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Abstract

This paper focuses on the problem of probability weighing in the evaluation of lotteries. According to Prospect Theory a probability of 0.5 has a weight of smaller than 0.5. We conduct an EEG experiment in which we compare the results of the evaluation of binary lotteries by certainty equivalents with the results of the bisection method. The bisection method gives the amount of money that corresponds to the midpoint of the utilities of the two payoffs in a binary lottery as it has been shown previously. In this method probabilities are not evaluated. We analyzed EEG data focused on whether a probability is evaluated or not. Our data show differences between the two methods connected with the attention towards sure monetary payoffs, but they do not show brain activity connected with a devaluation of the probability of 0.5.

Introduction and Theory

In risky decision making Prospect Theory (Kahneman and Tversky 1979; Tversky and Kahneman 1992) is one of the most accepted theories. One central point in Prospect Theory is probability weighting. One key aspect of the probability weighting function is that the probability of 0.5 has a weight smaller than 0.5. We design an EEG study in which we try to find brain activity associated with the perception of the probability of 0.5. In a previous EEG study (Heldmann et al. 2008) the bisection method as a direct method without risk was compared with the certainty equivalent method as an indirect method that is connected with risk. Both methods are used for eliciting a utility function and this study revealed that the bisection method is suitable as a reference method for eliciting utility functions. We use these two methods to isolate the effect of the evaluation of the probability of 0.5 in the experimental design and in the EEG data.

In the following part we shortly describe both methods and the problem in more detail. Then we present the experimental part with our results and the conclusion.

Certainty equivalent method

The certainty equivalent method elicits a utility function by determining certainty equivalents of lotteries in which the payoffs x^- and x^+ occur with a probability of $p = 0.5$. Based on decision of a subject between a binary lottery and a sure payoff, the certainty equivalent CE represents the sure payoff when the subject becomes indifferent between the lottery and the sure payoff.

Bisection method

Applying this method, a utility function is elicited by determining the amount of money CU that corresponds to the midpoint of the utilities of the two

amounts of money x^- and x^+ . During the experiment the subjects are asked to evaluate their perceived ‘happiness that money brings’ (Galanter 1962) in order to achieve a monetary valuation without using lotteries. This study uses the term ‘joy’ at receiving an amount of money when applying the bisection method in order to provide the subjects with a monetary valuation context (see figure 1).

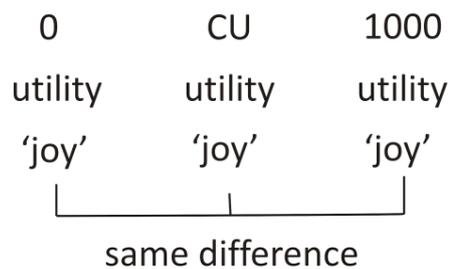


Figure 1: Schematic presentation of the bisection method for $x^- = 0$ and $x^+ = 1000$

Does CU equal CE?

After comparing the prediction of models of decision theory for both methods it can be stated that CU will equal CE does not apply for all theories. While $CU = CE$ can be reasoned by Expected Utility Theory, the same is not true for Prospect Theory (Kahneman and Tversky 1979; Tversky and Kahneman 1992) due to its use of a Probability Weighting Function.

If the utility function in both methods is normalized to 0 and 1 and the offered lottery of the CE method has a fifty-fifty chance ($p = 0.5$), a theoretical comparison can be made as follows:

The bisection method asks for the same difference of ‘joy’ between three outcomes x^- , CU and x^+ . This is achieved by perceiving CU as the monetary amount corresponding to the midpoint of joy between x^- and x^+ .

As far as normalization is concerned, the utility of x^- and x^+ is $u(x^-) = 0$ and $u(x^+) = 1$. Thus, the utility of the perceived midpoint CU is

$$u(CU) = \frac{u(x^-) + u(x^+)}{2} = \frac{1}{2}.$$

The offered lottery of the CE method has two values x^- and x^+ as in the bisection method. According to Expected Utility Theory, the utility of the certainty equivalent is equal to the probability p of the fifty-fifty lottery, since $u(CE)_{EUT} = u(x^+) \times p + u(x^-) \times (1 - p) = 0.5$. Hence, the perceived midpoint of the difference of joy has the same utility as the certainty equivalent of an indifference decision between a fifty-fifty lottery and a sure payment. It follows that a comparison of these two methods will not yield different results if Expected Utility Theory holds.

