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Different methods to define utility functions yield different results and engage different neural processes

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Abstract

Although the concept of utility is fundamental to many economic theories, up to now a generally accepted method determining a subject's utility function is not available. We investigated two methods that are used in economic sciences for describing utility functions by using response-locked event-related potentials in order to assess their neural underpinnings. For defining the certainty equivalent (CE), we used a lottery game with probabilities of 0.5, for identifying the subjects' utility functions directly a standard bisection task was applied. Although the lottery tasks' payoffs were only hypothetical, a pronounced negativity was observed resembling the error related negativity (ERN) previously described in action monitoring research, but this occurred only for choices far away from the indifference point between money and lottery. By contrast, the bisection task failed to evoke an ERN irrespective of the responses' correctness. Based on these findings we are reasoning that only decisions made in the lottery task achieved a level of subjective relevance that activates cognitive-emotional monitoring. In terms of economic sciences, our findings support the view that the bisection method is unaffected by any kind of probability valuation or other parameters related to risk and in combination with the lottery task can, therefore, be used to differentiate between payoff and probability valuation.

Keywords: Utility function; neuroeconomics; error-related negativity; executive functions; cognitive electrophysiology; lottery, bisection

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1. Introduction

The concept of utility functions is fundamental to economics. Most theoretical considerations are based on arguments concerning the utility an agent gets from a good, inasmuch as it is not a good's quantity or money per se that determines the actions of human beings, so called agents, but the utility they obtain from the good. Equilibrium concepts like the Nash equilibrium for strategic interactions of agents, the Walrasian equilibrium of economies, financial theory or the theory of political decision making are based on utility considerations. Expected utility theory and its modifications like Prospect theory (Kahneman and Tversky, 1979, 1992) are the most established theories for decision making under risk. Theoretically, utility theory is well-founded by an axiomatic approach with few intuitive axioms. However, and in contrast to the theoretical importance of utility considerations, up to now a generally accepted procedure how to measure utility does not exist. The need to have a method for determining utility functions is obvious, since in all areas, especially in risky decision making, violations of expected utility theory are known. Without a generally accepted approach for identifying utility, it will be impossible to figure out which theoretical predictions made by utility function related models do not fit observed decision making processes. If utility functions can not be measured, many predictions of economic models are neither testable nor implementable and, ultimately, models can not be falsified. Several key questions have therefore be answered: Is the concept of utility functions a normative construct, does it capture the key features of decision making processes or is it just a tool for describing behavioral data?

In this paper we want to focus on the utility of money. Two main methods measuring utility are discussed in the literature: the evaluation of lotteries and the bisection method. In the first

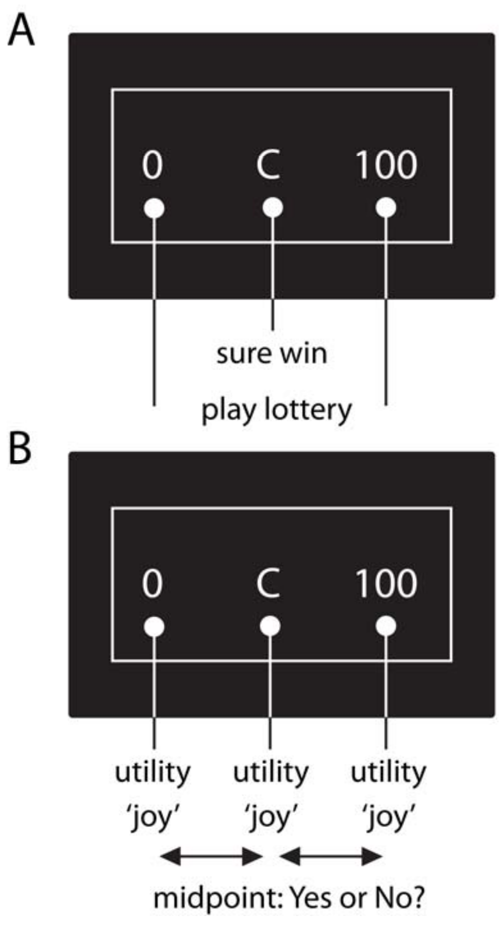

Figure 1: Prototypical decision task for the binary lottery (A) and the bisection task (B)

