to integrate at least 20 stimulus trials for averaging ERPs in one 'bin'. In this context, a 'bin' denotes a distinct collection of stimulus trials that is arranged for the ERP analysis.

Moreover, an enhancement of the signal-to-noise ratio can be realized through a further filtering of the derived ERP data. For example, endogenous ERP components typically have a frequency range from 0.5 Hz to 20 Hz, which allows for filtering noise with a frequency different from the target signal. For example, muscle activity that occurs in a frequency spectrum of around 70 Hz. This is achieved by applying a low pass or a high pass filter to the ERP data. But filtering should be handled with care since an ERP component will be distorted, if frequencies of interests are excluded. Thus, applying the right filter depends on the band pass in which the investigated ERP component is located.

4.4.4 Statistical analysis

During statistical analysis, a huge amount of non-independent data must be handled. Aside from an identification of significant differences in the data, the main purpose is to reduce the experiment-wise error. The experiment-wise error increases the more statistical tests are performed. With a large number of tests it is consequently more likely to observe a p-value smaller than 0.05. The standard approach in ERP data analysis is to perform repeated measures analyses of variance (ANOVAs). Repeated measures ANOVAs are able to identify main effects and further factor interactions in a crossed factorial design, integrating plenty of non-independent observations. For analyzing an ERP component, a group of electrodes around the scalp location of an ERP is used, because using electrode sites that are absent from the component location or in presence of another component may add noise to the analysis and can bias the results. The voltage at the electrode sites of the ERP component is analyzed within a certain time range, indicating the average peak amplitude. In case of significant main effects or further interactions revealed by an ANOVA, a final verification of the uncovered effects can be provided by performing electrode-based t-tests.

In this work, the statistical results of the performed ANOVAs will be reported with the degrees of freedom, the F-values, and the corresponding p-values. These values will always be indicated as Greenhouse-Geisser corrected. Furthermore, equivalent information will also be provided for the electrode-based t-tests where the corresponding T-values will be reported.

4.5 A selection of ERP components

In this section, a brief overview on the key ERP components concerned with this work will be given. The occurrence of ERPs is always related to underlying brain processes which are activated by the presence or absence of a distinct stimulus or response based on the experimental task. ERPs can be assorted into motor-driven, sensory and cognitive ERP components. Additionally, ERPs are investigated concerning the type of a stimulus (stimulus-locked) or concerning the type of a response (response-locked). This review particularly introduces ERP components related to cognitive functions since ERP components that are reflecting cognitive processes are of major interest in this work. Subsequently, two stimulus-locked ERP components, the P300 and the N200, and one response-locked ERP, the ERN, will be introduced.

4.5.1 The P300

The P300 component is probably the most frequently investigated endogenously evoked ERP component because of its very robust occurrence. In general, the P300 represents a group of positive deflections peaking at about 300 to 450 ms stimulus onset with a central-parietal scalp maximum. Although the P300 has been widely investigated, there is still no clear consensus about its underlying neural or cognitive processes. It is assumed that the P300 results from multiple activated neural sources located in different cortical and subcortical areas (see Johnson, 1986, 1988, 1993; McCarthy et al., 1997). The P300 component can be distinguished between a more frontal peaking P3a and a parietal P3b component (Squires et al., 1975).

The P3a component is assumed to appear in case of novel stimuli presentation and is therefore also labeled as ‘novelty P3’. In a study of Courchesne et al. (1975), it was found that a more frontally located P300 component is elicited when unexpected stimuli or from the experimental task deviating stimuli are presented to the subjects. The appearance of the P3a diminishes when the same stimulus is presented several times. Fabiani and Friedman (1995) suggested that the occurrence of the novelty P3 is related to an orienting function with regard to the original task goal. However, it still remains open whether the P3a and the P3b subcomponent belong to the same component (Pritchard, 1981) or whether they reflect different components (Donchin and Coles, 1988).

The P3b component in particular has been considered as being the ‘classic P300’, and up to now its functional significance has not been undoubtedly resolved. The P300 was found to be sensitive to a subjective stimulus probability (Duncan-Johnson and Donchin, 1977; Squires et al., 1976). The amplitude of the P300 increases for task-defined stimuli that have a smaller probability of occurrence.

Donchin (1979) presumed that the P300 modulation is reflected by stimulus evaluation and categorization processes. Furthermore, Donchin (1981) stated that the P300 could reflect a 'context updating' process regarding the experimental task. Such a process is assumed to be related to the updating of an environmental model or of the context in working memory, which would influence the current decision making process as well as the processing of future events. Although this context updating hypothesis is widely spread and accepted, the model has not been doubtlessly verified and some researchers have proposed alternative hypotheses of the functional significance of the P300 (see Desmedt, 1980; Rösler, 1983; Verleger, 1988). More recently, Verleger et al. (2005) suggested a mediating process between a perceptual stimulus analysis and a response initiation that is reflected by the P3b component. Moreover, Kok (2001) proposed that the P300 reflects an event categorization process indicated by smaller P300 amplitudes for stimuli that are difficult to discriminate. In this context, the P300 represents a process that evaluates a stimulus according to a match or a mismatch of an internal representation of a specific category. Furthermore, in a study of Isreal et al. (1980) it was found that P300 amplitudes are larger for tasks in which the subjects put more effort, which was considered to reflect a measurement of resource allocation. In summary, the P3b component can be related to evaluative processes of stimulus categorization or response selection and execution (see Luck, 1998).

With reference to this work, an analysis of the P300, the P3b subcomponent respectively, is appropriate for investigating the evaluation processes of different types of stimuli. Stimuli in lottery choice tasks concerning the elicitation of risk attitudes can be differentiated by the degree of risk. Different levels of risk may lead to different resource allocation processes during decision making. Furthermore, stimuli of similar choice tasks may be perceived differently by the subjects in case of different incentive structures. Hence, the underlying payoff mechanism of an experimental choice task can lead to a stimulus categorization process that is different from other payoff mechanisms.

4.5.2 The N200

The N200 component is an ERP component characterized by a negative maximum peaking at about 200 to 350 ms after stimulus presentation at fronto-central electrode sites. The functional significance of the N200 differs according to the experimental manipulation. Therefore, the N200 can be differentiated by three types: (1) an anterior located N2a component elicited for task-irrelevant but mismatched auditory stimuli, (2) an N2b component that is located at fronto-central electrode sites elicited for response conflicts and response inhibition, and (3) an N2pc component with a posterior scalp distribution elicited for attended visual stimuli selection. All three subcomponents are assumed to have different neural source generators.

The N2a component is labeled as 'mismatch negativity' (MMN), because its modulation is generated by the presentation of a diverging auditory stimulus in a sequence of frequently presented auditory stimuli (see Näätänen, 1992). The occurrence of the auditory stimuli is task irrelevant for the subject so that the modulation of the N200 in relation to these stimuli is assumed to reflect an environmental mismatch detector. The mismatch negativity was firstly described by Näätänen et al. (1978) and is presumably generated in auditory cortical brain areas.

The N2b component refers to the type of N200 that is observable in experiments regarding the incongruity of stimuli (Gehring et al., 1992; Wendt et al., 2007) in which larger N200 amplitude are elicited for incongruent stimuli in contrast to congruent stimuli. It is assumed that incongruent stimuli evoke higher action control conflicts for a subject. Furthermore, these N200 amplitudes are also increased in response inhibition task (Pfefferbaum et al., 1985), indicating that the N200 is sensitive to response control. This type of N200 is believed to be involved in a conflict monitoring system and is therefore a part of cognitive control functions (see Folstein and van Petten, 2008). A study by van Veen and Carter (2002a) found the location of the neural source in the anterior cingulate cortex (ACC).

The N2pc component, named by Luck and Hillyard (1994), is supposed to reflect attention to a visual target stimulus among a group of non-targets (Luck et al., 1997). The N2pc component appears to be posterior and located in contralateral relation to the target stimulus. A contralateral effect implies that a visual target stimulus on the right-hand side evokes an N2pc on the left-hand brain hemisphere. It is presumed that the neural source generator of this component is located in the visual cortex.

An analysis of the N200 component in this work is referred to the N2b subcomponent. The N2b subcomponent and its relation to cognitive control functions is an appropriate component for investigating the decision making process with the EEG technique. This subcomponent provides information about the level of conflict during decision making. An analysis of different levels of conflict evoked by different incentive structures allows for inferences on the characteristics of distinct payoff mechanisms in multiple choice task experiments. For that reason, the modulation of the N200 in relation to cognitive control functions is an essential part of this work and will therefore be discussed in more detail in the next chapter.

4.5.3 The ERN

The error-related negativity (ERN) is a response-locked ERP component. The ERN was first described by Falkenstein et al. (1990) and Gehring et al. (1993) as a negative deflection at fronto-central electrode sites peaking around 50-100 ms after an erroneous response has been occurred. Based on these findings, the ERN is supposed to reflect an error detecting process. However, further research (e.g. Botvinick et al., 2004; van Veen et al., 2004) has suggested that the neural mechanisms underlying the ERN cannot only be described as a pure error detection mechanism. Moreover, it is assumed that the ERN refers to a more general system that is monitoring responses and response conflicts between intended and performed responses. In addition, a study of Hajcak et al. (2005) proposed that the ERN component could further be related to a motivational significance of a task.

Furthermore, an ERN-like negative potential was also observed for giving negative feedback stimuli followed by an incorrect response (Gehring and Willoughby, 2002) as well as for observing someone else making an error (van Schie et al., 2004). These findings strengthen the hypothesis that the ERN reflects a process of error monitoring. Since the neural source of the ERN was also found to be located in the ACC (Dehaene et al., 1994; van Veen and Carter, 2002a), it is proposed that the ERN and the N200 refer to the same neural process that can be assigned to a conflict monitoring system.

The ERN component, as an indicator for response conflicts, is also appropriate for analyzing cognitive control functions in connection with decision making. An analysis of this component can provide inferences on the correctness of decisions. Different levels of response conflicts would indicate the relevance and importance of decisions when error-like choices are detected by the subjects. In this context, the presence of risk in lottery choice tasks can be investigated with reference to such error-like choices. Comparing risky and riskless choice task situations would allow for an analysis of the impact of risk on response conflicts.

Chapter V

5 The N200 and cognitive control

The present chapter introduces the N200 component as an appropriate indicator for investigating individual decision making behavior with reference to differences in neural information processing. The decision making process can be ascribed to the cognitive abilities of individuals and to neural functions of cognitive control in particular. Therefore, components that are reflecting processes of cognitive control during decision making are of interest for analyzing individual decision making behavior in a neurological approach. This chapter describes how the N200 component is related to processes of cognitive control and conflict monitoring. For that reason, a model of conflict monitoring is introduced with reference to the latent construct of cognitive control. A brief overview on how conflicts are induced in neuroimaging studies will be provided. Results of studies on the N200 in relation to these paradigms will be described. Consequently, the N200 will be discussed in conjunction to the model of conflict monitoring.

5.1 Cognitive control and the conflict monitoring hypothesis

Human beings have created the ability to adapt their behavior to varying environmental demands in a most flexible manner. Aside from automatic or routine processes of life regulation, humans are able to detect and to evaluate environmental relationships and to identify appropriate approaches for solving a problem. Performing mental operations is one key attribute of human behavior. The capability of adapting and adjusting behavior in relation to an internal goal and implementing a task strategy accordingly refers to a cluster of cognitive processes which is commonly described as ‘cognitive control’. In cognitive neuroscience, the latent construct ‘cognitive control’ is used to describe the mechanisms of information processing and decision making in the human brain. Several researchers have enunciated approaches for modeling these processes of cognitive control (see Norman and Shallice, 1980; Schneider and Detweiler, 1987; Baddeley and Della Sala, 1996; Meyer and Kieras, 1997).

Botvinick et al. (2001) propose a model of conflict monitoring regarding the occurrence of behavioral conflicts. They argue that information processing is attended by a function called ‘conflict monitoring’. Botvinick and colleagues describe a system which is sensitive to the occurrence of conflicts and which can be attributed to an evaluative component during information processing. Such an evaluative component is supposed to assess current demands and to result in an adjustment of executive processes. During information processing in which control is required, it can be implied that a demand for higher control is indicated by a higher level of conflict. Thus, the occurrence of conflicts is directly linked to processes of cognitive control. The hypothesis regarding conflict monitoring postulates (Botvinick et al., 2001, p. 625) that “[t]he conflict monitoring system first evaluates current levels of conflict, then passes this information on to centers responsible for control, triggering them to adjust the strength of their influence on processing.” Furthermore, it is presumed that such a function of conflict monitoring is located in the frontal lobe of the human brain and that the anterior cingulate cortex in particular plays a key role in this process. The ACC is considered to map a regulative system which is responsible for resolving a conflict rather than simply detecting a conflict. It is assumed that the ACC activation reflects a last-minute conflict resolution in a two stage control system for which a general anticipation of demanding activities already exists. In order to emphasize these assumptions, the work of Botvinick et al. (2001) discusses several studies regarding the ACC and its connection to cognitive processes, which will be considered later in this chapter.

Before that, the question of how processes of cognitive control in relation to potential response conflicts are identified and investigated in neuroimaging studies needs to be discussed. Experiments on conflicts in information processing are typically designed through interference tasks or response inhibition tasks in which a conflict for a subject is usually induced through incongruities between stimuli and prepotent responses. These paradigms are expected to evoke errors by the subjects and should therefore reveal brain areas or components of brain potentials related to response conflicts. In the next section, a brief introduction to the mainly used paradigms concerning these experiments will be given.

5.2 Experimental paradigms on response conflicts

Go/No-Go task

In the go/no-go task, subjects are instructed to give a response on a certain stimulus but to inhibit a response when another, different stimulus is presented. A correct response will be given, if the go-stimulus is responded and the no-go-stimulus is not. A prepotent response is induced through a more frequent presentation of the go-stimulus. If a no-go trial is followed by a go trial, a higher control conflict for the subject is expected, resulting in higher response time rates. The go/no-go task is used to measure stimulus attention and response control.

Eriksen flanker task

The Eriksen flanker task is similar to the go/no-go task and also refers to the category of response inhibition task. The task was developed by Eriksen and Eriksen (1974) and requests a subject to respond to a central letter of a sequence of five or seven letters. The central letter reflects the target stimulus whereas the other letters are non-targets. Non-targets are either equal to the target (e.g. HHHHH), which represents a congruent stimulus trial, or unequal to the target (e.g. SSHSS), which represents an incongruent stimulus trial. In this context, it is worth mentioning that targets and non-targets are not only restricted to letters but also to other types of signals or symbols, for example the direction of arrows (e.g. <<><<). However, for the incongruent stimulus trials, a higher response conflict is expected, which generally results in higher response times and increased error rates.

Stroop task

The Stroop task refers to the Stroop effect described by John Ridley Stroop (1935). He reported that the response times for naming a written color will be higher, if the ink color of the word is different to the name of the color. This interference task is widely used in experimental psychology when stimulus and response conflicts are investigated. Once again, the incongruence of the color name and the color ink obviously evokes a higher conflict, resulting in higher reaction times and increased error rates.

5.3 N200 modulations in response inhibition tasks

The role of the N200 component in Eriksen flanker and go/no-go experiments has been broadly investigated in the past decades. The N200 appears to be sensitive to response control when task conflicts are higher. In general, larger N200 amplitudes are revealed for incongruent or incompatible stimuli trials, indicating a higher action control conflict for the subjects.

In go/no-go tasks the N200 amplitude is larger for no-go trials and in case of withholding a prepotent response (see Pfefferbaum et al., 1985; Bruin and Wijers, 2002). A study by Jodo and Kayama (1992) showed that the no-go N200 was also increased when time pressure was applied. Furthermore, Falkenstein et al. (1999) elicited a larger N200 amplitude in no-go trials for subjects with smaller false alarm rates. These results previously implied that the N200 is connected with processes of response inhibition. However, further findings of other studies suggest that this interpretation has to be differentiated in more detail. A study of Bruin et al. (2001) investigated the N200 in relation to response priming and found an absence of the N200 modulation for this process. As a result, they conclude that the N200 modulation cannot be related to response inhibition. In addition, Nieuwenhuis et al. (2003) reported an apparent N200 for low-frequency no-go trials as well as for low-frequency go trials. Such a finding would further reject the implication that the N200 is modulated by a pure response inhibition process. Nieuwenhuis et al. (2003) presumed that an arising conflict between a response inhibition and a response execution could be responsible for the N200 modulation in go/no-go tasks. This supposition implicitly associates the N200 modulation in go/no-go tasks to conflict processing and therefore to a process related to cognitive control. Moreover, a direct link to the conflict monitoring hypothesis of Botvinick et al. (2001) was further drawn in the study of Donkers and van Boxtel (2004) in which the authors argued that the N200 in go/no-go tasks is reflected by conflict monitoring and not by response inhibition.

In Eriksen flanker tasks, apparent N200 amplitudes can be observed for incongruent flankers in contrast to congruent flankers (see Gehring et al., 1992; Yeung et al., 2004; Wendt et al., 2007), indicating that processes of response control are reflected by the N200 component. In a flanker study of Kopp et al. (1996) it is found that the N200 is largest for treatment conditions in which the conflict is highest. This finding suggests that the N200 modulation is not only driven by response control but also influenced by evaluative conflicts regarding a response execution. Additionally, Yeung et al. (2004) reported that the N200 is modulated on correct response trials, indicating a more general conflict monitoring process. The assumption that the N200 is modulated by a response conflict was further enhanced in the flanker study of Wendt et al. (2007) in which an influence on the N200 was also observed for stimulus conflicts. Hence, the findings of these studies suggest that the modulation of the N200 in interference tasks can be related to conflict processing for which the N200 component seems to be an indicator for the level of conflict. The N200 component in conjunction with a potential conflict monitoring system will be discussed next.

5.4 The N200 as an integrated part of a conflict monitoring system

A broad review of N200 studies concerning the influence of cognitive control processes on the N200 modulation was given by Folstein and van Petten (2008), where the authors contributed to the discussion of whether the N200 component reflects processes of conflict monitoring. Based on reviews of previous studies, Folstein and van Petten (2008) identified a control-related N200 subcomponent which is related to cognitive control mechanisms like response inhibition, response conflict, and error monitoring. The authors discussed potential relationships of the control-related N200 to functions of the anterior cingulate cortex and concluded that the control-related N200 reflects processes regarding cognitive control and that the component can be ascribed to a more complex conflict monitoring system. Hence, the N200 component can be assumed to be part of the conflict monitoring system as suggested by Botvinick et al. (2001) in which the ACC represents a regulative system responsible for conflict resolution.

In this respect, a dipole source localization performed by van Veen and Carter (2002a) in fact detected the source of the N200 component in the anterior cingulate cortex. Additionally, several investigations (see Kopp et al., 1996; van Veen and Carter, 2002a; van Veen and Carter, 2002b) have shown that the stimulus-locked N200 and the response-locked error-related negativity (ERN) represent the same cortical mechanism and that both components are associated with the anterior cingulate cortex (see Figure 6).

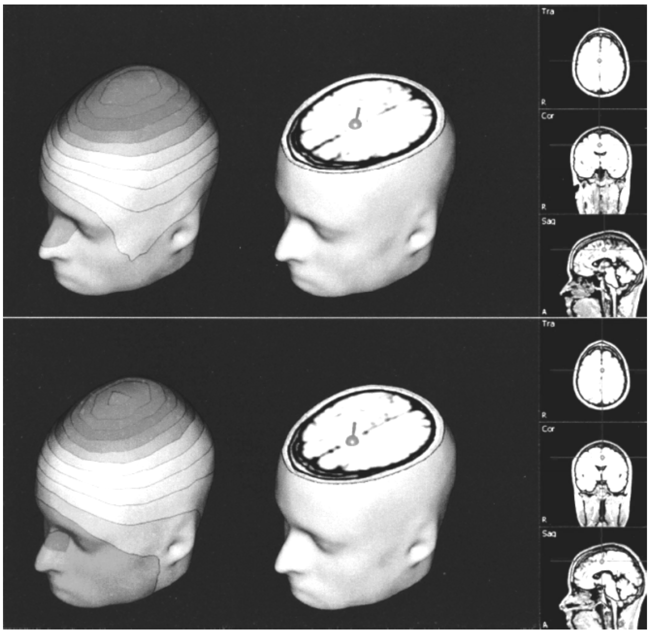

Figure 6: Dipole source localization of the N200 (top) and the ERN (bottom) in the anterior cingulate cortex as detected by van Veen and Carter (2002a, p. 579, fig. 3)

Van Veen and Carter (2002a) suggested that this relationship in combination with the characteristic of the ACC to be sensitive to the occurrence of conflicts reflects a conflict monitor during information processing. Hence, both ERP components are apparently reflecting similar processes of monitoring conflicts but at different points in time during the decision making process. Consequently, the connection of the control-related N200 with the ACC requires a brief review on the function of the ACC and its role regarding cognitive control and conflict monitoring in particular.

5.5 The anterior cingulate cortex and conflict monitoring

The model of conflict monitoring by Botvinick et al. (2001) suggests that the anterior cingulate cortex contributes to cognitive control by monitoring conflicts during information processing. As it was discussed in earlier studies (e.g. D'Esposito et al., 1995; Posner and DiGirolamo, 1998), the ACC is assumed to be engaged in processes of cognitive control, as for instance in learning and memory or language tasks (Paus et al., 1998). Furthermore, the ACC is also connected with brain areas that are assigned to play an essential role in cognitive control. Connections are existent to the prefrontal cortex, an area that is involved in executive processes (see Cohen et al., 1996), and neuroimaging studies (e.g. Braver et al., 1997; Carter et al., 1995; Posner et al., 1988) found a functional link between the prefrontal cortex and the ACC.

Concerning experiments on interference task, ACC activation is found to be higher for incongruent stimuli in Stroop tasks (Pardo et al., 1990; Carter et al., 1995; Bush et al., 1998) as well as in go/no-go tasks for the no-go condition (Casey et al., 1997; Kawashima et al., 1996). These findings imply that the ACC is highly involved when conflicts have to be resolved. Further results of an fMRI flanker study by van Veen et al. (2001) showed that the ACC is activated in response-based conflicts. Moreover and aside from a pure response conflict interpretation, the authors of this study suggested that the ACC is particularly sensitive to conflicts occurring between different goal states, plans, or rewards. Such a deduction directly links the ACC activation to a cognitive evaluation process during decision making.

In summary, the findings of the aforementioned neuroimaging studies (see also Carter et al., 1998; Botvinick et al., 1999; MacDonald et al., 2000) provide evidence that supports the hypothesis of conflict monitoring and that assigns a central role of this process to the anterior cingulate cortex. But for all that, the source of conflicts during information processing has to be considered differently and might correspond to different phases in the decision making process. This is also indicated by the occurrence of the N200 and the ERN which could represent different types of conflicts. As a consequence, distinguishing ACC activation directly from conflicts of stimulus encoding, target detection, response selection or response execution remains challenging and refers to the structure of the experimental task. The model of conflict monitoring rather proposes a mechanism of how conflicts are proceeded to be resolved in the brain. However, it has been shown that the N200 is suitable for investigating decision making processes with respect to different levels of conflict.

5.6 Implications for choice experiments in experimental economics

The concept of cognitive control and the conflict monitoring hypothesis seem to be an appropriate approach for investigating decision making processes in the brain. According to this neurological evidence, an implementation to research questions concerning the evaluation of economic choice tasks can be applied. The modulation of the N200 and the ERN as well as the activation of the ACC can be examined through EEG, PET or fMRI. Different occurrences of these components in contrast to specific choice tasks situations can provide further understanding of how decision making is performed with regard to the level of conflict resolution. The application of neuroimaging techniques in combination with the model of conflict monitoring can serve for reviewing theoretical assumptions, axioms, or incentivized goal systems in decision making theory when different levels of decision conflicts are predictable or reasonable.

In this work, the EEG technique is applied to investigate modulations of the N200 component in lottery choice task. The observation of different levels of conflict can shed light on the evaluation of choice alternatives in different choice task situations. For example, the level of conflict should be higher for a subject in case of indifference. Indifference itself means that a subject has no preference on a distinct choice alternative among all other choice alternatives. But most lottery choice experiments impose the subject to give a response, which should therefore result in an increased conflict situation for the subject. Thus, the behavioral evidence for indifferent choices should also be observable in the N200 modulation. This example is rather plausible and not the driving research question of this work. But it should emphasize how the model of conflict monitoring can be combined with research questions in experimental economics. In the following EEG studies, the modulation of the N200 will be used to provide neurological inferences on the decision making process with reference to an application of different incentive structures in economic experiments.

Chapter VI

6 The hypothetical bias

The discussion about the suitability of payoff mechanisms (see section 3.4.4) has shown that the application of payoff mechanisms in experimental economics is attended by potentially distorting influences on the individual decision making behavior. Basically, payoff mechanisms are extrinsic motivational incentives which have to ensure an incentivized experimental structure for a truthful response of subjects according to their real preferences. In this context, the concept of incentive compatibility provides a theoretical validation of payoff mechanisms in relation to a distinct theory. However, as discussed before, such a theoretical validation cannot warrant coherent behavior of subjects in relation to the applied incentive structure. Certainly, payoff mechanisms can be presumed to affect individual decision making behavior but not necessarily according to a theoretical assumption. In this respect, if researchers are interested in identifying truthful responses of subjects with reference to their real preferences, then payoff mechanisms may be reconsidered detached from theory and analyzed in relation to an impact on the evaluation process during decision making. An investigation of the evaluation process through neuroimaging techniques could provide inferences toward the characteristic of how a decision is performed in the brain. The truthfulness as well as the seriousness of responses may be reflected by eliciting a higher level of mental effort on a choice task or by evoking a smaller degree of conflict for a choice task. Therefore, cognitive models of information processing, as for instance the aforementioned model of conflict monitoring, can be used to enunciate suppositions in relation to the revelation of real preferences concerning a distinct choice task situation. Hence, the suitability of payoff mechanisms can be approached through a neuroscientific investigation of the decision making process.

As mentioned previously, conflict monitoring is assumed to represent an important neural process during decision making. In this context, the N200 component has been introduced as an indicator for an action control conflict in the evaluation process for a decision. Hence, investigating the N200 in relation to choice tasks of individual decision making allows for a direct examination of the evaluation process. As a consequence, assumptions and hypotheses for a different modulation of the N200 can be articulated in relation to the application of a distinct incentive structure reflected by a payoff mechanism.

The present chapter discusses the modulation of the N200 in hypothetical and real payoff choices. According to the introduction of payoff mechanisms, the flat-rate payoff mechanism and the random payoff mechanism are applied in an EEG experiment with a lottery choice task paradigm. The subsequent analysis ties up to the discussion on the reliability of hypothetical choices as well as the influence of monetary incentives in economic experiments and provides additional, neural-based evidence for the existence of a hypothetical bias. As a result, the flat-rate payoff mechanism has to be categorized as inappropriate for revealing truthful responses and real preferences.

Subsequently, an introduction to the hypothetical bias and a research hypothesis concerning a modulation of the N200 is presented. The EEG study is described and a presentation of the results is provided followed by a discussion concerning this topic. These parts are based on a working paper (Morgenstern et al., 2013a) which was developed in a joint work with Marcus Heldmann (Department of Neurology at the University of Lübeck) and Bodo Vogt (Faculty of Economics and Management at the University of Magdeburg). Additionally, the current chapter also provides an additional data analysis of the EEG study concerning the choice task reaction times and concerning a modulation of the P300 component. This additional material was not considered in the working paper of Morgenstern et al. (2013a).

6.1 Introduction[1]

An open question in experimental economics is how to verify observed behavior from an experiment in relation to behavior in the real world. It is a general goal in economic research to reduce biasing effects of a lab environment and its specific circumstances. One aspect in this discussion is the reward structure for decisions in experiments. In this respect, Smith (1982) has established the condition of "saliency" for microeconomic experiments, suggesting a monetary reward function according to the responses of subjects. This "salience condition" provides the basis for incentive-compatible reward structures, and ensures reliability of behavioral

[1] See also Morgenstern et al. (2013a)

observations. Subjects are incentivized to respond truthfully according to their real preferences. In this context, a hypothetical reward structure does not satisfy saliency and subjects are not incentivized to give truthful responses. For this reason, hypothetical decisions are supposed to be unreliable even though a hypothetical reward structure may not change the basic decision direction in general. Camerer and Hogarth (1999, p. 17) quoted that in "[…] games, auctions, and risky choices the most typical result is that incentives do not affect mean performance, but incentives often reduce variance in responses. In situations where there is no clear standard of performance, incentives often cause subjects to move away from favorable `self-presentation' behavior toward more realistic choices." However, overall evidence that hypothetical choices differ from real choices is ambiguous. Studies by Kühberger et al. (2002) and Beattie and Loomes (1997) addressing this question could not confirm a general difference between hypothetical and real choices. However, an early paper of Slovic (1969) discussed differential effects in real and hypothetical payoffs and the studies of Holt and Laury (2002, 2005) found differences in risk attitudes for high-stakes lotteries. Holt and Laury (2002, 2005) have shown that real decisions in high-stakes lotteries evoke more risk averse choice behavior in contrast to hypothetical decisions. The difference in risk attitude is related to the size of the payoffs and therefore is ascribed to an incentive effect. This incentive effect was particularly discussed by Harrison (2006). He reviewed former studies by Battalio et al. (1990), Holt and Laury (2002), and Harrison et al. (2005) with reference to a hypothetical bias over uncertain outcomes. Harrison confirmed a difference in choice behavior of subjects between hypothetical and real decisions in those studies. These findings generally support the unreliability of hypothetical decisions. However, we also have to consider that there are special cases in which a realization of decision outcomes is not possible. For instance, outcomes related to questions of moral conflicts, losses, or any kind of damages and even very high stakes are often not realizable. In those cases, hypothetical decisions may still provide valuable information as good forecast indicators.

Although the behavioral effects induced by the hypothetical bias in the context of high rewards are known, the factors causing this incentive effect are not fully investigated. It can be assumed that differences in risk attitude are evoked by differences in the evaluation of a decision task. For this reason, it is necessary to focus on the preceding evaluation processes of a decision. In standard behavioral experimental settings, preceding processes resulting in a decision cannot directly be observed. Because specific decision-related processes are known to have a neural correlate, event-related potentials (ERPs) derived from an electroencephalogram (EEG) can potentially reveal these hidden processes. The spontaneous EEG shows a signal originating from the brain's fast oscillating electrical activity. This EEG is typically recorded from the scalp using a set of electrodes placed at standardized positions. ERPs are neural reactions embedded in the spontaneous EEG, and time-locked to motor, sensory, or cognitive events. They are characterized by their temporal appearance, their polarity, and the location of their appearance. Just a few processes result in ERPs, which can be observed in a single trial; most ERPs are extracted from the spontaneous EEG by way of standard averaging techniques. In comparison to functional magnetic imaging, the striking advantage of ERPs is the temporal resolution. Because ERPs reflect the fast changing electrical sum potential of neocortical neuron ensembles, they are able to differentiate between processes in the range of milliseconds. In contrast, functional magnetic resonance imaging, which relies on the slow hemodynamic response to neural processes, has a temporal resolution of at least one second. In return, the spatial resolution of functional fMRI, used primarily for processes occurring in non-cortical/subcortical brain sites, is superior to an EEG's spatial resolution.

Here, we used ERPs that were time-locked to the presentation of a decision-requiring stimulus in order to reveal the hypothesized differences in cognitive processes taking place before a decision is made. In ERP research, the control of decisive behavior is indicated by a negative deflection at fronto-central electrode sites occurring approximately 200-300 ms after stimulus presentation. This so-called N200 (N2) is driven by activity in the fronto-medial part of the anterior cingulate cortex (ACC) and the prefrontal cortex (PFC), and is assumed to reflect the neural underpinnings of cognitive control (van Veen and Carter, 2002a; Folstein and van Petten, 2008). The latent construct "cognitive control" describes the ability of humans to control one's own behavior and to adapt it to changing environmental demands in a most flexible manner (van Veen and Carter, 2002a; Wendt et al., 2007). Several investigations have shown that in decision tasks, cognitive control increases when subjects have to choose between two or more competing alternatives (Bland and Schaefer, 2011; De Neys et al., 2011). Accordingly, the N200 should be able to reveal differences in the neural underpinnings of processes related to decisions in a lottery task when comparing hypothetical against real payoffs.

We applied a standard method for eliciting certainty equivalents in a binary lottery choice paradigm (see Farquhar, 1984) in order to investigate the differences in risk attitudes between hypothetical and real decisions. Eliciting certainty equivalents for hypothetical and real high-payoff choices in a within-subject design allows for an analysis of a potential hypothetical bias. According to findings in literature (e.g. Holt and Laury, 2002), we expect a higher degree of risk aversion for real payoff choices compared to hypothetical payoff choices. Thus, we hypothesize that elicited certainty equivalents are smaller for real decisions.

Moreover, the revelation of a hypothetical bias indicates that differences in the evaluation process of hypothetical and real choice tasks apparently exist. As a consequence, we expect differences in the appearance of the N200 component, which reflects a neural correlate of an evaluation process during decision making. As introduced previously, the N200 component is supposed to be affected by processes of cognitive control indicating a distinct level of conflict in the decision-making process. In this respect, an assumption of differences in the appearance of the N200 has to be related to the expected level of conflict between hypothetical and real choices. An fMRI study by Kang et al. (2011) investigated hypothetical and real choices for consumer goods. Kang et al. revealed an increased activity in cognitive control areas for real choices. The authors suggested that this finding could refer to a more careful comparison process between products and prices when real choices are made. Hence, the relevance of real choices may lead to more careful decision making, which would result in a higher level of cognitive control. According to this implication for consumer goods, real choices in a lottery choice paradigm should also provoke a more careful comparison process. We also expect to observe a higher level in cognitive control for real decisions because these decisions are more relevant for a subject. Thus, we hypothesize that higher N200 amplitudes are revealed for real choices.

6.2 Material and Methods[2]

6.2.1 Experimental procedure

The experimental procedure followed the method for eliciting certainty equivalents for binary lotteries (Farquhar, 1984). The subjects' task was to decide either to play a lottery or to receive a sure payoff. We used a 50–50 lottery, in which one payoff was constantly zero and the other payoff indicated a high-stake outcome. The experimental procedure provided a sequence of choice tasks in which the sure payoff value varied within the two outcomes of the binary lottery.

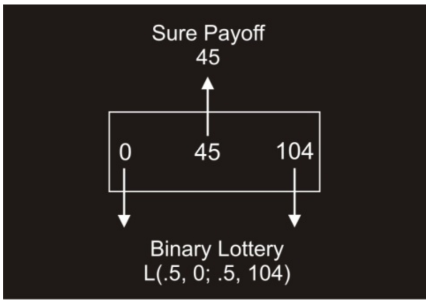

Figure 7: Choice task presented to the subjects

[2] See also Morgenstern et al. (2013a)

For each choice task, the subjects saw a string of three numbers surrounded by a white box on a computer screen (see Figure 7). The two outer numbers represented the two outcomes of the binary lottery in euros. The inner number indicated the sure payoff in euros. Both choice alternatives were presented successively within one decision trial. Each decision trial started with a presentation of the two outer numbers (lottery payoffs). After a duration of 1,000 ms, the inner number (sure payoff) was added to the string (see Figure 8). Subjects were instructed to make their decision directly after the presentation of the inner number value. The completed information of the choice task lasted for another 1,000 ms on the screen. Subsequently, the string was cleared from the screen and the next decision trial started. Altogether, each decision trial lasted approximately 3 seconds.

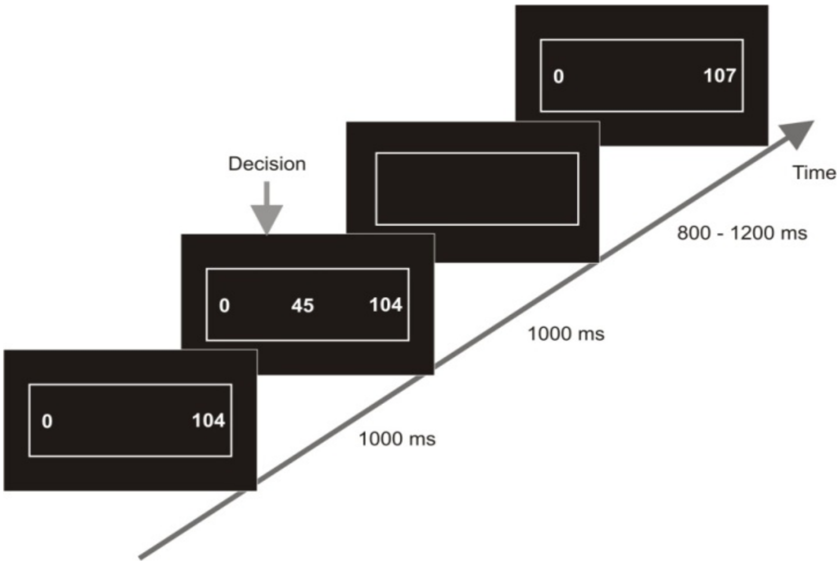

Figure 8: Sequence of screens of one choice task

The high-stakes payoff of the binary lottery was set to 100 and varied in eight values between 100 and 107. The sure payoff was assigned values of 10, 20, 30, 40, 50, 60, 70, 80, and 90. Furthermore, each sure payoff value varied in the last number digit between 0 and 7, resulting in values from 10 to 17, 20 to 27, 30 to 37, and so forth. Consequently, a total of 576 decision trials resulted from the combination of all lottery settings with all sure payoff values. An overview of all choice set combinations is provided in Table A8 of Appendix A. All decision trials were randomly assigned to the subjects, independent from previous choice tasks. Furthermore, subjects received no feedback on their choices.

During the experiment, all subjects were seated in a comfortable armchair in front of a 19 inch screen at a distance of 80 to 100 cm. Subjects made their decisions by pressing two buttons with their left or right index finger. The experiment consisted of two sessions for every participant within two weeks. Both sessions were conducted in the same way, except for the condition of either hypothetical or real payoffs. The two different treatments were indicated by different instructions (see A9-A12 of Appendix A) and were assigned in a random order to each subject. Each session consisted of 20 practice trials to familiarize subjects with the task. The experiment itself consisted of 9 blocks with 64 decision trials, each lasting approximately 35 minutes. The total duration of an experimental session was approximately 2 hours, including the preparation of the subjects for the EEG recording.

Twenty-one neurologically healthy, right-handed subjects (12 women, ages 20 to 31) participated in this study by completing a hypothetical and a real treatment in two separate EEG sessions. Most of the subjects were students from the Otto-von-Guericke University of Magdeburg who were recruited from the ORSEE (Greiner, 2004) subject pool of the university. Subjects received a fixed amount of 14 euros for their participation in the hypothetical treatment. For the real treatment, subjects were paid according to the random payoff mechanism. One randomly selected decision determined the payment for the subjects. Hence, subjects received a payment between 0 and 107 euros in the real treatment (average earnings was 54.05 euros).

6.2.2 Behavioral analysis

The behavioral data were analyzed according to the relative frequency of lottery choice. A normalized distance of the sure payoff compared to the expected value of the corresponding lottery was calculated in order to provide an objective measure for comparing the different lottery settings. For example, an offered lottery L(.5, 0; .5, 100) with the expected value of 50 and an offered sure payoff of 30 resulted in a distance category of -20. A sure payoff of 65 and an offered lottery L(.5, 0; .5, 106) resulted in a distance category of +12. Consequently, all 576 decisions of a subject were classified according to the aforementioned distance category, and the relative choice frequency for each distance category was calculated.

6.2.3 EEG recording

The electroencephalogram was recorded from 61 thin electrodes mounted in an elastic cap and placed according to the international 10-10 system (Chatrian et al., 1985). The EEG was re-referenced offline to the mean activity at the left and right mastoid. In order to enable offline rejection of eye movement artifacts, horizontal and vertical electrooculograms (EOGs) were recorded using bipolar montages. All channels were amplified (bandpass 0.05-70 Hz) and digitized with 4-ms resolution; all electrode impedances were kept below 10 kΩ. After epoching the data time-locked to stimulus onset (baseline -100 to 0, epoch length 1,000 ms), epochs confounded with eye blinks or other artifacts (muscle activity, step-like artifacts etc.) were excluded from the calculation of the subject's average by visual inspection. Finally, each subject's averages were filtered with a 12 Hz low-pass filter.