The CE method as used for the development of Prospect Theory differs in this comparison, given that the utility of an indifference decision between a sure outcome and a lottery does not equal the given probability p as a result of the weighting function, consequently $u(CE)_{PT} = u(x^+) \times w(p) + u(x^-) \times w(1 - p) = w(0.5)$. The Probability Weighting Function is stated to be inverse S-shaped, with a probability of 50 % being affiliated to a section of underweighting probabilities (Tversky and Kahneman 1992; Camerer and Ho 1994; Tversky and Fox 1995). Further studies (Gonzalez and Wu 1999; Abdellaoui 2000) also confirmed that the crossover point from an overweighting to an underweighting of probabilities is about $p = 0.35$. As a result, the value of $w(0.5)$ is actually lower than 0.5, leading to the conclusion that a comparison of these two methods yields different results, namely $u(CU) > u(CE)$.

Different results between CU and CE would also be expected by theories of Regret (Loomes and Sugden 1982), Disappointment (Bell 1985) and Tension (Albers et al. 2000), formed on the basis of additional effects throughout the decision process, such as emotional reactions etc. In order to investigate the neural underpinnings of risky and riskless decisions event-related brain potentials (ERPs) were used, an EEG technique where brain potentials are recorded time-locked to external stimuli (Münte et al. 2000). Different ERP components can be characterized by three criteria: time, place and polarity of

the components' appearance. The P300 (or P3), a positive deflection at centro-parietal electrode sites peaking at 300 ms or more after the stimulus' presentation, is basically related to the cognitive processes like working memory, allocation of attentional resources, stimulus novelty and the stimulus' dependence on a given task (Duncan-Johnson and Donchin 1977; Johnson 1988; Linden 2005; Polich 2007). Other cognitive processes having an impact on the P300 variability like stimulus frequency (Duncan-Johnson and Donchin 1977; Johnson 1988), emotional value (Pritchard 1981; Johnson 1988; Picton 1992) or the stimulus' relevance can be traced back to the aforementioned concepts.

Coming back to the economical question that CU equals CE, the P300 can be utilized to reveal processes that are not reflected in observable behavior. For example, according to Prospect Theory the information of performing a lottery should result in a devaluation of the amount used in this task. But when does this devaluation take place? And is this devaluation reflected in the processing of the information when providing stimuli? In the present paper the focus is directed on the attention-capturing processes of the bisection method and the certainty equivalent method. The expected result for the riskless method would be less attention allocation processes compared to the method that is connected with risk.

Material and Methods

Participants

16 right-handed (9 women) and neurologically healthy subjects participated in this study after giving informed consent. They were paid 7 Euro per hour for their participation.

Experimental procedure

The subjects took part in two sessions which were scheduled two weeks apart. They were seated in a comfortable chair in front of a 19 inch CRT display. Each session started with a test block to familiarize the subjects with the task. It was the subject's task to make decisions by clicking two mouse buttons with their left or right index finger.

First, two numbers (x^- and x^+) were shown to the subject within a white frame (see figure 2), which turned into one out of two colors, either light blue or pink. According to this color codification, the subjects distinguished between two conditions: the CE method termed as 'lottery condition' and the bisection method termed as 'bisection condition'. Then a third number was revealed, located between the numbers shown before, and the subjects had to make a decision by means of a YES/NO response. Finally the screen turned back into black.

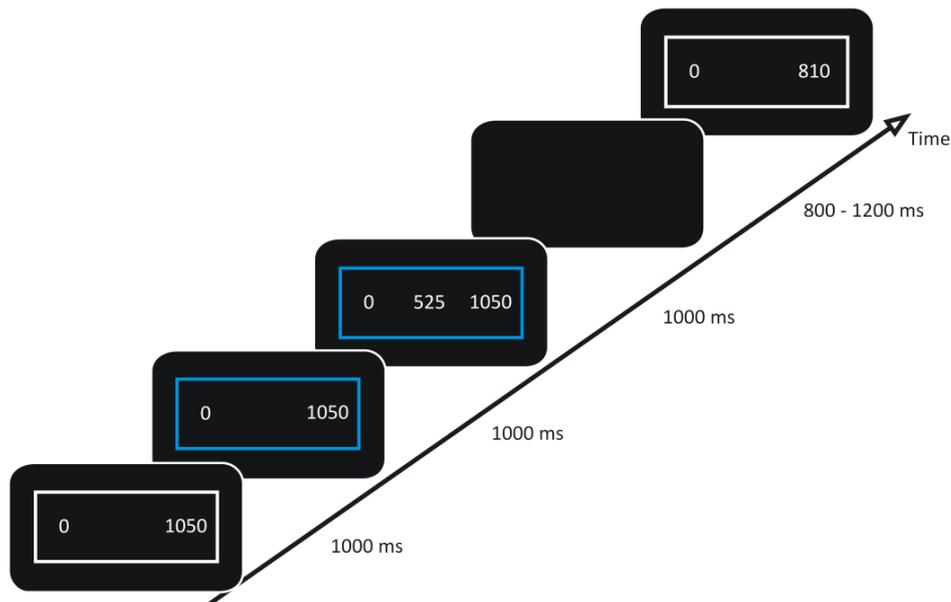


Figure 2: Sequence of screens shown to the subject

As for the lottery condition, the outer numbers represented payoffs of a fifty-fifty lottery and the inner number a sure payoff. The subjects were asked whether they preferred a sure payoff (YES), or opted for playing the fifty-fifty lottery (NO).