approach, certainty equivalents (CE) of lotteries are determined for various amounts of money and various probabilities. In a standard approach the certainty equivalent method elicits a utility function by determining certainty equivalents of lotteries. Payoffs are offered by a lottery (p=0.5) and a sure win ("C" in figure 1A). The certainty equivalent CE is represented by the sure payoff for which a subject should be indifferent between the two alternatives. Within this framework a utility function is determined based on its assumed functional form, a probability weighting and an econometric analysis. Different approaches for econometric analyses are Regret theory (Loomes and Sugden, 1982), Prospect theory (Kahneman and Tversky, 1979, 1992) and Disappointment theory (Bell, 1985). A key problem of econometric analyses is the specification of a functional form for the evaluation of risky decisions and binary lotteries, respectively. Since each model hypothesizes a distinct functional form for the evaluation of money and probabilities, the determination of utility functions differs. Therefore, results depend on the specification of the functions and even the separation between probability evaluation and evaluation of money depends on this specification. One major short-coming of the binary lottery approach is that the evaluation of probabilities and money are not fully separable. Thus, risk aversion can be attributed to the shape of the utility function or to the probability weighting. The statement of prospect theory that individuals are risk averse for positive payoffs or high probabilities crucially depends on the econometric analysis. On the other hand, one of this method's advantages is that agents really decide between options which lead to payoffs.

In the second approach, the bisection method, agents are asked to specify differences in the utility associated with monetary payoffs. In this method, a utility function is elicited by determining mean points of utility within two utility values, so that a mean point M refers to an indifference position of a subject between both utility values. One possibility is, to present agents two amounts of money, x_1 and x_2, and ask them which amount of money M divides the utility difference $u(x_1)-u(x_2)$ into halves, i.e. $u(M)=(u(x_1)+u(x_2))/2$. It is also feasible to show a third amount of money x_3 ("C" in figure 1B) and to ask if this value divides the difference of x_1 and x_2 into halves ($[u(x_1)+u(x_2)]/2=u(x_3)$). To achieve a monetary valuation without using lotteries, subjects are asked to evaluate their perceived 'happiness that money brings' (Galanter, 1962). In the present study the term 'joy' is used (associated with receiving a specified amount of money) in order to induce a monetary valuation context. By varying the parameters, a utility function can be obtained. The advantage of this method is that the utility function obtained does not depend on probabilities and the specification of a functional form, meaning that no theoretical presumptions are required. Its disadvantage is that decisions are neither connected to monetary nor to hypothetical payoffs. Both methods have been widely used and discussed in the literature. In most studies in experimental economics the evaluation of lotteries is used to determine utility functions or to test theories. The key argument for preferring the lottery method over the bisection method is that economic decisions should involve monetary payoffs, otherwise the decisions "are not for real". This latter argument implies that decisions may involve different cognitive and emotional processes and – by extension – different neural processes.

Compared to behavioral analyses the use of event-related potentials (ERP) during decision making tasks allows to reveal the neural underpinnings of cognitive processes related to response evaluation and thus to delineate the differences between decisions made in the lottery and bisection paradigms. In human beings cognitive control mechanisms are monitoring and evaluating ongoing actions permanently, enabling adaptation of behavior in a most flexible manner. Typical situations in which such mechanisms have been studied involve response selection from several action alternatives or the evaluation of currently made decisions. One ERP component related to response evaluation processes is the error-related negativity (ERN, Falkenstein et al., 1991; Gehring et al., 1993). This component was initially described to appear 50 to 100 ms following an incorrect response in choice-reaction tasks at fronto-central electrode sites and was postulated to reflect the perceived discrepancy between the intended and the actually performed motor action. Source analysis as well as simultaneous analysis of ERPs and functional magnetic resonance imaging (fMRI, Debener et al., 2006; Dehaene et al., 1994; Mathalon et al., 2003) have shown that the ERN is generated in the anterior cingulate cortex (ACC), an area that is closely linked to several cognitive control mechanisms involved in decision making (Gehring and Knight, 2000; Paus, 2001). Recent investigations have shown that the ERN is sensitive to characteristics in error processing that are not directly linked to the violation of objective criteria as well. For example, an error's relevance, as Hajcak et al. (2005) have shown by associating responses with different amounts of money, or differing emotional states in error processing (Luu et al., 2000; Tucker et al., 1999; Wiswede et al., 2009) are influencing the extent of an error's impact as indexed by varying ERN amplitudes. As Hewig has shown, the selection of high risk decisions resulted also in an ERN, inasmuch the selection of such a response implies a high chance not to get the response's intended outcome and will be processed as an erroneous deviation from internal choice strategies. Based on their initial approach explaining error processing in terms of reinforcement learning (Holroyd and Coles, 2002; see also Munte et al., 2007 for electrophysiological evidence) Holroyd and Coles (2008) described the occurrence of an ERN in the absence of external ascertainable response criteria. Accordingly, responses are matched against internal criteria that were formed by individual learning histories. Therefore, the occurrence of an ERN is not reflecting an error like in a typically speeded stimulus-response task, but the classification of a given response to be "sub-optimal" (Holroyd and Coles, 2008) with regard to internal representations. The ERN appearing in such kind of tasks may reflect the subjective value of a potential response.