For the statistical analysis, mean amplitudes are computed within the time range at which the N200 is observed. Mean amplitudes of the N200 are analyzed by the use of repeated measures analyses of variance (ANOVAs) for the electrode sites at which the N200 is located in order to identify main effects and further factor interactions. In this context, degrees of freedom, F-values, and p-values are reported as Greenhouse-Geisser corrected. Significant effects are further analyzed by a standard t-test.

6.2.4 EEG analysis

For both treatments, the EEG data were analyzed for the areas of indifferent choices and sure choices with regard to the subject's decision. According to the behavioral data, we identified an area of ambiguous choices for every subject in which the relative frequency of lottery choices changes from one to zero. Choices of this area were specified as indifferent choices. Furthermore, we determined an individual indifference point for a lottery choice frequency of 0.5 within this range of indifferent choices. Around the individual indifference point, an interval size of 13 digits determined the indifference choice area for which we analyzed the corresponding lottery choices and sure payoff choices.

Next, we identified two areas of sure choices in which either the lottery or the sure payoff was chosen for sure. We determined the two sure-choice areas based on the location of the individual indifference point in relation to the two lottery payoffs. The area of sure choices for the lottery was determined by the midpoint between the small lottery payoff and the individual indifference point. In contrast, the area of sure choices for the sure payoff was determined by the midpoint between the individual indifference point and the high lottery payoff. An interval size of seven digits around these two midpoints determined the two sure choice areas.

Based on these three sections of interest and according to the subjects' decisions, event-related potentials were obtained in four bins for each treatment: a *sure choice area for lottery choices* (bin 1), *lottery choices in the indifference area* (bin 2), *sure payoff choices in the indifference area* (bin 3), and a *sure choice area for sure payoff choices* (bin 4). This bin determination procedure is described in Figure 9, where the classification of the four bins for the EEG analysis is presented. The graph depicts the relative lottery choice frequency of a subject related to the distance of the sure payoff to the expected value of the lottery.

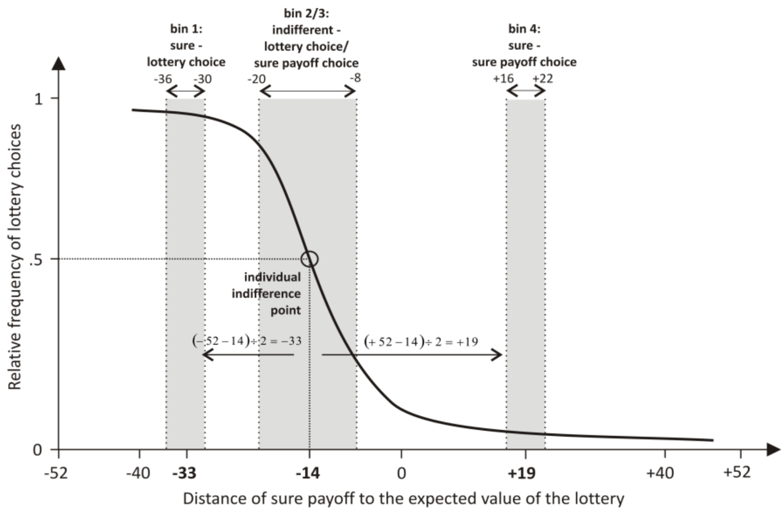

Figure 9: Description of bin classification

6.3 Results[3]

We primarily analyze the effect of change between the two treatments (hypothetical and real payoffs) on the certainty equivalents of the subjects. Then, we analyze the effect of these different incentive structures on the EEG data, particularly the N200 component. In this second part, we test our hypothesis that real payoff leads to higher cognitive control. Afterward we correlate the behavioral changes and the changes in the EEG caused by the parameter of the underlying incentive structure. In doing so, we extract an explanation for why the hypothetical bias occurs in behavioral data that are based on the mental evaluation process during decision making.

6.3.1 Behavior

Figure 10 depicts the relative frequency of lottery choices summarized across subjects. As shown, the relative frequency of lottery choices in the real treatment is constantly smaller compared to the hypothetical treatment. The total amount of lottery choices (see Table A1 of Appendix A) for each subject differs significantly between both treatments in a performed two-sided pair-wise Wilcoxon signed-rank test ($N=21$, $V=176$, $p=0.035$). Accordingly, the determined certainty equivalents in the real treatment have a median of –12 (mean=11.38, SE=2.42) as the distance to the expected value, whereas the median of certainty equivalents for hypothetical choices is –7 (mean=8.48, SE=2.51). In both treatments, subjects show risk averse behavior due to medians of certainty equivalents that are smaller than zero in their distance to the expected value of the lottery. Furthermore, certainty equivalents also differ between both treatments. A one-sided pair-wise Wilcoxon signed-rank

[3] See also Morgenstern et al. (2013a)

test confirmed on a 5% significance level (N=21, V=138, p=0.042) that the certainty equivalents are smaller in the real treatment. Thus, we can confirm a hypothetical bias in the behavioral data. This result is in line with the finding of Holt and Laury (2002) that for high-payoff lottery choices, subjects are more risk averse when the outcomes are for real.

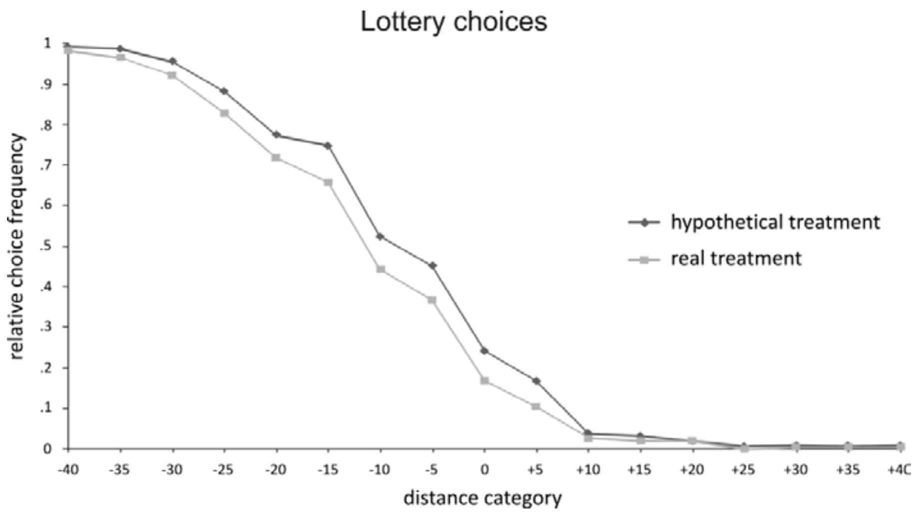

Figure 10: Relative frequency of lottery choices

6.3.2 Event-related potentials

Figure 11 and Figure 12 show the stimulus-locked event-related potentials at the Fz electrode extracted from the EEG recording. The Fz electrode is located in a fronto-central scalp area at which the N200 is supposed to occur. Both figures show a negative peak amplitude within a time range of 270 to 370 ms. This amplitude represents the N200 component and its maximum is at approximately 320 ms.

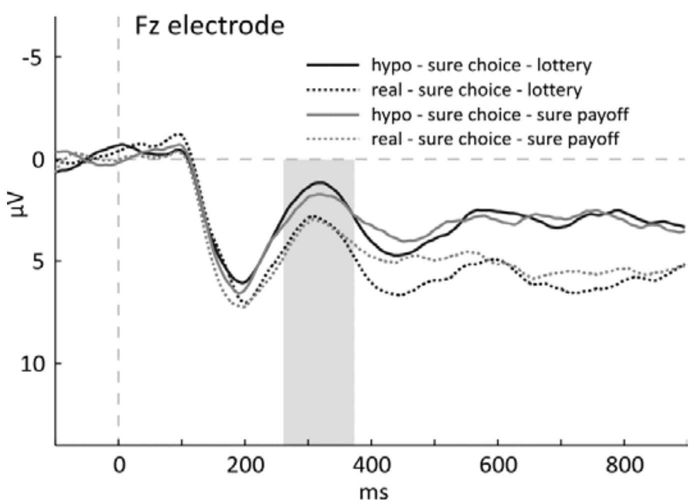

Figure 11: ERPs at the Fz electrode for choices outside the indifference area

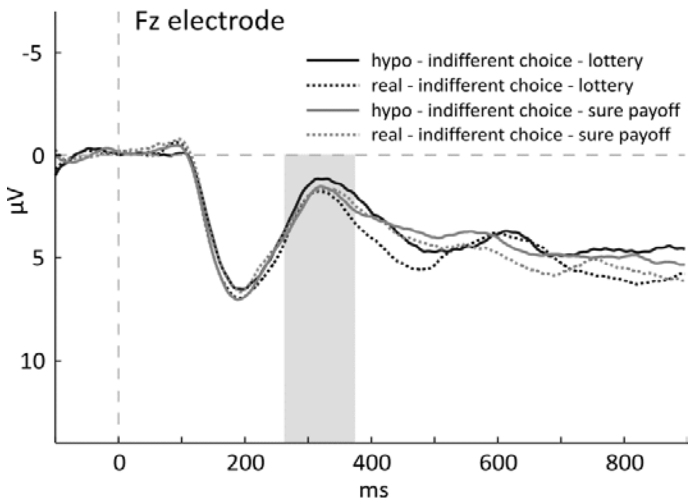

Figure 12: ERPs at the Fz electrode for choices inside the indifference area

Figure 11 depicts the event-related potentials of the sure-choice areas (bin 1, bin 4) for both treatments. Figure 12 illustrates the event-related potentials of the indifference area (bin 2, bin 3). N200 amplitudes for choices outside the indifference area (see Figure 11) differ between the two treatments. The N200 amplitudes for sure choices derived from the hypothetical treatment are apparently higher than the N200 amplitudes for real choices. This is not the case for choices inside the indifference area (see Figure 12).

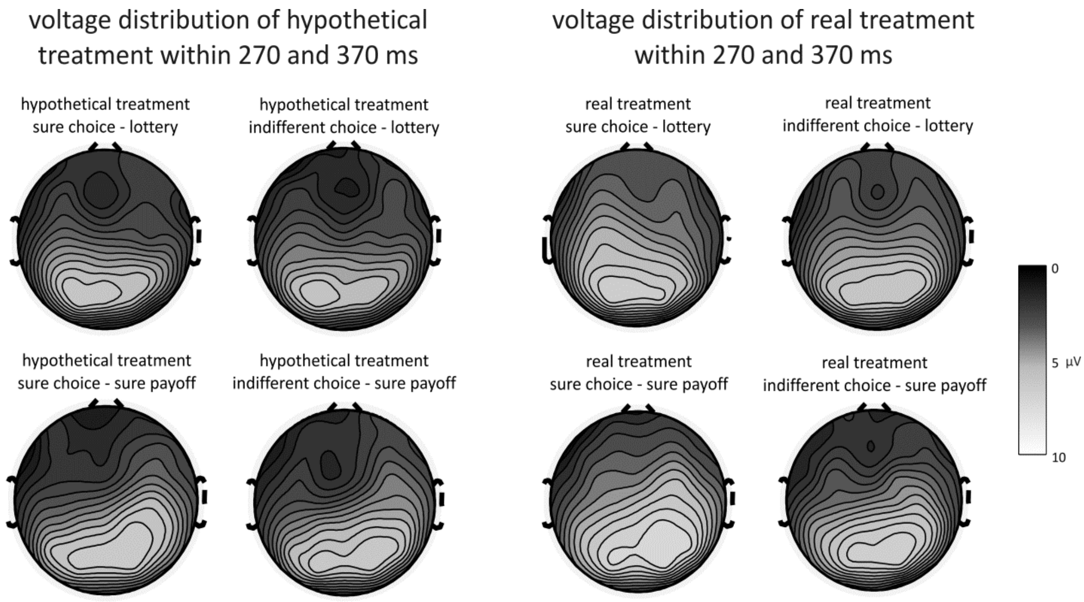

Figure 13: Topographies of voltage distribution within 270 and 370 ms

Moreover, Figure 13 shows the average voltage distribution on the scalp for hypothetical and real choices within 270 and 370 ms. The topography for the hypothetical treatment (on the left hand side) indicates an increased negative deflection at the fronto-central scalp area for all four bins. In contrast, an increased negative deflection in the topography for the real treatment (on the right hand side) is only observable for indifferent choices. Hence, the N200 component is located on the scalp at fronto-central electrode sites within a time range of 270 to 370 ms, and is more pronounced for choices of the hypothetical treatment.

On the basis of this observation, mean amplitudes within a time range of 270 to 370 ms are calculated for the statistical analysis. Calculated mean amplitudes for each subject are provided in Table A2 (Fz electrode), Table A3 (Cz electrode), and Table A4 (Pz electrode) in Appendix A. An overview of the averaged mean amplitudes at the Fz electrode is provided in Figure 14, illustrating the decreasing negative deflection for real payoff choices outside the indifference area.

Subsequently, a repeated measures ANOVA was performed for Fz, Cz, and Pz electrodes as *anterior–posterior electrode position* factor and with *treatment* (hypothetical, real), *choice* (lottery, sure payoff), and *indifferent position* (indifferent choice, sure choice) as further factors. A significant interaction ($F(1.361)=5.911$, $p=0.014$) for the *anterior–posterior*, *treatment*, and *indifferent position* factors was revealed (see also Table A5 of Appendix A). A further ANOVA (see also Table A6 of Appendix A) for the Fz electrode confirmed an interaction *treatment x indifferent position* ($F(1)=4.990$, $p=0.037$).

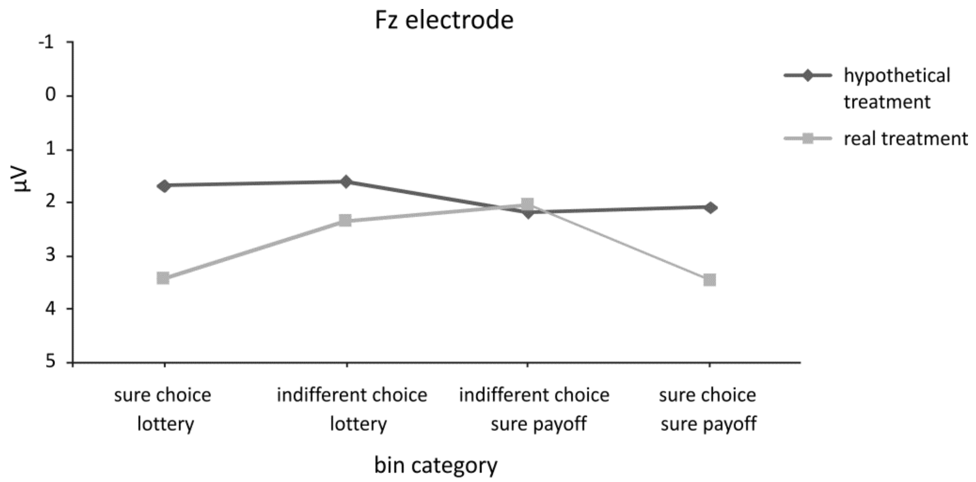

Figure 14: Mean amplitudes within 270 and 370 ms at the Fz electrode

To further clarify the found interaction, a pair-wise t-test controlling for differences in mean amplitudes was performed (see also Table A7 of Appendix A). The t-test revealed significant differences ($p<0.05$, one-sided) between both treatments for the choice areas outside the indifference area. Differences could also be confirmed within real choices between mean amplitudes inside and outside the indifference area ($p<0.05$, one-sided). Differences within hypothetical choices could not be found. Thus, the N200 amplitudes related to real choices outside the indifference area are significantly smaller compared to all other N200 amplitudes.

Because the N200 amplitude reflects the level of conflict in the decision-making process, this finding leads to a rejection of our primary hypothesis that real decisions elicit higher cognitive control. We also have to reject that the level of control is equal for both treatments. Hence, we adopt the complementary hypothesis that hypothetical decisions require higher cognitive control.

6.4 Discussion[4]

We investigated hypothetical and real payoff choices in an ERP paradigm. We addressed the question of whether differences in risk attitude between hypothetical and real decisions can result in different levels of cognitive control in the preceding phase of a decision. For that reason, we focused on the N200 component, an ERP component known to reflect cognitive control mechanisms. At the behavioral level, the determination of the individual indifference point for both treatments revealed the expected hypothetical bias effect. This result confirms the findings of former studies (e.g. Holt and Laury, 2002), showing that subjects are more risk averse in real treatments for high-payoff lotteries. Moreover, the analysis of the corresponding N200 component showed significant differences in the N200 amplitude between the hypothetical and the real treatment. Cognitive control is higher in the hypothetical treatment than in the real treatment.

For the real treatment, higher N200 amplitudes are shown for choices inside the indifference area in contrast to choices outside the indifference area. This indicates increased cognitive control during the decision-making process for indifferent choices. This is not surprising and seems to be reasonable since a decision for or against a choice alternative apparently causes a struggle for a subject when the subject is indifferent. In contrast, choice options outside the indifference area are easier to decide for a subject. Therefore, less cognitive control is required, and correspondingly smaller N200 amplitudes were observed.

In opposition to real choices, hypothetical decisions did not result in a significant N200 amplitude variation between choices inside and outside the indifference area. Instead, the N200 amplitude is equally high, indicating a comparable amount of cognitive control for all hypothetical decisions. This pattern of results clearly differs from our primary prediction, namely, that the level of cognitive control depends on the relevance of decisions. In a recent investigation, Kang et al. (2011) addressed a similar topic. Using fMRI, they investigated the neural underpinnings of the hypothetical bias during the selection of consumer goods. The authors reported no increased activations in brain sites related to cognitive control mechanisms for hypothetical decisions, although they formulated the explicit alternative hypothesis,

[4] See also Morgenstern et al. (2013a)

that hypothetical decisions do have the potential to result in increased cognitive control mechanisms (see also Paulus and Frank, 2003).

Putting aside the different recording techniques of both studies, we argue that this contrary result is based on different stimuli types. Kang et al. (2011) investigated consumer goods, we used binary lotteries. The inherent dimensions of choice criteria for consumer goods are obviously multifaceted. There are other determinant attributes of a product besides a monetary evaluation, like quality, shape, or functionality, which potentially influence a subject's decision. These criteria may not be in the mind of a decision maker when making hypothetical choices because involving all criteria would require additional and potentially disproportional mental effort. If these criteria become more relevant in real choices, then higher cognitive control for real payoffs is reasonable. In contrast, in the evaluation of lotteries, all relevant choice attributes that may influence the decision are known: probabilities and payoffs. Real payoffs do not change this. Given this interpretation, we would not expect the results of Kang et al. (2011) for the evaluation of lotteries. Lotteries have two obvious attributes that have to be considered in both treatments to state a certainty equivalent. For consumer goods, additional attributes of a product may only become important if the decision is for real.

Moreover, we assume that the higher level of cognitive control in hypothetical choices could be attributed to an extended range of decision alternatives, and therefore to a different focus on choice criteria for hypothetical choices. The presence of higher cognitive control allows us to draw the conclusion that there is at least one additional choice criterion that evokes the higher N200 component. This additional choice criterion could be the focus on the expected value of the lottery, which reflects the "rational" risk neutral indifference point. The difference between the two treatments in the behavioral data shows a shift in the hypothetical certainty equivalents toward the expected value of the lottery. Thus, the higher N200 component could reflect an additional action control conflict between the true individual certainty equivalent of a real decision and the expected value of a more rational, risk neutral decision. This difference in cognitive control for hypothetical decisions can lead to a different payoff evaluation, resulting in a shift of the certainty equivalent toward the expected value. Our results illustrate that the hypothetical bias is related to higher cognitive control for hypothetical decisions.

6.5 Additional data analysis

This section will provide a further review of the EEG study concerning the hypothetical bias. The main purpose of the study was located in the appearance of the N200, but the EEG data additionally showed a modulation of the P300 component with regard to an attentional categorization process of stimulus events. Consequently, potential differences of the P300 will be discussed. Before that, this section will also inform about the behavioral reaction times subjects required for responding on a given choice task and their relationship to the experimental findings of the ERP data.

6.5.1 Analysis of reaction times

The reaction times for responses on the experimental task were calculated with reference to each stimulus presentation. An overview of the calculated mean reaction times is provided in Table A19 of Appendix A. According to the ERP bin classification, the subjects responded on average between 500 and 700 ms after stimulus presentation. Figure 15 depicts the mean reaction times in both treatments separated by the bin classification. As can be seen, the reaction times between both payoff treatments do not diverge. Differences appear to be present across the stimulus values. Reaction times are about 100 ms higher for stimulus values within the indifference area of a subject. Furthermore, lottery choices seem to evoke higher reaction times than sure payoff choices.

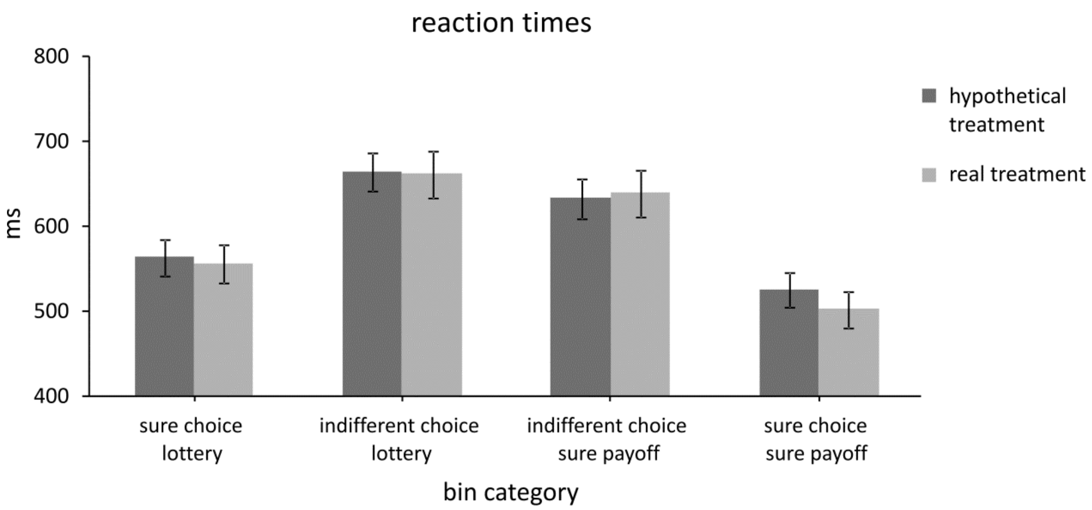

Figure 15: Mean reaction times

For a statistical analysis of the reaction time data, a repeated measures ANOVA was primarily performed with two factors: *treatment* (hypothetical, real) and *bin classification* (sure choice for the lottery, indifferent choice for the lottery, indifferent choice for the sure payoff, sure choice for the sure payoff). The performed ANOVA (see Table A20 of Appendix A) revealed a main effect for *bin* *classification* ($F(2.323)=105.694$, $p<0.001$). For a further clarification, a three factor ANOVA with *treatment* (hypothetical, real), *choice* (lottery, sure payoff) and *indifferent position* (indifferent choice, sure choice) was conducted subsequently. A main effect for *choice* ($F(1)=37.144$, $p<0.001$) as well as for *indifferent position* ($F(1)=182.751$, $p<0.001$) can be confirmed (see also Table A21 of Appendix A). An effect between both treatments is absent ($F(1)=0.201$, $p=0.658$), which is also indicated by insignificant results of pair-wise t-tests for each bin category ($T(20)<1.473$, $p>0.15$). In contrast, the revealed main effects could be confirmed by pair-wise t-tests (see Table A22 of Appendix A), indicating for both treatments that lottery choices yield higher reaction times ($T(20)>3.014$, $p<0.01$) than sure payoff choices while indifferent choices yield higher reaction times ($T(20)>8.407$, $p<0.001$) than sure choices.

Higher reaction times for indifferent choices can be related to the indecisiveness of subjects in this area. This further supports the result of the increased N200 for indifferent choices in both payoff mechanisms. Here, the higher action control conflict, reflected by the increased N200, represents the indecisiveness of the subject for indifferent choice stimuli resulting in higher reaction times.

In contrast, the higher action control conflict for hypothetical choices outside the indifference area cannot be explained by this reasoning since the reaction times are decreasing for sure choices. Decreasing reaction times indicate that the indecisiveness of subjects is reduced because smaller reaction times can be assumed to reflect higher confidence in making decisions. In this context, the constant level of the N200 amplitudes in the hypothetical treatment compared to the differences in reaction times would further imply that the underlying process does not reflect response inhibition. According to the conflict monitoring hypothesis, these findings rather suggest that the increased conflict can be related to a process of stimulus evaluation and not to response preparation.

In summary, the reaction times are corresponding to the results of the ERP data and support previous explanations concerning the different appearances of the N200. The absence of differences in reaction times between both treatments indicates a general similarity of both choice tasks implied by the experimental instructions. However, the difference in the behavioral results has provided evidence that both payoff mechanisms elicit different risk attitudes. This behavioral difference has to be ascribed to a decision conflict independent from a general task information processing. Hence, the hypothetical bias cannot be referred to a different response time process, which would have indicated a general difference in the mental effort. But, the neural evidence shows that the decision evaluation process is different, which results in a change of risk attitudes.

6.5.2 The P300 and attentional categorization processes

According to the introduction of the P300 component, the underlying cognitive processes reflected by the P300 are ambivalent and a modulation of the P300 has been observed in various types of EEG paradigms. Several theoretical and empirical implications have been suggested for the P300, from which the context updating model proposed by Donchin (1981) is the most prominent. The context updating hypothesis is related to novel or infrequent stimuli which influence the appearance of the P300. Higher P300 amplitudes are observed for those stimuli which are supposed to reflect an information updating process of the working memory with reference to the present environmental expectations. In this context, the present EEG study does not provide reliable accordance since the value range of stimuli was known by the subjects and all stimuli values had the same probability of occurrence. Hence, alternative explanations related to the paradigm of the present EEG study have to be taken into account.

In a model of the P300 by Johnson (1986), it is presumed that the P300 amplitude can be related to a reduction of uncertainty concerning the type of a stimulus. Accordingly, P300 amplitudes are proposed to be smaller when a distinct stimulus is difficult to discriminate among others. This assumption is also reflected by the event categorization hypothesis (Kok, 2001). With reference to event categorization, the P300 represents a process that evaluates a stimulus according to a match or a mismatch of an internal representation of a specific target category. Such a categorization process is supposed to require attentional and perceptual capabilities as well as working memory, which are presumed to be reflected by the P300. The model of Kok suggests that larger P300 amplitudes are elicited when a presented stimulus matches the target category.

Rather similar to the event categorization hypothesis, Verleger et al. (2005) suggested that the P300 reflects a process of mediating between a perceptual analysis and a response initiation. Such a process is presumed to classify the stimulus in relation to its consequence. Verleger et al. (2005) stated that the amplitude of the P300 decreases when stimuli cannot be classified easily. Hence, stimuli which are very close to an internal stimulus classification are supposed to evoke higher P300 amplitudes. In comparison to a reduction of uncertainty (Johnson, 1986), the P300 amplitude could further reflect different levels of attention to distinct stimulus consequences in order to resolve the degree of uncertainty concerning a stimulus categorization.

According to these suppositions, an analysis of the P300 can provide further clarifications on the stimulus evaluation in lottery choice paradigms. Since a decision reflects two types of consequences (a risky gamble and a certain alternative), a stimulus categorization could be conducted on whether the stimulus requires a choice for the lottery or for the sure payoff. In each choice task, a subject presumably compares his or her individual indifference point with the value of the sure payoff. Hence, a subject categorizes the stimulus information according to a preference for the lottery consequence or for the sure payoff consequence. Around the indifference point, an unambiguous categorization of sure payoff stimuli is more difficult for the subject. Consequently, smaller P300 amplitudes are expected to be elicited for stimuli inside the indifference area rather than for stimuli with values outside the indifference area. Furthermore, differences in the P300 amplitude are supposed to occur with reference to a comparison of both choice types. Since the consequences of both choice types differ in terms of risk, a potential disparity in stimulus attention can be expected. A lottery choice reflects a risky decision, and assuming that risky decisions are probably made more consciously, lottery choices might allocate more attentional resources than sure payoff choices. This indicates that more attention is attracted to risky decisions since a choice for a risky alternative remains with uncertain consequences in the moment of choice, which should therefore raise someone's awareness toward risk.

These assumptions on a potential P300 modulation in the present EEG study refer to general information processing and do not provide predictions for a different modulation related to the applied payoff procedures. Thus far, a review on the stated assumptions only affords implications for a general processing of stimuli in a standard gamble task. A different appearance of P300 amplitudes between the applied payoff mechanisms cannot be presumed. Basically, a categorization process of stimuli can be related to the instructed choice task. The instructions of both treatments motivated a random selection of one choice. Such a comparable motivation of stimuli can be assumed to provoke a similar categorization process in both treatments. If the P300 amplitudes of both treatments differ generally, then the basic perception of the choice task can be presumed as different. However, partial difference can be related to different levels of attracted attention to a distinct stimulus consequence. In this respect, it can be assumed that real payoffs allocate higher levels of attention to specific stimuli, as these choice tasks represent a real decision that is apparently more relevant for the subject.

6.5.3 Analysis of the P300 component

A P300 component was determined to occur at about 450 to 550 ms after stimulus presentation. Figure 16 and shows the averaged voltage distribution on the scalp within this time range for both treatments. As can be seen, a positive maximum is located at centro-parietal electrode sites which reflect the characteristic location of the P300 component.

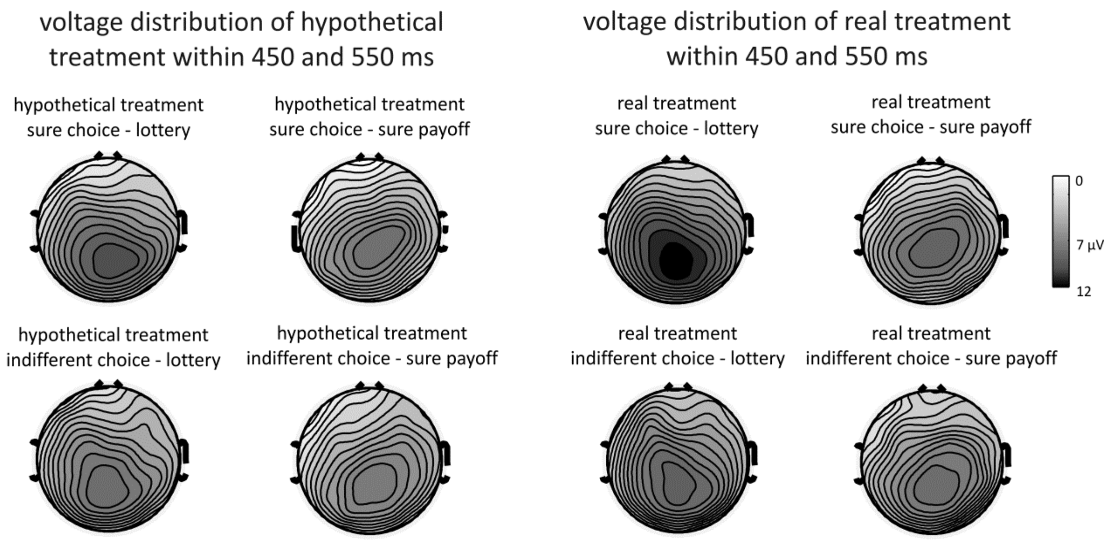

Figure 16: Topographies of voltage distribution within 450 and 550 ms

The following figures depict the event-related potentials for both treatments at the Pz electrode separated by indifferent choices (Figure 17) and sure choices (Figure 18). In that figure, the P300 component shows the most different appearance for the bin categories of sure choices. Here, the P300 amplitudes are most pronounced for sure lottery choices and seem to differ across both treatments. In contrast, P300 peak levels for indifferent choices appear rather similar. Furthermore, the maximum of the P300 amplitudes is higher for sure choices than for indifferent choices.

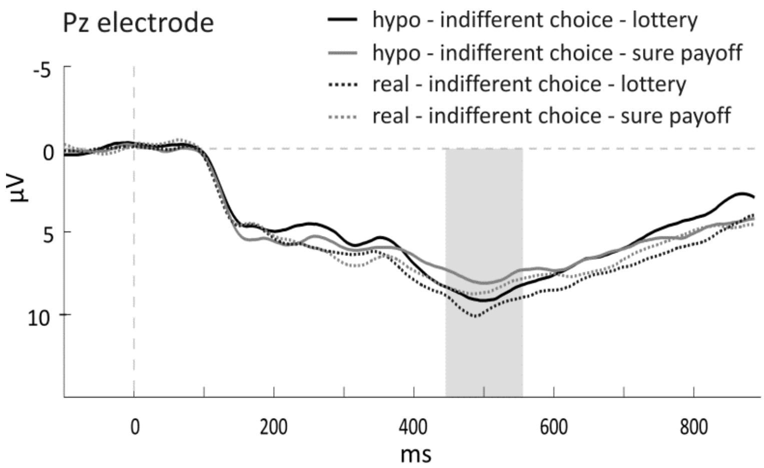

Figure 17: ERPs at the Pz electrode for choices inside the indifference area

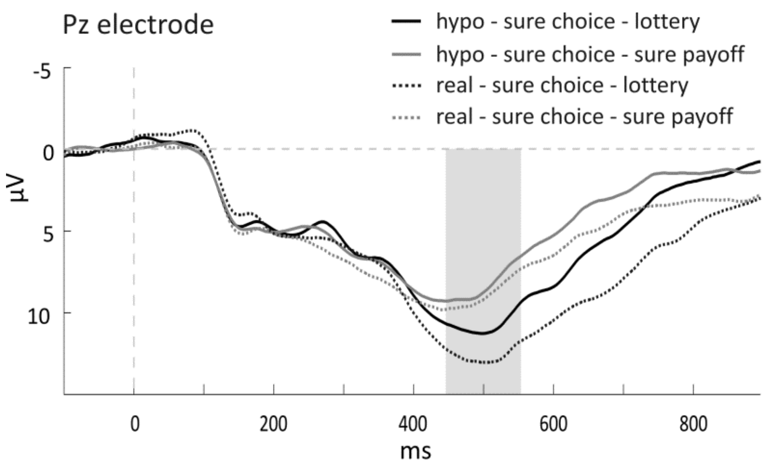

Figure 18: ERPs at the Pz electrode for choices outside the indifference area

For a statistical analysis of the P300 modulation, mean amplitudes within a time range of 450 to 550 ms were calculated (see also Table A13-A15 of Appendix A). Next, a repeated measures ANOVA was performed for the midline electrodes with *anterior-posterior electrode position* (Fz, Cz, Pz), *treatment* (hypothetical, real), *bin classification* (sure choice for the lottery, indifferent choice for the lottery, indifferent choice for the sure payoff, sure choice for the sure payoff) as factors (see Table A16 of Appendix A). The ANOVA revealed a main effect for *bin classification* ($F(2.253)=5.318$, $p=0.007$) as well as an interaction *anterior-posterior electrode position x bin classification* ($F(3.304)=8.957$, $p<0.001$). The main effect for *bin classification* was further analyzed by differentiating this factor into a factor *choice* (lottery, sure payoff) and a factor *indifferent position* (indifferent choice, sure choice). Consequently, an ANOVA for mean amplitudes at the Pz electrode was performed with *treatment* (hypothetical, real), *choice* (lottery, sure payoff) and *indifferent position* (indifferent choice, sure choice) as factors (see Table A17 of Appendix A). The ANOVA revealed main effects for *choice* ($F(1)=9.348$, $p=0.006$) and *indifferent position* ($F(1)=15.714$, $p=0.001$) as well as an interaction *choice x indifferent position* ($F(1)=7.963$, $p=0.011$).

In summary, the type of choice in relation to the stimulus value evokes different P300 amplitudes but general differences between both payoff mechanisms were not revealed. Figure 19 contrasts sure payoff choices against lottery choices outside the indifference area while Figure 20 depicts sure payoff choices and lottery choices inside the indifference area. In this comparison, P300 amplitudes for both treatments are significantly higher for lottery choices than for sure payoff choices in performed one-sided pair-wise t-tests (see Table A18 of Appendix A) but solely for choices outside the indifference area ($T(20)>2.738$, $p<0.007$) and not for indifferent choices ($T(20)<1.384$, $p>0.091$).

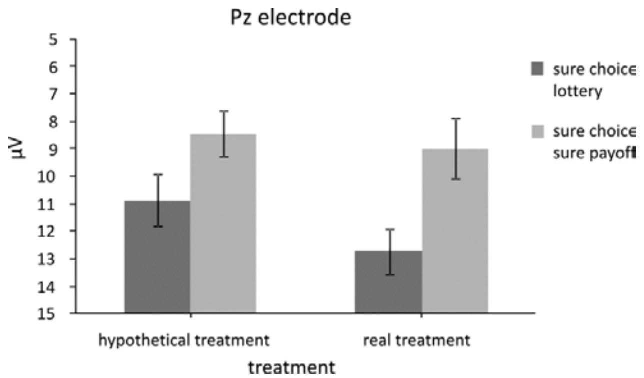

Figure 19: Mean amplitudes within 450 and 550 ms at the Pz electrode for choices outside the indifference area

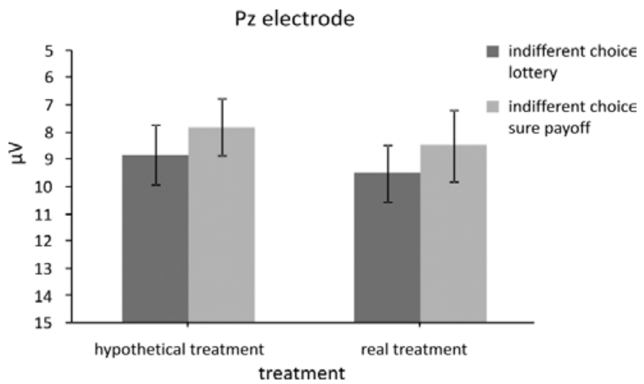

Figure 20: Mean amplitudes within 450 and 550 ms at the Pz electrode for choices inside the indifference area

Furthermore, a different comparison of mean amplitudes contrasting indifferent choices with sure choices is presented in Figure 21 and Figure 22. Here, indifferent lottery choices yield smaller mean amplitudes than sure lottery choices, which differ significantly for performed one-sided pair-wise t-tests ($T(20)>3.198$, $p<0.003$) in both treatments. Differences of sure payoff choices between indifferent choices and sure choices are not significant in this comparison ($T(20)<0.887$, $p>0.193$). Furthermore, the P300 amplitude of sure lottery choices in the real payoff mechanism is most pronounced and is significantly different for a one-sided pair-wise t-test ($T(20)=-1.773$, $p=0.046$) compared to the P300 amplitude of sure lottery choices in the hypothetical treatment.

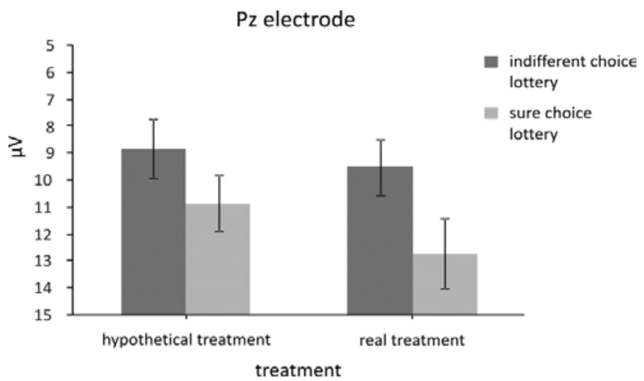

Figure 21: Mean amplitudes within 450 and 550 ms at the Pz electrode for lottery choices

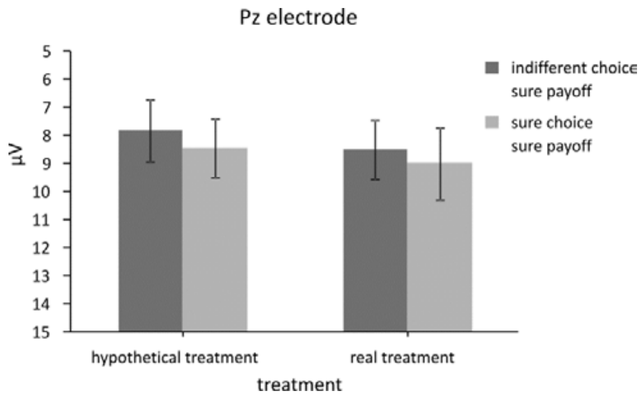

Figure 22: Mean amplitudes within 450 and 550 ms at the Pz electrode for sure payoff choices

The statistical analysis has shown that the P300 amplitudes are differently modulated by stimuli in relation to a distinct categorization of responses. With respect to the assumption of stimulus categorization, the revealed main effect concerning the indifference position of stimuli together with smaller P300 amplitudes for indifferent choices indicate that a stimulus categorization inside the indifference area is more difficult to discriminate for a subject. Hence, stimulus values of the sure payoff near the indifference point are reflected by a higher degree of uncertainty concerning a predominant choice category.