Additionally, for the bisection condition the outer numbers corresponded to the utility interval boundaries, while the inner number characterized the perceived utility interval center. The subjects had to decide whether they sensed the first utility interval as larger than the second utility interval (YES or NO) concerning the perceived joy at receiving these amounts of money.

Hence, the question in both conditions resulted in asking whether the same interval had been perceived as larger or not (see figure 3).

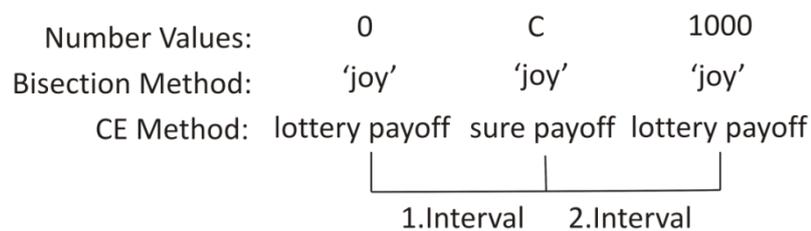


Figure 3: Comparison of the experimental question for the CE method and the bisection method

Furthermore, identical numerical values were presented in both conditions. The left number x^- was constantly zero, while the right number x^+ included 15 different values that were placed around 1000. The inner number varied between seven categories, containing the exact arithmetic mean C of the two outer numbers as well as ranges of 50 units ($C+50$, $C-50$), 150 units ($C+150$, $C-150$) and 300 units ($C+300$, $C-300$) from the center. All numerical values were multiplied by the factors 1, 10 and 100. Thus, not only values within the range of 1000 resulted, but additional values within the range of 10000 and 100000 were also induced.

Color codification and response configuration of the YES/NO answers to the right and left index finger were randomized among the subjects. The duration of the experiment was approximately one hour per session. The adjustment of the two conditions and the different number values during the experiment were distributed randomly.

In order to examine the stimulus presentation of the inner number, a fragmentation into the seven categories and the following YES/NO responses was conducted. The NO answers, in this respect, represent negative deflections from the center position C , and the YES answers positive deflections.

For analyzing the behavioral data only the averaged YES answers were taken into account, given that the NO answers are equivalent.

EEG recording and analysis

The electroencephalogram was recorded from 29 thin electrodes mounted in an elastic cap and placed according to the international 10-20 system. The EEG was re-referenced offline to the mean activity at the left and right mastoid. In order to enable the offline rejection of eye movement artifacts, horizontal and vertical electrooculograms (EOG) were recorded using bipolar

montages. All channels were amplified (bandpass 0.05 – 30 Hz) and digitized with 4 ms resolution, impedances were kept below 10 k Ω .

EEG-data with eye blinks were corrected using a blind source separation method (Joyce et al. 2004). EEG-periods with pulse artifacts were excluded from the data set. Following the artifact procedure, stimulus-locked bins were calculated (epoch length 900 ms, baseline 100 ms) for each subject and the following conditions (see table 1).

Table 1: Stimulus-locked bins for the EEG data

Condition	Inner Number Category	Followed Response	Bin
Lottery Condition	C-300	No	C-300NoLott
Lottery Condition	C-150	No	C-150NoLott
Lottery Condition	C-50	No	C-50NoLott
Lottery Condition	Center	No	CenterNoLott
Lottery Condition	Center	Yes	CenterYesLott
Lottery Condition	C+50	Yes	C+50YesLott
Lottery Condition	C+150	Yes	C+150YesLott
Lottery Condition	C+300	Yes	C+300YesLott
Bisection Condition	C-300	No	C-300NoBisec
Bisection Condition	C-150	No	C-150NoBisec
Bisection Condition	C-50	No	C-50NoBisec
Bisection Condition	Center	No	CenterNoBisec
Bisection Condition	Center	Yes	CenterYesBisec
Bisection Condition	C+50	Yes	C+50YesBisec
Bisection Condition	C+150	Yes	C+150YesBisec
Bisection Condition	C+300	Yes	C+300YesBisec

Results

Behavioral data

A within-subject analysis of variance (ANOVA) was performed for the behavioral data, with the condition, the inner number category and the scaled factor serving as inner subject factors. The ANOVA revealed no significant difference between both conditions ($F=0.307$, $df=1$, $p=0.588$). Further verification of both conditions using a paired t-test resulted in no significant values on a 5 % significant level (see table 3 in the APPENDIX). Figure 4 shows that both curves cross each other near the center position and are almost identical.