To summarize, ERN indexes decisions associated with errors and depends on the significance of response alternatives whereas choices that are unequivocally correct or fit the subject's response strategies do not give rise to an ERN. In the present investigation we use the ERN as a tool to differentiate the neural responses associated with decisions made in the lottery and bisection paradigms. Our prediction is that lottery decisions will be associated with increased monitoring, since the payoff instruction increases the subjective relevance or value in this task and should be reflected by the ERN amplitude. ERPs in the bisection task should not feature an ERN, because here responses have neither to be matched against set criteria nor are they associated with subjective relevance. Ultimately, we want to use the results of this investigation to argue for an approach allowing one to determine a utility function for money and separate the effects of risk and the utility of money in the evaluation of money.

2. Material and Methods

2.1. Participants

Sixteen neurological healthy, right-handed subjects participated in our study (10 women, age range 21 to 29). Two subjects were excluded from data analysis because of technical problems. Additionally, one subject made no disadvantageous responses in the range from 390 to 100 and was excluded from data analysis as well. Therefore we performed the analysis with 13 subjects. Subjects were paid for participation receiving seven Euros per hour. The study protocol was approved by the ethics committee of Magdeburg University.

2.2. General Procedure

Participants were seated in a comfortable chair in front of a 19"-CRT monitor. A modified computer mouse was positioned under each index finger as a response device. The experiment consisted of two sessions which took place within 3-7 days. In both sessions identical stimulus material was presented but with differing task instructions. Every session began with 20 practice trials to familiarize subjects with the task. Thereafter the session started comprising 10 blocks of 82 trials each.

2.3. Task

In each trial, lasting between 2700 to 3400 ms, a string of 3 numbers surrounded by a white box was presented (see figure 1). The two outer numbers were shown first. After 1000 ms, the