Furthermore, the revealed main effect concerning the choice type and the higher P300 amplitudes for lottery choices supports the assumption that both choice categories differently allocate attentional resources. Additionally, the difference in reaction times between lottery choices and sure payoff choices indicates that both types of choices are perceived in different ways. A reason for a higher attentional resource allocation of lottery choices can be referred to the presence of a risky decision. In this context, the more pronounced P300 in the real treatment further supports this assumption reasonably since this treatment condition reflects real risk consequences and a choice for the risky alternative has to be deliberated more consciously. If risky decisions are evaluated more carefully than riskless decisions, then these decisions need more time, which is reflected by higher reaction times, and are more focused in attention, which is reflected by higher P300 amplitudes.

Apart from that, a general difference between both treatments could not be confirmed, which indicates a similar categorization process of stimulus values between hypothetical and real payoffs attended by equal reaction times. This can be ascribed to the framing of an equal choice task situation of introducing a random payoff selection. Thus, the subjects responded to the same environmental choice situation which resulted in the same categorization process.

Chapter VII

7 The portfolio effect

This chapter will continue on the first EEG study concerning the hypothetical bias focusing on the influence of incentive structures in economic experiments. According to the discussion about the suitability of payoff mechanisms (see section 3.4.4), the following EEG study contrasts the random payoff mechanism and the averaged payoff mechanism with reference to their applicability for multiple choice task experiments. As discussed previously, a theoretical comparison of both payoff mechanisms entails the problem of an arising portfolio effect for the averaged payoff mechanism in which all decisions are realized for a subject. Since most individual decision making models are considering one task decisions, the averaged payoff mechanism is presumed to be inappropriate for multiple choice task experiments, because the incentive structure induces the subject to form portfolios over a certain amount of choices. Hence, the portfolio effect arises from a non-independent valuation of a single choice task. But again, aside from a theoretical comparison, the individual choice behavior does not necessarily warrant a coherent result according to this theoretical prediction. In this respect, the evaluation process during decision making gets into focus with reference to the independence of a single choice in multiple choice task experiments. As already applied in the EEG study concerning the hypothetical bias, an analysis of the N200 component in relation to conflict monitoring provides an appropriate construct for investigating an evaluation process in a neuroscientific approach.

Therefore, the subsequent EEG study will focus on the neural difference in the modulation of the N200 with reference to an independent valuation of the applied choice tasks. In this respect, different levels of conflict between both payoff mechanisms can be assumed to be evoked by a different valuation of the choice task. The neural analysis of the evaluation process therefore contributes to the discussion about the suitability of payoff mechanisms by identifying neural differences that can be ascribed to a potential portfolio effect.

Similar to the previous chapter, an introduction to the portfolio effect and a research hypothesis concerning a modulation of the N200 will be presented next. The design of the EEG study and the corresponding results will be presented followed by a discussion on this topic. These parts are based on a working paper (Morgenstern et al., 2013b) which was developed in a joint work with Marcus Heldmann (Department of Neurology at the University of Lübeck) and Bodo Vogt (Faculty of Economics and Management at the University of Magdeburg). Moreover, this chapter will further report an additional data analysis of the EEG study with reference to the choice task reaction times and a modulation of the P300 component. This additional material has not been mentioned in the working paper of Morgenstern et al. (2013b).

7.1 Introduction[5]

In experimental economics, payoff mechanisms are important procedures to ensure the incentive compatibility of choice tasks in an experiment. The concept of incentive compatibility (Smith, 1982) is one essential issue in experiments addressing questions in economics and making behavioral results of such experiments reliable. Incentive compatibility is achieved by connecting a decision of a subject in an experiment to the subject's reward for participating in the experiment. This is realized by informing the subjects about the payoff mechanism before the experiment starts. The aim is to provide incentives for a truthful response of the subjects. Thus, payoff mechanisms determine the reward for a subject and have therefore an influence on the choice behavior. Several approaches for appropriate incentivized payoff mechanisms have been discussed in the research field of experimental economics (see for example Starmer and Sugden, 1991; Camerer and Hogarth, 1999; Lee, 2007; Cox et al., 2011).

Basically, experiments in which subjects are faced with one single decision that is realized can serve as the most fitting reference for real choice behavior (Cox et al., 2011). This single decision is independent of potential influences that are present in multiple choice task experiments. However, single choice experiments are not always suitable for analyzing individual choice behavior under risk, such as determining certainty equivalents as well as measuring weighting or value functions. Therefore, experimenters commonly use multiple choice experiments.

[5] See also Morgenstern et al. (2013b)

In multiple choice task experiments, a choice between alternatives can depend on previous choices, meaning that any previously made choice potentially influences a subsequent choice. For this reason, it is preferable to incentivize subjects to make independent decisions. This isolation is theoretically achieved by implementing a random payoff mechanism in which only one randomly chosen decision is realized for a subject. Starmer and Sugden (1991) showed that the random payoff mechanism is appropriate to elicit true preferences of the subjects. But, the probability of an individual decision being chosen decreases with the number of choice tasks. Although the random payoff mechanism implies conditional rationality, the importance of one single choice could decrease for a subject. Hence, it is also worthy considering that every single choice is realized for the subject. In contrast to the random payoff mechanism, paying out all decisions in an experiment does not warrant that every single choice is considered as independent by the subject. Since every decision is realized, the decreasing variance of risky outcomes in a portfolio can induce the subjects to behave in a more risk neutral way. This can crucially influence the behavior, or the risk attitudes of subjects respectively, and is mentioned as the portfolio effect.

Up to now, just a few studies have directly addressed the question whether the behavior in individual decision making tasks differs between a random payoff procedure and a procedure in which all decisions are realized. Laury (2006) compared these two payoff mechanisms on a low payoff level and found no significant difference in the choice behavior. Differences only occurred between low and high payoff choices within the random payoff mechanism. A treatment with high payoff choices realizing all decisions was not conducted in this study. In contrast, Lawson and Lawson (2011) confirmed a difference in choice behavior for an experiment in which they applied both payoff procedures in the experimental design of Holt and Laury (2002). They found that subjects are less risk averse in their choices when all decisions are paid. In contrast, a study by Selten et al. (1999) conducted a binary lottery choice experiment in which all decision were realized and found no evidence for an inducement of risk neutral choice behavior. A more recent study of Cox et al. (2011) investigated several multiple choice task payoff mechanisms in comparison to a one task experiment in a between subject design. They attributed behavioral differences between a “one task” treatment and a “paying out all decisions” treatment to the portfolio effect. Differences between a “paying one randomly” treatment and “paying out all decisions” treatment concerning a portfolio effect were not directly discussed. In summary, unambiguous evidence indicating a portfolio effect between the payoff mechanisms of paying out one or paying out all decisions cannot be provided. Considering portfolio choice theory, there should be a behavioral difference among both payoff procedures. Hence, a further clarification on the presence of a portfolio effect is still necessary.

In our study, we will focus on these two payoff mechanisms in conjunction with a potential portfolio effect and address the question of how these two payoff mechanisms differ in their evaluation process resulting in the portfolio effect. In this context, event-related brain potentials are applicable for analyzing differences in information processing related to the evaluation of both choice task designs. Aside from incentivized differences in behavior, the decision making process itself should be different, if a non-independent evaluation of portfolio choices takes place in contrast to an independent evaluation of random payoff choices. Choices in a portfolio framed choice task should allocate more cognitive resources, if previous choices are involved in the decision making process. Hence, an analysis of processes of cognitive control is suitable for addressing this issue since these processes are existent when an evaluation of a choice task and its subsequent response takes place.

Therefore, we designed an EEG study to examine different levels of cognitive control for these kinds of decisions. Several investigations have shown that cognitive control increases in decision tasks when subjects have to choose between two or more competing alternatives (Bland and Schaefer, 2011; De Neys et al., 2011). We identified the N200 component as being appropriate for measuring processes of cognitive control. In stimulus-locked EEGs, the N200 component, a negative deflection at fronto-central electrode sites appearing 200-300 ms after stimulus presentation, is assumed to reflect the neural underpinnings of cognitive control (van Veen and Carter, 2002a; Wendt et al., 2007; Folstein and van Petten, 2008). The N200 component is supposed to reveal an action control conflict when a subject comes to a decision. We assume that different levels of involvement of cognitive control between the two payoff mechanisms should result in a different appearance of the N200 component.

The experimental procedure comprised a lottery choice paradigm for eliciting certainty equivalents. We applied two EEG experiments in which for one session one randomly chosen decision was paid out (single treatment) while for the other session all decisions were paid out on average (portfolio treatment). Paying out all decisions on average should ensure that both treatments have the same payoff scale for the subjects. The subjects performed both treatments with equal choice tasks in which they always had to choose between a fifty-fifty lottery and a sure payoff. In the comparison of both treatments, we presume that a potential portfolio effect in the behavior of the subjects would lead to less risky choices in the portfolio treatment.

As a result of behavioral differences, we would also expect differences in the N200 component. An evoked portfolio effect in the behavioral data between both payoff mechanisms indicates that these decisions are also different in the evaluation of the subjects. If the portfolio effect can be ascribed to a non-independent valuation of the decision task, then the decision making process in the portfolio treatment should allocate more cognitive resources because previous decisions are involved. Furthermore, an absence of independent decisions in the portfolio treatment should evoke a higher action control conflict due to a higher resource allocation. Hence, we expect to observe a higher level of cognitive control appearing in an increased N200 component for choices in the portfolio treatment.

7.2 Material and Methods[6]

7.2.1 Experimental procedure

The study was arranged in two EEG sessions. In one session the random payoff mechanism was applied, paying the subjects according to one randomly chosen decision (single treatment), while in the other session a portfolio treatment was used, in which all decisions of the subjects were realized by paying out all decisions on average. In order to avoid any order effects, the time interval between the two sessions was about half a year. Across the sessions, only the payoff procedures varied while the subjects' task itself remained constant (see given instructions B11-B14 of Appendix B).

The choice task followed the procedure for eliciting certainty equivalents (Farquhar, 1984) by offering the subjects a fifty-fifty lottery and a sure payoff. The fifty-fifty lottery provided a high payoff with a probability of 0.5 and a small payoff of zero with the complementary probability. The sure payoff was arranged between the two payoffs of the lottery. The subjects had to decide in each decision trial either to play the fifty-fifty lottery or to receive the sure payoff instead.

The high payoff of the lottery was set to 100 euros. The small payoff of the lottery was set to 0 euros. Values of the sure payoff were set to 10, 20, 30, 40, 50, 60, 70, 80 and 90 euros. In addition, all values were varied between 0 and 7 resulting in high lottery payoffs between 100 and 107 combined with sure payoff values between 10 and 97. Thus, a total amount of 576 decision trials was presented randomly to the subjects.

During the experiment, a subject saw three numbers in a white framed box (see Figure 23). The two outer numbers indicated the fifty-fifty lottery. The inner number indicated the sure payoff.

[6] See also Morgenstern et al. (2013b)

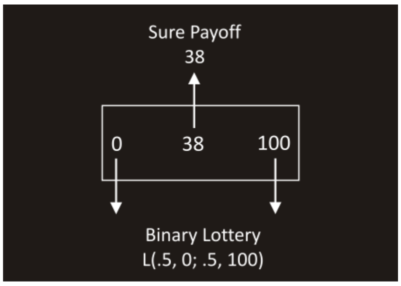

Figure 23: Choice task presented to the subjects

Each decision trial started with an empty box. Subsequently, the two outer numbers (lottery payoffs) were shown and one second later the inner number (sure payoff) appeared. After the presentation of the sure payoff, the subjects had to make a decision. The subjects indicated their decision by pressing a mouse button with their left or right index fingers. Finally, the next decision trial started (see Figure 24).

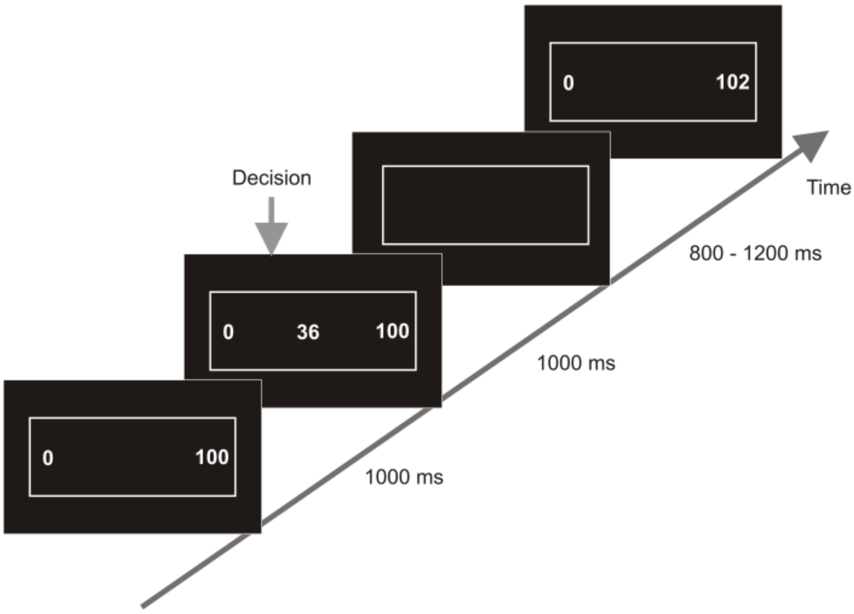

Figure 24: Sequence of screens of one choice task

The experiment consisted of 9 blocks with 64 decision trials each comprising a 30 seconds break for the subjects between each block. In order to familiarize the subjects with the task, 20 practice trials were performed by each subject. All subjects were seated in a comfortable armchair in front of a 19 inch screen at a distance of 80 to 100 cm.

In our study, the participants were 18 right-handed and neurologically healthy subjects (9 women, age range 20 to 31) which were recruited from the ORSEE (Greiner, 2004) subject pool of the University of Magdeburg. The subjects were paid according to the realization of the two payoff mechanisms. No further endowment was given to the subjects. According to the random payoff mechanism, the subjects received a payment between 0 and 107 euros in the single treatment. For the portfolio treatment, subjects earned an averaged payment between 57.87 and 66.63 euros.

7.2.2 Behavioral analysis

The behavioral data were examined in the relative frequency of lottery choice related to the decision trials. Therefore, all decision trials were categorized by the distance of the offered sure payoff to the expected value of the lottery. For example, a decision trial, in which a lottery L(.5, 0, .5, 100) with an expected value of 50 and a sure payoff of 20 had been offered to a subject, was assorted into a distance category of -30 (20-50=-30). Subsequently, for every distance category the relative frequency of lottery choices of each subject was calculated.

7.2.3 EEG recording

The electroencephalogram was recorded from 61 thin electrodes mounted in an elastic cap and placed according to the international 10-10 system (Chatrian et al., 1985). The EEG was re-referenced offline to the mean activity at the left and right mastoid. Horizontal and vertical electrooculograms (EOG) were recorded using bipolar montages in order to enable offline rejection of eye movement artifacts. All channels were amplified (bandpass 0.05-70 Hz) and digitized with 4 ms resolution. Electrode impedances were kept below 10 kΩ. After epoching the data time locked to stimulus onset (baseline -100 to 0, epoch length 1,000 ms), epochs containing eye blinks or other artifacts (muscle activity, step-like artifacts etc.) were excluded from averaging. Finally, a 12 Hz low-pass filter was applied to the subjects' averages.

7.2.4 EEG analysis

For both payoff mechanisms, the EEG data were analyzed for indifferent choices and for sure choices in relation to the subject's decision. For this purpose, we identified for every subject an area of ambiguous choices in which the relative frequency of lottery choices changes from one to zero. The choices in this area were specified as indifferent choices. Furthermore, we determined an individual indifference point for a lottery choice frequency of 0.5 within this range of indifferent choices. Around the individual indifference point, an interval size of 13 digits determined the *indifference choice area* bin sections for which we analyzed the corresponding lottery choices and sure payoff choices.

Next, we identified two areas of sure choices in which either the lottery or the sure payoff had been chosen frequently by the subject. We determined the two sure choice areas based on the individual indifference point and its location in relation to the two lottery payoffs. The area of sure choices for the lottery was determined by the midpoint between the small lottery payoff and the individual indifference point. In contrast, the area of sure choices for the sure payoff was determined by the midpoint between the individual indifference point and the high lottery payoff. An interval size of 7 digits around these two midpoints determined the *sure choice area* bin sections.

This bin determination procedure is illustrated in Figure 25 where the classification of the four bins for the EEG analysis is presented. The graph shows exemplarily the relative lottery choice frequency of a subject related to the distance of the sure payoff to the expected value of the lottery. The averaged expected value of all lotteries is at about 52 euros (high payoff variation between 100 and 107). Thus, a distance category of -52 corresponds to a sure payoff of 0 euros while a distance category of +52 corresponds to a sure payoff of 104 euros. In this example, the individual indifference point is at -14, which corresponds to a sure payoff, or a certainty equivalent respectively, of 38 euros. Hence, the area of sure choices for the lottery is at the midpoint between -52 and -14, namely at -33. In contrast, the area of sure choices for the sure payoff is at the midpoint between -14 and +52, namely at +19.

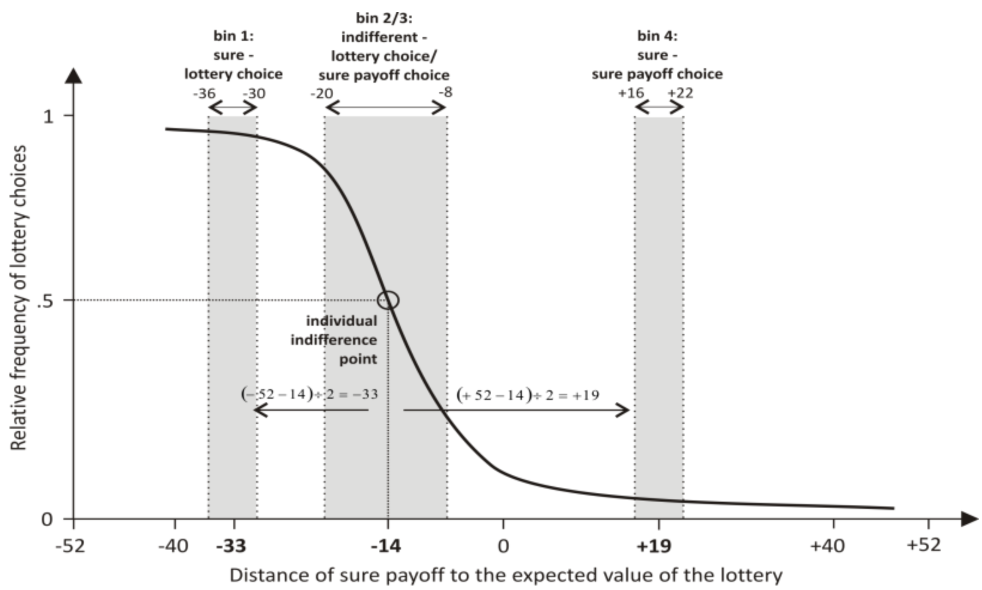

Figure 25: Description of bin classification

7.3 Results[7]

7.3.1 Behavior

The behavioral results summarized over all subjects are presented in Figure 26, which shows the relative frequency of lottery choices in relation to the distance of the sure payoff to the expected value of the lottery. The lottery choice frequency of the two payoff mechanisms differs for choices within a distance of -10 and -5 (behavioral results are provided in Table B1 of Appendix B). Around this section, the medians of the determined indifference points of both treatments are located. The single treatment has a median of -11 (mean=-10.11, SE=2.53) while the portfolio treatment has a median of -4 (mean=-8.39, SE=2.36). A one-sided pair-wise Wilcoxon signed-rank test revealed a significant difference on a 5 % level (V=21.5, p=0.05) for the lottery choice frequency within a distance of -8 to -7. Lottery choices are significantly higher in this section when subjects are faced with the decision task in the portfolio treatment. Thus, we observe a sharper change in the choices of subjects from the lottery to the sure payoff when the sure payoff moves toward the expected value of the lottery in the portfolio treatment.

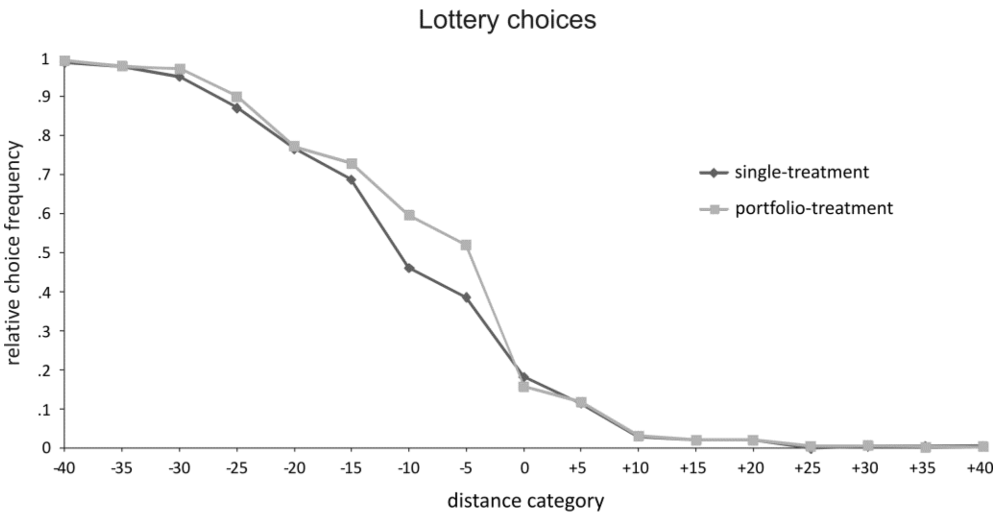

Figure 26: Relative frequency of lottery choices

An overall difference in the amount of risky choices cannot be confirmed. In the single treatment, 36.1 % of all choices are risky choices, whereas in the portfolio treatment, 38.0 % of all choices are risky choices. The absence of a general impact on risk attitudes is similar to the finding of Laury (2006) for low payoff choices.

However, the difference in choice behavior can particularly be ascribed to the area of indifferent choices. We analyzed the lottery choice frequency for ambiguous

[7] See also Morgenstern et al. (2013b)

choices related to an interval of indifference. Such an indifference interval determines an area for which the subjects are switching from a lottery choice frequency of one to a lottery choice frequency of zero. The lottery choice frequency within these indifference intervals (see Table B2 of Appendix B) is significantly higher in the single treatment (single: 55.0 %; portfolio: 47.1 %) revealed by a one-sided, pair-wise Wilcoxon signed-rank test (V=43, p=0.033). This indicates that a sharper change from a sure choice area for lottery choices to an indifferent choice area is present.

7.3.2 Event-related potentials

Based on our previous assumption concerning the role of cognitive control for choices in the single treatment and for choices in the portfolio treatment, we analyzed the N200 component for both treatments. We identified an N200 component at the fronto-central electrode positions, peaking between 260 and 360 ms after stimulus presentation.

Figure 5 shows the event-related potentials of the two payoff mechanisms at the FCz electrode elicited for the four determined bins. The four graphs in Figure 27 compare indifferent choices with sure choices. On the left hand side, the event-related potentials of the portfolio treatment are displayed. On the right hand side, the event-related potentials of the single treatment are shown. In the upper row, the sure payoff choices and in the lower row, the lottery choices are compared.

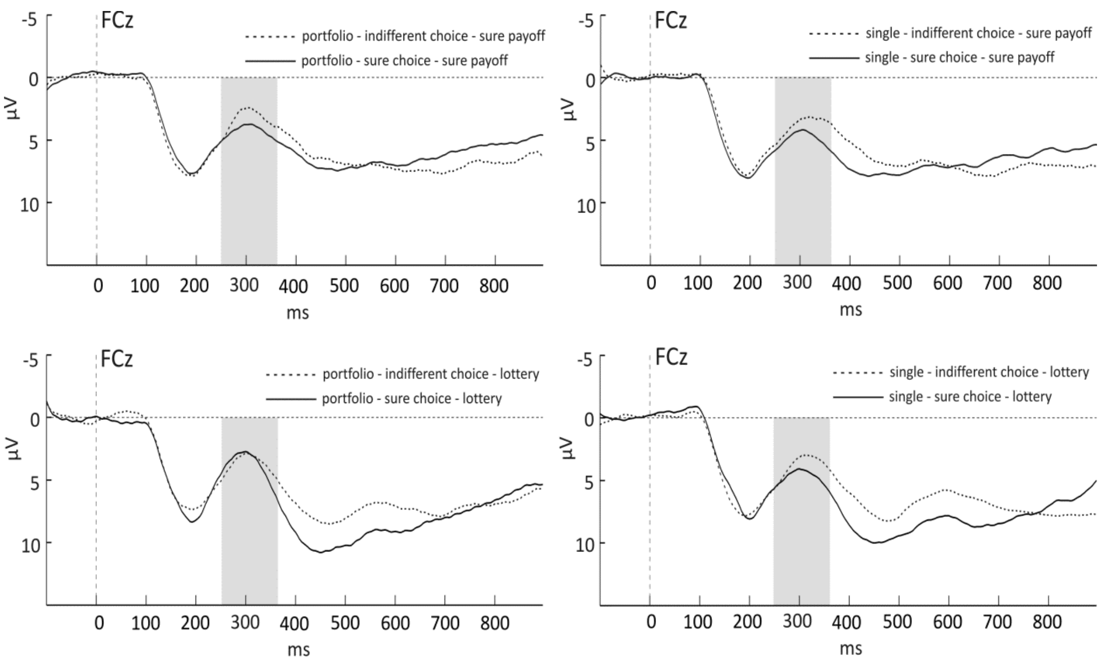

Figure 27: ERPs at the FCz electrode separated by the type of choice and treatment

As can be seen, the indifferent choices tend to have a higher N200 peak at about 310 ms in contrast to sure choices. But for lottery choices of the portfolio treatment, this pattern cannot be found (see Figure 27 on the bottom left-hand side). Here, both peaks are at the same level. The following figures distinguish the ERPs at the FCz electrode between choices inside the indifference area (Figure 28) and outside the indifference area (Figure 29). Here we observe that for choices outside the indifference area the N200 peak is higher in the portfolio treatment when the lottery is chosen.

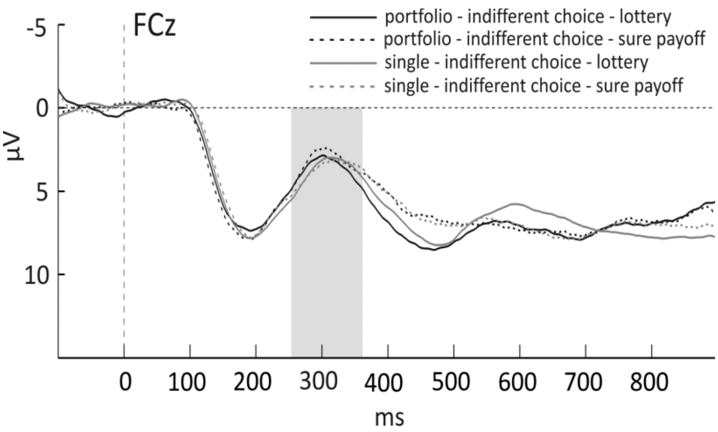

Figure 28: ERPs at the FCz electrode for choices inside the indifference area

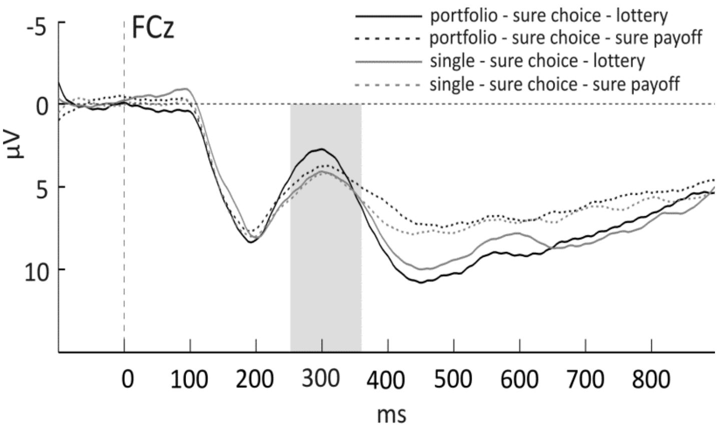

Figure 29: ERPs at the FCz electrode for choices outside the indifference area

Subsequently, mean amplitudes within 260 and 360 ms were calculated (see Table B3-B7 of Appendix B). A repeated measures ANOVA for mean amplitudes between 260 and 360 ms was performed for the midline electrodes (see Table B8 of Appendix B). The ANOVA contained the factors *anterior-posterior electrode position* (Fz, FCz, Cz, CPz, and Pz), *treatment* (portfolio, single), *choice* (lottery, sure payoff) and *indifferent position* (indifferent choice, sure choice). An interaction for *anterior-posterior x treatment x indifferent position* (F(1.956)=6.792, p=0.004) and a main effect for *indifferent position* (F(1)=8.198, p=0.011) was revealed. The difference between indifferent and sure choices was confirmed by an ANOVA for the FCz electrode (see Table B9 of Appendix B) with *treatment* (portfolio, single), *choice* (lottery, sure payoff) and *indifferent position* (indifferent choice, sure choice) as factors, which revealed a main effect for *indifferent position* (F(1)=9.125, p=0.008). All degrees of freedom, F-values, and p-values are reported as Greenhouse-Geisser corrected.

Mean amplitudes at the FCz electrode are presented in Figure 30 and Figure 31. The observation of higher N200 amplitudes for indifferent choices is present in the single treatment for lottery choices as well as for sure payoff choices, indicating an increased action control conflict for indifferent choices. These differences are confirmed by a one-sided pair-wise t-test (lottery choices: T(17)=-2.016, p=0.030; sure payoff choices: T(17)=-1.796, p=0.045).

In contrast, this pattern is different in the portfolio treatment. The N200 amplitude shows a difference between sure choices and indifferent choices in case of choosing the sure payoff. But no difference is observed between indifferent lottery choices and sure lottery choices. This observation in the portfolio treatment is confirmed by a one-sided pair-wise t-test (see also Table B10 of Appendix B) for which the sure payoff choices differ significantly on a 5 % level (T(17)=-1.854, p=0.041) but not the lottery choices (T(17)=-0.297, p=0.385).

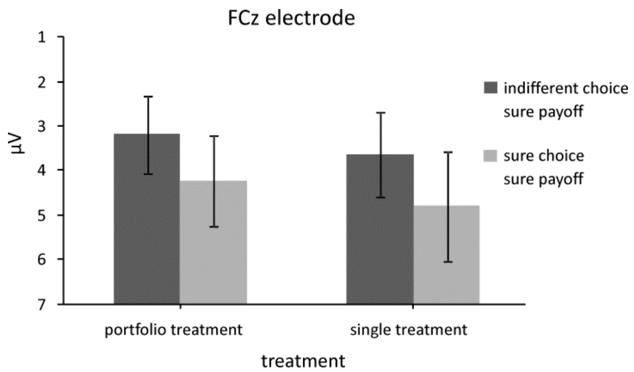

Figure 30: Mean amplitudes within 260 and 360 ms at the FCz electrode for sure payoff choices

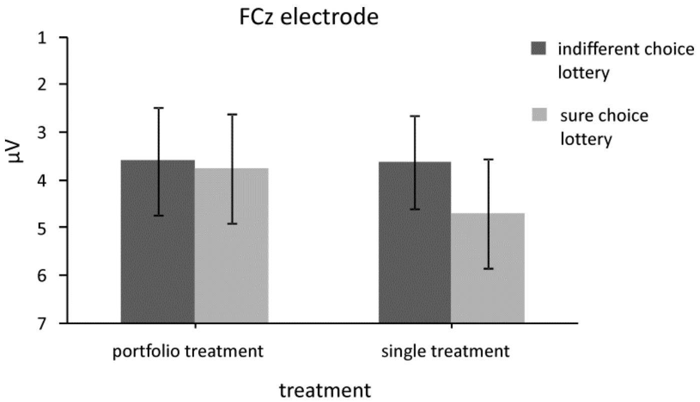

Figure 31: Mean amplitudes within 260 and 360 ms at the FCz electrode for lottery choices

Thus, the results show a characteristic pattern of the N200 amplitude between choices inside and outside the indifference area. Indifferent choices evoke a higher N200 amplitude. Furthermore, in the portfolio treatment this higher N200 amplitude is also present for lottery choices outside the indifference area.

7.4 Discussion[8]

In the present study, we investigated the neural underpinnings of cognitive control mechanisms related to the portfolio effect by recording EEGs while the participants were performing a lottery choice task. In this respect, event-related brain potentials were used to analyze differences in the evaluation process, which can be ascribed to a potential portfolio effect. We conducted two identical multiple choice task experiments in which we used two different payoff mechanisms. We applied the random payoff mechanism (single treatment) by paying out one randomly chosen decision and a payoff mechanism in which all decisions were paid out on average (portfolio treatment). The averaged payoff mechanism, in comparison to the random payoff mechanism, was assumed to result in a more risk neutral behavior, which can be attributed to the portfolio effect. We addressed the question of neural differences in the evaluation process of these two payoff mechanisms because a predicted behavioral difference is caused by an inconsistency in the independent evaluation of each lottery choice task. Based on the assumption that the evaluation of a choice task is connected with processes of cognitive control, we examined the N200 component in relation to these processes.

A comparison of the behavioral results shows that the subjects chose a higher frequency of lottery choices in the portfolio treatment when the sure payoff is close to the expected value of the lottery. Furthermore, the steeper change of choice frequency in this area can be referred to a higher decrease of lottery choices in the indifference area. An overall difference concerning the risk attitudes of subjects toward a less risky choice frequency is absent. This general result is in line with the study of Laury (2006). However, the difference in lottery choice frequencies between both treatments near the expected value of the lottery can be attributed to a portfolio effect to a certain extent. This difference in the behavioral data shows that the subjects are choosing the lottery more frequently when the sure payoff is close to, but still smaller than the expected value of the lottery. This would imply that the subjects are in some degree aware of the decreasing variance of risky outcomes in a portfolio and adjust their choice frequency toward the expected value of the lottery accordingly.

[8] See also Morgenstern et al. (2013b)

The EEG analysis shows differences between indifferent choices and sure choices for the two payoff mechanisms. In both treatments, the N200 amplitudes are higher for indifferent choices, which indicate an increased action control conflict for these choices. This seems plausible since subjects are less decisive in their decision when they are indifferent and one out of two alternatives has to be chosen. In contrast, the subjects seem to be more certain in their decisions outside their indifference area. The increased action control conflict is missing outside the indifference area for sure payoff choices in both treatments and for lottery choices in the single treatment. However, we cannot confirm a difference in the N200 amplitudes between sure lottery choices and indifferent lottery choices in the portfolio treatment. This implies that the level of conflict during decision making is higher in a portfolio choice task for the risky choice alternative.

The increased action control conflict for risky choices can be attributed to a non-independent evaluation of the present choice task. If the subjects involve previous choices into their decision making, then the range of decision making is extended, which could lead to such an increased action control conflict. Interestingly, we do not find this higher level of conflict for the sure payoff choices in the portfolio treatment, which indicates that sure payoff choices do not evoke an increased action control conflict. Thus, the portfolio effect can be assigned to a portfolio-based thinking for risky choices but not for riskless choices. This would imply that a higher decision conflict is evoked when subjects are at odds with their true risk attitude for an independent decision and the more risk neutral portfolio decision.

7.5 Additional data analysis

Similar to the additional data analysis of the study concerning the hypothetical bias, further results of the EEG study concerning the portfolio effect will be discussed in this section. Aside from a focus on the N200 modulation, the ERP data also provide a different appearance of the P300 component. Hence, as already discussed for the hypothetical bias, the modulation of the P300 component will also be analyzed concerning the applied payoff mechanisms of this study. Consequently, potential differences of the P300 will be discussed. Before that, the behavioral reaction times will be provided and discussed in the next section.

7.5.1 Analysis of reaction times

According to each stimulus presentation, mean response times corresponding to the four ERP bin classifications were calculated for every subject. Figure 32 shows the mean reaction times for both treatments separated by the bin classification. As can be seen, the mean reaction times differ between both payoff treatments. Mean reaction times in the single treatment are higher than those in the portfolio treatment (see also Table B21 of Appendix B). The subjects responded on average between 500 and 700 ms in the single treatment and between 450 and 650 ms in the portfolio treatment. Furthermore, differences are also present across the stimulus values. Reaction times are about 100 ms higher for stimulus values within the individual indifference area. Additionally, reaction times for lottery choices seem to be higher than for sure payoff choices.

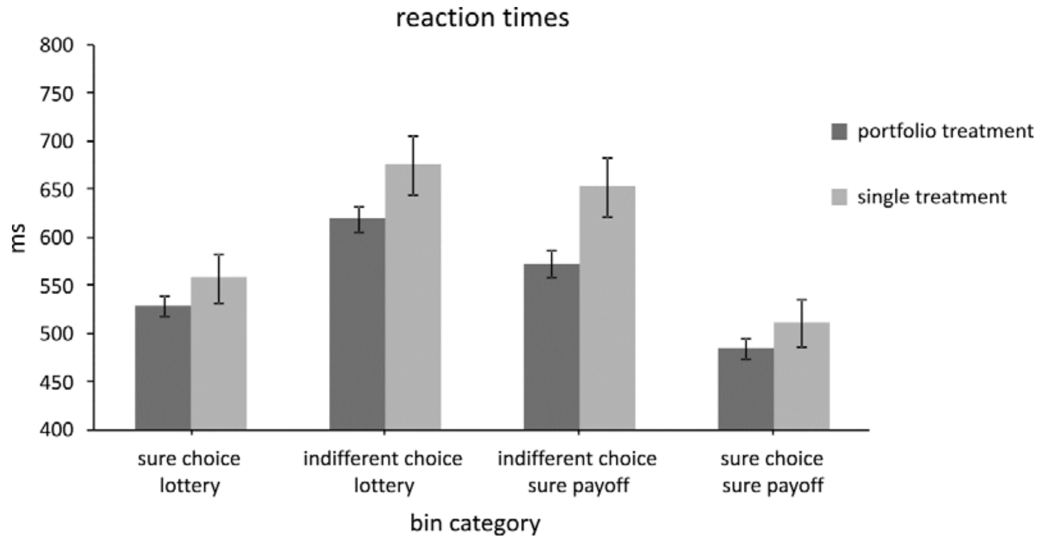

Figure 32: Mean reaction times

For statistical analysis of the mean reaction times, a repeated measures ANOVA was conducted with *treatment* (single, portfolio) and *bin classification* (sure choice for the lottery, indifferent choice for the lottery, indifferent choice for the sure payoff, sure choice for the sure payoff) as factors (see Table B22 of Appendix B). The performed ANOVA revealed a main effect for *treatment* ($F(1)=4.468$, $p=0.05$) as well as for *bin classification* ($F(2.574)=88.318$, $p<0.001$) and detected an interaction for *treatment x bin classification* ($F(2.555)=6.360$, $p=0.002$). Subsequently, a three factor ANOVA with *treatment* (single, portfolio), *choice* (lottery, sure payoff) and *indifferent position* (indifferent choice, sure choice) was performed for a further clarification of the bin classification effect (see also Table B23 of Appendix B). For all three factors a main effect (*treatment*: $F(1)=4.468$, $p=0.05$; *choice*: $F(1)=40.338$, $p<0.001$; *indifferent position*: $F(1)=149.222$, $p<0.001$) can be confirmed as well as an interaction for *treatment x indifferent position* ($F(1)=15.977$, $p=0.001$). According to this interaction, mean reaction times between both treatments differ significantly for indifferent choices in performed pair-wise t-tests ($T(17)>2.145$, $p<0.047$) but not for sure choices ($T(17)<1.308$, $p>0.208$). Furthermore, the revealed main effects concerning *choice* and *indifferent position* could be confirmed by pair-wise t-tests (see Table B24 of Appendix B), indicating for both treatments that lottery choices yield higher reaction times ($T(17)>2.588$, $p<0.019$) as sure payoff choices while indifferent choices yield higher reaction times ($T(17)>6.862$, $p<0.001$) than sure choices.