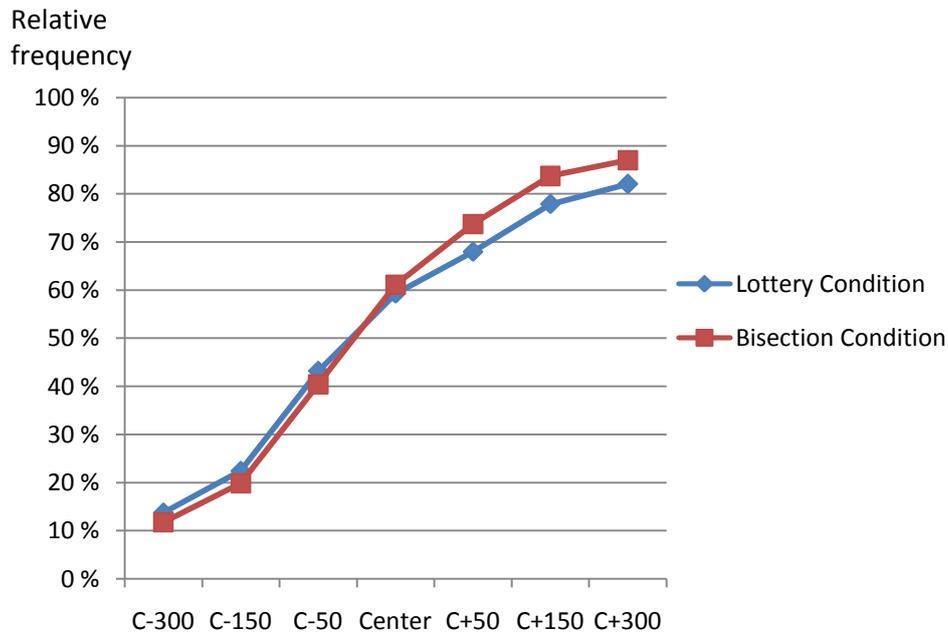


Figure 4: Empirical distribution function of the YES-answers for both conditions

Furthermore, a significant value is existent for the scaled factors ($F=1.313$, $df=6.762$, $p=0.012$), but not for other factor interactions (see table 3 in the APPENDIX).

EEG data

The figures 5 and 6 show stimulus-locked ERPs at the CZ electrode for the bins described in the previous section. Most pronounced differences are located about 500 ms poststimulus. ERPs related to the center position (C-50, C, C+50) hardly deviate, whereas the categories C-300, C-150, C+150 and C+300 tend to have a larger positivity. Obviously, the most pronounced positivity is related to the bin in the lottery condition.

ERP waveforms were analyzed by a set of ANOVAs, with the focus being directed on the mean amplitudes in different time periods and differentiated by the lateral, parasagittal and midline location as well as by the followed response.

A high significant difference could be determined at a time period of 450-600 ms poststimulus ($p < 0.02$, see table 4 and 5 in the APPENDIX) for the inner number categories. Based on a 5% significant level, no significant differences exist when regarding both conditions as within-subject factor (see table 3 and 4 in the APPENDIX); neither for the YES answers nor for the NO answers.