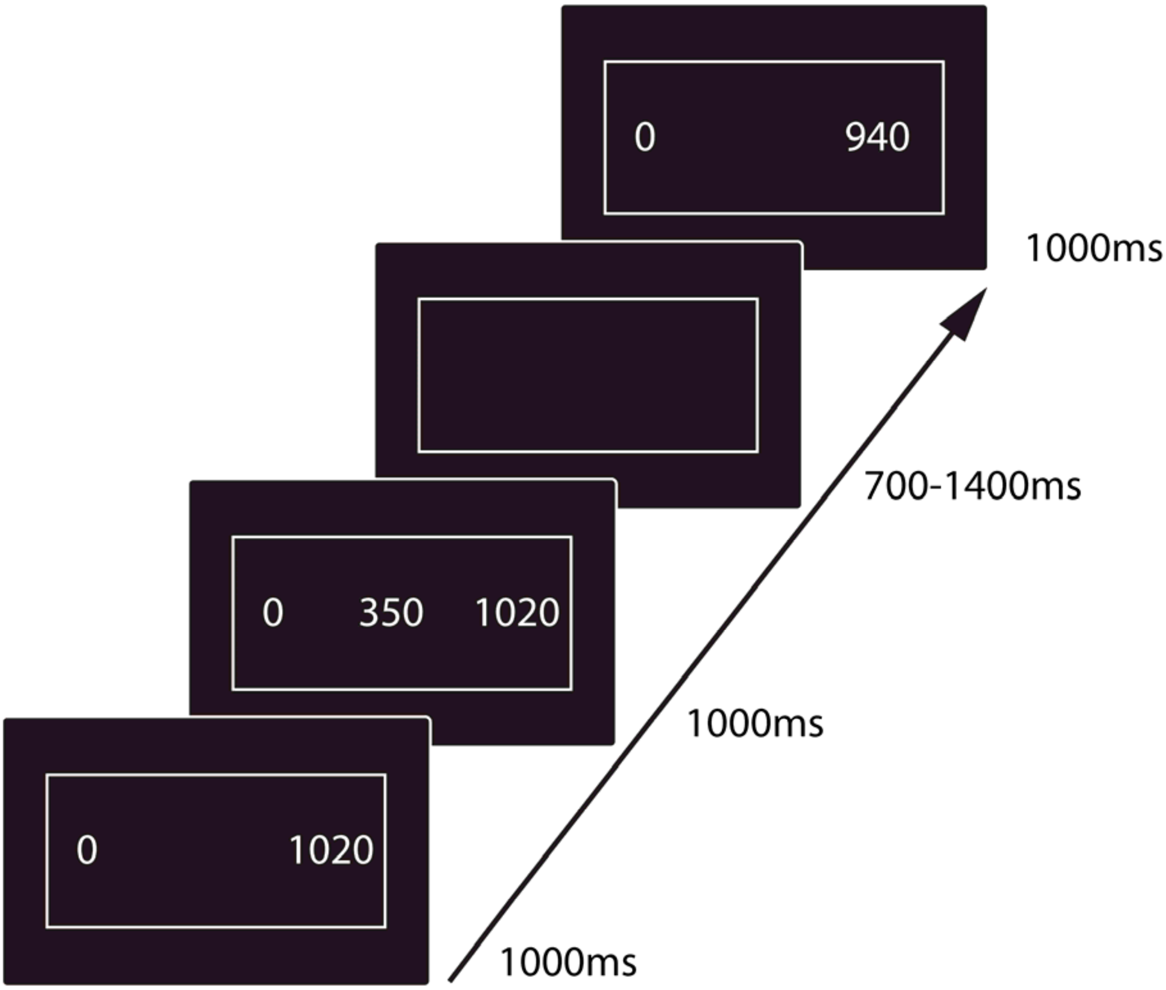

Figure 2: experimental paradigm

inner number was added and the completed string stayed on the screen for another 1000 ms. The string's left number was always zero. If numbers on the right were between 800 and 1000, the mid position numbers varied between 100 and 700, in case the right-sided numbers were between 1020 and 1200, mid position numbers were in the range of 300 to 900. Numbers in the middle were varied in steps of 50, right-sided numbers in steps of 20. Before presentation numbers within each string were multiplied by 1, 10 or 100, resulting in three strings being '0 350 1120', '0 3500 11200' and '0 35000 112000'.

In the bisection task, the outer numbers corresponded to the utility interval's boundaries and the inner number to this interval's center. By pressing the left or right index finger (YES/NO) subjects indicated whether the number presented was their perceived mean point/ center (YES) or not (NO).

In the binary lottery task subjects had to choose to either get the amount of money corresponding to the center number or to play a lottery in which the outer numbers were the lottery's stakes of a fifty-fifty chance. Subjects were explicitly told that the lottery game was hypothetical only; to that effect subjects expected no real payoff. Again they indicated their choices by pressing a button with the left or right index finger.

2.4. EEG-Recording and Analysis

The electroencephalogram was recorded from 28 tin electrodes, referenced against an electrode place on the left mastoid process, mounted in an elastic cap and placed according to the international 10-20 system. EEG was re-referenced offline to the mean activity at the left and right mastoid processes. All channels were amplified (bandpass 0.05 – 30 Hz) and digitized with 4 ms resolution. To control for eye movement artifacts, horizontal and vertical electrooculograms (EOG) were recorded using bipolar montages. To eliminate eye movement contamination from EEG signals we used the method described by Joyce et al (2004; for a comparison to other methods see Kierkels et al., 2006). Additionally, we controlled for other artifacts, e.g. muscle or heart rate, by visual inspection and removed afflicted epochs if necessary.

The computation of bins for ERP analysis was based on the difference between the number presented in the middle of the string and the arithmetic middle of the outer numbers, which can be calculated by the arithmetic middle of the two outer numbers. To give an example: assume the mid-number is 300, the number on the left side is always 0, and the right side number 800, then the arithmetic middle of the two outer numbers is 400. Accordingly, the resulting difference is 300 – (0+800)/2 = -100. Thus, negative differences are smaller and differences with a positive algebraic sign are larger than the expected value. We sorted trials into 5 bins including the differences 390 to 100, 90 to 50, 40 to -40, -50 to -90 and -100 to -400. For each of these bins, we computed response-locked averages with an epoch-length of 900 ms (baseline -300-0) separately for "yes" and "no" responses. For each subject, averages were filtered using a 1 to 8 Hz band pass filter before calculating the mean amplitude 30 – 70 ms after response for statistical analysis. This time-window has been shown to capture the ERN-component which typically has a maximum around 50 ms. To test for effects, we calculated an ANOVA with the factors condition (lottery/center judgement), response (yes/no, whereas 'yes' in the lottery condition is related to choosing money and 'no' choosing the lottery) and bin (5 bins) for the electrode site Cz. Significance values will be reported Greenhouse-Geisser corrected, but the degrees of freedom uncorrected. In order to identify conditions causing significant interactions or main effects the corresponding post-hoc t-tests were performed. To adjust the significance level of one-tailed post-hoc t-tests for multiple comparisons α was set to 0.05 and an improved Bonferroni procedure based on the ordered p-values was applied (Simes, 1986). According to Simes (1986), let $p_{(1)} \leq p_{(2)} \leq ... \leq p_{(j)}$ be the ordered p-values for testing $H_0=\{H_1,H_2,..,H_i\}$. H_0 will be rejected, whenever $p_i < i*\alpha/j$ for i=1 … j (see also Samuel-Cahn, 1996; Sen, 1999; for a critical discussion and Wendt et al., 2007 for its application on EEG data). We grouped our post hoc testing in the comparison of decisions at indifference point of the bisection task and decisions made at the endpoints (bins [-400;-100] and [100;390]). Correspondingly, we calculated critical p-values for 5 and 6 post-hoc comparisons. The resulting critical values are shown in table 1 and 2 respectively.