The higher reaction times for indifferent choices compared to those of sure choices support the assumption that subjects are more indecisive for these stimuli. This is also indicated by an increased action control conflict reflected by higher N200 amplitudes. In contrast, the decreasing reaction times in both treatments outside the indifference area disagree with the presence of an increased N200 component. Decreasing reaction times indicate that subjects are more confident in their decisions. The increased N200 amplitude in the portfolio treatment for risky choices outside the indifference area therefore requires a different reasoning. As already stated for hypothetical choices in the previous study, the decrease of reaction times and the presence of an increased N200 amplitude cannot be referred to a conflict with regard to response inhibition. Hence, this finding also suggests that the increased conflict can be related to a process during stimulus evaluation, which is presumed by the conflict monitoring hypothesis.

Moreover, reaction time differences between both treatments indicate that both choice tasks are performed differently. Smaller reaction times in the portfolio treatment suggest that these choice tasks are easier to perform for a subject. This could be referred to the reduction of risk variance by forming portfolios, which reduces the uncertainness of a distinct outcome consequence. The importance of making the right choice decreases compared to the single treatment.

The pattern of reaction times provides further clarifications of the ERP data, and the presumed explanations of the findings concerning the N200 are supported by the mean reaction time data. In contrast to the study concerning the hypothetical bias, the differences between both payoff mechanisms can be ascribed to a different choice task environment. This further indicates that both payoff mechanisms are processed in different manners by the subjects.

7.5.2 Analysis of the P300 component

For the analysis of the P300 component in this study, the same approach was employed as the one used in the previous study concerning the hypothetical bias. Hence, the assumptions concerning a P300 modulation can also be applied for this section. According to the event categorization hypothesis (Kok, 2001) of the P300, higher P300 amplitudes are generally expected outside the indifference area of the subjects because these stimulus values are easier to categorize in relation to a predominant response. Furthermore, lottery choices should also evoke higher P300 amplitudes than sure payoff choices in both payoff procedures, presuming that risky decisions demand higher attentional resources due to a risk awareness. In addition and in contrast to the study about the hypothetical bias, differences in the P300 amplitude between both treatment conditions are possible, if both choice task paradigms are perceived in different ways. Assuming that the subjects in the portfolio treatment are aware of a potential portfolio strategy, then the attraction of attentional resources toward the risky decision could be less pronounced than in the single treatment. Moreover, a distinct categorization of stimuli toward the predominant response could also diminish for the portfolio treatment since forming portfolios in a portfolio strategy could comprise both types of responses and a categorization is therefore not unambiguous. Hence, P300 amplitudes are presumed to be different between both treatments, expecting generally higher P300 amplitudes for the single treatment.

In the ERP data of the present study, a P300 component was determined to occur at about 450 to 550 ms after stimulus onset. Figure 33 depicts the averaged voltage distribution on the scalp within this time range for both treatments. The figure shows that a positive maximum is located at centro-parietal electrode sites, reflecting the characteristic location of the P300 component.

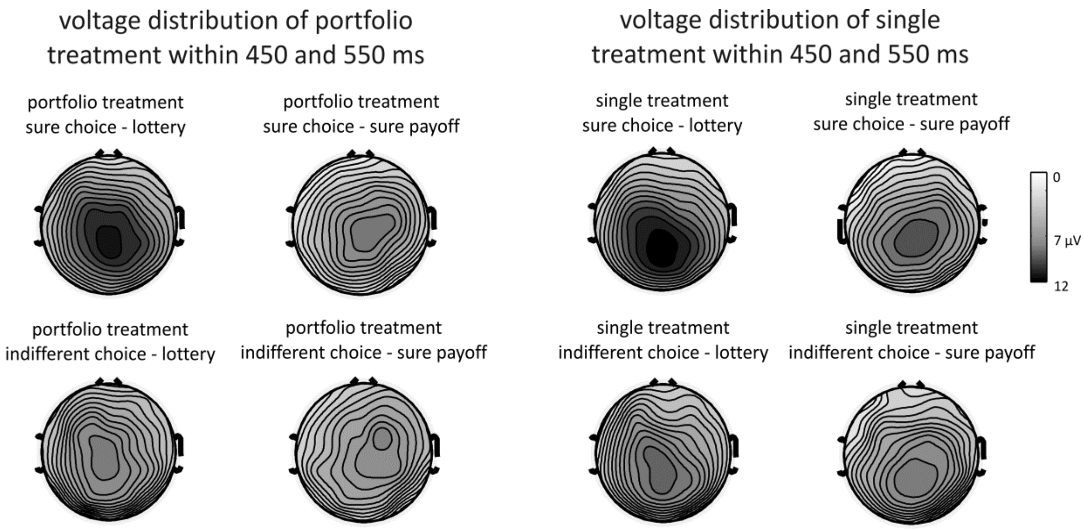

Figure 33: Topographies of voltage distribution within 450 and 550 ms

The following figures show the event-related potentials at the Pz electrode for both treatments separated by indifferent choices (Figure 34) and sure choices (Figure 35). As can be seen, the P300 component is most diverging for choices outside the indifference area. In this area, the P300 amplitudes are most pronounced for sure lottery choices and presumably differ across both treatments. Moreover, P300 amplitudes of portfolio treatment choices appear to be smaller than single treatment choices.

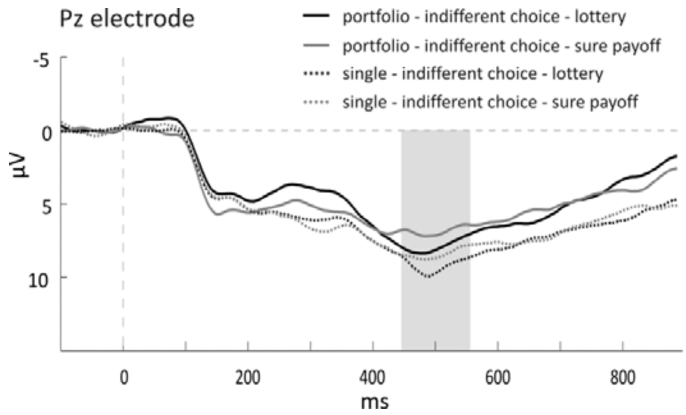

Figure 34: ERPs at the Pz electrode for choices inside the indifference area

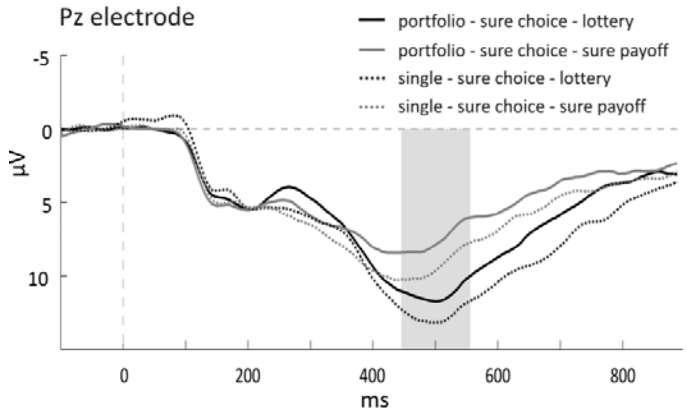

Figure 35: ERPs at the Pz electrode for choices outside the indifference area

Mean amplitudes between 450 and 550 ms after stimulus onset were calculated (see Table B15-B17 of Appendix B) and analyzed in a repeated measures ANOVA for the midline electrodes with three factors, comprising *anterior-posterior electrode position* (Fz, Cz, Pz), *treatment* (single, portfolio) and *bin classification* (sure choice for the lottery, indifferent choice for the lottery, indifferent choice for the sure payoff, sure choice for the sure payoff) as factors (see also Table B18 of Appendix B). The ANOVA revealed a main effect for *bin classification* ($F(2.821)=10.176$, $p<0.001$) as well as an interaction *anterior-posterior electrode position x bin classification* ($F(3.392)=6.895$, $p<0.001$). A further interaction *anterior-posterior electrode position x treatment* ($F(1.220)=16.594$, $p<0.001$) could also be detected. Subsequently, mean amplitudes at the Pz electrode were analyzed in a further ANOVA (see Table B19 of Appendix B) with *treatment* (single, portfolio), *choice* (lottery, sure payoff) and *indifferent position* (indifferent choice, sure choice) as factors. For all three factors, a main effect was revealed (*treatment*: $F(1)=10.532$, $p=0.005$; *choice*: $F(1)=12.618$, $p=0.002$; *indifferent position*: $F(1)=32.882$, $p<0.001$). Moreover, an interaction *choice x indifferent position* ($F(1)=7.860$, $p=0.012$) was detected for mean amplitudes at the Pz electrode.

The revealed main effect at the Pz electrode for the treatment condition indicates a general difference of P300 amplitudes between both payoff mechanisms. Figure 36 illustrates the mean amplitudes of the P300 component within 450 and 550 ms at the Pz electrode. As can be seen, the mean amplitudes in the single treatment are constantly higher than mean amplitudes in the portfolio treatment among all four bin categories. A pair-wise comparison of both treatment conditions for each bin category revealed significantly higher mean amplitudes ($T(17)>1.996$, $p<0.031$) for the single treatment in performed one-sided t-tests (see Table B20 of Appendix B).

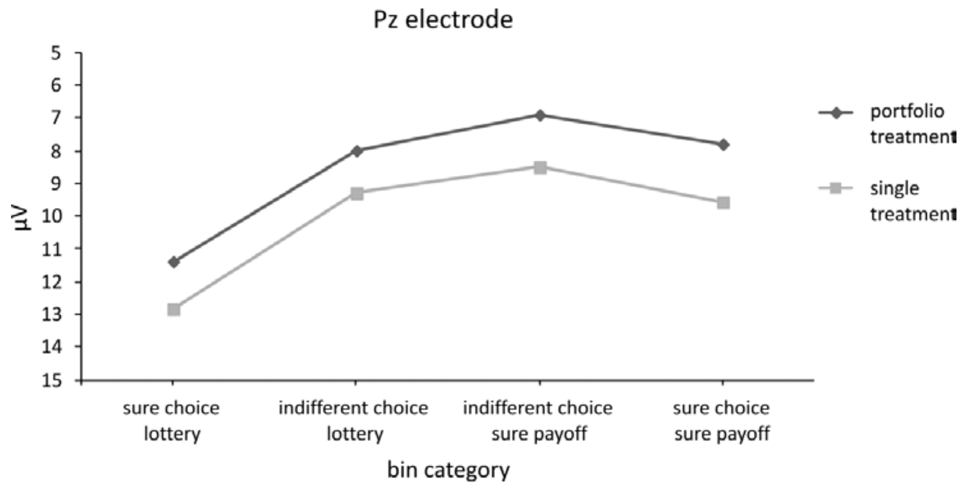

Figure 36: Mean amplitudes within 450 and 550 ms at the Pz electrode

According to the main effects for the type of choice and the indifferent position of stimuli, a pair-wise analysis of mean amplitudes showed a similar pattern as revealed in the EEG study concerning hypothetical and real payoff choices. P300 amplitudes of sure lottery choices and sure payoff choices differ significantly in both treatments for performed one-sided pair-wise t-tests ($T(17)>3.060$, $p<0.004$). Furthermore, P300 amplitudes of indifferent lottery choices are significantly smaller than P300 amplitudes of sure lottery choices ($T(17)>4.348$, $p<0.001$) in both treatments. Figure 37 and Figure 38 depict both comparisons, indicating the different appearance of the P300 for sure lottery choices.

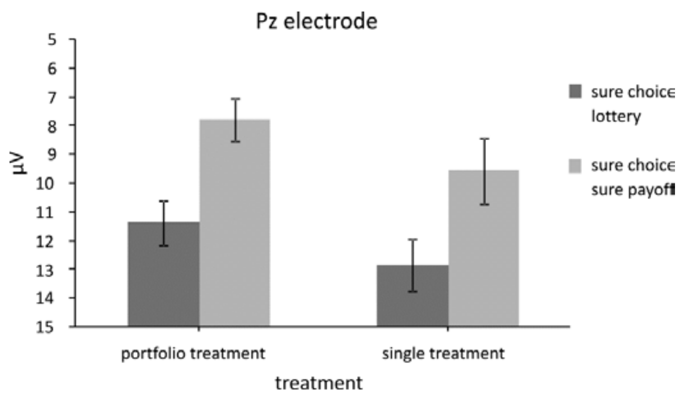

Figure 37: Mean amplitudes within 450 and 550 ms at the Pz electrode for choices outside the indifference area

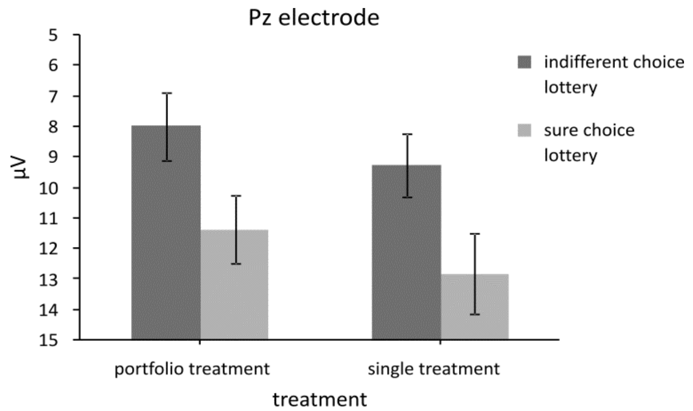

Figure 38: Mean amplitudes within 450 and 550 ms at the Pz electrode for lottery choices

The results illustrate similarities to the study of hypothetical and real payoffs. The difference in P300 amplitudes between indifferent and sure choices is also confirmed in this study, indicated by the main effect that refers to the indifferent position of a stimulus. Smaller P300 amplitudes are evoked by indifferent choices which imply a more difficult discrimination of stimuli according to a potential categorization process which is reflected by the P300. In addition, higher reaction times for indifferent choices in both treatments also support this assumption.

Furthermore, the revealed main effect with reference to the type of choice denotes different information processing of risky and riskless decisions. Assuming that attentional processes are also modulating the P300 component, this result can be ascribed to a higher attraction of attention toward the risky alternative. This pattern was also found for hypothetical payoffs indicating a general difference between these types of choice alternatives. Additionally, the mean reaction time differences also imply different stimulus information processing. Lottery choices evoke higher reaction times than sure payoff choices, indicating a more careful stimulus evaluation. In this context, a more careful evaluation might induce a higher attraction of attentional resources.

Finally, the main effect revealed for the treatment condition further indicates that the stimulus perception between both choice task situations differs. With reference to the differently introduced choice tasks, the smaller P300 amplitudes in the portfolio treatment could refer to a potential forming of portfolios. Forming portfolios across different choices reduces the risk in its variance and could therefore lead to a decreasing attraction of attentional resources on each stimulus. This assumption is also supported by the reaction time data for which constantly smaller reaction times could be revealed in the portfolio treatment. Smaller reaction times can be referred to the reduction of risk for portfolio choices, indicating a smaller importance of each decision. As a result, the difference in P300 amplitudes between both treatments provides an indicator for the differentness of both choice task situations.

Chapter VIII

8 The ERN modulation in risky and riskless decision making

According to the previously discussed modulation of the N200 component in relation to conflict monitoring processes, this chapter will additionally describe the response-related ERN component and its relation to conflict processing in risky decision making. The ERN component is assumed to be generated in the anterior cingulate cortex which represents a brain region affiliated to the conflict monitoring system (Botvinick et al., 2001). Basically, the ERN is supposed to reflect a perceived divergence of afore intended and finally performed responses. Occurrences of the ERN can therefore be ascribed to specific levels of a response conflict which can result from a different subjective relevance or valuation of a given choice task (Heldmann et al., 2009). In this context, investigating risky decision making with reference to the response-related ERN can provide clarifications of how responses are evaluated toward the presence of different levels of risk.

The subsequent response-related analysis of the ERN component is an additional data analysis and refers to the study of Morgenstern et al. (2009) in which a stimulus-related ERP analysis was provided. The study compared two methods for eliciting utility functions and focused on the stimulus evaluation process concerning a potential probability weighting in risky outcomes. Morgenstern et al. (2009) did not comprise a response-related analysis for the research hypothesis in this study. The utility assessment methods applied in their study were characterized by a riskless and a risky method. The riskless method followed a bisection task of evaluating the midpoint in utility of two monetary outcomes. The risky method followed the certainty equivalent procedure for determining an indifference point between a sure monetary outcome and two unsure monetary outcomes represented by a fifty-fifty lottery. According to an EEG study by Heldmann et al. (2009), both methods yield similar behavioral results, and the bisection task is therefore presumed to be applicable for determining utility functions. Furthermore, an ERP comparison concerning response-related conflict processes was conducted in this study. As a result, Heldmann and colleagues found that both methods differ in the occurrence of the ERN for choices outside an individual indifference area of the subjects. ERN amplitudes were larger for error-like choices in the risky assessment method when an apparently predominant choice has not been chosen. The authors suggested that risky choices are subjectively more engaged in response control processes as a result of the presence of risk. Interestingly, the effect was revealed although all payoffs had been hypothetical, which emphasizes a general subjective relevance of the intended behavioral outcomes in this method. However, the experimental setting in the Morgenstern et al. (2009) paradigm allows for an additional analysis of the response-locked ERP components addressing the question of response conflicts in risky decision making as mentioned in the study by Heldmann et al. (2009).

8.1 Introduction

According to the concept of utility functions integrated in most economic theories (e.g. EUT or Prospect Theory), the determination of utility functions for economic goods is a fundamental concern in experimental economics. Utility functions are well-established in decision theory, and most models addressing individual decision making behavior rely on the assumption that an individual evaluates a decision consequence according to the subjective utility he or she receives from the decision's outcomes. Identifying an individual utility of a distinct economic good and its functional relationship is the aim of utility assessment methods. Although several approaches for determining utility functions are used, so far no generally accepted procedure exists. With reference to risky decision making, utility functions are determined by applying a choice task situation with risky gambles (see Farquhar, 1984). The behavioral results of such risky gamble choices reflect an evaluation of consequences and its underlying probabilities. Hence, risky gamble choices are influenced by two aspects: (1) the size of outcome consequences and (2) the level of risk reflected by the probability of occurrence. The functional form of a utility function can be inferentially determined from the behavioral results with reference to a theoretical model. But theoretical models differ in their assumptions concerning the functional form as well as regarding the evaluation process of a risky decision. For example, in Expected Utility Theory a decision is evaluated according to the utility of outcomes and their probability of occurrence. In contrast, a decision in Prospect Theory (Kahneman and Tversky, 1979) is evaluated according to a value function of outcomes and a probability weighting. In case of determining a value function according to Prospect Theory, the process of probability weighting and its underlying functional form has to be separated from the result of a utility assessment method. This shortcoming can be resolved by applying a utility assessment method that is not connected to risk and therefore not connected to a potential probability weighting.

An approach for eliciting utility of monetary outcomes without risk is the bisection method suggested by Galanter (1962). This method applies a bisection task questionnaire for a subject in which differences in utility associated with monetary outcomes have to be evaluated by the subject. An identification of the midpoint in utility between two monetary outcomes can be used for determining the functional form of utility. Assuming that a risky elicitation method and a riskless elicitation method are based on the same utility function, then both methods can be combined to separate a utility function, or a value function respectively, from a potential probability weighting process, or probability weighting function respectively. However, the question arises how both procedures differ in their evaluation processes even if they rely on the same utility function. The presence of risk in a gamble choice task compared to a riskless monetary evaluation can be used to analyze neural processes with regard to the sensitivity toward risk in decision making.

In this context, cognitive control mechanisms are involved in decision making processes, and the degree of perceived risk during decision making can be assumed to result in a distinct level of response conflict. Higher variances of risky outcomes presumably induce an increased awareness of potential choice errors for a subject in order to prevent undesirable outcomes. Hence, the model of conflict monitoring (Botvinick et al., 2001) seems to be applicable to this assumption. One component that reflects the activity of an integrated part of the presumed conflict monitoring system is the error-related negativity (ERN). The ERN component, a negative deflection at fronto-central electrode sites peaking at about 50 to 150 ms after a response, is assumed to be sensitive to response conflicts, indicating the significance of errors (Gehring et al., 1993). Furthermore, the ERN is presumed to be generated in the anterior cingulate cortex (van Veen and Carter, 2002a) which represents an area associated with cognitive control mechanisms (Gehring and Knight, 2000; Paus, 2001).

With reference to risky decision making and its potential influence on the ERN, Hewig et al. (2007) analyzed risk taking behavior and the modulation of the ERN in a Blackjack gambling task. They have shown that choices with an increased risk result in an increased ERN amplitude. Hewig et al. (2007) argue that an increased ERN amplitude is associated with a negative evaluation of the current decision and that the amplitude of the ERN can therefore be related to risk taking behavior. In addition, Yu and Zhou (2009) conducted an EEG study in which subjects had to decide whether to participate in a bet for winning or losing a certain amount of money. The results of this study also show that the ERN is modulated by risk taking behavior indicated by increased ERN amplitudes for bets with a higher variance. Hence, the riskiness of choices reflected by the variance of a decision outcome seems to modulate the ERN amplitude. Moreover, the ERN is further observed to be influenced by the size of a potential monetary outcome. Hajcak et al. (2005) revealed increased ERN amplitudes for high monetary values in contrast to small monetary values, indicating an ERN modulation influenced by the size of the expected outcome value. Hajcak et al. (2005) attributed this finding to an increased significance of errors induced by the higher outcome value. Hence, the factors that are presumed to determine the utility of a subject in risky decision making, the expected outcome and the variance of risk, both influence the appearance of the ERN component. As a result, the ERN component seems to be suitable for investigating the role of risk between a utility assessment method without risk and a method connected with risk.

Considering the previously discussed aspects concerning a modulation of the ERN amplitude under risk, a comparison of both methods should result in more pronounced ERN amplitudes for the method that is connected with risk. In the presence of risk, it can be assumed that a deviation from an advantageous choice reflects a potentially undesirable outcome, resulting in an increased subjective relevance for a correct response. An absence of risk should preclude a potential response conflict that is caused by an error-like deviation from an apparently predominant choice since an undesirable outcome is not induced by such a choice task.

Subsequently, the implementation of both utility assessment methods as used in this study will be described. Besides a theoretical comparison and its implication to differences in behavioral results, the focus here is rather drawn on a comparison regarding the application of risk. For a more detailed theoretical consideration see Morgenstern et al. (2009).

As mentioned before, a bisection task similar to the procedure of Galanter (1962) was applied for determining midpoints in utility between two monetary outcomes. Therefore, three monetary values in ascending order were presented to the subjects. The subjects were requested to indicate whether they perceive the interval within the first two monetary values as greater in utility than the interval within the last two monetary values. In order to induce a monetary valuation context, the subjects were instructed to evaluate each monetary value according to their 'happiness' they would feel by receiving these amounts of money (see

Galanter, 1962). In this context, the study used the term of ‘joy’ as a substitute for indicating utility.

The lottery choice task followed the procedure for eliciting certainty equivalents (see Farquhar, 1984) of a fifty-fifty lottery. Each choice task similarly comprised three monetary values in ascending order, indicating a fifty-fifty lottery with the first and the last value as potential outcomes and a sure amount of money represented by the center value. The subjects were requested to indicate whether they prefer receiving the sure amount of money or not. Here, it is important to note that all decisions were made hypothetically and that the subjects were not paid according to their decisions. The hypothetical context is necessary for an equivalent comparison of both utility assessment methods since the bisection choice task cannot be incentivized by an extrinsic incentive structure.

Comparing the lottery choice task with the bisection task, the lottery choice task would indirectly ask for the same utility interval evaluation as requested in the bisection task (see Figure 39). Therefore, both procedures determine a midpoint in utility of a normalized utility function under Expected Utility Theory. In this regard, an evaluation of the choice task would solely differ in the presence of risk. If both utility intervals are diverging extensively in the perception of a subject, then an error-like choice in the lottery choice task provides a potentially undesirable outcome for the risky choice situation. In contrast, an error-like choice in the bisection task would only account for an incorrect choice. In this comparison, a higher ERN amplitude is assumed to be evoked for error-like choices of the lottery choice task.

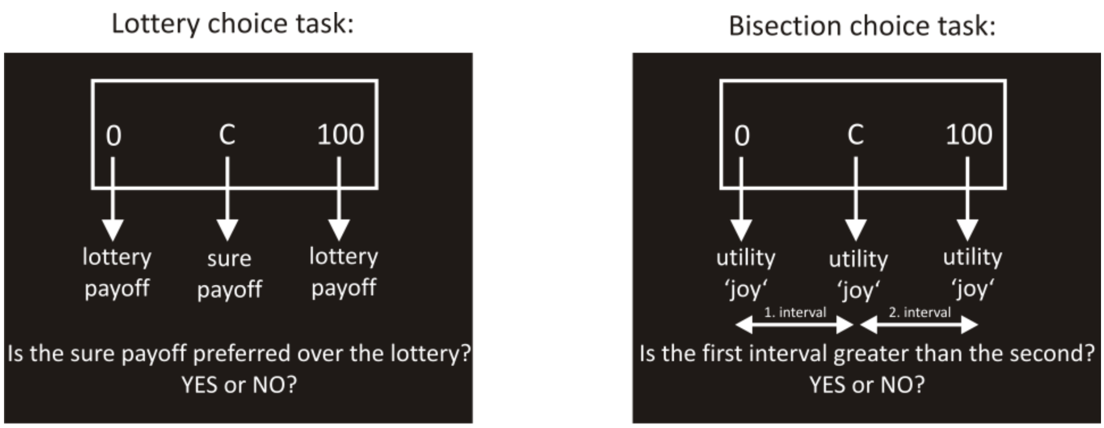

Figure 39: Comparison of choice tasks between CE method and bisection method

8.2 Material and Methods

8.2.1 Experimental procedure

Sixteen right handed and neurologically healthy subjects (9 women, age range 19 to 27) participated in this study after giving informed consent. The study was arranged in two EEG sessions with identical choice task instructions and stimulus material. The experimental instruction comprised a bisection task and a lottery choice task, which were performed concurrently by the subjects (see given instruction C12 of Appendix C). In the experimental proceeding, both choice tasks were differently indicated by a specific color signal. Both sessions were conducted for every subject within two weeks and lasted about two hours each. The subjects were paid 7 euros per hour for their participation. During the experiment, the participants were seated in a comfortable armchair in front of a 19 inch monitor with a distance of 80 to 100 cm. The subjects gave responses by pressing two mouse buttons with their left and right index finger. For both choice task situations, the subjects received no feedback on their performance. Furthermore, each session began with 20 practice trials in order to familiarize the subjects with the task. After that, the experiment started, comprising nine blocks with 70 decision trials each.

In each decision trial, a row of three number values enclosed by a colored box was presented to the subjects. When the decision trial started, the two outer number values surrounded by a white box were shown first. After 1,000 ms, the white frame of the box turned into one out of two colors (light blue and pink). The color of the frame indicated for a subject which kind of choice task was currently requested. Hence, the color of the frame requested the subject either to decide according to the lottery choice task or to decide according to the bisection task. Next, the inner number was added after 1,000 ms, and the completed array remained for another 1,000 ms on the screen. Within this time range, the subjects had to make a decision with their index fingers according to the present choice task. Figure 40 depicts the sequence of screens for one decision trial.

In the row of the three numbers, the left number was constantly zero. The right number comprised 15 different values around 1,000 (790; 810; 850; 890; 910; 950; 990; 1,010; 1,050; 1,090; 1,110; 1,150; 1,190; 1,210; 1,250). Furthermore, the inner number varied in seven different categories, comprising the exact arithmetic mean 'C' of the two outer numbers as well as categories with positive and negative deviations from the arithmetic center position. Number values deviate in steps of 50 units (C+50, C-50), 150 units (C+150, C-150), and 300 units (C+300, C-300) from the arithmetic center position. In addition, all numerical values were multiplied by the factors 1, 10, and 100 to result in three scale factor categories.

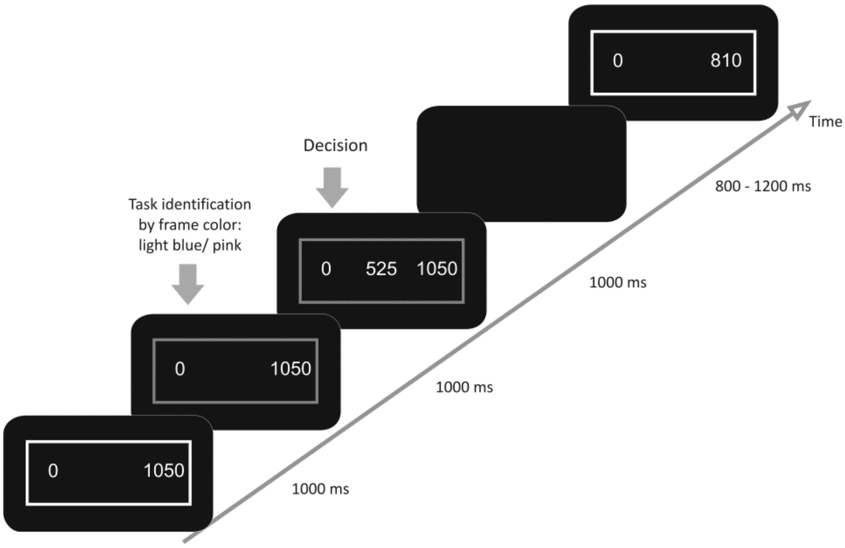

Figure 40: Sequence of screens of one choice task with task identification

According to the bisection task, the two outer numbers corresponded to the boundaries of a utility interval while the inner number represented the midpoint in utility. For all three number values of a given decision trial, the subjects were requested to imagine the 'joy' they would feel when receiving these amounts of money in euro. Consequently, subjects had to indicate whether they perceive the distance in joy between the left and the center number as greater than the distance in joy between the center and the right number. If this was true, then subjects gave a 'Yes' response, otherwise they responded with 'No'.

According to the lottery choice task, the two outer numbers corresponded to a fifty-fifty lottery while the inner number represented a sure payoff. For a given decision trial, the subjects had to indicate whether they prefer to receive the sure payoff or opt for playing the fifty-fifty lottery. In this context, the subjects were confronted with the question whether they want to receive the sure payoff or not. This question had to be answered with a 'Yes' or a 'No' response. Hence, if a subject preferred the lottery, then the decision had to be indicated with 'No'.

8.2.2 EEG recording and analysis

The electroencephalogram (EEG) was recorded from 29 thin electrodes mounted in an elastic cap and placed according to the international 10-20 system (Jasper, 1958). The EEG was re-referenced offline to the mean activity at the left and right mastoid. Horizontal and vertical electrooculograms (EOG) were recorded using bipolar montages in order to enable offline rejection of eye movement artifacts. All channels were amplified (bandpass 0.05-30 Hz) and digitized with 4 ms resolution. Impedances were kept below 10 kΩ. After epoching the data time locked to responses (baseline -300 to 0, epoch length 900 ms), epochs containing eye blinks or other artifacts (muscle activity, step-like artifacts etc.) were excluded from averaging by visual inspection. Furthermore, the subjects' averages were filtered using a 1-8 Hz band pass filter.

According to the presumption that a higher response conflict is present in error-like choices of the lottery choice task, the EEG data were sorted into three bin clusters based on the deviations of the inner number value. Error-like choices were assumed to occur for choice tasks in which the inner number value strongly deviates from its center position. Therefore, positive and negative deflections from the center position had to be taken into account for revealing error-like responses. In Table 1, the conducted bin classification according to the deviation of the inner number and the subsequent response is given. According to these bin clusters, averages of response-locked ERPs were calculated.

Table 1: Description of bin classification based on the deviation from the center position

bin cluster	enclosed deviation categories	subsequent response	presumed type of choice	bin category
Strong negative deviation from center position	C-300, C-150	Yes	Error-like choice	MinusYES
		No	Predominant choice	MinusNO
Center position with minor deviation	C-50, C, C+50	Yes	Indifferent choice	CenterYES
		No	Indifferent choice	CenterNO
Strong positive deviation from center position	C+150, C+300	Yes	Predominant choice	PlusYES
		No	Error-like choice	PlusNO

8.3 Results

As earlier discussed in the paper of Morgenstern et al. (2009), behavioral differences between both methods are not revealed. According to this work, choice frequencies of both methods had been analyzed for each deviation category of the inner number, showing no significant results. Concerning the focus of this analysis, an overview of relative choice frequencies of 'Yes' responses among the three bin clusters is provided in Figure 41 (see also Table C1 of Appendix C). With respect to this comparison, a performed repeated measures ANOVA with *method* (bisection, lottery), *scale factor* (1, 10, 100) and *bin category* (MinusYES, CenterYES, PlusYES) as factors shows no main effect for the factor *method* ($F(1)=0.581$, $p=0.458$). This indicates that both methods are comparable for eliciting utility functions, which has already been argued by Morgenstern et al. (2009) and Heldmann et al. (2009). Furthermore, the figure shows that in the two categories with strong negative and strong positive deviations from the center, about one-fifth of all choices have not been the predominant choice. These choices are qualified for an error-like choice comparison of both methods concerning the ERN component.

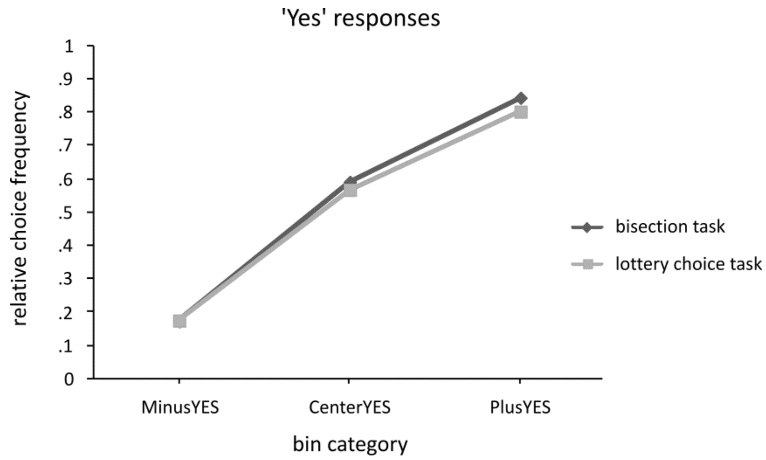

Figure 41: Relative choice frequency of 'Yes' responses

Figure 42 depicts the response-locked event-related potentials at the Fz electrode for all three bin clusters. An ERN amplitude can be identified peaking between 30 and 70 ms after response onset. ERPs in Figure 42 illustrate more pronounced ERN amplitudes for error-like choices than for predominant choices in the two bin clusters with a strong deviation of the inner number from the center position (see upper left and upper right graph). ERPs of choices around the center position show no deviation of ERN amplitudes (see middle graph).

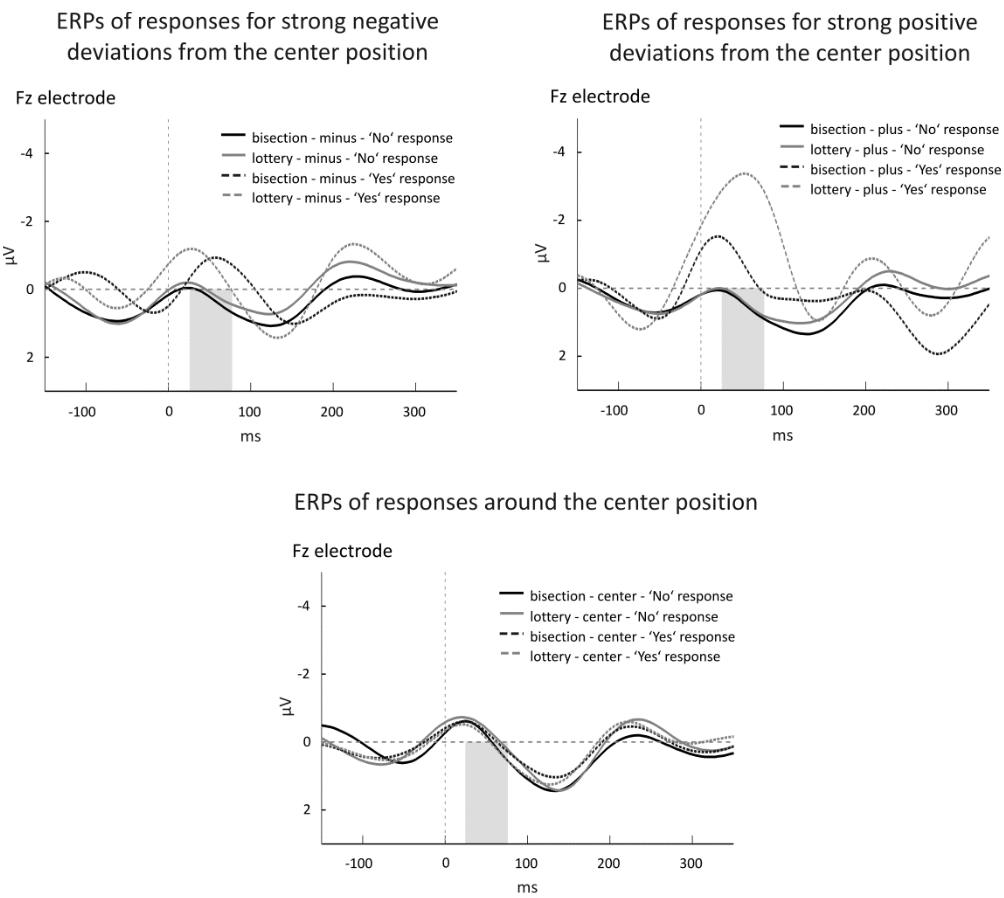

Figure 42: Response-locked ERPs at the Fz electrode for all bin clusters

Furthermore, the ERN amplitude in the lottery choice task for a strong positive deviation from the center position is most pronounced. Figure 43 contrasts solely the error-like choices of the two applied methods. As can be seen, the ERN amplitude of lottery choices with a strong positive deviation from the center position shows a very high negative peak in contrast to the other ERN amplitudes. Hence, error-like choices in this area presumably evoke a higher response conflict for the subjects in the lottery choice task in contrast to the bisection task.

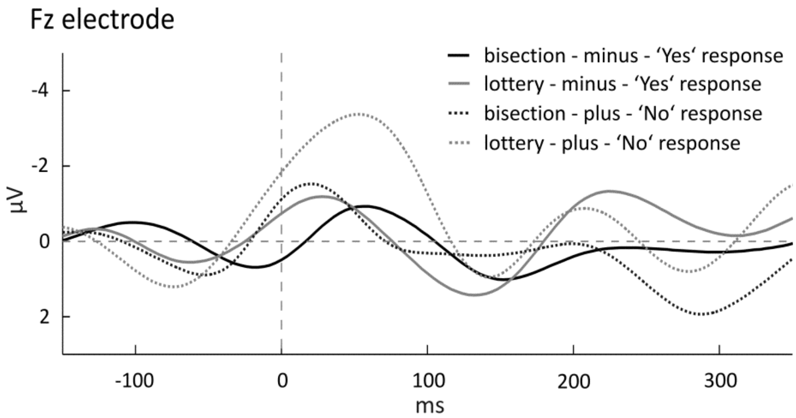

Figure 43: Response-locked ERPs at the Fz electrode for error-like choices

In this comparison, Figure 44 illustrates the voltage distribution on the scalp for the error-like choices within a time range of 30 to 70 ms. The fronto-central scalp distribution of the negative peak is present for both methods, indicating the typical pattern of the ERN. Moreover, the picture emphasizes the observation of a very pronounced ERN component for error-like lottery choices in an area for which the inner number has a strong positive deviation to the center position.