2.5. Behavioral Analysis

Response frequencies were calculated for every subject by computing the percentage of 'yes' and 'no' responses given to each difference value. The same bins as used for the EEG analysis were assessed. For statistical analysis the mean percentage values of 'yes' response were used only, since percentage values of both response categories are inversely related. For global effect testing, we performed a repeated measures ANOVA with the factors condition (lottery/center judgement) and bin (5 bins, see previous section for details). Significance values will be reported Greenhouse-Geisser corrected, but the degrees of freedom uncorrected. For correction of post-hoc test's alpha value see section 2.4.

3. Results

3.1. Behavior

Choices made for each difference value (in mean percentage) are depicted for the lottery and bisection tasks in figure 2A and B, respectively. In the lottery game, participants show risk averse behavior, indicated by the preferred choice getting a fixed hypothetical amount of money for difference values deviating slightly from the expected value in negative direction. The median of the certainty equivalents is given by the intersection of the colored lines. The

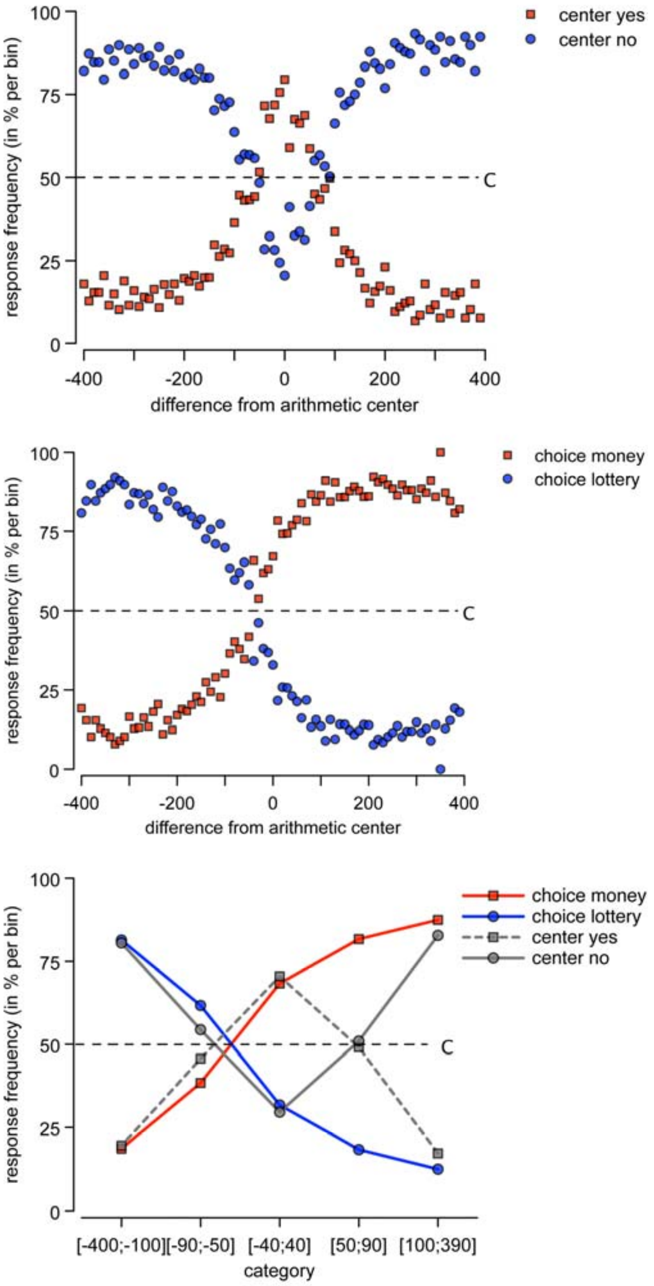

Figure 3: Behavioral data. Mean percentage of choices are shown for the binary lottery (A) and the bisection task (B). The center is indicated by a dotted line and refers to the indifference point in the bisection task. (C) depicts the cumulated choices per bin for both task. Circles referring to "YES"-, squares to "NO"-responses. Indifference point was

indicated by a dotted line. Please note, that statistical comparisons were only calculated for YES responses.

choices in the bisection task are peaked at zero for the ‘yes’ responses. Collapsing choices into 5 bins as done for the EEG analysis clearly illustrates the differences between the tasks (see figure 2C). Statistical analysis reveals a significant interaction condition by bin ($F(4,48)=33.38$, $p<0.001$) as well as significant main effects (condition $F(1,12)=14.39$, $p=0.003$; bin $F(4,48)=32.04$, $p<0.001$). Comparing bins between conditions post-hoc contrasts are significant for the bins [100; 390] and [50; 90], but not for the remaining bins [-40; 40], [50; -90] and [-100; -400]. For example, these tests show that the difference in the means of the CE and the mean point are not significant.

Order	Contrast	t-value	p_{emp}	p_{crit}
1	[100; 390]	9.47	0.01	**<0.001**
2	[50; 90]	4.53	0.0125	**<0.001**
3	[-90; -50]	-0.833	0.025	0.21
4	[-40; 40]	-0.345	0.0375	0.36
5	[-100; -400]	-0.167	0.05	0.43

Table 1: Ordered p-values of the comparison of the relative frequency of “YES”-responses between conditions. Significant tests are indicated by p_{crit} values written in bold.

3.2. Event-related potentials

The response-locked grand average ERPs are illustrated in figure 3. A clear negativity with a peak latency of approximately 50 ms and a mediofrontal distribution akin the ERN

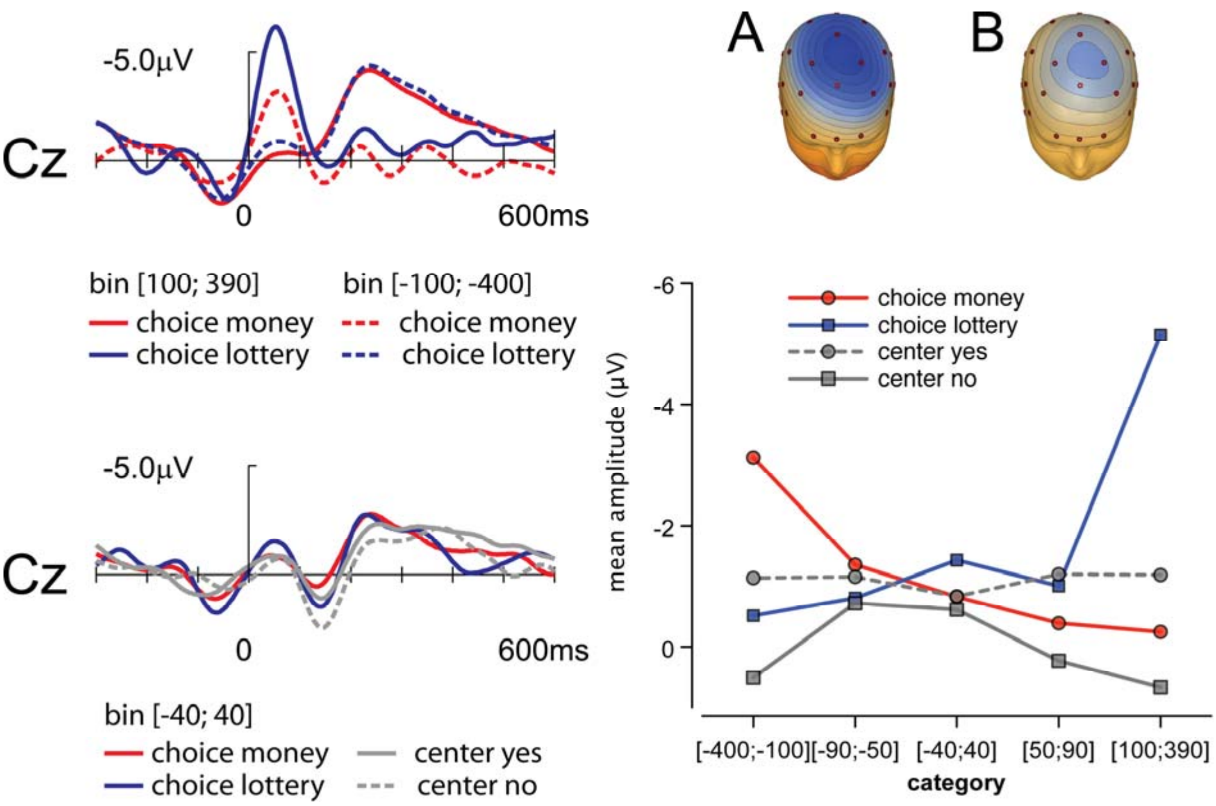

Figure 4, left side: response locked event related potentials for the lottery’s task endpoints (upper panel) and the indifference point for all conditions (lower panel) are shown.