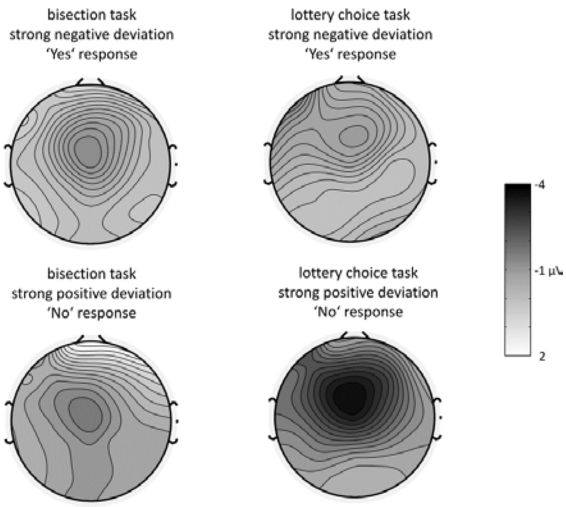

Figure 44: Topographies of voltage distribution within 30 and 70 ms for error-like choices

For a statistical analysis, mean amplitudes within a time range of 30 to 70 ms were calculated (see Table C3-C8 of Appendix C). A repeated measures ANOVA for the midline electrodes was conducted with the factors *anterior posterior electrode* *position* (Fz, Cz, Pz), *method* (bisection task, lottery choice task), *bin cluster* (minus, center, plus), and *choice* (Yes, No). Interactions for *anterior posterior electrode position x method* (F(1.264)=5.876, p=0.023), *anterior posterior electrode position x method x bin cluster* (F(1.429)=4.955, p=0.026), *bin cluster x choice* (F(1.379)=9.500, p=0.003), *anterior posterior electrode position x method x bin cluster x choice* (F(1.697)=5.327, p=0.015) could be revealed (see also Table C9 of Appendix C). A further ANOVA for the Fz electrode (see Table C10 of Appendix C) comprising *method* (bisection task, lottery choice task), *bin cluster* (minus, center, plus) and *choice* (Yes, No) as factors confirmed the interaction *bin cluster x choice* (F(1.345)=7.008, p=0.010) and showed a tendency for a slightly significant main effect for the factor *method* (F(1)=3.815, p=0.070). All degrees of freedom, F-values, and p-values are reported as Greenhouse-Geisser corrected.

Figure 45 depicts the response-locked mean amplitudes at the Fz electrode within 30 to 70 ms separated by the bin clusters. The figure shows an opposed trend of mean amplitudes for 'Yes' and 'No' responses. Mean amplitudes increase in their negative deflection when choices drift into a more error-like response, which is similar for both methods. Additionally, the mean amplitude in the lottery choice task for an error-like choice in the area of a strong positive deviation to the center position shows an intense deflection in this trend. Here, the ERN amplitude differs not only between 'Yes' and 'No' responses but also between both applied methods. A one-sided pair-wise t-test (see also Table C11 of Appendix C) revealed a significant difference in ERN amplitudes between lottery choices of 'Yes' and 'No' responses (T(15)=2.239, p=0.021) as well as between 'No' responses of the lottery choice task and the bisection task (T(15)=1.766, p=0.049). Hence, the ERN amplitude is significantly larger for error-like choices in the lottery choice task when subjects decide for the lottery although the sure payoff is extremely attractive in this comparison. These unfavorable choices apparently cause a higher response conflict for the subjects.

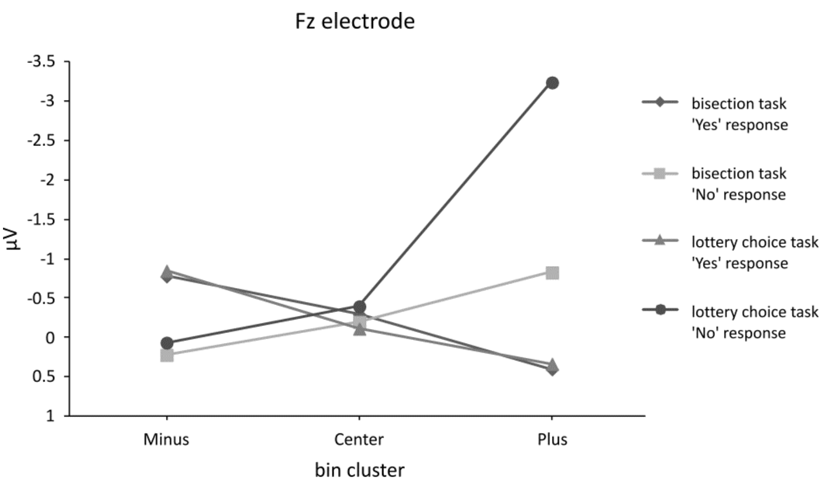

Figure 45: Mean amplitudes within 30 and 70 ms at the Fz electrode

8.4 Discussion

The present analysis investigated an ERN modulation in the presence of risk. The ERN component is presumed to reflect response conflicts in decision making processes and is associated with conflict monitoring as proposed by Botvinick et al. (2001). Moreover, the ERN is involved in action monitoring processes, and differences in its modulation can provide implications on the subjective relevance of a given choice task. A higher subjective relevance is presumed to evoke a more pronounced ERN amplitude, which implies that responses are reflected by a more careful comparison process, resulting in an increased response conflict. As a result of different response conflict levels, decision making might be influenced in its behavioral outcome due to a different conflict resolution. Therefore, the revelation of differences in conflict monitoring could serve as an indicator for verifying differences in neural evaluation processes of decision making even in the absence of behavioral differences.

In this comparison, the ERN was used as a tool for identifying differences in the perception of risk. Two methods for eliciting utility functions were applied in a parallel experimental setup. One method represented a bisection task which derives a utility function of monetary outcomes that are not connected with risk. The other method represented a lottery choice task which derives a utility function of monetary outcomes in the presence of risk. Both methods yielded similar behavioral results (see also Morgenstern et al., 2009). However, an analysis of the ERN component revealed differences between both methods with reference to error-like unfavorable lottery choices. A higher response conflict was detected for choices in the lottery choice task when the sure payoff choice outperformed the lottery choice but the lottery was chosen. In this case, the lottery choice would reflect an error-like choice, and a decision for the lottery would further represent an unfavorable risk taking. This is in contrast to the bisection task for which an apparently error-like choice would not involve an additional risk taking for the decision maker.

This result has also been found in the study of Heldmann et al. (2009). But in contrast to the present analysis, Heldmann and colleagues additionally found an increased ERN amplitude for the lottery choice task when the sure payoff is chosen but the lottery would have been the favorable choice. The absence of such a second increased ERN amplitude in this analysis could refer to the degree of deviation of the inner number value to the arithmetic center. Heldmann et al. (2009) used a rather similar approach but varied the inner number value up to a deviation of 400 digits. They also showed that an adjustment of the deviation interval equidistant to the indifference point of apparently risk averse subjects resulted in a decreased ERN for unfavorable lottery choices and in an increased ERN for unfavorable sure payoff choices. Hence, with an increasing deviation, an error-like choice would become more relevant for a subject. A maximum deviation of 300 digits would probably not arouse an increased response conflict for unfavorable sure payoff choices in the lottery choice task in contrast to the bisection task. This can be reasoned by the assumption that a potential risk averse behavior of the subjects would further shift the perception of an error-like choice toward a higher negative deviation. Consequently, such an assumption would suggest that the ERN amplitudes of error-like choices could depend on the degree of risk averse behavior, resulting in a different subjective relevance of error-like choices. In this context, the ERN in error-like choices in conjunction with risk would reflect the level of conflict in relation to an individual attitude toward the riskiness of the present choice. More precisely, this would indicate a relationship between risk attitudes and processes of conflict monitoring in which an unfavorable choice according to the individual risk attitude of a subject yield a higher response conflict.

Alternatively, the absence of an increased ERN for error-like sure payoff choices could further indicate that unfavorable sure payoff choices are not reflected by an additional risk taking. This would imply that the difference of the ERN amplitude between both methods results from an increased level of risk. According to Yu and Zhou (2009), these increased ERN amplitudes can be assumed to signal the riskiness of choices and prepare the brain for potential negative consequences. A similar argumentation has also been stated by Hewig et al. (2007) who suggested that an increased ERN amplitude can be associated with a negative evaluation of a current decision and that the ERN can be connected to risk taking behavior. Hence, the ERN amplitude can be presumed to be sensitive toward the presence of risk, which is further confirmed by the present data analysis. The level of individual risk taking behavior modulates the ERN amplitude according to the subjective relevance of a potential negative outcome.

In summary, the difference of the ERN amplitude between both utility assessment methods can directly be ascribed to a subjective relevance in the sensitivity of risk perception. Aside from an absence of behavioral differences, it has been shown that both evaluation processes are partially different for distinct choice task situations. Under the presence of risk, error-like choices in conjunction with a potentially unfavorable risky outcome evoke a higher response conflict for the subjects. Although the applied choices under risk had been hypothetical, the result indicates that subjects seem to be aware of the different choice task environments. This finding emphasizes that the perception of risk is observable in event-related brain potentials with reference to a distinct response conflict and that the ERN can be used as a tool for investigating decision making processes under risk.

Chapter IX

9 Indifference intervals and decision thresholds

This chapter will provide an additional analysis of the behavioral data obtained from the EEG study concerning the hypothetical bias. Aside from the neurological research background, the data is suitable for an analysis regarding the existence of indifference intervals for certainty equivalents. The procedure of determining the individual indifference point has indicated that the subjects did not adjust their choice behavior constantly to a specific certainty equivalent but rather on the basis of a distinct area of indecisiveness. Additionally, the analysis of the P300 has shown that a stimulus categorization process for the indifferent choice areas is less pronounced, which can further be reasoned by the existence of indifference intervals. Therefore, this chapter will additionally analyze the behavioral data in more detail with a focus on the characteristics of such indifference intervals. Evidence will be provided that the boundaries of such intervals are systematically distributed and that they can be related to processes of numerical response. In this context, the transition in the decimal of sure payoff values seems to serve as a certain threshold or a focal point for the range of indifferent choices of subjects.

9.1 Introduction to imprecision intervals

Eliciting certainty equivalents is an essential issue in the research field of experimental economics. Certainty equivalents can inform researchers about risk attitudes of subjects in risky decision making. The certainty equivalent in binary lottery choice tasks represents a point at which a subject values a risky and a riskless alternative equally, indicating indifference between these two alternatives. The certainty equivalent of a subject is a precise value and therefore enables a defined determination of risk attitudes. But determining an exact certainty equivalent for a subject is different to observations in lab experiments. Subjects are often unsure about the exact point at which they are indifferent between two alternatives and tend to respond more intuitively to such questions in an experiment (see Butler and Loomes, 1988).

Basically, a non-exact certainty equivalent can be reasoned by an error rate of the subjects in multiple choice task experiments (e.g. Hey, 2001, 2005) but also by an intentional range of indifference around the supposed certainty equivalent (e.g. Butler and Loomes, 1988). Error rates of subjects are a non-negligible distortion of choice behavior but are presumably underlying a more random incidence. In this context, a potential range of indifference can be ascribed to a more systematic imprecision of choice behavior directly related to an uncertainty of subjects in decision making around the certainty equivalent. Butler and Loomes (1988) described this imprecision as a ‘sphere of haziness’.

With reference to a systematic imprecision of choice behavior, Beach et al. (1974) investigated the accuracy of judgments and ranges of subjectively acceptable judgment errors in experiments and enunciated the term ‘equivalence interval’. Furthermore, MacCrimmon and Smith (1986) initially described an imprecision in certainty equivalents as ‘imprecise equivalences’. The suggestion of MacCrimmon and Smith (1986), that the presence of ‘imprecise equivalences’ in certainty equivalents can potentially explain the phenomenon of the preference reversal, was enhanced and further investigated by Loomes (1988) and Butler and Loomes (1988, 2007). Butler and Loomes argue that individuals cannot state their true certainty equivalent with complete confidence and “[…] that even for simple lotteries involving just two monetary consequences well within normal experience and straightforward probabilities, many people find it difficult to be precise about their certainty equivalent valuation.“ (Butler and Loomes, 1988, p. 193) As a consequence, the certainty equivalent is not an exact value but rather reflects an interval of imprecision. This supposition differs from an interpretation that the presence of imprecise responses is referred to an error rate of subjects. In this respect, the certainty equivalent reflects an exact value with a distinct error term that is related to a kind of noise in the responses of the subjects. Hey (2001) analyzed this noise in subjects’ responses concerning its consistency in repeated experiments. He found that for some subjects the variability decreased across repetitions but an overall decrease could not be confirmed. Hence, subjects are able to get more precise in their responses but an interval of imprecision still remains.

Moreover, the presence of imprecision intervals may further reflect the result of a numerical response interval for certainty equivalents. According to Spengler and Vogt (2008), a set of reasonable alternatives on a numerical stimulus is generated through an iterative numerical response process. In this comparison, the width of an imprecise interval represents the degree of exactness of a response regarding the individual certainty equivalent of a subject. Furthermore, the boundaries of these intervals reflect the perception of numbers in the decimal system and the frequency scale of these boundary values rely on the theory of prominence (see Albers and Albers, 1983; Vogt and Albers, 1992; Albers, 1997; Albers, 2000). According to prominence theory, some numbers are more easily accessible to individuals than others which are labeled as 'prominent'. Prominent numbers in a decimal system are the powers of 10 ($10^z\ z \in Z$), their halves ($5 \cdot 10^z\ z \in Z$) and their doubles ($2 \cdot 10^z\ z \in Z$). Hence, especially '0' and '5' are the most frequent last digits of the interval boundaries related to this type of numerical response process. This would imply that the range of imprecision has a distinct characteristic around an individual certainty equivalent.

In this context, these interval boundaries can also be described as psychological thresholds indicating a change in choice preferences. Psychological thresholds in choices have been enunciated by Georgescu-Roegen (1958) and are generally discussed and investigated in marketing research in terms of price thresholds (e.g. Monroe, 1971, 1973; Han et al., 2001). In this respect, the location of price thresholds is also assigned to prominent numbers of the decimal system. Aside from marketing research, Sugden (1995) described a theory of focal points which decision makers use to indentify strategies in coordination games. These focal points can be ascribed to a kind of psychological anchor in decision making and may rely on the fact that individuals are using mental heuristics for facilitating the decision making process. In this respect, Tversky and Kahneman (1974) also discussed heuristics occurring in judgments under uncertainty which can result in behavioral biases. In summary, psychological aspects regarding individual decision making have to be taken into account, and even for the elicitation of certainty equivalents, psychological thresholds for determining a decision are presumed to exist. Hence, the question arises whether a potential interval of indifference in the valuation of certainty equivalents is reflected by a systematic distribution in its boundaries caused by psychological thresholds.

Behavioral data from an EEG study can be used to analyze the presence of imprecision intervals in certainty equivalent valuation tasks and their potential relationship to psychological thresholds. There are two advantages why these data are suitable for an analysis of imprecision intervals: (1) The data provide a high amount of repetitions of the same choice task, and (2) the variation of the certainty equivalent is applied in a small step size. Thus, the high amount of repetitions should reduce the noise in the subjects' decisions while the small step size of the offered sure payoff allows for a detailed determination of an area for which subjects are indifferent or imprecise in their choices. Therefore, the present section reconsiders the behavioral data of the EEG study concerning the hypothetical bias with reference to a detailed analysis of imprecision intervals.

9.2 Material and Methods

The experimental method has already been described in the study concerning the hypothetical bias. Therefore, only a short recapitulation on the main issues of the experimental procedure, those which are important for the subsequent analysis, is presented. For a detailed comparison, see section 6.2.1 of this work.

As mentioned before, 21 subjects took part in two EEG sessions in which a method for eliciting certainty equivalents was applied in a standard gamble approach. Both experimental sessions comprised equal choice settings in which one session comprised hypothetical payoffs and the other session real payoffs. The subjects' task was to choose between a fifty-fifty lottery and a sure payoff. The low payoff of the binary lottery was set to 0 euros. The high payoff of the binary lottery was at about 100 euros, meaning that the payoff was varied in eight values between 100 and 107 euros. The sure payoff was assigned to values of 10, 20, 30, 40, 50, 60, 70, 80 and 90 euros. Furthermore, each sure payoff value was varied in the last number digit between 0 and 7, resulting in values from 10 to 17, 20 to 27, 30 to 37 and so forth. Hence, a total amount of 576 decision trials were presented to the subjects by combining all lottery payoff settings with all sure payoff values. This amount was necessary to ensure that enough decision trials could be provided for the EEG analysis. During the experiment, each decision trial was randomly assigned to the subject. The random order of all decision trials should therefore avoid order effects in the frequency of choices. Furthermore, each decision trial lasted about 3 seconds. Despite the high time pressure, almost all decision trials (mean rate of missing values=0.006, SD=0.016) were responded by each subject.

9.3 Behavioral analysis concerning the range of indifference

In the analysis of the behavioral data, the relative frequency of lottery choices was analyzed according to the normalized distance of the sure payoff compared to the expected value of the lottery. Previously, the data had been analyzed for an accumulated choice frequency within an interval of 5 units in the distance category (for a review see Figure 10, p. 55). In a more detailed comparison, Figure 46 depicts the relative lottery choice frequency over all subjects for every distance category. In this analysis, a distinct pattern in choice frequency can be observed, indicating decision thresholds for certain areas in a constant interval. As can be seen, a kind of plateaus and thresholds for the relative lottery choices is obtained reflected by a steeper change in choice frequency for a frequent interval with 10 number digits.

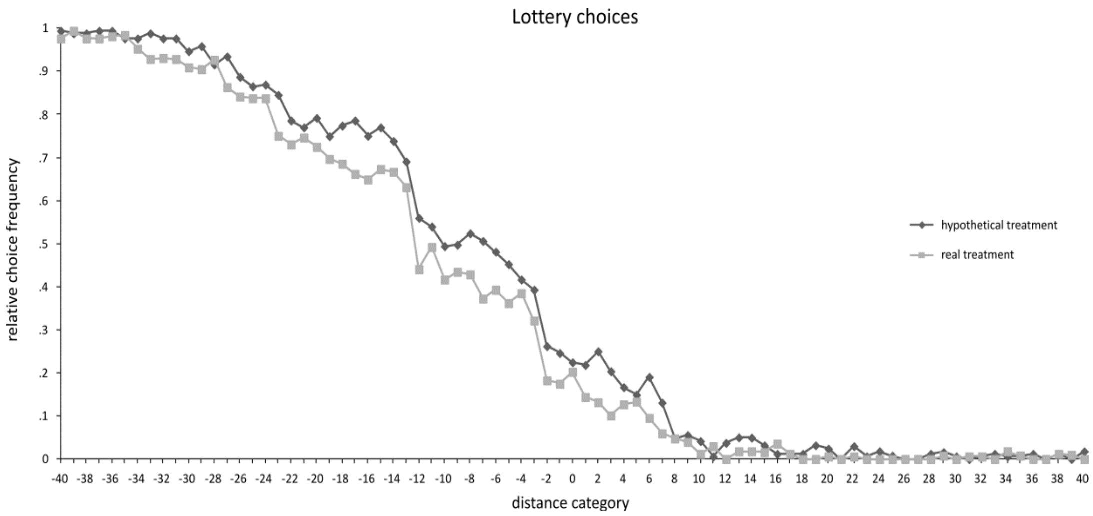

Figure 46: Relative frequency of lottery choices illustrated for the smallest step size in the distance category

This descriptive consistency is presumed to be related to the characteristic of the presented sure payoff value. Therefore, the relative choice frequency is directly analyzed by the sure payoff without a normalized comparison to the expected value of the binary lottery. In this respect, the relative choice frequency is estimated according to the presented sure payoff value within an interval of 3 number digits for the first digits of a decimal (0-2) and for the later digits (5-7) in equal distance. Figure 47 shows the relative frequency of lottery choices in these categories (see also Table D1 and D2 of Appendix D). Again, a characteristic pattern of steeper changes in choice frequency for a transition from one decimal to another can be observed.

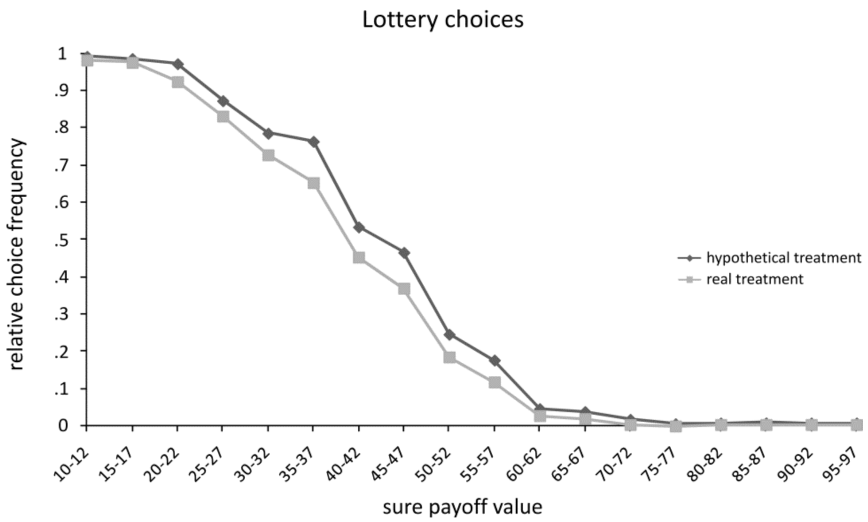

Figure 47: Relative frequency of lottery choices in the first (0-2) and the last (5-7) number digits of the sure payoff values

Subsequently, the mean rate of change in the relative choice frequency from one category to another will be calculated for every subject. The rate of change inside a decimal, which is the change from the '0-2' category to the '5-7' category, has a mean of 0.032 (SD=0.026) in the hypothetical treatment and a mean of 0.037 (SD=0.019) in the real treatment. In contrast, the rate of change from one decimal to another, which is the change from the '5-7' category to the '0-2' category, has a mean of 0.088 (SD=0.029) in the hypothetical treatment and a mean of 0.080 (SD=0.021) in the real treatment.

The mean rate of change of every subject separated by these two categories is displayed in Table 2. As can be seen, the mean rate of change inside a decimal is only for 3 out of 21 subjects higher than the mean rate of change from one decimal to another in both treatments. This observation is significant for a binomial test on a 1 % significance level. Even for a comparison of both treatments, 5 out of 21 subjects show a higher mean rate of change inside a decimal, which is still significant on a 5 % level for a binomial test.

Table 2: Mean rates of change within a decimal and in the transition of a decimal

	hypothetical treatment		**real treatment**	
subject	Mean rate of change within a decimal	Mean rate of change in the transition of a decimal	Mean rate of change within a decimal	Mean rate of change in the transition of a decimal
1	**0.074**	**0.042**	0.050	0.068
2	0.037	0.078	0.039	0.081
3	0.032	0.089	0.025	0.097
4	0.028	0.094	0.042	0.078
5	**0.088**	**0.021**	**0.074**	**0.036**
6	0.000	0.120	0.037	0.083
7	0.001	0.119	0.037	0.083
8	0.032	0.083	**0.060**	**0.052**
9	0.000	0.125	-0.005	0.130
10	0.037	0.083	0.042	0.078
11	0.028	0.093	0.028	0.083
12	0.032	0.083	0.042	0.078
13	0.005	0.120	0.051	0.063
14	0.028	0.083	0.015	0.109
15	0.032	0.089	0.023	0.099
16	0.031	0.090	0.028	0.094
17	**0.083**	**0.031**	0.014	0.089
18	0.001	0.124	0.022	0.094
19	0.051	0.068	**0.068**	**0.043**
20	0.028	0.094	0.044	0.075
21	0.013	0.110	0.047	0.073
mean	**0.032**	**0.088**	**0.037**	**0.080**
SD	**0.026**	**0.029**	**0.019**	**0.021**

This result shows that the change of the decimal value leads to a higher change in choice frequencies by the subjects. This higher rate of change can supposedly be obtained by subjects who adjust their choice behavior in these areas. For a detailed review of this supposition, the range of indifferent choices is determined for every subject (see also Table D3 of Appendix D), which reflects the region of changing from one choice alternative to another.

Therefore, a region is identified in which the relative frequency of lottery choices constantly changes from one to zero. This region refers to an individual area of indifference, for which a lower and upper boundary can be obtained. According to an increasing sure payoff value, the lower boundary reflects the change from a sure choice for the lottery to an area of indifferent choices. In contrast, the upper boundary reflects the change from an area of indifferent choices to a sure choice of the sure payoff. In this comparison, the mean sure payoff value of the lower boundary is 40.10 (SD=10.93) for hypothetical choices and 35.76 (SD=10.57) for real choices. The upper boundary of the indifference interval has an averaged sure payoff value of 47.33 (SD=12.45) for hypothetical choices and 45.33 (SD=11.11) for real choices. The lower boundary value between the hypothetical and the real treatment differs significantly for a pair-wise Wilcoxon signed-rank test (V=104, p=0.013). In contrast, the difference of the upper boundary between both treatments is not significant. Thus, the previously found evidence of this study (see section 6.3.1) that real choices evoke higher risk aversion is further reflected by an earlier change from choices for the lottery to choices for the sure payoff.

Furthermore, the averaged width of the indifference interval was estimated for hypothetical choices at 8.24 (SD=3.74) and for real choices at 10.57 (SD=5.78) which reflects 9.8 % of all choices in the hypothetical treatment and 12.4 % of all choices in the real treatment. The difference in the width of the indifference interval between both treatments is significant for a one-sided pair-wise t-test (t=-1.7618, p=0.047). This indicates that subjects have a broader indifference interval when choices are for real.

In this context, the potential error rate of subjects has to be reviewed in general due to the fact that over 500 decisions were performed within a short amount of time. Therefore, the amount of imprecise choices, or rather ambiguous choices, for each sure payoff value was examined. Ambiguous choices were determined by a relative frequency in the sure payoff category that is unequal to zero or one (see also Table D4 of Appendix D). In the hypothetical treatment, 19.2 % of all sure payoff categories were reflected by ambiguous choices and 17.5 % in the real treatment. In this comparison, choices of the indifference area are included. Ambiguous choices that can directly be assigned to potential errors are on average at 9.4 % for hypothetical choices and at 5 % for real choices. The error rate exclusive of indifferent choices is significantly different between both treatments for a pair-wise Wilcoxon signed-rank test (V=146.5, p=0.008). Thus, the subjects were more precise in their choices outside their indifference interval for real choices.

Finally, the boundaries of the indifference intervals will be examined in more detail with regard to the last number digit of the related sure payoff value. According to the experimental procedure, all sure payoff values included eight last digits (0-7). Consequently, the amount of interval boundary values for each ending digit was calculated and is presented in Table 3.

Table 3: Occurrences of last number digits in interval boundaries

	hypothetical treatment		**real treatment**	
Last number digit	**Amount of lower interval boundary values**	**Amount of upper interval boundary values**	**Amount of lower interval boundary values**	**Amount of upper interval boundary values**
0	10	7	11	3
1	3	3	2	3
2	2	1	0	4
3	3	1	2	3
4	1	0	2	0
5	1	2	1	1
6	0	3	1	2
7	1	4	2	5

As can be seen, the amount of lower interval boundary values at the ‘0’ digit is extremely high, indicating that 10 out of 21 lower interval boundary values for hypothetical choices and 11 out of 21 for real choices are located at the beginning of a decimal. Assuming that a uniform distribution among the eight digits is existent, these amounts are significantly different from such a distribution on a 0.1 % significant level for a performed binomial test. Furthermore, even if such a clustering at ’0’ can be ascribed to the missing number digits of ‘8’ and ‘9’, the uniform distribution for this cluster is also rejected by a one-sided binomial test on a 5 % level of significance. Thus, the occurrence of the lower interval boundary values at the beginning of a decimal is systematic. The subjects seemed to have a preferred threshold for which they are changing from a sure lottery choice to a range of indifferent choices. In contrast, this pattern cannot be confirmed for the upper interval boundary. There seem to be a tendency for hypothetical choices, but these observations are not significant.

9.4 Discussion

The characteristic pattern of plateaus and thresholds in the behavioral data can be traced back to the existence of indifference intervals and to the systematic location of the corresponding boundaries caused by processes related to numerical response. These results contribute to the line of argumentation of Butler and Loomes (1988) of 'imprecise intervals', that an individual can be unsure about his or her true certainty equivalent. In contrast to Butler and Loomes, the imprecise intervals of this study were revealed through a process of repetition instead of asking the subjects about their own confidence in the responses. An area of indifference was determined for a sequence of choices in which the relative choice frequency constantly changes from one to zero. As a result, interval boundaries of imprecise choices were obtained. A further examination revealed that the values of the lower interval boundary are highly accumulated to the first number digit of a decimal of the sure payoff value. Thus, it can be concluded that the initiation of an area of imprecision is related to the appearance of the sure payoff value. The transition of the decimal seems to serve as a kind of focal point for the subjects. Each subject appears to set a response threshold from which each choice task is evaluated, and the beginning of a new decimal interval of the sure payoff value could be the most pronounced focal point. This kind of heuristic facilitates the decision making process and reduces the complexity for the subjects. Interestingly, a significant accumulation of the upper interval boundary values is not found, which indicates that an overall interval-related decision evaluation is missing. The end of the imprecision area depends on the individual degree of imprecision of each subject and is not systematically distributed. According to a numerical response process as introduced by Spengler and Vogt (2008), it can be confirmed that the response interval is partially related to prominent numbers, indicated by an accumulation of boundary values at '0'.

Furthermore, the high amount of choice tasks shed light on the averaged error rate or noisiness of the subjects' responses. The majority of all ambiguous choices, which could reflect potential response errors, can be assigned to the indifference interval. Aside from the determined indifference intervals, the error rate is quite small (<0.1) for an experiment in which the predetermined response time is very short. Thus, the noise of the subjects' responses is mostly assigned to an area of imprecision around the indifference points, and the argumentation of noise in behavioral data (see Hey, 2005) can be ascribed to such intervals. The subjects are rather certain about their decisions outside the indifference interval even in case of high time pressure.

The finding of decision thresholds with regard to a transition in decimal values can be connected with the research on price thresholds in the marketing literature. Here, the price sensitivity of customers should increase when a certain price threshold is exceeded. Price thresholds are broadly discussed, but an overall validation is still absent. Some studies confirmed the existence of such price thresholds, others did not (see Gedenk and Sattler, 1999). But if so, price thresholds are generally supposed to emerge between price endings from ‘9’ to ‘0’. This pattern is also present if the relative frequency is considered as a demand rate and the sure payoff value as a price of sale.

The transition of decimals seems to be an important signal in the perception and judgment of numerical stimuli. Hence, processes of numerical response should be reconsidered in the validation of eliciting certainty equivalents. As a consequence, the presence of imprecise intervals along with a systematic focus on prominent numerical values has to be reconsidered in the estimation of utility functions.

Chapter X

10 Summary

Thus far, the present work has investigated neural processes regarding individual decision making behavior under risk. The major purpose of this work has been to provide neural inferences on the behavioral effects of incentive structures and the suitability of payoff mechanisms in experimental economics. Therefore, two EEG studies have been conducted in which three different payoff mechanisms were investigated with reference to conflict monitoring. In these studies, the N200 component served as an indicator for the level of conflict in the evaluation process of choice tasks. In addition to behavioral differences, the results of the EEG data have shown a characteristic pattern of the N200 in relation to the different choice task situations and with respect to the underlying incentive structure. Basically, for all applied payoff mechanisms a higher level of conflict was detected for choices around an area of indifference. Distinct differences in the level of conflict between the applied payoff mechanisms were solely detectable outside an indifference area.

This stands to reason a more general decision conflict for indifferent choices which may superpose incentive-related differences in the level of conflict. In this respect, the increased level of conflict for indifferent choices is therefore not surprising but rather expectable since the demand for a decision in case of indifference apparently evokes a decision conflict for a subject. Hence, the attention has to be drawn to an area in which the subjects have a strong preference for a distinct choice alternative. In this area, the analyzed N200 component differs across the applied payoff mechanisms. According to the experimental choice task, the level of conflict for unambiguous choice preferences can be distinguished between risky choices (lottery choices) and riskless choices (sure payoff choices). The following table (Table 4) illustrates for the three applied payoff mechanisms whether the level of conflict has decreased for risky and riskless choices in relation to choices of the indifference area.

Table 4: Comparison of the applied payoff mechanisms regarding a decreasing level of conflict

	Sure risky choices	Sure riskless choices
Random payoff mechanism	Yes	Yes
Flat-rate payoff mechanism	No	No
Averaged payoff mechanism	No	Yes

In this comparison, the random payoff mechanism reveals a decreasing level of conflict for both sure choice categories, which indicates that the appearing decision conflict for indifferent choice is dissolved for choices in which subjects have a strong preference. This finding reflects an expectable pattern for a decision conflict that is solely related to an uncertainness of the subjects in case of indifference. The results do not provide evidence for an additional decision conflict in the random payoff mechanism. Hence, if the increased level of conflict represents the uncertainness of indifferent choices, then the decreasing level of conflict indicates that subjects are more confident in their decision. As a result of this neural evidence, the area in which the conflict is increased can be assumed to represent the true indifference area. Consequently, the individual choice behavior underlying the random payoff mechanism is reflected by truthful responses.

This pattern cannot be confirmed for choice tasks underlying the flat-rate payoff mechanism. A decreasing level of conflict is absent, and in comparison to the random payoff mechanism, the level conflict is significantly increased outside the indifference area. Hence, there is evidence that the decision conflict is higher for hypothetical choices. Furthermore, this increased conflict cannot be related to the uncertainness of indifferent choices. As a consequence, this finding indicates the presence of an additional source of conflict during decision making, which suggests that this kind of choice behavior cannot be related to truthful responses. The additional decision conflict can further be assumed to affect the individual choice behavior, resulting in the detected behavioral differences. Thus, the absence of an incentive structure in relation to the choice task yields a distinct decision conflict which biases the individual choice behavior.

The averaged payoff mechanism also evokes an additional decision conflict that cannot be related to an uncertainness of indifferent choices. But in contrast to the flat-rate payoff mechanism, the increased level of conflict outside the indifference area is only present for risky choices. This pattern can be reasoned by the characteristic of the underlying incentive structure. Subjects are incentivized to generate portfolio choices which provoke a non-independent evaluation of the choice tasks. Considering that individuals are in general risk averse decision makers, and that they are also aware of forming portfolios, then these individuals would have to deviate from their true indifference point of an independent decision to a more risk neutral position. Hence, these subjects have to dispose their choice behavior according to a more frequent choice of risky decisions, which may induce an additional decision conflict for these risky choices. As a consequence, the higher level of conflict for risky choices can be related to the awareness of forming portfolio choices. This implies that a choice task in the averaged payoff mechanism is not evaluated independently.

Concerning a comparison of the investigated payoff mechanisms with reference to a methodological applicability for experiments on individual decision making behavior, the implications on the results of the two EEG studies would infer that the random payoff mechanism is most suitable for these kinds of experiments. The EEG analysis has shown that the random payoff mechanism causes least decision conflicts. Moreover, no neural evidence was found that indicates a diverging decision conflict in the evaluation process between the applied incentive structure and other motivational influences on the decision. With respect to the averaged payoff mechanism, the EEG data further indicates that the random payoff mechanism induces an independent evaluation of multiple choice tasks. Admittedly, a direct comparison to a single choice task experiment is not possible. This would have afforded a direct analysis regarding the influence of multiple decisions on the individual choice behavior. However, the neurological indications argue for a suitability of the random payoff mechanism in multiple choice task experiments.

In contrast, the flat-rate payoff mechanism cannot be described as suitable for investigating individual decision making behavior. An absence of a task-related incentive structure causes a different choice behavior yielding a hypothetical bias. Hypothetical choices provoke additional decision conflicts which are presumably responsible for the different choice behavior. Hence, behavioral results derived from the flat-rate payoff mechanism cannot provide reliability for truthful responses since the results may be influenced by a decision conflict that is not present in real decision situations.

In this comparison, the averaged payoff mechanism remains ambiguous. The behavioral data show that there is no apparent portfolio effect yielding a modification of risk attitudes. But there is an influence on the individual choice behavior and there is neural evidence for an additional decision conflict for risky choices. Thus, the incentive structure of the averaged payoff mechanism differently modulates the decision making process in contrast to the random payoff mechanism, indicating an awareness for a non-independent evaluation of the choice tasks. As a consequence, the averaged payoff mechanism cannot be stated as suitable for experiments on individual choice behavior since an independence of choices is not warranted by the neural evidence.

In summary, the neural as well as the behavioral evidence of this work fits into other behavioral findings of empirical investigations concerning the applicability of payoff mechanisms in experimental economics. As previous behavioral studies have shown (see Starmer and Sugden, 1991; Cubitt et al., 1998; Hey and Lee, 2005), the random payoff mechanism is applicable for inducing an independent choice task evaluation in multiple choice task experiments. This conclusion can deductively be supported by the neural analysis of this work. However, a direct comparison to a single choice task experiment cannot be provided, which would have indicated a potential cross task contamination effect as revealed by Cox et al. (2011). Furthermore, an implication for a decreasing importance of choices in the random payoff mechanism can also not be specified. According to the argument of Wilcox (1993), that the probability of a decision being selected needs to be sufficiently large in order to exert an appropriate effort, the huge amount of choices would result in a negligible probability of each choice task for being chosen. This would imply that even real choices would have become rather hypothetical. In this context, the observed differences between hypothetical and real choices emphasizes that real choices of the random payoff mechanism are perceived differently in contrast to hypothetical choices. This indicates that both incentive structures have a different influence on the choice behavior. Thus, the subjects were apparently aware of a potential realization of each choice task which supports the assumption of conditional rationality. Moreover, the evidence for a hypothetical bias, which has also been shown in other studies (see Holt and Laury, 2002; Harrison, 2004), can additionally be explained by the EEG data, indicating an additional decision conflict for hypothetical choices. This strongly recommends the application of a task-related incentive structure in economic experiments and disproves the reliability of the flat-rate payoff mechanism. In this respect, the averaged payoff mechanism provides a task-related incentive structure, but these incentives do not provide an independent choice task evaluation. The behavioral result in this work concerning a portfolio effect lacks in its expressiveness, which may also explain the ambiguous findings of other studies (see Selten et al., 1999; Laury, 2006; Lawson and Lawson, 2011). But the EEG results provide an indication for a non-independent evaluation and, consequently, serve as an argument for the presence of a portfolio effect. The evidence of different neural processing between the random payoff mechanism and the averaged payoff mechanism suggests that the averaged payoff mechanism is unsuitable when an independent choice task evaluation is required.

Aside from the focus on conflict monitoring, both EEG studies have been analyzed in relation to event categorization as suggested by Kok (2001). This analysis provided a general review of stimuli processing for lottery choice tasks. According to the assumption of event categorization, it can be concluded that choices of the indifference area are more difficult to classify by the subjects with reference to a distinct response. Additionally, a different stimulus processing of risky and riskless choices could be revealed. Risky choices outside the indifference area allocate more attentional resources, indicating a kind of awareness toward the riskiness of such a decision. Furthermore, the stimulus categorization process is less pronounced in the averaged payoff mechanism. This further indicates that the choice task alternatives are less categorized by the subjects. As a consequence, this analysis provides an additional implication for portfolio-based thinking of the subjects because a strong classification for a risky or riskless choice is not present.

In addition to a neuroeconomic investigation of incentive structures, this work has further studied the subjective relevance of risk during decision making. A third EEG study investigated the appearance of error-like response conflicts in the presence of risk. The results of the EEG analysis have shown that there is a difference in error-like response conflicts between risky and riskless choice tasks. Hence, the presence of risk evokes an additional error-like response conflict. This result supports previous findings of a study by Heldmann et al. (2009) and provides evidence for the subjective relevance of risk. Moreover, the findings of Heldmann et al. (2009) in comparison to the present analysis indicate that the error-like response conflict can further be related to the individual risk attitude. In this respect, the appearance of the error-like response conflict supposedly depends on the disparity between an unfavorable choice in relation to an individual indifference position since the error-like response conflict is more pronounced for an increased disparity (see Heldmann et al., 2009). Hence, the level of a response conflict in decision making under risk depends on the individual position of the indifference point. This would imply that the risk attitude of the subjects can further be derived and verified from such a neural indicator.

Finally, this work has utilized the huge amount of behavioral data to analyze individual choice behavior with reference to imprecision intervals (see Butler and Loomes, 1988). In this respect, it was found that such intervals, located around the individual indifference point of the subjects, are arranged according to a specific heuristic. In the investigated lottery choice task, the change in choice behavior from an explicit lottery choice preference to an area of indifference is frequently located at the beginning of a new decimal of the sure payoff value. Thus, the transition of a decimal seems to serve as a decision threshold for an adjustment of choice behavior. Such a threshold can be assumed to reflect a heuristic for decision making and the focus on the beginning of a new decimal can be related to prominent numbers.