Right side: Topographies for the lottery conditions (A) choice lottery [bin 100;390] and (B) choice money [-100;-400] are shown. Lower panel depicts the mean amplitudes of the response locked ERPs at CZ per category. Circles referring to "YES"-, squares to "NO"-responses.

component emerged in the lottery task for those responses which entailed a divergence from the optimal behavior (i.e. choosing the lottery in bin 100;390 and choosing money for bin -100;-400). By contrast, as illustrated by figure 4 (right panel), response-locked ERPs in the bisection task were not associated with a negativity. Statistical analysis of response locked ERPs resulted in the significant interactions condition x response x bin ($F(4,48)=7.18$, $p=0.002$), condition x response ($F(1,12)=5.29$, $p=0.03$), condition x bin ($F(4,48)=3.23$, $p=0.03$) and response x bin ($F(4,48)=3.91$, $p=0.03$). With regard to main effects, only the 'condition' factor became significant
($F(1,12)=5.78$, $p=0.03$; for the remaining main effects response and bin $F<0.9$, $p>.4$). Post-hoc comparisons comparing decisions between bins within and between conditions are illustrated in table 4.

order	Contrast	t-value	p_{emp}	p_{crit}
1	[-40;40] choice lottery vs. center no	-1.437	0.008	0.085
2	[-40;40] choice lottery vs. center yes	-1.09	0.01	0.15
3	[-40;40] choice lottery vs. choice money	-1.01	0.0125	0.16
4	[-40;40] choice money vs. center no	-0.481	0.025	0.34
5	[-40;40] center no vs. center yes	0.377	0.0375	0.36
6	[-40;40] choice money vs. center yes	0.015	0.05	0.49
1	[100;390] choice lottery vs. [100;390] choice money	-4.55	0.01	**<0.001**
2	[100;390] choice lottery vs. [-400;-100] choice money	-3.58	0.0125	**0.002**
3	[100;390] choice lottery vs. [100;390] center yes	-3.05	0.025	**0.005**
4	[-400;-100] choice money vs. [-400;-100] choice lottery	-2.6	0.0375	**0.011**
5	[-400;-100] choice money vs. [-400;-100] center yes	-1.7	0.05	**0.05**

Tabelle 2: Ordered p-values for the comparison of the mean ERN amplitudes between conditions. Significant tests are indicated by p_{crit} values written in bold. The ordering of the critical p-values was performed for the indifference point and both endpoints respectively.

4. Discussion

In the present study, action monitoring processes as indexed by the ERN component were differentially engaged in two decision making paradigms that have been frequently used in economic sciences to determine the utility of money. This suggests fundamental differences between the lottery and bisection methods at the cognitive and neural level. More specifically, whereas no ERN was found in the bisection task throughout the whole range of decisions, it characterized decisions of the less advantageous options at either endpoint of the range of possible decisions. That is, an ERN was found for "lottery"-decisions in trials that would have yielded a sure win greater than the mean outcome of the lottery. Similarly, an ERN was present for "money"-decisions in trials in which the mean outcome of the lottery would have exceeded the sure win. In general, the occurrence of an ERN in this task can be interpreted as an evidence for the subjects' motivational participation even though the lottery's payoffs were only hypothetical. It is known from previous research that the appearance of an ERN depends on the subjective significance in a given task (Hajcak et al., 2005; Holroyd and Coles, 2008). The differences between the bins releasing the two most prominent ERNs indicates different degrees in action monitoring and is likely caused by the interaction of two factors: the difference between expected value and sure payoff on the one hand and the risk to loose on the other. In both ERN releasing decisions the difference between expected value and sure payoff was similar and in both situations the ERN occurred when subjects selected the (potentially) smaller payoff or expected value respectively. Nevertheless, the ERN's amplitude was larger when subjects have chosen disadvantageously the lottery compared to the erroneous selection of a sure payoff. Obviously, the anticipation of a risky decision's potentially negative outcome, namely to win nothing instead of getting a small but sure payoff in the unfavorable payoff selection, leads to increased activation of monitoring mechanisms despite similar expected values.