Summing up, this work has shown that an application of neurological methods to economic experiments can provide additional inferences and implications on research question in experimental economics. With reference to individual decision making behavior under risk, the EEG technique can serve as a tool for revealing the neural underpinnings of the decision making process. The characteristics of event-related potentials and their functional modulation to specific choice tasks allow for a formulation of research hypotheses that directly addresses distinct aspects of the decision making process. Especially cognitive ERP components, like the N200, the P300, and the ERN, are appropriate objects of investigation for analyzing the decision making process. In this respect, the model of conflict monitoring provides a suitable neurological construct that can be applied to EEG paradigms with a focus on cognitive processes. Thus, the EEG technique by itself may not be the state of the art in neuroeconomic research but does also afford reasonable fields of application for economic research.

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Appendix

Appendix A: Data from the EEG study concerning the hypothetical bias

Table A1: Individual choice behavior of both treatments

subject	total amount of lottery choices		total amount of sure payoff choices		determined individual indifference point	
No.	Hypo	Real	Hypo	Real	Hypo	Real
1	217	237	357	327	-8	-4
2	317	313	254	262	7	6
3	177	158	399	417	-15	-18
4	258	294	317	282	-2	3
5	105	108	470	468	-27	-26
6	205	153	370	422	-11	-19
7	114	116	462	460	-25	-25
8	191	193	385	383	-13	-13
9	171	186	405	389	-16	-14
10	274	263	299	313	-1	-2
11	189	180	386	396	-13	-14
12	324	261	251	313	7	-2
13	250	228	326	348	-4	-6
14	235	197	339	379	-7	-12
15	285	320	257	254	4	7
16	122	85	453	490	-24	-29
17	314	211	262	364	6	-10
18	245	237	329	314	-6	-4
19	271	262	305	314	-1	-2
20	272	126	303	406	-1	-23
21	94	67	481	509	-28	-32
median	**235**	**197**	**339**	**379**	**-7**	**-12**

Table A2: Calculated mean amplitudes within 270 and 370 ms at the Fz electrode

subject	bin 1 sure choice lottery		bin 2 indifferent choice lottery		bin 3 indifferent choice sure payoff		bin 4 sure choice sure payoff	
No.	Hypo	Real	Hypo	Real	Hypo	Real	Hypo	Real
1	0.849	5.173	1.469	-1.621	2.492	0.792	3.422	5.688
2	4.956	6.865	3.889	8.256	7.058	5.484	7.179	9.355
3	4.438	8.591	5.690	1.564	6.673	0.180	4.315	6.211
4	-0.754	1.237	1.398	-0.473	1.495	3.035	2.466	2.790
5	10.804	8.192	11.731	5.156	5.769	3.638	3.632	5.053
6	-1.439	-2.788	-3.130	-3.974	-1.607	-1.002	1.184	0.920
7	7.302	8.252	6.337	7.512	6.931	7.595	3.647	9.405
8	-0.850	5.851	0.587	3.201	2.660	5.521	5.793	3.179
9	0.467	-0.572	-0.990	-0.087	1.384	0.410	-1.362	0.661
10	3.900	9.511	4.497	9.647	2.844	7.130	2.856	13.153
11	1.429	3.408	2.522	1.861	2.950	0.822	6.228	2.370
12	-2.266	-2.426	-1.045	-0.342	0.740	-5.265	1.817	-0.597
13	2.974	2.295	1.894	3.264	-0.090	2.092	1.460	2.311
14	7.884	1.452	3.608	3.139	5.162	1.653	2.791	1.198
15	-6.070	-5.492	-5.218	-6.791	-3.922	-4.111	-4.842	-4.429
16	-0.935	0.693	-0.773	-0.043	3.844	-0.502	3.747	1.081
17	3.545	1.626	3.885	3.875	1.662	1.288	-0.543	-1.954
18	-1.670	2.891	-3.243	0.671	0.938	2.161	-0.395	5.823
19	1.157	4.038	0.162	1.932	-2.493	0.123	-2.578	-2.266
20	2.703	12.012	3.200	10.859	6.328	10.516	5.645	12.820
21	-2.933	1.248	-2.693	1.664	-4.976	1.327	-2.436	0.269
mean	**1.690**	**3.431**	**1.608**	**2.346**	**2.183**	**2.042**	**2.096**	**3.478**
SE	**0.876**	**0.974**	**0.847**	**0.939**	**0.763**	**0.812**	**0.693**	**1.037**

Table A3: Calculated mean amplitudes within 270 and 370 ms at the Cz electrode

subject	bin 1 sure choice lottery		bin 2 indifferent choice lottery		bin 3 indifferent choice sure payoff		bin 4 sure choice sure payoff	
No.	**Hypo**	**Real**	**Hypo**	**Real**	**Hypo**	**Real**	**Hypo**	**Real**
1	-0.218	6.478	3.398	2.378	5.661	3.951	6.564	7.826
2	8.061	7.985	4.113	9.581	7.934	6.735	7.167	9.900
3	12.258	15.778	13.158	9.280	11.303	9.067	10.982	13.811
4	1.988	5.633	3.619	3.419	3.903	6.731	4.614	4.669
5	13.625	9.438	14.952	7.502	4.571	6.839	7.221	5.401
6	5.065	-1.023	4.851	0.856	5.472	6.066	8.132	6.094
7	13.990	12.255	9.403	10.394	12.446	11.790	7.395	17.057
8	0.196	7.438	-0.032	4.511	1.715	6.196	5.765	5.293
9	-0.306	-1.360	-2.413	-1.060	1.996	-1.043	0.080	-0.146
10	1.651	8.972	5.857	9.853	3.027	7.706	2.518	12.345
11	1.351	3.287	1.483	2.495	1.624	2.435	5.264	2.969
12	4.310	6.755	1.630	4.944	6.429	0.721	5.670	3.396
13	4.030	3.515	5.861	4.227	3.779	3.450	3.620	2.924
14	7.955	0.798	2.788	3.784	4.328	2.634	2.159	2.835
15	-6.289	-6.778	-7.507	-6.108	-7.660	-4.959	-6.057	-3.055
16	3.267	3.719	1.882	3.368	3.818	1.859	6.773	2.762
17	6.290	2.016	3.859	4.212	3.942	2.390	0.787	0.339
18	-1.116	5.420	-1.053	3.617	1.683	5.066	2.235	6.412
19	0.707	-0.653	-2.834	-2.050	-3.453	-3.032	-2.411	-0.949
20	2.410	11.153	4.669	10.203	7.247	11.726	5.517	12.989
21	-3.279	4.014	-0.501	5.237	-4.309	5.800	-1.199	6.173
mean	**3.616**	**4.992**	**3.199**	**4.316**	**3.593**	**4.387**	**3.943**	**5.669**
SE	**1.157**	**1.139**	**1.122**	**0.933**	**1.024**	**0.940**	**0.881**	**1.131**

Table A4: Calculated mean amplitudes within 270 and 370 ms at the Pz electrode

subject	bin 1 sure choice lottery		bin 2 indifferent choice lottery		bin 3 indifferent choice sure payoff		bin 4 sure choice sure payoff	
No.	**Hypo**	**Real**	**Hypo**	**Real**	**Hypo**	**Real**	**Hypo**	**Real**
1	1.711	6.633	3.481	5.544	3.278	3.838	4.790	6.996
2	8.742	6.942	6.327	9.696	7.082	6.448	8.229	9.203
3	13.871	11.799	14.039	8.763	12.579	9.292	14.387	12.771
4	6.510	8.586	6.031	6.468	6.923	7.074	6.510	4.485
5	11.563	9.732	9.323	6.778	1.941	6.183	6.928	4.504
6	10.953	4.611	10.766	7.907	12.655	10.764	15.122	12.114
7	14.995	9.875	9.851	8.886	13.385	12.223	10.130	16.270
8	6.364	11.394	5.467	6.719	8.717	11.826	10.616	9.983
9	1.876	2.526	0.552	1.631	3.686	1.904	0.786	2.531
10	2.699	9.465	6.376	11.011	5.160	9.138	6.168	12.748
11	3.234	3.569	2.756	2.690	1.942	3.095	5.278	3.579
12	9.831	10.494	8.069	9.065	11.204	6.694	10.722	8.294
13	5.490	5.453	10.215	5.605	7.789	5.789	4.837	5.157
14	8.328	2.672	3.322	4.722	5.523	4.817	2.995	5.468
15	0.195	-4.484	-2.667	-0.922	-2.733	-0.900	-0.166	1.040
16	4.408	4.281	2.564	6.291	6.061	3.814	6.830	4.107
17	10.447	4.585	8.538	6.924	6.516	4.848	4.970	4.741
18	3.200	9.934	3.063	7.818	6.543	10.801	4.133	7.917
19	2.478	2.115	-0.137	-0.901	-1.082	0.057	2.246	1.876
20	5.084	10.025	6.836	12.304	10.841	13.852	7.907	13.401
21	-3.615	5.375	-1.567	5.412	-3.821	8.490	1.750	6.516
mean	**6.113**	**6.456**	**5.391**	**6.305**	**5.914**	**6.669**	**6.437**	**7.319**
SE	**1.035**	**0.874**	**0.950**	**0.754**	**1.064**	**0.873**	**0.893**	**0.925**

Table A5: Results of performed ANOVA for mean amplitudes within 270 and 370 ms at the midline electrodes (Fz, Cz, Pz)

factor/ interaction	degree of freedom (Greenhouse-Geisser corrected)	F-value	p-value (Greenhouse-Geisser corrected)
anterior posterior position	1.554	25.414	**0.000***
treatment	1.000	2.541	0.127
choice	1.000	0.783	0.387
indifferent position	1.000	10.145	**0.005**
anterior posterior position x treatment	1.635	1.269	0.289
anterior posterior position x choice	1.514	0.781	0.434
anterior posterior position x indifferent position	1.322	0.241	0.694
treatment x choice	1.000	0.061	0.807
treatment x indifferent position	1.000	1.390	0.252
choice x indifferent position	1.000	0.191	0.667
anterior posterior position x treatment x choice	1.822	2.390	0.110
anterior posterior position x treatment x indifferent position	1.361	5.911	**0.014***
anterior posterior position x choice x indifferent position	1.648	0.092	0.878
treatment x choice x indifferent position	1.000	0.343	0.565
anterior posterior position x treatment x choice x indifferent position	1.687	0.032	0.951

Table A6: Results of performed ANOVA for mean amplitudes within 270 and 370 ms at the Fz electrode

factor/ interaction	degree of freedom (Greenhouse-Geisser corrected)	F-value	p-value (Greenhouse-Geisser corrected)
treatment	1.000	2.429	0.135
choice	1.000	0.162	0.692
indifferent position	1.000	7.417	**0.013***
treatment x choice	1.000	1.321	0.264
treatment x indifferent position	1.000	4.990	**0.037***
choice x indifferent position	1.000	0.049	0.827
treatment x choice x indifferent position	1.000	0.286	0.599

Table A7: Results of one-sided pair-wise t-tests for mean amplitudes within 270 and 370 ms at the Fz electrode

pair	degree of freedom	T-value	p-value
bin 1: sure choice for lottery hypothetical vs. real	20	-2.245	**0.018***
bin 2: indifferent choice for lottery hypothetical vs. real	20	-1.021	0.160
bin 3: indifferent choice for sure payoff hypothetical vs. real	20	0.192	0.425
bin 4: sure choice for sure payoff hypothetical vs. real	20	-1.768	**0.046***
lottery choices (hypothetical) indifferent choice vs. sure choice	20	-0.253	0.401
sure payoff choices (hypothetical) indifferent choice vs. sure choice	20	0.196	0.424
lottery choices (real) indifferent choice vs. sure choice	20	-2.007	**0.029***
sure payoff choices (real) indifferent choice vs. sure choice	20	-2.435	**0.012***

Table A8: Combinations of lottery pairs and sure payoff values presented to the subjects

lottery pairs		sure payoff values (categorized by each decimal)								
50 %	50 %	10	20	30	40	50	60	70	80	90
0	100	10, 11, 12, 13, 14, 15, 16, 17	20, 21, 22, 23, 24, 25, 26, 27	30, 31, 32, 33, 34, 35, 36, 37	40, 41, 42, 43, 44, 45, 46, 47	50, 51, 52, 53, 54, 55, 56, 57	60, 61, 62, 63, 64, 65, 66, 67	70, 71, 72, 73, 74, 75, 76, 77	80, 81, 82, 83, 84, 85, 86, 87	90, 91, 92, 93, 94, 95, 96, 97
0	101	10, 11, 12, 13, 14, 15, 16, 17	20, 21, 22, 23, 24, 25, 26, 27	30, 31, 32, 33, 34, 35, 36, 37	40, 41, 42, 43, 44, 45, 46, 47	50, 51, 52, 53, 54, 55, 56, 57	60, 61, 62, 63, 64, 65, 66, 67	70, 71, 72, 73, 74, 75, 76, 77	80, 81, 82, 83, 84, 85, 86, 87	90, 91, 92, 93, 94, 95, 96, 97
0	102	10, 11, 12, 13, 14, 15, 16, 17	20, 21, 22, 23, 24, 25, 26, 27	30, 31, 32, 33, 34, 35, 36, 37	40, 41, 42, 43, 44, 45, 46, 47	50, 51, 52, 53, 54, 55, 56, 57	60, 61, 62, 63, 64, 65, 66, 67	70, 71, 72, 73, 74, 75, 76, 77	80, 81, 82, 83, 84, 85, 86, 87	90, 91, 92, 93, 94, 95, 96, 97
0	103	10, 11, 12, 13, 14, 15, 16, 17	20, 21, 22, 23, 24, 25, 26, 27	30, 31, 32, 33, 34, 35, 36, 37	40, 41, 42, 43, 44, 45, 46, 47	50, 51, 52, 53, 54, 55, 56, 57	60, 61, 62, 63, 64, 65, 66, 67	70, 71, 72, 73, 74, 75, 76, 77	80, 81, 82, 83, 84, 85, 86, 87	90, 91, 92, 93, 94, 95, 96, 97
0	104	10, 11, 12, 13, 14, 15, 16, 17	20, 21, 22, 23, 24, 25, 26, 27	30, 31, 32, 33, 34, 35, 36, 37	40, 41, 42, 43, 44, 45, 46, 47	50, 51, 52, 53, 54, 55, 56, 57	60, 61, 62, 63, 64, 65, 66, 67	70, 71, 72, 73, 74, 75, 76, 77	80, 81, 82, 83, 84, 85, 86, 87	90, 91, 92, 93, 94, 95, 96, 97
0	105	10, 11, 12, 13, 14, 15, 16, 17	20, 21, 22, 23, 24, 25, 26, 27	30, 31, 32, 33, 34, 35, 36, 37	40, 41, 42, 43, 44, 45, 46, 47	50, 51, 52, 53, 54, 55, 56, 57	60, 61, 62, 63, 64, 65, 66, 67	70, 71, 72, 73, 74, 75, 76, 77	80, 81, 82, 83, 84, 85, 86, 87	90, 91, 92, 93, 94, 95, 96, 97
0	106	10, 11, 12, 13, 14, 15, 16, 17	20, 21, 22, 23, 24, 25, 26, 27	30, 31, 32, 33, 34, 35, 36, 37	40, 41, 42, 43, 44, 45, 46, 47	50, 51, 52, 53, 54, 55, 56, 57	60, 61, 62, 63, 64, 65, 66, 67	70, 71, 72, 73, 74, 75, 76, 77	80, 81, 82, 83, 84, 85, 86, 87	90, 91, 92, 93, 94, 95, 96, 97
0	107	10, 11, 12, 13, 14, 15, 16, 17	20, 21, 22, 23, 24, 25, 26, 27	30, 31, 32, 33, 34, 35, 36, 37	40, 41, 42, 43, 44, 45, 46, 47	50, 51, 52, 53, 54, 55, 56, 57	60, 61, 62, 63, 64, 65, 66, 67	70, 71, 72, 73, 74, 75, 76, 77	80, 81, 82, 83, 84, 85, 86, 87	90, 91, 92, 93, 94, 95, 96, 97

A9: Original instruction (German) as used for the hypothetical treatment

Instruktion

In der folgenden Untersuchung werden von Ihnen hypothetische Entscheidungen verlangt. Treffen Sie diese bitte so, als wären es reale Entscheidungen. Für diese Untersuchung werden Sie eine Aufwandsentschädigung von 7 Euro pro Stunde erhalten.

Anleitung Untersuchung

Wir werden Ihnen in der heutigen Untersuchung Kombinationen von drei Zahlen präsentieren. Diese drei Zahlen repräsentieren einen Betrag in Euro. Dabei steht der kleinste mögliche Gewinn, eine Null, immer links, der größte mögliche Gewinn steht immer rechts. Außerdem zeigen wir Ihnen mit einer Verzögerung von einer Sekunde einen sicheren Gewinn in der Mitte, der immer größer als der linke und kleiner als der rechte mögliche Gewinn sein wird. Die folgende Abbildung stellt diese Entscheidungssituation in einem Beispiel dar.

Sie sollen sich nun entscheiden, ob Sie den Betrag in der Mitte sicher bekommen wollen oder lieber eine Lotterie spielen, bei dem die Wahrscheinlichkeit zu gewinnen, 50% beträgt. Wenn Sie sich für die Lotterie entscheiden, haben Sie eine Chance von 50%, den Betrag, der auf der rechten Seite steht, zu gewinnen und eine Chance von 50%, den Betrag, der auf linken Seite steht, also Null, zu gewinnen. Sie entscheiden sich für eine der beiden Möglichkeiten über einen Tastendruck mit dem rechten oder dem linken Zeigefinger:

Nehmen Sie den rechten Zeigefinger, um den mittleren, sicheren Betrag auszuwählen, und nehmen Sie den linken Zeigefinger, um die Lotterie zu wählen. Sie haben für jede Auswahl eine Sekunde Zeit. Die Zahlen in der Mitte variieren dabei zwischen 10 und 97, die Zahlen auf der rechten Seite zwischen 100 und 107.

Wir werden Ihnen eine Reihe von Entscheidungen zeigen. Am Ende der Untersuchung würden wir durch Zufall eine der von Ihnen getroffenen Entscheidungen ziehen. Haben Sie sich bei der zufällig ausgewählten Entscheidung für die Zahl in der Mitte entschieden, so würden Sie diesen Betrag in Euro unmittelbar vom Versuchsleiter ausgezahlt bekommen. Haben Sie sich bei der zufällig ausgewählten Entscheidung für eine Lotterie entschieden, so würde per Münzwurf entschieden, ob Sie den Betrag auf der rechten Seite vom Versuchsleiter direkt bekommen oder nicht. Wenn Kopf fällt, bekämen Sie den Betrag auf der linken Seite, wenn Zahl fällt, erhielten Sie den rechten Betrag.

Um es noch einmal deutlich zu machen: Ist Kopf oben, so würden Sie keinen Gewinn erhalten. Ist hingegen Zahl oben, so würden Sie den Betrag der rechten Zahl in Euro unmittelbar vom Versuchsleiter ausgezahlt bekommen.

Haben Sie sich beispielsweise bei dem obigen Beispiel dafür entschieden, die Zahl in der Mitte sicher zu erhalten, dann würden Sie, so diese Entscheidung gezogen wird, 10 Euro vom Versuchsleiter bekommen. Haben Sie sich für die Lotterie mit den Zahlen 0 und 40 entschieden, würden wir eine Münze werfen. Bei Zahl gewinnen Sie 40 Euro, die Sie dann ebenfalls unmittelbar vom Versuchsleiter erhalten. Bei Kopf gehen Sie leer aus.

Die Abfolge der verschiedenen Entscheidungen wird relativ rasch erfolgen, lassen Sie sich davon nicht beeindrucken. Es wird vor dem eigentlichen Experiment zwei Probedurchgänge geben, in welchen Sie sich an die Bedingungen gewöhnen können.

Bitte vergewissern Sie sich, dass Sie die Instruktion richtig verstanden haben und stellen Sie ansonsten Ihre Fragen an den Versuchsleiter.

Noch ein Hinweis: Bitte versuchen Sie während der Untersuchung nicht zu blinzeln und die Augen so wenig wie möglich zu bewegen. Sie haben in mehreren Pausen Zeit, sich „auszublinzeln". Sie tragen damit wesentlich zur Qualität der EEG-Daten bei.

Vielen Dank,

Ihr Untersuchungsteam

A10: Translated instruction (English) of the hypothetical treatment

Instruction

In this experiment, you are asked to make a series of decisions involving hypothetical payoffs. Please make all your decisions, as if real payoffs were used. You receive a show-up fee of 7 euros per hour for your participation in the experiment.

Instruction

In our today's experiment, we will present to you combinations of three numbers. Each of the numbers represents an amount in euros. The smallest possible payoff of 0 euros is always listed on the left side of a given combination of numbers, while the largest possible payoff is always listed on the right side. A sure payoff, that is larger than the payoff given on the left side but smaller than the one given on the right side, will be shown with a delay of one second in the middle of a given combination of numbers. An illustrative example of this decision problem is presented in the following figure.

Your task is to decide whether you would like to receive the sure payoff shown in the middle, or you would rather play a lottery with a success probability of 50%. If you decide to play the lottery, you will receive the payoff shown on the right side with a probability of 50% and nothing otherwise. You choose between receiving the sure payoff and playing the lottery by pressing a button with your right or left index finger:

Please use the right index finger to choose the sure payoff; and the left index finger to choose the lottery. You have one second time for each decision. The numbers shown in the middle vary between 10 and 97, and those shown on the right side, between 100 and 107.

You are asked to make a series of decisions for different combinations of numbers. At the end of the experiment, we would randomly select one of your decisions. If, for that particular decision, you would have chosen the sure payoff, you would immediately receive that from the experimenter. If, you would have chosen the lottery, the flip of a coin would determine whether you will be paid-out the right or the left payoff. If head falls, you would receive the payoff on the left side. If tails falls, you would receive the payoff on the right side.

That is: if head falls, you would receive a payoff of 0 euros; otherwise you would immediately receive from the experimenter the payoff shown on the right side.

For example, if for the combinations of numbers shown above, you have chosen the sure payoff and that particular decision is selected at the end of the experiment, you would immediately receive 10 euros from the experimenter. Alternatively, if you have chosen the lottery with the numbers 0 and 40, a coin would be flipped. If tails falls, you would immediately receive 40 euros from the experimenter. If head falls, you would receive nothing.

Please note that the combinations of numbers shown to you will change relatively quickly. Prior to the actual experiment, you will be given the chance to get used to the experimental conditions in two probe trials.

Please make sure that you have understood the experimental instructions and ask the experimenter any questions you may have.

Note: Please try to move your eyes as little as possible and not to blink during the experiment. This will significantly contribute to the quality of the EEG data. There will be several breaks in which your eyes can relax.

Thank you

The Experimenter-Team

A11: Original instruction (German) as used for the real treatment

Instruktion

In der folgenden Untersuchung werden von Ihnen reale Entscheidungen verlangt. Eine dieser von Ihnen getroffenen Entscheidungen wird am Ende Ihre Aufwandsentschädigung für diese Untersuchung sein.

Anleitung Untersuchung

Wir werden Ihnen in der heutigen Untersuchung Kombinationen von drei Zahlen präsentieren. Diese drei Zahlen repräsentieren einen Betrag in Euro. Dabei steht der kleinste mögliche Gewinn, eine Null, immer links, der größte mögliche Gewinn steht immer rechts. Außerdem zeigen wir Ihnen mit einer Verzögerung von einer Sekunde einen sicheren Gewinn in der Mitte, der immer größer als der linke und kleiner als der rechte mögliche Gewinn sein wird. Die folgende Abbildung stellt diese Entscheidungssituation in einem Beispiel dar.

Sie sollen sich nun entscheiden, ob Sie den Betrag in der Mitte sicher bekommen wollen oder lieber eine Lotterie spielen, bei dem die Wahrscheinlichkeit zu gewinnen, 50% beträgt. Wenn Sie sich für die Lotterie entscheiden, haben Sie eine Chance von 50%, den Betrag, der auf der rechten Seite steht, zu gewinnen und eine Chance von 50%, den Betrag, der auf linken Seite steht, also Null, zu gewinnen. Sie entscheiden sich für eine der beiden Möglichkeiten über einen Tastendruck mit dem rechten oder dem linken Zeigefinger:

Nehmen Sie den rechten Zeigefinger, um den mittleren, sicheren Betrag auszuwählen, und nehmen Sie den linken Zeigefinger, um die Lotterie zu wählen. Sie haben für jede Auswahl eine Sekunde Zeit. Die Zahlen in der Mitte variieren dabei zwischen 10 und 97, die Zahlen auf der rechten Seite zwischen 100 und 107.

Wir werden Ihnen eine Reihe von Entscheidungen zeigen. Am Ende der Untersuchung ziehen wir durch Zufall eine der von Ihnen getroffenen Entscheidungen. Haben Sie sich bei der zufällig ausgewählten Entscheidung für die Zahl in der Mitte entschieden, so bekommen Sie diesen Betrag in Euro unmittelbar vom Versuchsleiter ausgezahlt. Haben Sie sich bei der zufällig ausgewählten

Entscheidung für eine Lotterie entschieden, so wird per Münzwurf entschieden, ob Sie den Betrag auf der rechten Seite vom Versuchsleiter direkt bekommen oder nicht. Wenn Kopf fällt, bekommen Sie den Betrag auf der linken Seite, wenn Zahl fällt, erhalten Sie den rechten Betrag.

Um es noch einmal deutlich zu machen: Ist Kopf oben, so erhalten Sie keinen Gewinn. Ist hingegen Zahl oben, so bekommen Sie den Betrag der rechten Zahl in Euro unmittelbar vom Versuchsleiter ausgezahlt.

Haben Sie sich beispielsweise bei dem obigen Beispiel dafür entschieden, die Zahl in der Mitte sicher zu erhalten, dann würden Sie, so diese Entscheidung gezogen wird, 10 Euro vom Versuchsleiter bekommen. Haben Sie sich für die Lotterie mit den Zahlen 0 und 40 entschieden, würden wir eine Münze werfen. Bei Zahl gewinnen Sie 40 Euro, die Sie dann ebenfalls unmittelbar vom Versuchsleiter erhalten. Bei Kopf gehen Sie leer aus.

Die Abfolge der verschiedenen Entscheidungen wird relativ rasch erfolgen, lassen Sie sich davon nicht beeindrucken. Es wird vor dem eigentlichen Experiment zwei Probedurchgänge geben, in welchen Sie sich an die Bedingungen gewöhnen können.

Bitte vergewissern Sie sich, dass Sie die Instruktion richtig verstanden haben und stellen Sie ansonsten Ihre Fragen an den Versuchsleiter.

Noch ein Hinweis: Bitte versuchen Sie während der Untersuchung nicht zu blinzeln und die Augen so wenig wie möglich zu bewegen. Sie haben in mehreren Pausen Zeit, sich „auszublinzeln“. Sie tragen damit wesentlich zur Qualität der EEG-Daten bei.

Vielen Dank,

Ihr Untersuchungsteam

A12: Translated instruction (English) of the real treatment

Instruction

In this experiment, you are asked to make a series of decisions involving real payoffs. At the end of the experiment, one of these decisions will determine the payment for your participation in this experiment.

Instruction

In our today's experiment, we will present to you combinations of three numbers. Each of the numbers represents an amount in euros. The smallest possible payoff of 0 euros is always listed on the left side of a given combination of numbers, while the largest possible payoff is always listed on the right side. A sure payoff, that is larger than the payoff given on the left side but smaller than the one given on the right side, will be shown with a delay of one second in the middle of a given combination of numbers. An illustrative example of this decision problem is presented in the following figure.

Your task is to decide whether you would like to receive the sure payoff shown in the middle, or you would rather play a lottery with a success probability of 50%. If you decide to play the lottery, you will receive the payoff shown on the right side with a probability of 50% and nothing otherwise. You choose between receiving the sure payoff and playing the lottery by pressing a button with your right or left index finger:

Please use the right index finger to choose the sure payoff; and the left index finger to choose the lottery. You have one second time for each decision. The numbers shown in the middle vary between 10 and 97, and those shown on the right side, between 100 and 107.

You are asked to make a series of decisions for different combinations of numbers. At the end of the experiment, we will randomly select one of your decisions. If, for that particular decision, you have chosen the sure payoff, you will immediately receive that amount from the experimenter. If, you have chosen the lottery, the flip of a coin will determine whether you will be paid-out the right or the left payoff. If head falls, you will receive the payoff on the left side. If tails falls, you will receive the payoff on the right side.

That is: if head falls, you will receive a payoff of 0 euros; otherwise you will immediately receive the payoff shown on the right side from the experimenter.

For example, if you have chosen the sure payoff for the combinations of numbers shown above and that particular decision is selected at the end of the experiment, you will immediately receive 10 euros from the experimenter. Alternatively, if you have chosen the lottery with the numbers 0 and 40, a coin will be flipped. If tails falls, you will immediately receive 40 euros from the experimenter. If head falls, you will receive nothing.

Please note that the combinations of numbers shown to you will change relatively quickly. Prior to the actual experiment, you will be given the chance to get used to the experimental conditions in two probe trials.

Please make sure that you have understood the experimental instructions and ask the experimenter any questions you may have.

Note: Please try to move your eyes as little as possible and not to blink during the experiment. This will significantly contribute to the quality of the EEG data. There will be several breaks in which your eyes can relax.

Thank you

The Experimenter-Team

Table A13: Calculated mean amplitudes within 450 and 550 ms at the Fz electrode

subject	bin 1 sure choice lottery		bin 2 indifferent choice lottery		bin 3 indifferent choice sure payoff		bin 4 sure choice sure payoff	
No.	Hypo	Real	Hypo	Real	Hypo	Real	Hypo	Real
1	5.4552	3.7798	8.1707	-0.3815	0.3560	3.0105	4.4392	4.0444
2	7.1584	4.1267	7.4757	11.9925	8.8193	6.3889	7.3272	11.8817
3	4.4599	9.7247	7.4620	3.2133	6.9041	1.1700	4.1858	8.9113
4	4.9352	10.0453	4.7146	4.8045	4.2580	6.8302	7.3939	8.6416
5	5.2115	8.3124	9.6549	10.2631	2.2169	4.1684	2.0207	5.3606
6	2.6449	0.3896	1.9562	-2.6780	-0.4395	2.4717	2.7217	4.0962
7	1.9735	14.1992	4.7784	17.2089	6.1187	14.9897	4.5107	8.3982
8	1.8327	6.1749	0.6228	4.3021	6.6907	6.5403	7.6111	3.8280
9	2.2777	-0.6560	3.9441	0.2013	7.0667	2.5725	1.9601	-0.4583
10	7.5796	12.4155	7.2815	13.1654	4.4817	8.7841	4.6443	16.0989
11	5.5530	5.3963	5.6909	4.8096	7.1817	5.3629	8.0284	1.3132
12	3.0695	1.0097	3.3151	1.7102	7.4793	-2.5276	2.8094	-0.1815
13	3.7556	10.7760	5.3686	9.6360	2.0150	7.4936	3.6760	7.7735
14	8.4984	1.4718	2.7650	6.3988	5.7474	2.5066	5.2734	2.5996
15	-1.9450	-2.2939	-0.9604	-4.6622	0.5407	-2.1834	-1.8532	-1.2344
16	-4.5857	-0.0371	1.7007	0.6022	1.2198	-2.6346	-0.1883	-2.6869
17	8.9505	8.7614	8.4932	9.7529	2.1181	4.7359	0.4276	-0.2304
18	5.9072	7.0606	0.0040	1.9793	2.1752	6.3570	-1.1610	7.4279
19	2.8104	6.1264	3.8898	0.4906	-1.9491	0.4395	1.9121	2.4423
20	2.2422	12.4585	6.3860	8.5704	5.6916	7.4839	2.7363	4.3483
21	5.0790	6.8847	1.8951	6.0754	1.2551	6.0891	5.3901	8.5496
mean	**3.9459**	**6.0060**	**4.5052**	**5.1169**	**3.8070**	**4.2881**	**3.5174**	**4.8059**
SE	**0.7028**	**1.0389**	**0.6518**	**1.2146**	**0.6727**	**0.9154**	**0.6169**	**1.0323**

Table A14: Calculated mean amplitudes within 450 and 550 ms at the Cz electrode

subject	bin 1 sure choice lottery		bin 2 indifferent choice lottery		bin 3 indifferent choice sure payoff		bin 4 sure choice sure payoff	
No.	Hypo	Real	Hypo	Real	Hypo	Real	Hypo	Real
1	6.1944	9.5714	10.2305	4.1264	5.3985	7.4243	9.4698	7.7096
2	9.9310	7.7962	11.6640	13.9789	10.7681	8.0623	9.1741	16.8384
3	15.3784	18.4528	16.5788	13.4877	12.9663	9.8668	10.7025	15.1242
4	11.2454	18.6400	10.9371	11.2174	8.7632	14.4068	13.2995	17.3291
5	15.0089	15.2737	18.3350	15.7413	5.8901	8.7584	9.8827	8.2096
6	7.6760	2.1204	9.3233	0.6139	4.8400	8.3755	9.0242	6.2434
7	17.6940	24.8694	14.7187	22.0643	15.4637	19.5512	14.2872	16.7428
8	7.1207	13.1670	2.3786	9.4334	8.7754	9.1538	12.9007	11.4552
9	7.2150	2.3486	4.7347	0.8013	11.2645	4.1911	5.4867	3.7366
10	11.3136	16.2671	11.1439	14.3030	7.8385	9.9905	8.6080	17.5489
11	5.6166	6.8765	4.4360	6.1439	5.5961	4.5885	7.8415	2.7867
12	10.2497	14.7818	8.4972	11.1132	15.2163	8.5380	9.7550	8.0865
13	4.1414	11.9901	7.8697	9.9727	5.6341	6.1368	5.1458	8.6230
14	9.0305	2.2333	2.0608	5.5216	4.6197	2.7767	6.0470	4.7097
15	1.1574	0.6526	-0.8857	-1.9357	1.3363	-0.4689	3.3160	2.4164
16	2.9660	3.8709	1.8606	4.4575	3.0398	2.0919	3.6409	-0.6974
17	13.9600	10.0985	9.2781	11.7556	6.0806	7.0981	3.0600	4.3580
18	8.2374	14.9253	2.9347	7.5687	6.2992	11.6769	6.0248	10.8211
19	5.8995	4.9496	3.3198	0.5340	-1.3141	1.8326	3.8211	6.0857
20	6.0341	15.9366	9.7564	10.8888	8.7424	10.6547	5.1058	8.0221
21	8.1523	15.7316	4.8703	12.4572	3.1756	13.5109	8.8611	18.1779
mean	**8.7725**	**10.9787**	**7.8115**	**8.7736**	**7.1616**	**8.0103**	**7.8788**	**9.2537**
SE	**0.9229**	**1.4554**	**1.1262**	**1.3068**	**0.9353**	**1.0211**	**0.7308**	**1.2512**

Table A15: Calculated mean amplitudes within 450 and 550 ms at the Pz electrode

subject	bin 1 sure choice lottery		bin 2 indifferent choice lottery		bin 3 indifferent choice sure payoff		bin 4 sure choice sure payoff	
No.	Hypo	Real	Hypo	Real	Hypo	Real	Hypo	Real
1	5.6306	11.3069	7.2247	5.2216	2.6674	7.4298	4.3658	6.1469
2	12.9579	10.5945	13.2120	14.2525	9.9184	8.7045	12.4284	17.3042
3	18.8853	19.3842	18.1088	13.1294	14.3476	9.2256	12.0269	10.1397
4	13.6466	17.9796	11.8489	9.6699	8.4336	9.9697	9.9592	13.4766
5	14.0529	18.1306	13.7999	14.3979	3.2602	8.4746	6.4138	5.6505
6	11.1251	5.3224	11.2849	3.8377	8.8227	7.5417	12.0455	5.4422
7	21.8738	22.7093	16.7102	16.9943	13.5958	14.4275	16.3887	15.5072
8	10.7374	15.5207	4.4544	10.9272	11.5923	11.2410	13.5775	11.9569
9	6.5255	4.5826	4.0182	1.9953	6.6123	2.8572	0.6496	2.4768
10	14.2146	18.3663	12.7676	16.2685	9.3304	11.8985	8.3826	17.5597
11	5.0532	6.6763	2.3884	3.3977	3.2187	2.9319	6.9142	2.4655
12	12.0744	17.9349	12.3861	14.0028	15.0937	8.9987	10.9318	5.5816
13	5.3699	12.6715	10.6402	10.8365	8.1729	7.1767	5.4782	8.2562
14	10.2546	4.3263	4.1378	4.7300	5.9052	4.0074	7.4948	5.9716
15	6.6998	3.3983	2.1260	2.6903	3.4575	4.2247	4.7234	6.2156
16	6.8200	5.9341	3.4839	6.7969	5.8976	4.8967	4.9444	1.7049
17	18.8536	13.0571	13.9506	14.8434	8.1712	8.8477	5.6793	5.3872
18	11.0018	20.0421	6.6055	10.5404	12.9132	16.7617	11.7891	12.9725
19	8.7722	10.4269	5.5026	4.2197	1.2210	4.4473	4.8778	5.7640
20	6.8848	11.9671	7.9954	10.9960	11.0043	11.2836	9.4950	11.9633
21	6.6264	16.9813	2.8303	10.2109	0.4512	13.0202	8.7933	16.6862
mean	**10.8600**	**12.7292**	**8.8322**	**9.5219**	**7.8137**	**8.4937**	**8.4457**	**8.9823**
SE	**1.0543**	**1.3031**	**1.0906**	**1.0539**	**0.9533**	**0.8285**	**0.8339**	**1.1143**

Table A16: Results of performed ANOVA for mean amplitudes within 450 and 550 ms at the midline electrodes (Fz, Cz, Pz)

factor/ interaction	degree of freedom (Greenhouse-Geisser corrected)	F-value	p-value (Greenhouse-Geisser corrected)
anterior posterior position	1.638	49.319	**0.000*** **
treatment	1.000	3.127	0.092
bin classification	2.253	5.318	**0.007** **
anterior posterior position x treatment	1.409	0.274	0.684
anterior posterior position x bin classification	3.304	8.957	**0.000*** **
treatment x bin classification	2.912	0.946	0.423
anterior posterior position x treatment x bin classification	3.299	0.355	0.804

Table A17: Results of performed ANOVA mean amplitudes within 450 and 550 ms at the Pz electrode

factor/ interaction	degree of freedom (Greenhouse-Geisser corrected)	F-value	p-value (Greenhouse-Geisser corrected)
treatment	1.000	1.900	0.183
choice	1.000	9.348	**0.006** **
indifferent position	1.000	15.714	**0.001** **
treatment x choice	1.000	0.845	0.369
treatment x indifferent position	1.000	0.751	0.396
choice x indifferent position	1.000	7.963	**0.011***
treatment x choice x indifferent position	1.000	1.050	0.318

Table A18: Results of one-sided pair-wise t-tests for mean amplitudes within 450 and 550 ms at the Pz electrode

pair	degree of freedom	T-value	p-value
bin 1: sure choice for lottery hypothetical vs. real	20	-1.773	**0.046***[*]**
bin 2: indifferent choice for lottery hypothetical vs. real	20	-0.921	0.184
bin 3: indifferent choice for sure payoff hypothetical vs. real	20	-0.778	0.223
bin 4: sure choice for sure payoff hypothetical vs. real	20	-0.621	0.271
lottery choices (hypothetical) indifferent choice vs. sure choice	20	-3.198	**0.003**[**]
sure payoff choices (hypothetical) indifferent choice vs. sure choice	20	-0.887	0.193
lottery choices (real) indifferent choice vs. sure choice	20	-4.303	**0.000**[***]
sure payoff choices (real) indifferent choice vs. sure choice	20	-0.703	0.245
sure choices (hypothetical) lottery choice vs. sure payoff choice	20	2.738	**0.007**[**]
indifferent choices (hypothetical) lottery choice vs. sure payoff choice	20	1.096	0.143
sure choices (real) lottery choice vs. sure payoff choice	20	3.592	**0.001**[***]
indifferent choices (real) lottery choice vs. sure payoff choice	20	1.384	0.091

Table A19: Calculated mean reaction times

subject	**bin 1 sure choice lottery**		**bin 2 indifferent choice lottery**		**bin 3 indifferent choice sure payoff**		**bin 4 sure choice sure payoff**	
No.	**Hypo**	**Real**	**Hypo**	**Real**	**Hypo**	**Real**	**Hypo**	**Real**
1	582.43	693.28	695.98	948.90	681.18	924.90	518.69	689.15
2	553.89	477.10	786.70	631.28	734.89	621.90	621.33	474.99
3	639.34	523.44	746.24	685.16	698.92	680.80	563.10	423.25
4	577.72	515.93	654.92	664.84	646.96	592.76	504.05	493.07
5	431.08	501.92	480.15	541.45	451.74	516.83	366.54	439.57
6	557.89	503.14	593.32	554.90	544.78	541.63	479.15	478.82
7	471.18	495.22	577.62	625.26	602.48	626.04	485.60	440.86
8	590.27	538.47	669.13	643.91	590.31	600.49	500.43	479.26
9	510.35	542.47	577.15	606.87	525.22	589.84	457.12	448.12
10	552.26	566.38	687.90	693.53	717.07	723.67	493.50	522.80
11	675.65	564.56	801.58	675.47	792.40	741.99	667.46	592.39
12	480.89	481.50	571.99	536.33	556.77	499.81	483.22	383.98
13	932.25	928.21	985.88	1062.70	928.73	990.95	830.57	827.55
14	575.43	525.08	727.18	628.53	687.34	613.16	581.00	505.75
15	519.73	598.40	602.25	646.60	533.65	624.19	465.54	523.22
16	517.87	522.11	619.03	584.69	579.80	544.75	455.69	430.91
17	562.55	635.07	643.55	638.12	677.97	620.07	489.49	480.54
18	475.39	482.87	622.02	640.82	569.01	577.02	557.74	501.08
19	550.56	555.96	634.51	709.46	609.84	632.78	442.08	447.14
20	533.48	579.05	659.96	648.33	592.38	658.17	553.19	505.80
21	530.74	440.38	614.95	518.62	563.99	490.84	508.71	455.41
mean	562.90	555.74	664.38	661.23	632.64	638.69	524.96	502.08
SE	22.12	22.43	23.07	27.75	23.23	27.24	20.89	21.45

Table A20: Results of performed ANOVA for reaction times with bin classification as factor

factor/ interaction	degree of freedom (Greenhouse-Geisser corrected)	F-value	p-value (Greenhouse-Geisser corrected)
treatment	1.000	0.201	0.658
bin classification	2.323	105.694	**0.000*****
treatment x bin classification	2.648	2.447	0.081

Table A21: Results of performed ANOVA for reaction times separated by choice type and indifferent position

factor/ interaction	degree of freedom (Greenhouse-Geisser corrected)	F-value	p-value (Greenhouse-Geisser corrected)
treatment	1.000	0.201	0.658
choice	1.000	182.751	**0.000*****
indifferent position	1.000	37.144	**0.000*****
treatment x choice	1.000	0.214	0.649
treatment x indifferent position	1.000	3.369	0.081
choice x indifferent position	1.000	3.069	0.095
treatment x choice x indifferent position	1.000	3.199	0.089

Table A22: Results of two-sided pair-wise t-tests for mean reaction times

pair	degree of freedom	T-value	p-value
bin 1: sure choice for lottery hypothetical vs. real	20	0.508	0.617
bin 2: indifferent choice for lottery hypothetical vs. real	20	0.166	0.870
bin 3: indifferent choice for sure payoff hypothetical vs. real	20	-0.355	0.726
bin 4: sure choice for sure payoff hypothetical vs. real	20	1.473	0.156
lottery choices (hypothetical) indifferent choice vs. sure choice	20	10.726	**0.000*****
sure payoff choices (hypothetical) indifferent choice vs. sure choice	20	9.585	**0.000*****
lottery choices (real) indifferent choice vs. sure choice	20	8.407	**0.000*****
sure payoff choices (real) indifferent choice vs. sure choice	20	11.228	**0.000*****
sure choices (hypothetical) lottery choice vs. sure payoff choice	20	3.269	**0.004****
indifferent choices (hypothetical) lottery choice vs. sure payoff choice	20	4.514	**0.000*****
sure choices (real) lottery choice vs. sure payoff choice	20	5.006	**0.000*****
indifferent choices (real) lottery choice vs. sure payoff choice	20	3.014	**0.007****

Appendix B: Data from the EEG study concerning the portfolio effect

Table B1: Individual choice behavior of both treatments

subject	total amount of lottery choices		total amount of sure payoff choices		Lottery choice frequency within the distance categories of -8 and -7	
No.	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**
1	237	252	327	311	0.79	1.00
2	313	261	262	313	1.00	1.00
3	158	148	417	423	0.00	0.00
4	294	277	282	296	1.00	0.94
5	108	94	468	482	0.00	0.00
6	153	132	422	444	0.00	0.00
7	116	253	460	320	0.00	1.00
8	193	262	383	313	0.00	0.94
9	186	182	389	386	0.06	0.06
10	263	256	313	313	1.00	1.00
11	180	126	396	443	0.06	0.00
12	261	271	313	299	0.88	1.00
13	228	261	348	313	0.56	0.94
14	197	249	379	325	0.00	0.88
15	320	152	254	420	1.00	0.19
16	85	328	490	246	0.00	1.00
17	211	244	364	329	0.31	0.63
18	237	196	314	379	0.81	0.19
median	**204**	**250.5**	**371.5**	**322.5**	**0.19**	**0.91**
mean	**207.78**	**219.11**	**365.61**	**353.06**	**0.42**	**0.60**
SE	**16.13**	**15.31**	**16.45**	**15.38**	**0.105**	**0.106**

Table B2: Data of determined indifference areas

subject	begin of indifference interval		end of indifference interval		determined individual indifference point		Lottery choice frequency within the indifference area	
No.	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**
1	-10	-3	-3	-3	-4	-3	0.72	0.50
2	0	-6	10	3	6	-2	0.59	0.46
3	-23	-27	-13	-13	-18	-18	0.49	0.57
4	-2	-3	7	7	3	2	0.54	0.47
5	-32	-35	-20	-23	-26	-28	0.53	0.57
6	-23	-23	-14	-22	-19	-22	0.44	0.38
7	-30	-3	-18	-2	-25	-3	0.46	0.50
8	-13	-3	-13	4	-13	-2	0.50	0.18
9	-18	-18	-11	-13	-14	-14	0.54	0.71
10	-3	-5	0	4	-2	-2	0.50	0.34
11	-23	-23	-10	-23	-14	-23	0.64	0.50
12	-7	-6	0	5	-2	-1	0.59	0.44
13	-21	-4	0	5	-6	-3	0.65	0.23
14	-13	-8	-11	-3	-12	-4	0.50	0.80
15	-3	-28	16	-5	7	-19	0.53	0.42
16	-33	4	-25	14	-29	8	0.46	0.45
17	-18	-12	-3	2	-10	-5	0.53	0.50
18	-10	-17	-2	-7	-4	-12	0.68	0.47
median	**-15.5**	**-7**	**-6.5**	**-2.5**	**-11**	**-3.5**	**0.529**	**0.468**
mean	**-15.67**	**-12.22**	**-6.11**	**-3.89**	**-10.11**	**-8.39**	**0.550**	**0.471**
SE	**2.479**	**2.615**	**2.544**	**2.584**	**2.532**	**2.360**	**0.019**	**0.034**

Table B3: Calculated mean amplitudes within 260 and 360 ms at the Fz electrode

subject	bin 1 sure choice lottery		bin 2 indifferent choice lottery		bin 3 indifferent choice sure payoff		bin 4 sure choice sure payoff	
No.	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**
1	5.5498	5.5313	-1.2768	6.6005	1.0918	7.1051	5.5644	6.3611
2	7.1930	9.3849	8.2236	7.0275	5.4622	7.1368	9.5816	9.6061
3	8.0006	6.3240	2.2864	5.0987	0.4682	4.7177	6.2360	3.4232
4	1.2918	-2.3744	-0.2236	4.0082	3.4356	1.8161	2.8061	6.9480
5	8.3460	11.6460	5.1264	11.5658	3.8869	5.5952	5.6317	2.8199
6	7.0604	8.6529	6.8393	8.6128	7.5358	6.1940	8.2406	9.9957
7	5.5112	2.6880	2.9367	3.6410	5.6270	3.2058	2.9329	4.1024
8	-0.4925	-2.8189	-0.0241	-2.5740	0.4846	0.0556	0.4417	0.5468
9	10.0646	5.3668	9.8749	4.4812	7.4446	3.9226	13.3703	1.6583
10	3.0210	4.7029	1.6985	0.4110	0.6767	2.5323	2.4101	4.1910
11	1.5788	1.1723	3.1617	2.8531	1.7005	2.1843	2.1192	3.3554
12	1.9234	1.6654	3.5104	4.9052	1.9407	3.4596	1.8155	3.3285
13	-5.3710	-1.7350	-5.7843	-2.1433	-3.7376	-2.2866	-3.9887	-1.9012
14	0.4210	1.7582	-0.3561	1.2351	-0.4041	2.3098	1.1173	4.2393
15	2.4716	1.1928	0.4094	0.5031	1.7730	1.5983	5.3020	2.1247
16	4.2683	-2.3214	2.3442	-0.7766	0.6933	2.5855	-2.0337	2.0365
17	13.0986	8.0829	11.8850	4.9710	11.5436	9.1522	13.7951	7.7218
18	1.3049	0.0467	1.4582	2.3145	1.4214	-0.0503	-0.0459	0.4897
mean	**4.1801**	**3.2759**	**2.8939**	**3.4853**	**2.8358**	**3.4019**	**4.1831**	**3.9471**
SE	**1.0338**	**1.0387**	**1.0078**	**0.8739**	**0.8434**	**0.6781**	**1.1362**	**0.7455**

Table B4: Calculated mean amplitudes within 260 and 360 ms at the FCz electrode

subject	bin 1 sure choice lottery		bin 2 indifferent choice lottery		bin 3 indifferent choice sure payoff		bin 4 sure choice sure payoff	
No.	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**
1	6.5067	5.5298	1.2852	5.9057	2.9774	6.8150	6.4980	5.7526
2	8.1855	9.4535	8.7422	7.0818	5.9845	8.2023	9.6768	10.2975
3	11.6951	11.2194	6.3924	10.1424	5.4162	6.0949	10.0316	8.0874
4	2.4828	-0.9604	0.7726	3.2900	4.7137	1.2723	3.4894	8.1737
5	8.7798	11.6959	6.3220	12.5131	4.6387	5.7290	5.0949	4.7181
6	10.3139	10.2686	8.2891	9.8500	9.8796	9.4245	13.5409	13.7099
7	6.2792	2.6312	3.0496	2.3036	5.7348	2.5499	3.0314	1.9066
8	-1.4466	-3.9165	-1.8121	-4.0640	-0.9219	-0.8751	-0.8767	-1.1194
9	9.7123	3.9489	9.5242	4.4779	7.9279	3.6595	12.6001	1.1217
10	2.7957	4.7891	2.5108	-0.6863	4.6004	0.6230	-0.2622	4.0133
11	1.6329	4.2585	3.5330	5.1327	1.3999	1.9619	1.2891	1.0384
12	1.1970	1.8281	4.0055	4.6340	2.0396	1.6156	2.3940	4.1284
13	-6.5940	-1.8683	-5.8772	-3.5981	-4.7747	-4.3130	-3.3346	-3.4711
14	3.5442	3.2130	2.2384	2.0406	0.4815	2.1668	4.2042	4.8462
15	3.4629	0.6395	2.1490	-1.1764	1.6630	2.0913	5.7260	2.2612
16	1.8539	-3.7720	-0.0882	-3.4081	-1.4620	-0.0015	-2.2536	-0.4134
17	11.9329	6.8826	10.1163	5.6660	12.0387	9.2031	13.4300	7.6349
18	2.1921	1.7827	4.1901	4.7396	3.3270	1.0987	2.2384	3.6077
mean	**4.6959**	**3.7569**	**3.6302**	**3.6025**	**3.6480**	**3.1843**	**4.8065**	**4.2385**
SE	**1.1508**	**1.1379**	**0.9789**	**1.1341**	**0.9627**	**0.8720**	**1.2398**	**1.0076**

Table B5: Calculated mean amplitudes within 260 and 360 ms at the Cz electrode

subject	bin 1 sure choice lottery		bin 2 indifferent choice lottery		bin 3 indifferent choice sure payoff		bin 4 sure choice sure payoff	
No.	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**
1	6.6314	4.0471	2.6301	7.8930	3.9489	4.0794	7.6117	5.8842
2	8.1457	9.6229	9.6309	6.5028	6.6450	8.9709	9.7399	9.4333
3	15.2020	11.3789	9.8734	11.8460	9.1759	8.2878	13.7125	10.6723
4	5.3437	2.1097	3.4239	6.5689	7.1131	4.3438	4.3673	9.7794
5	9.1635	10.6975	7.2313	12.1277	6.9841	6.7067	5.8809	6.1031
6	11.1386	9.7009	9.7322	9.7154	11.8572	9.8696	15.5096	15.0343
7	6.5374	2.6226	3.8143	1.0871	5.9401	1.3095	4.4597	-0.5570
8	-1.5204	-3.2088	-1.3169	-4.7687	-1.3002	-0.0625	-0.8387	-1.2952
9	9.0787	3.7611	9.6336	4.4324	7.5870	4.2845	12.3055	1.5029
10	3.1116	4.5352	2.3437	-1.8551	2.3949	0.4429	2.8157	4.8316
11	2.9391	2.2218	4.1038	2.9656	3.1799	4.6500	2.7343	4.4913
12	1.1511	1.5111	4.0892	4.3523	2.8587	2.5233	3.2447	3.5431
13	-6.6746	-2.1890	-5.1518	-3.7191	-4.3769	-5.4527	-2.6028	-2.9655
14	3.1548	5.4573	2.7511	3.1762	1.6639	3.5686	2.4781	6.1192
15	4.8124	2.8014	3.4542	2.1371	4.4266	2.9030	5.9039	3.9212
16	-0.5512	-4.3425	-1.7730	-5.4536	-2.6478	-1.1473	-1.0845	-1.8631
17	12.2017	7.5452	11.0300	6.9353	12.5242	9.0975	13.8184	7.6817
18	3.9311	1.7987	5.2313	3.7089	5.7306	1.9915	5.4578	4.5847
mean	**5.2109**	**3.8928**	**4.4851**	**3.7585**	**4.6503**	**3.6870**	**5.8619**	**4.8279**
SE	**1.2507**	**1.0835**	**1.0543**	**1.2395**	**1.0717**	**0.9386**	**1.2579**	**1.1177**

Table B6: Calculated mean amplitudes within 260 and 360 ms at the CPz electrode

subject	bin 1 sure choice lottery		bin 2 indifferent choice lottery		bin 3 indifferent choice sure payoff		bin 4 sure choice sure payoff	
No.	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**
1	7.6759	6.7404	5.1507	4.0870	6.3978	6.0393	8.0553	5.3581
2	7.2546	9.6495	10.6827	7.0519	6.5714	8.9352	9.6889	9.2456
3	14.0794	11.5261	9.4985	9.2236	9.8258	7.7927	13.2317	12.4288
4	7.8726	3.4775	5.7732	7.4674	7.9634	5.3367	5.7186	9.2055
5	10.1876	10.1828	6.9833	10.5086	7.6251	6.2018	5.6335	6.4281
6	11.1216	8.8551	10.1217	7.7973	12.2999	9.1856	15.5311	14.3899
7	7.5232	3.3096	4.4207	2.2156	7.0910	3.4560	7.1549	0.8936
8	-0.1153	-2.0402	-0.2450	-4.3558	0.1248	0.6870	0.3359	-0.7807
9	9.3307	3.9403	10.5633	4.5575	8.0633	5.2207	12.7270	2.1852
10	2.6042	4.3760	2.3086	-2.0060	2.9637	-0.8945	3.1594	5.3546
11	4.0944	5.4854	6.9360	5.4093	5.1344	6.6089	5.5385	7.9352
12	2.0715	2.6141	4.3342	4.9840	3.9622	3.2707	4.1128	4.5794
13	-6.2903	-0.4549	-2.9161	-2.1525	-2.6503	-3.3130	-0.8513	-0.2529
14	4.7126	6.7513	3.1007	4.4239	1.9898	4.2415	2.4016	6.7863
15	7.0080	4.7747	5.3586	1.5851	8.2339	5.9910	8.4245	5.0505
16	-2.1952	-1.7913	-1.8881	-3.2563	0.0703	0.6785	1.2257	0.5246
17	11.4008	8.2175	11.4693	7.6580	13.2357	9.0192	12.4425	7.4207
18	3.5866	1.7599	4.7020	3.2367	7.3502	3.3868	5.0874	5.4675
mean	**5.6624**	**4.8541**	**5.3530**	**3.8020**	**5.9029**	**4.5469**	**6.6454**	**5.6789**
SE	**1.2156**	**0.9404**	**1.0018**	**1.0346**	**0.9909**	**0.8268**	**1.1072**	**0.9851**

Table B7: Calculated mean amplitudes within 260 and 360 ms at the Pz electrode

subject	bin 1 sure choice lottery		bin 2 indifferent choice lottery		bin 3 indifferent choice sure payoff		bin 4 sure choice sure payoff	
No.	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**
1	6.8072	3.4948	5.7867	1.0509	3.6683	5.3868	6.7617	5.2434
2	6.8796	8.2669	9.4999	6.0880	6.0663	9.1896	8.8260	8.2950
3	11.1974	10.2931	9.0613	7.5587	9.1453	6.2003	12.4637	11.2043
4	8.2064	2.4080	6.4743	7.0895	7.4817	3.3658	4.4868	4.6462
5	9.3180	9.2673	6.5687	9.0058	6.3589	5.6013	4.8639	6.0987
6	9.1306	7.5807	8.5251	5.7504	12.4673	8.6748	14.7959	12.0749
7	10.8785	4.8266	6.3457	4.6358	11.4921	6.3671	9.3537	3.8830
8	2.4676	-0.0349	1.4997	-1.7823	1.8902	3.0720	2.1018	0.6670
9	9.1674	4.7960	10.5875	5.3329	8.8039	6.7717	12.5172	3.4581
10	3.4577	4.3207	2.6848	-2.0312	3.0853	-0.5545	3.4391	4.4066
11	4.9082	5.8286	5.4381	6.3117	5.4571	7.7314	4.9397	8.7429
12	2.7465	2.9345	4.8637	5.1872	4.7272	4.0498	5.4092	5.6404
13	-4.4112	1.9969	-0.2781	0.0066	-0.4993	-1.2282	1.1773	1.6260
14	3.5061	7.8532	5.5344	5.5101	3.3223	5.0905	3.5054	7.1300
15	9.3016	4.8468	7.3546	1.0065	9.9343	6.4902	7.2414	7.1553
16	1.8110	0.4902	-0.9936	-0.6767	0.0560	3.0487	1.6928	2.1464
17	10.8335	8.7160	12.9181	8.2913	14.3155	9.1287	13.7581	8.1561
18	5.2427	3.3589	5.5446	3.6830	8.6461	5.0991	5.9583	6.7385
mean	**6.1916**	**5.0691**	**5.9675**	**4.0010**	**6.4677**	**5.1936**	**6.8496**	**5.9618**
SE	**0.9651**	**0.7170**	**0.8499**	**0.8278**	**0.9856**	**0.6880**	**0.9984**	**0.7299**

Table B8: Results of performed ANOVA for mean amplitudes within 260 and 360 ms at the midline electrodes (Fz, FCz, Cz, CPz, and Pz)

factor/ interaction	degree of freedom (Greenhouse-Geisser corrected)	F-value	p-value (Greenhouse-Geisser corrected)
anterior posterior position	2.108	11.526	**0.000*** **
treatment	1.000	2.508	0.132
choice	1.000	1.841	0.193
indifferent position	1.000	8.198	**0.011***
anterior posterior position x treatment	1.555	6.405	**0.009****
anterior posterior position x choice	1.668	2.937	0.078
anterior posterior position x indifferent position	2.087	0.557	0.585
treatment x choice	1.000	0.136	0.717
treatment x indifferent position	1.000	0.113	0.741
choice x indifferent position	1.000	0.710	0.411
anterior posterior position x treatment x choice	2.099	0.485	0.629
anterior posterior position x treatment x indifferent position	1.956	6.792	**0.004****
anterior posterior position x choice x indifferent position	2.477	1.168	0.328
treatment x choice x indifferent position	1.000	0.052	0.822
anterior posterior position x treatment x choice x indifferent position	2.584	1.309	0.283

Table B9: Results of performed ANOVA for mean amplitudes within 260 and 360 ms at the FCz electrode

factor/ interaction	degree of freedom (Greenhouse-Geisser corrected)	F-value	p-value (Greenhouse-Geisser corrected)
treatment	1.000	0.862	0.366
choice	1.000	0.012	0.914
indifferent position	1.000	9.125	**0.008****
treatment x choice	1.000	0.003	0.955
treatment x indifferent position	1.000	2.321	0.414
choice x indifferent position	1.000	0.826	0.376
treatment x choice x indifferent position	1.000	0.544	0.471

Table B10: Results of one-sided pair-wise t-tests for mean amplitudes within 260 and 360 ms at the FCz electrode

pair	degree of freedom	T-value	p-value
bin 1: sure choice for lottery portfolio vs. single	17	-1.303	0.105
bin 2: indifferent choice for lottery portfolio vs. single	17	-0.036	0.486
bin 3: indifferent choice for sure payoff portfolio vs. single	17	-0.843	0.206
bin 4: sure choice for sure payoff portfolio vs. single	17	-0.660	0.259
lottery choices (portfolio) indifferent choice vs. sure choice	17	-0.297	0.385
sure payoff choices (portfolio) indifferent choice vs. sure choice	17	-1.854	**0.041***
lottery choices (single) indifferent choice vs. sure choice	17	-2.016	**0.030***
sure payoff choices (single) indifferent choice vs. sure choice	17	-1.796	**0.045***

B11: Original instruction (German) as used for the single treatment

Instruktion

In der folgenden Untersuchung werden von Ihnen reale Entscheidungen verlangt. Eine dieser von Ihnen getroffenen Entscheidungen wird am Ende Ihre Aufwandsentschädigung für diese Untersuchung sein.

Anleitung Untersuchung

Wir werden Ihnen in der heutigen Untersuchung Kombinationen von drei Zahlen präsentieren. Diese drei Zahlen repräsentieren einen Betrag in euros. Dabei steht der kleinste mögliche Gewinn, eine Null, immer links, der größte mögliche Gewinn steht immer rechts. Außerdem zeigen wir Ihnen mit einer Verzögerung von einer Sekunde einen sicheren Gewinn in der Mitte, der immer größer als der linke und kleiner als der rechte mögliche Gewinn sein wird. Die folgende Abbildung stellt diese Entscheidungssituation in einem Beispiel dar.

Sie sollen sich nun entscheiden, ob Sie den Betrag in der Mitte sicher bekommen wollen oder lieber eine Lotterie spielen, bei dem die Wahrscheinlichkeit zu gewinnen, 50% beträgt. Wenn Sie sich für die Lotterie entscheiden, haben Sie eine Chance von 50%, den Betrag, der auf der rechten Seite steht, zu gewinnen und eine Chance von 50%, den Betrag, der auf linken Seite steht, also Null, zu gewinnen. Sie entscheiden sich für eine der beiden Möglichkeiten über einen Tastendruck mit dem rechten oder dem linken Zeigefinger:

Nehmen Sie den rechten Zeigefinger, um den mittleren, sicheren Betrag auszuwählen, und nehmen Sie den linken Zeigefinger, um die Lotterie zu wählen. Sie haben für jede Auswahl eine Sekunde Zeit. Die Zahlen in der Mitte variieren dabei zwischen 10 und 97, die Zahlen auf der rechten Seite zwischen 100 und 107.

Wir werden Ihnen eine Reihe von Entscheidungen zeigen. Am Ende der Untersuchung ziehen wir durch Zufall eine der von Ihnen getroffenen Entscheidungen. Haben Sie sich bei der zufällig ausgewählten Entscheidung für die Zahl in der Mitte entschieden, so bekommen Sie diesen Betrag in euros unmittelbar vom Versuchsleiter ausgezahlt. Haben Sie sich bei der zufällig ausgewählten

Entscheidung für eine Lotterie entschieden, so wird per Münzwurf entschieden, ob Sie den Betrag auf der rechten Seite vom Versuchsleiter direkt bekommen oder nicht. Wenn Kopf fällt, bekommen Sie den Betrag auf der linken Seite, wenn Zahl fällt, erhalten Sie den rechten Betrag.

Um es noch einmal deutlich zu machen: Ist Kopf oben, so erhalten Sie keinen Gewinn. Ist hingegen Zahl oben, so bekommen Sie den Betrag der rechten Zahl in euros unmittelbar vom Versuchsleiter ausgezahlt.

Haben Sie sich beispielsweise bei dem obigen Beispiel dafür entschieden, die Zahl in der Mitte sicher zu erhalten, dann würden Sie, so diese Entscheidung gezogen wird, 10 euros vom Versuchsleiter bekommen. Haben Sie sich für die Lotterie mit den Zahlen 0 und 40 entschieden, würden wir eine Münze werfen. Bei Zahl gewinnen Sie 40 euros, die Sie dann ebenfalls unmittelbar vom Versuchsleiter erhalten. Bei Kopf gehen Sie leer aus.

Die Abfolge der verschiedenen Entscheidungen wird relativ rasch erfolgen, lassen Sie sich davon nicht beeindrucken. Es wird vor dem eigentlichen Experiment zwei Probedurchgänge geben, in welchen Sie sich an die Bedingungen gewöhnen können.

Bitte vergewissern Sie sich, dass Sie die Instruktion richtig verstanden haben und stellen Sie ansonsten Ihre Fragen an den Versuchsleiter.

Noch ein Hinweis: Bitte versuchen Sie während der Untersuchung nicht zu blinzeln und die Augen so wenig wie möglich zu bewegen. Sie haben in mehreren Pausen Zeit, sich „auszublinzeln“. Sie tragen damit wesentlich zur Qualität der EEG-Daten bei.

Vielen Dank,

Ihr Untersuchungsteam

B12: Translated instruction (English) of the single treatment

Instruction

In this experiment, you are asked to make a series of decisions involving real payoffs. At the end of the experiment, one of these decisions will determine the payment for your participation in this experiment.

Instruction

In our today's experiment, we will present to you combinations of three numbers. Each of the numbers represents an amount in euros. The smallest possible payoff of 0 euros is always listed on the left side of a given combination of numbers, while the largest possible payoff is always listed on the right side. A sure payoff, that is larger than the payoff given on the left side but smaller than the one given on the right side, will be shown with a delay of one second in the middle of a given combination of numbers. An illustrative example of this decision problem is presented in the following figure.

Your task is to decide whether you would like to receive the sure payoff shown in the middle, or you would rather play a lottery with a success probability of 50%. If you decide to play the lottery, you will receive the payoff shown on the right side with a probability of 50% and nothing otherwise. You choose between receiving the sure payoff and playing the lottery by pressing a button with your right or left index finger:

Please use the right index finger to choose the sure payoff; and the left index finger to choose the lottery. You have one second time for each decision. The numbers shown in the middle vary between 10 and 97, and those shown on the right side, between 100 and 107.

You are asked to make a series of decisions for different combinations of numbers. At the end of the experiment, we will randomly select one of your decisions. If, for that particular decision, you have chosen the sure payoff, you will immediately receive that amount from the experimenter. If, you have chosen the lottery, the flip of a coin will determine whether you will be paid-out the right or the left payoff. If head falls, you will receive the payoff on the left side. If tails falls, you will receive the payoff on the right side.

That is: if head falls, you will receive a payoff of 0 euros; otherwise you will immediately receive the payoff shown on the right side from the experimenter.

For example, if you have chosen the sure payoff for the combinations of numbers shown above and that particular decision is selected at the end of the experiment, you will immediately receive 10 euros from the experimenter. Alternatively, if you have chosen the lottery with the numbers 0 and 40, a coin will be flipped. If tails falls, you will immediately receive 40 euros from the experimenter. If head falls, you will receive nothing.

Please note that the combinations of numbers shown to you will change relatively quickly. Prior to the actual experiment, you will be given the chance to get used to the experimental conditions in two probe trials.

Please make sure that you have understood the experimental instructions and ask the experimenter any questions you may have.

Note: Please try to move your eyes as little as possible and not to blink during the experiment. This will significantly contribute to the quality of the EEG data. There will be several breaks in which your eyes can relax.

Thank you

The Experimenter-Team

B13: Original instruction (German) as used for the portfolio treatment

Instruktion

In der folgenden Untersuchung werden von Ihnen reale Entscheidungen verlangt. Alle getroffenen Entscheidungen führen zu einer Auszahlung. Wie dies genau geschieht, ist am Ende der Anleitung beschrieben.

Anleitung Untersuchung

Wir werden Ihnen in der heutigen Untersuchung Kombinationen von drei Zahlen präsentieren. Diese drei Zahlen repräsentieren einen Betrag in Euro. Dabei steht der kleinste mögliche Gewinn, eine Null, immer links, der größte mögliche Gewinn steht immer rechts. Außerdem zeigen wir Ihnen mit einer Verzögerung von einer Sekunde einen sicheren Gewinn in der Mitte, der immer größer als der linke und kleiner als der rechte mögliche Gewinn sein wird. Die folgende Abbildung stellt diese Entscheidungssituation in einem Beispiel dar.

Sie sollen sich nun entscheiden, ob Sie den Betrag in der Mitte sicher bekommen wollen oder lieber eine Lotterie spielen, bei dem die Wahrscheinlichkeit zu gewinnen, 50% beträgt. Wenn Sie sich für die Lotterie entscheiden, haben Sie eine Chance von 50%, den Betrag, der auf der rechten Seite steht, zu gewinnen und eine Chance von 50%, den Betrag, der auf linken Seite steht, also Null, zu gewinnen. Sie entscheiden sich für eine der beiden Möglichkeiten über einen Tastendruck mit dem rechten oder dem linken Zeigefinger:

Nehmen Sie den rechten Zeigefinger, um den mittleren, sicheren Betrag auszuwählen, und nehmen Sie den linken Zeigefinger, um die Lotterie zu wählen. Sie haben für jede Auswahl eine Sekunde Zeit. Die Zahlen in der Mitte variieren dabei zwischen 10 und 97, die Zahlen auf der rechten Seite zwischen 100 und 107.

Wir werden Ihnen eine ganze Reihe dieser Entscheidungssituationen zeigen, welche in einem Log-File protokolliert werden. Am Ende dieser Untersuchung werden alle von Ihnen getroffenen Entscheidungen realisiert. Der Auszahlungsbetrag gemäß einer Entscheidung für den sicheren Betrag entspricht der mittleren Zahl des jeweiligen Entscheidungsproblems. Der Auszahlungsbetrag für den Fall der

Lotterieentscheidungen wird über einen Münzwurf im Computer ermittelt. Dabei gilt, dass „Kopf“ den Auszahlungsbetrag der linken Zahl und „Zahl“ den Auszahlungsbetrag der rechten Zahl des jeweiligen Entscheidungsproblems zur Folge hat. Um es noch einmal deutlich zu machen: Ist der jeweilige Münzwurf „Kopf“, so erhalten Sie keinen Gewinn. Ist hingegen der jeweilige Münzwurf „Zahl“, so bekommen Sie den Betrag der rechten Zahl. Aus allen Auszahlungsbeträgen wird anschließend die Summe gebildet und durch die Anzahl der getroffenen Entscheidungen dividiert, welches dem Durchschnitt aller Auszahlungen entspricht. Dieser Betrag wird dann vom Versuchsleiter an Sie direkt ausgezahlt.

Haben Sie sich beispielsweise bei dem obigen Beispiel dafür entschieden, die Zahl in der Mitte sicher zu erhalten, würde ein Betrag von 10 Euro in die Berechnung der Auszahlung einfließen. Haben Sie sich für die Lotterie mit den Zahlen 0 und 40 entschieden, würden in Abhängigkeit des jeweiligen Münzwurfs entweder 0 Euro oder 40 Euro in die Berechnung der Auszahlung einfließen.

Die Abfolge der verschiedenen Entscheidungen wird relativ rasch erfolgen, lassen Sie sich davon nicht beeindrucken. Es wird vor dem eigentlichen Experiment zwei Probedurchgänge geben, in welchen Sie sich an die Bedingungen gewöhnen können.

Bitte vergewissern Sie sich, dass Sie die Instruktion richtig verstanden haben und stellen Sie ansonsten Ihre Fragen an den Versuchsleiter.

Noch ein Hinweis: Bitte versuchen Sie während der Untersuchung nicht zu blinzeln und die Augen so wenig wie möglich zu bewegen. Sie haben in mehreren Pausen Zeit, sich „auszublinzeln“. Sie tragen damit wesentlich zur Qualität der EEG-Daten bei.

Vielen Dank,

Ihr Untersuchungsteam

B14: Translated instruction (English) of the portfolio treatment

Instruction

In this experiment, you are asked to make a series of decisions involving real payoffs. Each of your decisions will be paid out. The exact payment mechanism is explained at the end of the experimental instructions.

Instruction

In our today's experiment, we will present to you combinations of three numbers. Each of the numbers represents an amount in euros. The smallest possible payoff of 0 euros is always listed on the left side of a given combination of numbers, while the largest possible payoff is always listed on the right side. A sure payoff, that is larger than the payoff given on the left side but smaller than the one given on the right side, will be shown with a delay of one second in the middle of a given combination of numbers. An illustrative example of this decision problem is presented in the following figure.

Your task is to decide whether you would like to receive the sure payoff shown in the middle, or you would rather play a lottery with a success probability of 50%. If you decide to play the lottery, you will receive the payoff shown on the right side with a probability of 50% and nothing otherwise. You choose between receiving the sure payoff and playing the lottery by pressing a button with your right or left index finger:

Please use the right index finger to choose the sure payoff; and the left index finger to choose the lottery. You have one second time for each decision. The numbers shown in the middle vary between 10 and 97, and those shown on the right side, between 100 and 107.

You will be shown a sequence of such decision situations and your choices will be recorded in a Log-File. At the end of the experiment, all of your decisions will be actualized. In the cases in which the sure payoff is selected, the payoff is given by the middle number in the corresponding decision situations. In the cases in which the lottery is selected, your payoff will be determined by a flip of a coin simulated on the computer. If head falls, you will receive the payoff on the left side. If tails falls, you will receive the payoff on the right side. That is: if head falls, you will receive a payoff of zero euros; if tails falls you will receive the payoff shown on the right side. The average payoff will be calculated by first summing up the payoffs obtained in all decision situations and then dividing this amount to the total number of decisions you have made. You will be paid out the average payoff.

For example, if for the combinations of numbers shown in the above example, you have chosen the sure payoff, 10 euros will be added to the total sum of your payoffs on the basis of which the average payoff is calculated. Alternatively, if you have chosen the lottery with the numbers 0 and 40, depending on the exact realization of the coin flip, 0 euros or 40 euros will be added to the total sum of your payoffs on the basis of which the average payoff is calculated.

Please note that the combinations of numbers shown to you will change relatively quickly. Prior to the actual experiment, you will be given the chance to get used to the experimental conditions in two probe trials.

Please make sure that you have understood the experimental instructions and ask the experimenter any questions you may have.

Note: Please try to move your eyes as little as possible and not to blink during the experiment. This will significantly contribute to the quality of the EEG data. There will be several breaks in which your eyes can relax.