How can these neurophysiological findings inform economic reasoning? By looking at the economic starting point of our analysis shown in Figure 1 we discuss the differences and similarities between these two methods. In the bisection method the mean point in utility between the two monetary amounts is determined only by the utility function of money by the following formula:

$$u(M)=0.5*u(x1)+0.5*u(x2).$$

In the binary lottery method the certainty equivalent is determined by the utility function of money and other factors connected with the risk of the lottery, like probability weighting in prospect theory or regret or disappointment. According to prospect theory the certainty equivalent is:

$$u(CE)=w(0.5)*u(x1)+(1-w(0.5))*u(x2)$$

If we compare both formulas the difference is obvious: the weighting of probabilities w(prob). For other theories other differences can be expressed. If we use the formula of Prospect theory we would expect that the certainty equivalent CE and the mean point in the bisection task M are equal if we assume $w(0.5)=0.5$. In this case only the utility function of money determines the certainty equivalent. As we will see in our discussion with respect to this point the methods are similar. We find similarities for decisions around the indifference point. Differences occur for decisions far away from the indifference point. We start our discussion with these differences which are detectable by combining both methods and analyzing the influence of risk.

We observed an ERN in the binary lottery condition, but not in the bisection method, for decisions far away from the indifference point, i.e. for decisions for which they had clear preferences. This appearance of an ERN indicates that hypothetical wins are engaging subjects. This finding is observed after the decision has been made. This implies that decisions are subjectively more important in the lottery condition and might be caused by the fact that the lottery task is phrased as if actual payoffs might be possible, but not in the bisection method. According to other findings (see below) in the bisection task the evaluations are the same, but in the lottery condition decisions might lead to different importance compared to the bisection method. This finding supports our arguments given in the discussion above that the observed differences between the methods used for determining the utility of money can be ascribed to the risk perception in the lottery task.

It is important to note that an ERN is observed even though money was not paid. This means the effect is not caused by paying money, but by the task (without payoffs). This is interesting since it shows that even under hypothetical conditions reactions to the presentation of risk occurs. Subjects behave at least partly as if the choice was for real. By paying money for these lotteries one would expect increased ERN amplitudes only since the risk to loose would be experienced to be more real. Assuming that the remaining findings would be stable our argumentation that hypothetical payoff reflects the lower end of a parametric variation of risk would get additional support.

According to standard economic theory of risky decision making only consequences and probabilities of the decision problem determine the choice of an individual. The influence of time between the presentation of the problem, the decision and the realisation of the outcome is very often neglected. By using ERPs we were able to identify the point in time where one part of post-decision evaluation processes takes place, namely, if the performed choice fits the subject's response strategies and finally their long-term goals (for economic theories considering the impact of timing on decision processes see e.g. Albers et al., 2000). Neuroscientific methods such as ERPs and fMRI thus allow also to test theories of risky decision that suggest that lotteries engage emotional processes.

Regarding similarities both methods used in the present investigation are resulting in similar utility functions of money. This conclusion is based on behavioral as well as on EEG data. Figure 3C shows no significant difference between the medians of the certainty equivalent and the mean point in the bisection method. The lower panel of Figure 4 does also not show a significant difference in the EEG data when making a decision at the indifference point which corresponds to the median in the behavioral data. Postulating the bisection method captured utility of money itself and, as argued previously, the binary lottery the combination of utility and risk, an implication of our finding is that utility function and probability weighting can be separated by initially determining the utility function with the bisection method and afterwards using the obtained function as input in the lottery method to get the lottery's probability weighting experimentally. This procedure should be applied to lotteries with probabilities different from 0.5. In this case a simultaneous determination of the utility function and the probability weighting by only using the certainty equivalent method does not always lead to a clear separation between effects of the utility function of money and the probability weighting. The same procedure also allows to separate other effects related to risk and not to money evaluation. For example, the implications of Regret theory, Disappointment theory can be more easily tested by a combination of these two methods since the result of the determination of the utility function can be used in the analysis of the lottery method. In general using both methods and looking at the differences helps to characterize situations connected with risk (money and probabilities) in comparison to situations connected with certainty (only money).

In our experiment the two tasks as implemented lead to the same results. In this simple version the problems observed by Galanter (1962) for the bisection method are not present showing that changing the task as in Galanter leads to disturbances, but the fundamental tasks (bisection method, lottery method) lead to the same neural reactions and the same behavioral data around the indifference point. Therefore, the bisection method can be used as a standard to determine utility functions.

In summary we show that it is possible to combine two methods which are used to determine utility functions of money. We characterize common properties and differences of these two methods. The evaluation of money is the same in both conditions. By using this result it is possible to separate aspects of risky decision making. Our second finding shows one difference: Disadvantageous choices made in the risky decision making task are perceived as being relevant showing that even though payoffs were hypothetical they were treated by the participants as if they were "real".

Our study allows for several extensions. One extension is to test the impact of real monetary payoffs by performing a treatment in which lotteries are paid. Another extension is to combine the bisection method and the binary lottery method to obtain a probability weighting function experimentally.

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Conflict-of-Interest Statement
The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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