Thank you

The Experimenter-Team

Table B15: Calculated mean amplitudes within 450 and 550 ms at the Fz electrode

subject	bin 1 sure choice lottery		bin 2 indifferent choice lottery		bin 3 indifferent choice sure payoff		bin 4 sure choice sure payoff	
No.	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**
1	3.7798	10.1421	-0.3815	10.5917	3.0105	7.3501	4.0444	7.1072
2	4.1267	7.6736	11.9925	11.6015	6.3889	9.2351	11.8817	8.7820
3	9.7247	14.8014	3.2133	10.0982	1.1700	9.6904	8.9113	12.6392
4	10.0453	7.0319	4.8045	6.7534	6.8302	7.1787	8.6416	10.9935
5	8.3124	11.8195	10.2631	10.0947	4.1684	11.4411	5.3606	5.3716
6	14.1992	14.6705	17.2089	12.7098	14.9897	9.4096	8.3982	9.0058
7	6.1749	6.0171	4.3021	6.1633	6.5403	6.0008	3.8280	6.0679
8	-0.6560	0.4701	0.2013	-0.7075	2.5725	1.2737	-0.4583	1.0934
9	12.4155	8.7461	13.1654	9.8407	8.7841	8.6104	16.0989	3.1781
10	5.3963	7.5803	4.8096	6.6271	5.3629	7.9567	1.3132	4.5315
11	10.7760	12.3155	9.6360	9.7448	7.4936	5.4194	7.7735	8.2870
12	1.4718	2.1642	6.3988	5.5605	2.5066	2.1791	2.5996	-0.6782
13	-2.2939	1.5523	-4.6622	-0.7783	-2.1834	-1.0487	-1.2344	0.2053
14	-0.0371	2.0208	0.6022	1.1613	-2.6346	5.6704	-2.6869	3.6338
15	7.0606	5.5734	1.9793	1.8973	6.3570	3.0026	7.4279	1.7183
16	6.1264	3.7093	0.4906	1.3038	0.4395	1.4185	2.4423	1.7560
17	12.4585	10.5730	8.5704	5.3964	7.4839	8.5458	4.3483	4.3854
18	6.8847	10.4911	6.0754	9.1866	6.0891	8.0436	8.5496	11.1643
mean	**6.4425**	**7.6307**	**5.4817**	**6.5136**	**4.7427**	**6.1876**	**5.4022**	**5.5135**
SE	**1.1228**	**1.0495**	**1.3078**	**1.0226**	**0.9872**	**0.8210**	**1.1295**	**0.9428**

Table B16: Calculated mean amplitudes within 450 and 550 ms at the Cz electrode

subject	bin 1 sure choice lottery		bin 2 indifferent choice lottery		bin 3 indifferent choice sure payoff		bin 4 sure choice sure payoff	
No.	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**
1	9.5714	8.6369	4.1264	13.9016	7.4243	3.9663	7.7096	11.5411
2	7.7962	11.9050	13.9789	13.2869	8.0623	11.7975	16.8384	10.9844
3	18.4528	22.4404	13.4877	19.9054	9.8668	13.5842	15.1242	19.1094
4	18.6400	13.6631	11.2174	11.1747	14.4068	14.5878	17.3291	17.1908
5	15.2737	15.6060	15.7413	14.4507	8.7584	12.0601	8.2096	7.1110
6	24.8694	22.2208	22.0643	17.7304	19.5512	12.8182	16.7428	14.0060
7	13.1670	11.0252	9.4334	4.3863	9.1538	4.7456	11.4552	9.5249
8	2.3486	4.7970	0.8013	-2.1954	4.1911	4.6109	3.7366	3.8017
9	16.2671	12.2630	14.3030	11.6720	9.9905	10.3519	17.5489	6.6567
10	6.8765	8.7178	6.1439	4.3805	4.5885	6.0487	2.7867	6.7434
11	11.9901	13.6069	9.9727	11.3191	6.1368	6.3009	8.6230	10.2987
12	2.2333	2.7153	5.5216	5.0176	2.7767	1.8569	4.7097	1.6171
13	0.6526	3.5915	-1.9357	-0.4770	-0.4689	-1.2187	2.4164	3.5170
14	3.8709	6.2322	4.4575	3.4722	2.0919	5.7783	-0.6974	5.6983
15	14.9253	11.0438	7.5687	8.1546	11.6769	7.1717	10.8211	5.6824
16	4.9496	6.0815	0.5340	-3.3155	1.8326	0.7882	6.0857	2.8017
17	15.9366	11.3668	10.8888	8.0344	10.6547	11.2372	8.0221	7.9685
18	15.7316	17.7023	12.4572	14.5746	13.5109	9.1716	18.1779	14.8470
mean	**11.3085**	**11.3120**	**8.9312**	**8.6374**	**8.0114**	**7.5365**	**9.7578**	**8.8389**
SE	**1.6107**	**1.3496**	**1.4415**	**1.5870**	**1.1946**	**1.0961**	**1.4218**	**1.1821**

Table B17: Calculated mean amplitudes within 450 and 550 ms at the Pz electrode

subject	bin 1 sure choice lottery		bin 2 indifferent choice lottery		bin 3 indifferent choice sure payoff		bin 4 sure choice sure payoff	
No.	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**
1	11.3069	5.5036	5.2216	6.5551	7.4298	2.7264	6.1469	4.5639
2	10.5945	12.7112	14.2525	13.4946	8.7045	12.6100	17.3042	11.1332
3	19.3842	20.1474	13.1294	14.9122	9.2256	9.2341	10.1397	13.1901
4	17.9796	10.9325	9.6699	10.0113	9.9697	8.4824	13.4766	6.4666
5	18.1306	15.0939	14.3979	11.9590	8.4746	8.9350	5.6505	4.8054
6	22.7093	20.3368	16.9943	12.6505	14.4275	8.3979	15.5072	11.8069
7	15.5207	10.6169	10.9272	5.1570	11.2410	7.0623	11.9569	11.6532
8	4.5826	3.9781	1.9953	-0.5883	2.8572	4.6710	2.4768	1.4791
9	18.3663	14.8550	16.2685	13.3701	11.8985	12.7273	17.5597	7.1410
10	6.6763	7.0421	3.3977	1.2132	2.9319	1.4340	2.4655	5.0418
11	12.6715	13.9042	10.8365	12.6430	7.1767	5.8996	8.2562	9.5578
12	4.3263	4.1789	4.7300	5.6159	4.0074	2.4151	5.9716	3.3599
13	3.3983	6.4090	2.6903	2.7074	4.2247	2.2492	6.2156	5.9550
14	5.9341	9.6147	6.7969	6.2195	4.8967	5.7645	1.7049	6.3622
15	20.0421	15.0538	10.5404	5.7132	16.7617	11.2445	12.9725	11.6900
16	10.4269	8.0680	4.2197	0.9108	4.4473	4.5934	5.7640	5.4286
17	11.9671	9.7121	10.9960	6.9330	11.2836	10.4106	11.9633	9.3785
18	16.9813	16.6910	10.2109	14.4478	13.0202	5.4216	16.6862	11.3553
mean	**12.8333**	**11.3805**	**9.2931**	**7.9959**	**8.4988**	**6.9044**	**9.5677**	**7.7983**
SE	**1.4359**	**1.1925**	**1.1214**	**1.1920**	**0.9684**	**0.8400**	**1.2502**	**0.8174**

Table B18: Results of performed ANOVA for mean amplitudes within 450 and 550 ms at the midline electrodes (Fz, Cz, Pz)

factor/ interaction	degree of freedom (Greenhouse-Geisser corrected)	F-value	p-value (Greenhouse-Geisser corrected)
anterior posterior position	1.998	24.939	**0.000*****
treatment	1.000	0.397	0.537
bin classification	2.821	10.176	**0.000*****
anterior posterior position x treatment	1.220	16.594	**0.000*****
anterior posterior position x bin classification	3.392	6.895	**0.000*****
treatment x bin classification	2.644	0.367	0.752
anterior posterior position x treatment x bin classification	3.710	0.525	0.704

Table B19: Results of performed ANOVA mean amplitudes within 450 and 550 ms at the Pz electrode

factor/ interaction	degree of freedom (Greenhouse-Geisser corrected)	F-value	p-value (Greenhouse-Geisser corrected)
treatment	1.000	10.532	**0.005****
choice	1.000	12.618	**0.002****
indifferent position	1.000	32.882	**0.000*****
treatment x choice	1.000	0.222	0.644
treatment x indifferent position	1.000	0.057	0.814
choice x indifferent position	1.000	7.860	**0.012***
treatment x choice x indifferent position	1.000	0.000	0.988

Table B20: Results of one-sided pair-wise t-tests for mean amplitudes within 450 and 550 ms at the Pz electrode

pair	degree of freedom	T-value	p-value
bin 1: sure choice for lottery portfolio vs. single	17	-1.997	**0.031***
bin 2: indifferent choice for lottery portfolio vs. single	17	-2.018	**0.030***
bin 3: indifferent choice for sure payoff portfolio vs. single	17	-2.263	**0.019***
bin 4: sure choice for sure payoff portfolio vs. single	17	-1.996	**0.031***
lottery choices (portfolio) indifferent choice vs. sure choice	17	-4.686	**0.000*****
sure payoff choices (portfolio) indifferent choice vs. sure choice	17	-1.164	0.131
lottery choices (single) indifferent choice vs. sure choice	17	-4.348	**0.000*****
sure payoff choices (single) indifferent choice vs. sure choice	17	-1.481	0.079
sure choices (portfolio) lottery choice vs. sure payoff choice	17	4.844	**0.000*****
indifferent choices (portfolio) lottery choice vs. sure payoff choice	17	1.138	0.136
sure choices (single) lottery choice vs. sure payoff choice	17	3.060	**0.004****
indifferent choices (single) lottery choice vs. sure payoff choice	17	1.072	0.150

Table B21: Calculated mean reaction times

subject	**bin 1 sure choice lottery**		**bin 2 indifferent choice lottery**		**bin 3 indifferent choice sure payoff**		**bin 4 sure choice sure payoff**	
No.	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**	**Single**	**Portfolio**
1	693.28	540.28	948.90	715.63	924.90	583.98	689.15	488.31
2	477.10	477.28	631.28	584.66	621.90	670.79	474.99	524.14
3	523.44	575.99	685.16	601.40	680.80	597.45	423.25	434.25
4	515.93	482.08	664.84	625.13	592.76	542.61	493.07	462.78
5	501.92	468.15	541.45	525.82	516.83	444.57	439.57	364.06
6	495.22	527.61	625.26	585.42	626.04	631.58	440.86	491.49
7	538.47	552.24	643.91	604.01	600.49	549.73	479.26	517.25
8	542.47	500.69	606.87	608.03	589.84	542.94	448.12	479.26
9	566.38	564.77	693.53	687.34	723.67	663.54	522.80	491.14
10	564.56	581.86	675.47	618.87	741.99	582.53	592.39	509.49
11	928.21	586.98	1062.70	636.26	990.95	610.62	827.55	550.70
12	525.08	559.32	628.53	717.74	613.16	579.83	505.75	513.61
13	598.40	525.30	646.60	613.97	624.19	585.13	523.22	528.04
14	522.11	532.59	584.69	587.37	544.75	601.03	430.91	480.89
15	482.87	566.14	640.82	603.43	577.02	576.35	501.08	524.15
16	555.96	475.95	709.46	698.55	632.78	566.12	447.14	475.44
17	579.05	569.58	648.33	609.10	658.17	509.44	505.80	473.45
18	440.38	437.85	518.62	524.22	490.84	467.21	455.41	419.26
mean	**558.38**	**529.15**	**675.36**	**619.27**	**652.84**	**572.52**	**511.13**	**484.87**
SE	**25.35**	**10.66**	**30.91**	**13.09**	**30.20**	**13.83**	**24.04**	**10.55**

Table B22: Results of performed ANOVA for reaction times with bin classification as factor

factor/ interaction	degree of freedom (Greenhouse-Geisser corrected)	F-value	p-value (Greenhouse-Geisser corrected)
treatment	1.000	4.468	**0.050***
bin classification	2.574	88.318	**0.000*****
treatment x bin classification	2.555	6.360	**0.002****

Table B23: Results of performed ANOVA for reaction times separated by choice type and indifferent position

factor/ interaction	degree of freedom (Greenhouse-Geisser corrected)	F-value	p-value (Greenhouse-Geisser corrected)
treatment	1.000	4.468	**0.050***
choice	1.000	149.222	**0.000*****
indifferent position	1.000	40.338	**0.000*****
treatment x choice	1.000	0.793	0.386
treatment x indifferent position	1.000	15.977	**0.001*****
choice x indifferent position	1.000	0.921	0.351
treatment x choice x indifferent position	1.000	3.124	0.095

Table B24: Results of two-sided pair-wise t-tests for mean reaction times

pair	degree of freedom	T-value	p-value
bin 1: sure choice for lottery portfolio vs. single	17	-1.308	0.208
bin 2: indifferent choice for lottery portfolio vs. single	17	-2.145	**0.047***
bin 3: indifferent choice for sure payoff portfolio vs. single	17	-2.938	**0.009****
bin 4: sure choice for sure payoff portfolio vs. single	17	-1.260	0.225
lottery choices (portfolio) indifferent choice vs. sure choice	17	6.862	**0.000*****
sure payoff choices (portfolio) indifferent choice vs. sure choice	17	8.590	**0.000*****
lottery choices (single) indifferent choice vs. sure choice	17	9.360	**0.000*****
sure payoff choices (single) indifferent choice vs. sure choice	17	10.491	**0.000*****
sure choices (portfolio) lottery choice vs. sure payoff choice	17	4.330	**0.000*****
indifferent choices (portfolio) lottery choice vs. sure payoff choice	17	3.279	**0.004****
sure choices (single) lottery choice vs. sure payoff choice	17	4.446	**0.000*****
indifferent choices (single) lottery choice vs. sure payoff choice	17	2.588	**0.019***

Appendix C: Data from the EEG study concerning the ERN modulation

Table C1: Individual choice behavior

subject	Relative choice frequency in bin category 'MinusYES'		Relative choice frequency in bin category 'CenterYES'		Relative choice frequency in bin category 'PlusYES'	
No.	bisection	lottery	bisection	lottery	bisection	lottery
1	0.173	0.190	0.862	0.746	0.965	0.915
2	0.399	0.113	0.506	0.437	0.616	0.908
3	0.088	0.090	0.649	0.680	0.983	0.943
4	0.247	0.253	0.780	0.733	0.888	0.820
5	0.017	0.074	0.549	0.299	0.925	0.875
6	0.061	0.164	0.708	0.836	0.904	0.988
7	0.089	0.194	0.622	0.794	0.944	0.977
8	0.145	0.096	0.407	0.459	0.817	0.894
9	0.180	0.077	0.832	0.829	0.987	0.982
10	0.098	0.099	0.524	0.094	0.896	0.244
11	0.065	0.132	0.513	0.523	0.926	0.903
12	0.281	0.335	0.312	0.284	0.344	0.300
13	0.473	0.534	0.661	0.597	0.677	0.621
14	0.308	0.248	0.486	0.409	0.787	0.633
15	0.089	0.039	0.446	0.474	0.844	0.833
16	0.050	0.156	0.597	0.880	0.989	0.989
mean	**0.173**	**0.175**	**0.591**	**0.567**	**0.843**	**0.802**
SE	**0.033**	**0.031**	**0.038**	**0.058**	**0.043**	**0.059**

Table C2: Results of performed ANOVA for behavioral results

factor/ interaction	degree of freedom (Greenhouse-Geisser corrected)	F-value	p-value (Greenhouse-Geisser corrected)
method	1.000	0.581	0.458
scale factor	1.208	5.283	**0.028***
bin category	1.380	75.001	**0.000*****
method x scale factor	1.356	0.244	0.698
method x bin category	1.498	0.433	0.597
scale factor x bin category	3.195	0.661	0.589
method x scale factor x bin category	3.310	0.768	0.529

Table C3: Calculated mean amplitudes within 30 and 70 ms at the Fz electrode for 'Yes'-responses

subject	MinusYES		CenterYES		PlusYES	
No.	bisection	lottery	bisection	lottery	bisection	lottery
1	2.4180	-0.7746	0.7346	1.6061	1.9527	-0.2676
2	0.3169	-0.2772	0.1872	-0.3433	-0.0552	-0.8572
3	-7.8465	-1.5305	0.3186	-0.7980	0.0892	0.0032
4	-1.3913	-0.8692	0.4619	1.1146	1.1976	3.5206
5	2.3968	0.5618	-0.7363	0.0521	1.9264	1.4341
6	-1.3760	0.3334	0.0711	-0.3192	1.1458	1.6985
7	-1.8858	-2.4409	-1.3756	0.3769	0.7032	1.1541
8	2.3581	0.1781	-0.1715	0.4801	1.0302	0.4045
9	-2.9279	0.1084	-1.2621	-1.6314	-1.1026	-0.7332
10	-0.3064	-1.1912	-0.4651	-0.3954	1.9546	0.4661
11	-0.1074	-4.4322	-0.5257	0.1821	1.0618	1.0621
12	-0.6339	-1.6452	-1.7972	0.8320	-0.1951	0.8127
13	-3.4462	-4.4125	-3.3435	-4.7462	-3.6505	-4.4778
14	-0.3457	0.6977	0.3362	-0.1649	0.5056	1.2304
15	2.9067	-1.0416	2.0979	1.3603	1.1299	0.7554
16	-2.5724	3.1838	0.7395	0.5481	-1.3117	-0.8928
mean	**-0.7777**	**-0.8470**	**-0.2956**	**-0.1154**	**0.3989**	**0.3321**
SE	**0.6852**	**0.4729**	**0.3130**	**0.3713**	**0.3656**	**0.4250**

Table C4: Calculated mean amplitudes within 30 and 70 ms at the Fz electrode for 'No'-responses

subject	MinusNO		CenterNO		PlusNO	
No.	bisection	lottery	bisection	lottery	bisection	lottery
1	1.6739	2.0610	-1.4186	0.4866	6.0185	-3.7558
2	-1.1960	-1.1881	-0.2794	-0.9029	-0.7317	-0.9056
3	-0.1770	-1.8158	-2.5401	-2.3343	4.5002	7.8646
4	1.0607	1.7163	-0.3738	0.8133	-1.5415	-2.2329
5	2.2531	2.3162	0.6367	0.9264	-0.1776	1.0499
6	1.2003	0.0543	-0.3825	2.0876	-3.2912	-10.0087
7	1.1842	0.1905	1.5977	-2.1183	-3.6782	-12.4098
8	-0.2975	-0.3476	0.3272	-0.2357	-0.4600	-2.9766
9	-3.1895	-2.5814	-0.5084	-2.9737	-5.9692	-11.7477
10	2.9496	1.6427	1.6005	0.5518	-1.1005	1.4675
11	-0.2014	0.0413	-1.7631	-2.2832	-4.4683	2.1486
12	-0.4284	0.5613	0.1430	-0.6145	0.7353	0.4978
13	-1.6848	-1.5238	-2.2920	-2.4887	-3.3560	-2.3128
14	0.6246	0.3910	-0.1922	-0.4810	-0.2647	-1.0968
15	0.3915	0.9839	1.8006	3.0975	2.5254	-1.0881
16	-0.6707	-1.5011	0.4360	0.1019	-1.9624	-16.2661
mean	**0.2183**	**0.0625**	**-0.2005**	**-0.3980**	**-0.8264**	**-3.2358**
SE	**0.3849**	**0.3693**	**0.3286**	**0.4338**	**0.7958**	**1.5755**

Table C5: Calculated mean amplitudes within 30 and 70 ms at the Cz electrode for 'Yes'-responses

subject	MinusYES		CenterYES		PlusYES	
No.	bisection	lottery	bisection	lottery	bisection	lottery
1	2.2006	-2.6581	1.5242	1.3849	2.2167	-0.4941
2	0.2497	-0.6219	0.3342	-0.8070	-0.4342	-1.2960
3	-10.7073	-0.0952	-1.0035	-1.2869	-1.6598	-0.5144
4	0.0637	0.1082	1.0397	1.9506	2.4113	3.5563
5	0.3458	0.0564	0.1030	0.1741	2.2552	2.3770
6	-0.7463	-1.0227	0.3044	-0.0115	0.6990	1.9756
7	-2.7117	-2.5066	-0.8001	1.4724	1.7874	2.8911
8	1.2681	0.3774	-0.0663	0.8854	0.6663	0.6511
9	-2.3878	0.4235	-0.3352	-0.7385	-0.1746	0.5387
10	-1.5960	-0.7921	-0.5480	-0.3072	2.1984	0.5483
11	-1.2057	-4.4206	-0.5933	0.6461	1.9172	1.6774
12	-1.1892	-0.9303	-1.7593	1.3463	-0.5973	0.2548
13	-1.1639	-2.2703	-0.7120	-1.7574	0.1413	-1.0497
14	-0.4539	1.5065	1.3535	1.2793	2.4985	2.9533
15	3.7077	2.1340	2.4091	2.3151	0.7839	0.7306
16	-3.4779	0.5330	-1.1738	-1.1122	-2.6449	-1.9062
mean	**-1.1128**	**-0.6362**	**0.0048**	**0.3396**	**0.7540**	**0.8059**
SE	**0.7850**	**0.4181**	**0.2788**	**0.3120**	**0.3903**	**0.4095**

Table C6: Calculated mean amplitudes within 30 and 70 ms at the Cz electrode for 'No'-responses

subject	MinusNO		CenterNO		PlusNO	
No.	bisection	lottery	bisection	lottery	bisection	lottery
1	1.8571	2.5629	0.7830	0.8600	5.2453	-2.1384
2	-1.5151	-1.1209	-0.9377	-1.2658	-0.6253	-1.4403
3	-2.8858	-3.4202	-4.3907	-4.3967	0.8021	5.0502
4	-0.1124	2.4109	-0.2426	0.3114	-3.0027	-2.8186
5	3.0810	3.0457	0.8736	1.4333	-0.7101	0.8157
6	1.7190	0.3490	-0.9574	0.9762	-3.3136	-4.3735
7	2.7222	1.0779	1.9999	-1.8946	-5.1669	-10.1061
8	-0.3110	-0.4176	0.1367	-0.9350	-0.9408	-2.5997
9	-3.1502	-1.9654	-0.8854	-2.1398	-7.4270	-12.4443
10	4.6361	1.4950	2.6301	0.9090	1.0159	1.0278
11	0.5953	1.1698	-1.3535	-1.9719	-4.4138	1.8629
12	-0.2437	0.7789	0.3040	-0.3384	0.1971	0.0808
13	1.3913	1.4251	0.1444	0.0933	-0.6918	-0.6242
14	1.5715	1.0131	0.4516	0.2502	0.3760	-1.1249
15	2.0370	3.2723	3.0387	4.3836	1.3294	-0.1439
16	-2.5004	-2.8468	-2.6933	-0.9143	-10.3223	-22.6680
mean	**0.5557**	**0.5519**	**-0.0687**	**-0.2900**	**-1.7280**	**-3.2278**
SE	**0.5618**	**0.5047**	**0.4690**	**0.4892**	**0.9432**	**1.6795**

Table C7: Calculated mean amplitudes within 30 and 70 ms at the Pz electrode for 'Yes'-responses

subject	MinusYES		CenterYES		PlusYES	
No.	bisection	lottery	bisection	lottery	bisection	lottery
1	2.9146	-3.1070	1.3445	1.2772	2.3703	-0.1677
2	1.4979	-0.2305	0.7568	-0.0227	0.3370	0.0441
3	-7.2863	1.8938	1.1787	1.3118	0.9091	2.1149
4	2.0777	1.1262	1.0314	2.3093	2.7911	3.8473
5	0.5523	-0.0629	0.6838	-0.5430	1.2517	1.8648
6	1.0273	0.2174	0.6095	0.1557	0.9908	2.1199
7	-1.0947	-1.0963	0.1176	2.5106	2.5926	4.1056
8	1.1454	1.5020	-0.1096	0.3844	0.7304	0.6808
9	-0.7063	1.0569	0.8897	0.2083	0.9965	1.6914
10	-0.4875	0.4303	-0.0626	0.3847	2.0342	0.7356
11	-0.2951	-3.8127	-0.0195	0.6782	2.3192	2.1663
12	-0.8631	-0.0073	-0.2578	1.6924	-0.5996	0.8132
13	1.2123	0.1817	1.5205	1.2271	2.2796	0.7582
14	-0.1097	1.6374	1.6107	1.7100	3.0371	3.6139
15	3.1338	2.7277	1.7047	1.2274	0.2555	1.2824
16	-2.5965	0.7178	-1.5932	-0.9141	-1.6930	-0.9720
mean	**0.0076**	**0.1984**	**0.5878**	**0.8498**	**1.2877**	**1.5437**
SE	**0.6179**	**0.4279**	**0.2178**	**0.2431**	**0.3282**	**0.3620**

Table C8: Calculated mean amplitudes within 30 and 70 ms at the Pz electrode for 'No'-responses

subject	MinusNO		CenterNO		PlusNO	
No.	bisection	lottery	bisection	lottery	bisection	lottery
1	2.0594	2.4669	0.8784	0.5995	2.4249	-0.0929
2	-1.0472	-0.4457	-0.8855	-0.7004	-0.9915	-0.5338
3	-0.1003	-0.6846	-2.4261	-2.5407	1.9494	8.6359
4	1.2856	2.8397	1.1905	0.6151	-2.4801	-1.8870
5	2.7128	2.0711	1.2513	1.1170	0.3349	1.2778
6	2.2389	1.5138	-1.1231	1.9516	-2.1071	4.9585
7	5.3290	3.3053	2.7593	0.2757	-1.5563	-1.6989
8	-0.5990	-0.8429	-0.4183	-1.7065	-1.7232	-1.8518
9	-2.1986	-0.5734	-0.6042	-1.3073	-5.2313	-6.8206
10	4.8286	1.1975	3.2174	0.5820	2.5605	0.6149
11	1.4923	1.4701	-0.4466	-0.8766	-2.7937	2.8437
12	0.0885	1.8324	1.0449	0.6236	0.0076	0.3843
13	3.2611	3.1686	2.3425	1.8841	1.7739	1.1851
14	0.6771	0.2069	-0.0291	-0.2352	0.0725	-0.7396
15	2.7011	3.8013	2.7286	3.7788	0.4135	0.7188
16	-1.0257	-1.2922	-2.9146	-1.9296	-8.2411	-18.0342
mean	**1.3565**	**1.2522**	**0.4103**	**0.1332**	**-0.9742**	**-0.6900**
SE	**0.5343**	**0.4155**	**0.4574**	**0.4096**	**0.7204**	**1.4233**

Table C9: Results of performed ANOVA for mean amplitudes within 30 and 70 ms at the midline electrodes (Fz, Cz, Pz)

factor/ interaction	degree of freedom (Greenhouse-Geisser corrected)	F-value	p-value (Greenhouse-Geisser corrected)
anterior posterior position	1.543	6.388	**0.010***
method	1.000	0.468	0.504
bin cluster	1.082	0.893	0.367
choice	1.000	1.827	0.197
anterior posterior position x method	1.264	5.567	**0.023***
anterior posterior position x bin cluster	2.137	1.912	0.162
anterior posterior position x choice	1.594	0.563	0.538
method x bin cluster	1.638	0.783	0.445
method x choice	1.000	1.700	0.212
bin cluster x choice	1.379	9.500	**0.003****
anterior posterior position x method x bin cluster	1.429	4.955	**0.026***
anterior posterior position x method x choice	1.150	1.727	0.208
anterior posterior position x bin cluster x choice	1.830	3.222	0.059
method x bin cluster x choice	1.851	0.404	0.656
anterior posterior position x method x bin cluster x choice	1.697	5.327	**0.015***

Table C10: Results of performed ANOVA for mean amplitudes within 30 and 70 ms at the Fz electrode

factor/ interaction	degree of freedom (Greenhouse-Geisser corrected)	F-value	p-value (Greenhouse-Geisser corrected)
method	1.000	3.815	0.070
bin cluster	1.186	0.828	0.395
choice	1.000	1.591	0.226
method x bin cluster	1.455	1.950	0.174
method x choice	1.000	2.071	0.171
bin cluster x choice	1.345	7.008	**0.010***
method x bin cluster x choice	1.799	1.728	0.199

Table C11: Results of one-sided pair-wise t-tests for mean amplitudes within 30 and 70 ms at the Fz electrode

pair	degree of freedom	T-value	p-value
bin 'MinusYES' bisection vs. lottery	15	0.090	0.465
bin 'MinusNO' bisection vs. lottery	15	0.786	0.222
bin 'CenterYES' bisection vs. lottery	15	-0.681	0.253
bin 'CenterNO' bisection vs. lottery	15	0.516	0.307
bin 'PlusYES' bisection vs. lottery	15	0.251	0.403
bin 'PlusNO' bisection vs. lottery	15	1.766	**0.049***
bisection task MinusYES vs. MinusNO	15	-1.546	0.072
lottery choice task MinusYES vs. MinusNO	15	-1.507	0.077
bisection task PlusYES vs. PlusNO	15	1.646	0.061
lottery choice task PlusYES vs. PlusNO	15	2.239	**0.021***

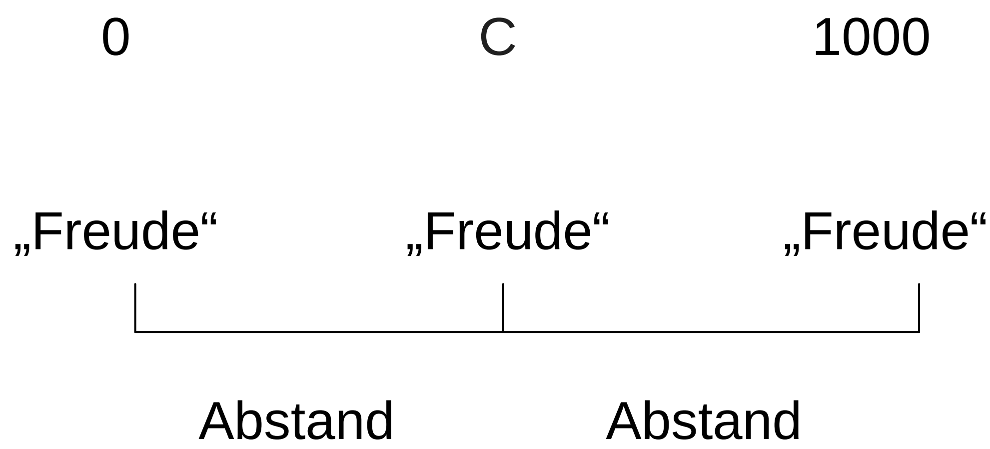
C12: Original instruction (German) as used for both EEG sessions

Instruktion

In dieser Untersuchung werden Sie Antworten unter zwei Bedingungen geben, der Mittenabfrage und der Lotteriebedingung. Diese beiden Bedingungen werden in der Instruktion als erstes beschrieben. Welche Bedingung ausgeführt wird, entscheidet eine Farbcodierung, diese wird am Ende der Instruktion beschrieben.

Bedingung „Mittenabfrage“

Es werden Ihnen drei Zahlen gezeigt. Bitte stellen Sie sich zu jeder Zahl die Freude vor, die Sie erleben würden, wenn Sie diesen Geldbetrag in € bekämen. Betrachten Sie den Abstand zwischen der erlebten Freude bei der linken Zahl und der erlebten Freude bei der mittleren Zahl. Vergleichen Sie diesen mit dem Abstand zwischen der erlebten Freude bei der mittleren Zahl und der erlebten Freude bei der rechten Zahl. Ist dieser erste Abstand größer als der zweite oder gleich groß, so antworten Sie mit „JA“. Ist der erste Abstand kleiner, antworten Sie bitte mit „NEIN“.



Um es deutlicher zu machen ein Beispiel:

Wenn Sie hier mit „JA“ antworten, ist für Sie der Abstand zwischen der erlebten Freude bei einer Auszahlung von 0 € und der erlebten Freude bei einer Auszahlung von 330 € größer oder gleich groß als der Abstand zwischen der erlebten Freude bei einer Auszahlung von 330 € und der erlebten Freude bei einer Auszahlung von 820 €.

Würden Sie mit „NEIN“ antworten, ist für Sie der Abstand der erlebten Freude bei den Auszahlungen von 0 € und 330 € kleiner als der Abstand der erlebten Freude bei den Auszahlungen von 330 € und 820 €.

Bedingung „Lotterie“

Im Falle der Lotteriebedingung müssen Sie sich vorstellen, dass Sie entweder eine Lotterie spielen könnten oder stattdessen einen festen Geldbetrag erhalten würden. Bei der Lotterie könnten Sie mit einer Wahrscheinlichkeit von 50% 0 € gewinnen und mit einer Wahrscheinlichkeit von 50% einen Geldbetrag, der größer ist als der feste Geldbetrag. Sie müssen nun die Entscheidung treffen, ob Sie den festen Geldbetrag bekommen möchten oder nicht. Wenn Sie mit „JA“ antworten, würden Sie den festen Geldbetrag wählen, wenn Sie mit „NEIN“ antworten, bedeutet es, dass Sie lieber die Lotterie spielen. Bei den gezeigten drei Zahlen wird die linke Zahl immer eine Null sein. In der Mitte zeigen wir Ihnen den Betrag, den Sie als festen Geldbetrag erhalten würden, auf der rechten Seite immer den Betrag, um den in der Lotterie gespielt wird.

Um es deutlicher zu machen ein Beispiel:

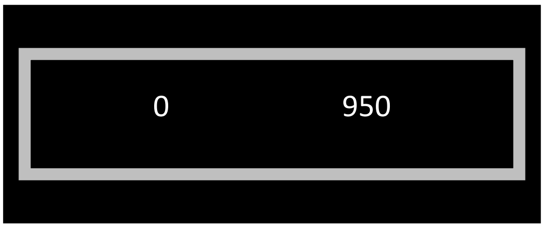
Wenn Sie jetzt die Taste für „JA“ drücken, bedeutet es, dass Sie lieber 230 € sofort nehmen würden als eine Lotterie zu spielen, bei der Sie mit einer Wahrscheinlichkeit von 50% 0 € gewinnen und mit einer Wahrscheinlichkeit von 50% 950 € gewinnen würden. Wenn Sie stattdessen die Taste für „NEIN“ drücken, würden Sie lieber die Lotterie spielen, als den festen Gewinn garantiert zu bekommen.

Farbcodierung und Ablauf im Experiment

Wir werden Ihnen zuerst nur zwei Zahlen zeigen. Die linke und die rechte Zahl, wobei die linke Zahl immer eine Null sein wird. Daraufhin wird ein Rahmen um die beiden Zahlen kurz erscheinen, welcher entweder rosa oder hellblau ist. Diese Farbe sagt Ihnen, ob im Folgenden eine Lotterie gespielt wird oder es sich um eine Mittenabfrage handelt. Dabei steht rosa für die Lotterie und hellblau für die Mittenabfrage.

Im Laufe des Experiments erscheint der Rahmen stets zufällig rosa oder hellblau. Nachdem dieser wieder verschwunden ist, erscheint die mittlere Zahl und Sie müssen entsprechend der Bedingung, Mittenabfrage oder Lotteriebedingung, antworten.

Mittenabfrage **Lotterie**



Die Antworten geben Sie mit den beiden Computermäusen, welche links und rechts vor Ihnen liegen. Hierbei steht ein Tastendruck bei der linken Maus für die Antwort „JA“ und ein Tastendruck bei der rechten Maus für die Antwort „NEIN“.

Die Abfolge der Zahlen wird die ganze Zeit relativ rasch erfolgen, lassen Sie sich davon nicht beeindrucken. Es wird vor dem eigentlichen Experiment 2 Probedurchgänge geben, in welchen Sie sich an die Bedingungen gewöhnen können.

Falls Sie noch Fragen haben, dann stellen Sie sie bitte jetzt. Vergewissern Sie sich, dass Sie die Instruktion verstanden haben.

Noch ein Hinweis: Bitte versuchen Sie während der Untersuchung nicht zu blinzeln und die Augen so wenig wie möglich zu bewegen. Sie haben in mehreren Pausen Zeit, sich „auszublinzeln“. Sie tragen damit wesentlich zur Qualität der EEG-Daten bei.

Vielen Dank,

Ihr Untersuchungsteam

Appendix D: Data from the analysis of indifference intervals

Table D1: Relative choice frequency of the hypothetical treatment

subject	ranges of sure payoff values																	
No.	10 - 12	15 - 17	20 - 22	25 - 27	30 - 32	35 - 37	40 - 42	45 - 47	50 - 52	55 - 57	60 - 62	65 - 67	70 - 72	75 - 77	80 - 82	85 - 87	90 - 92	95 - 97
1	1.00	1.00	1.00	1.00	0.92	1.00	0.88	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.96	0.96	1.00	0.96	0.96	1.00	0.96	0.96	0.95	0.79	0.29	0.17	0.04	0.00	0.00	0.00	0.00	0.00
3	1.00	1.00	0.92	0.96	0.92	0.63	0.08	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	1.00	1.00	1.00	0.92	1.00	1.00	1.00	0.92	0.21	0.08	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
5	0.96	0.92	0.96	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	1.00	1.00	0.96	1.00	0.83	0.96	0.88	0.92	0.38	0.25	0.17	0.13	0.08	0.04	0.04	0.00	0.00	0.04
7	0.96	1.00	1.00	1.00	0.92	0.96	0.30	0.21	0.00	0.00	0.00	0.00	0.04	0.04	0.00	0.00	0.00	0.00
8	0.96	1.00	0.92	0.58	0.08	0.04	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	1.00	1.00	1.00	1.00	0.96	1.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	1.00	1.00	1.00	1.00	0.83	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	1.00	0.96	0.96	1.00	1.00	1.00	0.96	0.91	0.33	0.13	0.08	0.04	0.04	0.00	0.00	0.13	0.04	0.00
12	1.00	0.96	1.00	1.00	1.00	1.00	0.92	0.83	0.38	0.29	0.00	0.00	0.08	0.00	0.00	0.00	0.04	0.04
13	1.00	1.00	1.00	0.96	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.67	0.13	0.17	0.00	0.04	0.08	0.00	0.04	0.08
15	1.00	1.00	1.00	0.96	0.96	1.00	0.88	0.75	0.21	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	1.00	1.00	1.00	1.00	1.00	0.96	0.70	0.46	0.08	0.08	0.00	0.04	0.04	0.00	0.00	0.00	0.00	0.00
17	1.00	0.96	0.79	0.13	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	1.00	1.00	0.96	1.00	0.96	1.00	0.90	1.00	0.59	0.51	0.22	0.14	0.04	0.00	0.04	0.05	0.00	0.00
19	1.00	0.96	0.96	0.67	0.13	0.04	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.71	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00
21	1.00	1.00	1.00	1.00	1.00	0.96	0.74	0.67	0.13	0.13	0.00	0.04	0.00	0.00	0.00	0.00	0.04	0.00
mean	0.99	0.99	0.97	0.87	0.79	0.76	0.53	0.47	0.25	0.18	0.05	0.04	0.02	0.01	0.01	0.01	0.01	0.01
SE	0.00	0.01	0.01	0.06	0.08	0.09	0.10	0.10	0.07	0.06	0.02	0.01	0.01	0.00	0.00	0.01	0.00	0.00

Table D2: Relative choice frequency of the real treatment

subject	ranges of sure payoff values																	
No.	10 - 12	15 - 17	20 - 22	25 - 27	30 - 32	35 - 37	40 - 42	45 - 47	50 - 52	55 - 57	60 - 62	65 - 67	70 - 72	75 - 77	80 - 82	85 - 87	90 - 92	95 - 97
1	1.00	0.96	0.96	1.00	1.00	1.00	0.88	0.63	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	1.00	1.00	0.96	1.00	1.00	1.00	1.00	0.96	0.96	0.77	0.17	0.04	0.00	0.00	0.04	0.00	0.00	0.00
3	1.00	1.00	0.96	0.92	0.56	0.46	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	1.00	1.00	1.00	0.96	1.00	1.00	1.00	1.00	0.75	0.46	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.96	0.92	0.96	0.42	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	1.00	1.00	1.00	1.00	1.00	0.96	0.96	0.79	0.29	0.13	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
7	1.00	1.00	1.00	1.00	0.58	0.21	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.96	0.96	0.88	0.54	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	1.00	1.00	1.00	1.00	1.00	0.96	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00
10	1.00	1.00	1.00	1.00	1.00	0.67	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.92	1.00	0.96	1.00	1.00	1.00	1.00	1.00	0.33	0.00	0.04	0.04	0.04	0.00	0.00	0.00	0.00	0.00
12	1.00	0.91	0.96	0.67	0.35	0.39	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	1.00	0.92	0.92	0.96	0.79	0.63	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
14	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.87	0.21	0.13	0.04	0.08	0.00	0.00	0.00	0.00	0.00	0.00
15	1.00	1.00	0.92	0.96	0.79	0.83	0.67	0.50	0.21	0.13	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	1.00	1.00	1.00	1.00	1.00	0.96	0.21	0.04	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
17	0.83	0.88	0.25	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	1.00	1.00	1.00	1.00	1.00	0.96	1.00	1.00	0.83	0.75	0.25	0.21	0.00	0.00	0.04	0.00	0.04	0.04
19	0.96	1.00	0.70	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	1.00	1.00	1.00	0.96	0.96	0.75	0.54	0.27	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00
21	1.00	0.96	1.00	0.96	0.96	0.95	0.85	0.63	0.11	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00
mean	0.98	0.98	0.92	0.83	0.73	0.65	0.45	0.37	0.19	0.12	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00
SE	0.01	0.01	0.04	0.07	0.08	0.09	0.10	0.09	0.07	0.05	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table D3: Data of indifference intervals

subject	lower indifference interval boundary (according to sure payoff value)		upper indifference interval boundary (according to sure payoff value)		total width of indifference interval (according to sure payoff value)		normalized width of indifference interval (according to sure payoff value)	
No.	**Hypo**	**Real**	**Hypo**	**Real**	**Hypo**	**Real**	**Hypo**	**Real**
1	40	40	47	52	8	13	8	11
2	53	51	63	61	11	11	9	9
3	33	30	41	41	9	12	7	10
4	50	50	55	57	6	8	6	8
5	25	23	26	33	2	11	2	9
6	47	47	60	53	14	7	10	5
7	40	30	47	37	8	8	8	8
8	22	24	30	32	9	9	7	7
9	40	40	40	40	1	1	1	1
10	31	35	37	40	7	6	7	4
11	50	50	56	52	7	3	7	3
12	50	26	57	40	8	15	8	11
13	40	30	40	43	1	14	1	12
14	52	43	61	51	10	9	8	7
15	44	30	52	56	9	27	7	23
16	41	40	50	42	10	3	8	3
17	20	17	26	27	7	11	7	9
18	50	50	65	67	16	18	14	16
19	21	20	30	26	10	7	8	7
20	53	34	60	47	8	14	6	12
21	40	41	51	55	12	15	10	13
mean	**40.10**	**35.76**	**47.33**	**45.33**	**8.24**	**10.57**	**7.10**	**8.95**
SD	**10.93**	**10.57**	**12.45**	**11.11**	**3.74**	**5.78**	**2.96**	**4.89**

Table D4: Data of ambiguous choices

subject	total amount of ambiguous choices among all sure payoff categories		amount of sure payoff categories inside the indifference interval		relative frequency of all ambiguous choices		relative frequency of ambiguous choices exclusive of indifferent interval	
No.	**Hypo**	**Real**	**Hypo**	**Real**	**Hypo**	**Real**	**Hypo**	**Real**
1	11	14	8	11	0.153	0.194	0.042	0.042
2	23	11	9	9	0.319	0.153	0.194	0.028
3	12	14	7	10	0.167	0.194	0.069	0.056
4	16	10	6	8	0.222	0.139	0.139	0.028
5	5	13	2	9	0.069	0.181	0.042	0.056
6	32	10	10	5	0.444	0.139	0.306	0.069
7	13	8	8	8	0.181	0.111	0.069	0.000
8	12	11	7	7	0.167	0.153	0.069	0.056
9	3	3	1	1	0.042	0.042	0.028	0.028
10	7	5	7	4	0.097	0.069	0.000	0.014
11	22	10	7	3	0.306	0.139	0.208	0.097
12	17	14	8	11	0.236	0.194	0.125	0.042
13	2	19	1	12	0.028	0.264	0.014	0.097
14	15	14	8	7	0.208	0.194	0.097	0.097
15	13	28	7	23	0.181	0.389	0.083	0.069
16	14	7	8	3	0.194	0.097	0.083	0.056
17	9	12	7	9	0.125	0.167	0.028	0.042
18	22	22	14	16	0.306	0.306	0.111	0.083
19	14	9	8	7	0.194	0.125	0.083	0.028
20	10	15	6	12	0.139	0.208	0.056	0.042
21	19	15	10	13	0.264	0.208	0.125	0.028
mean	**13.857**	**12.571**	**7.095**	**8.952**	**0.192**	**0.175**	**0.094**	**0.050**
SD	**7.164**	**5.600**	**2.965**	**4.894**	**0.100**	**0.078**	**0.073**	**0.028**