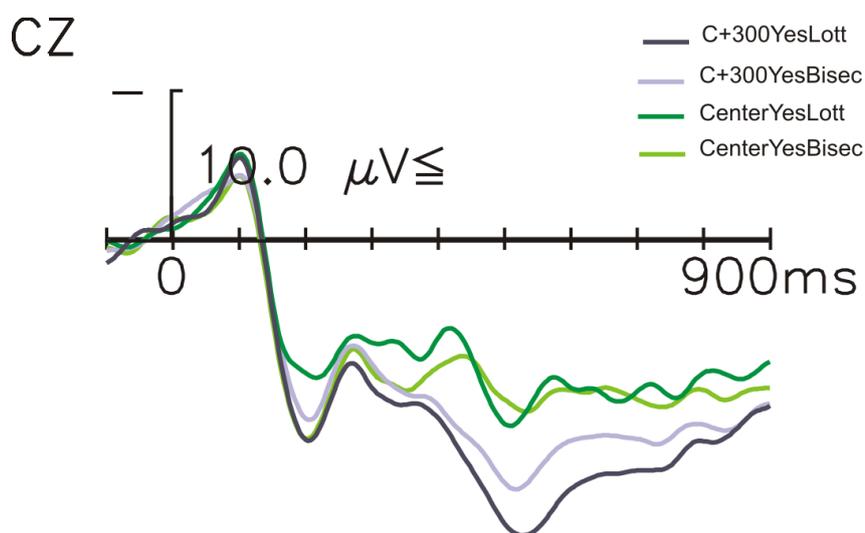


Figure 5: Stimulus-locked ERPs of the inner number stimulus at the CZ electrode for the YES-answers

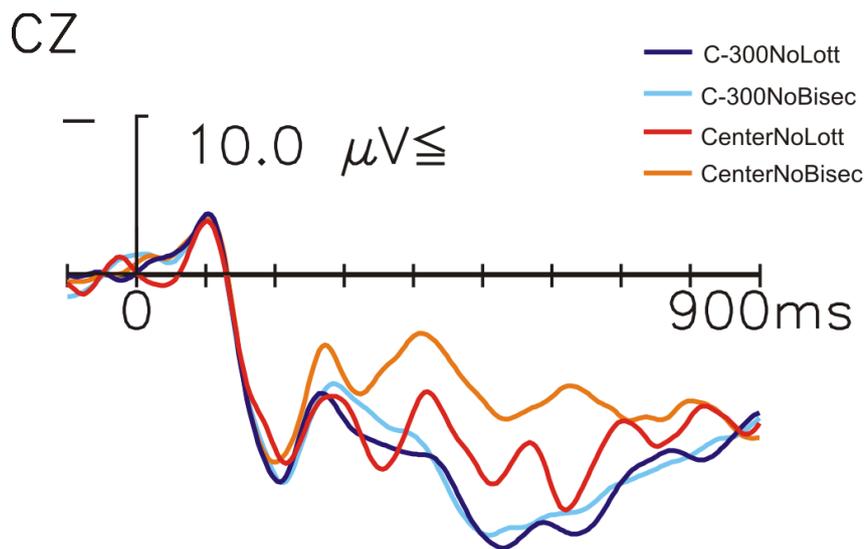


Figure 6: Stimulus-locked ERPs of the inner number stimulus at the CZ electrode for the NO-answers

Furthermore, an ERP verification of the extreme categories C-300 and C+300 had been conducted. Figure 7 and 8 present the voltage distribution among the scalp at 450-600 ms and the ERPs at the CZ electrode for these categories. It is obvious that the C+300 category of the lottery condition is marked by a higher positivity at the centro-parietal electrodes (CZ, PZ, CP2 and P4). A paired t-test for CZ and PZ revealed a significant difference for the C+300 category ($p < 0.05$, see table 6 in the APPENDIX).

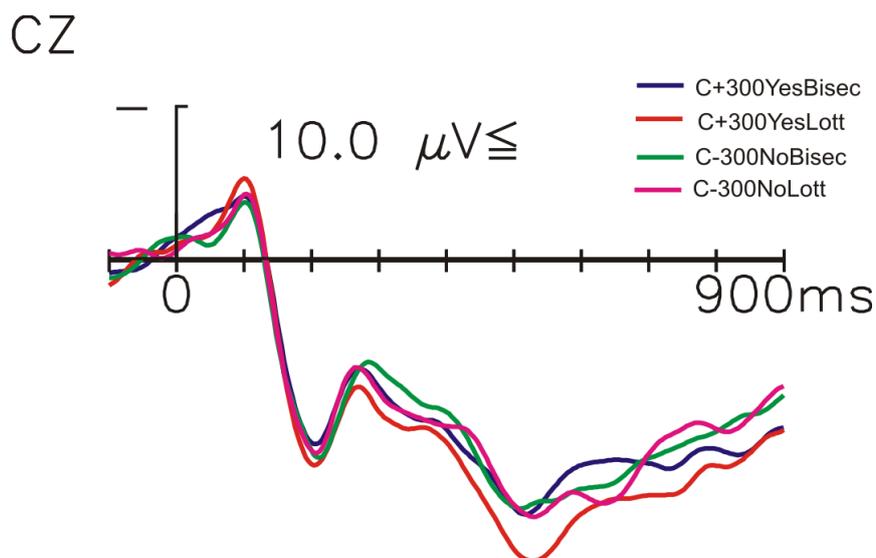


Figure 7: Stimulus-locked ERPs of the extreme categories at the CZ electrode

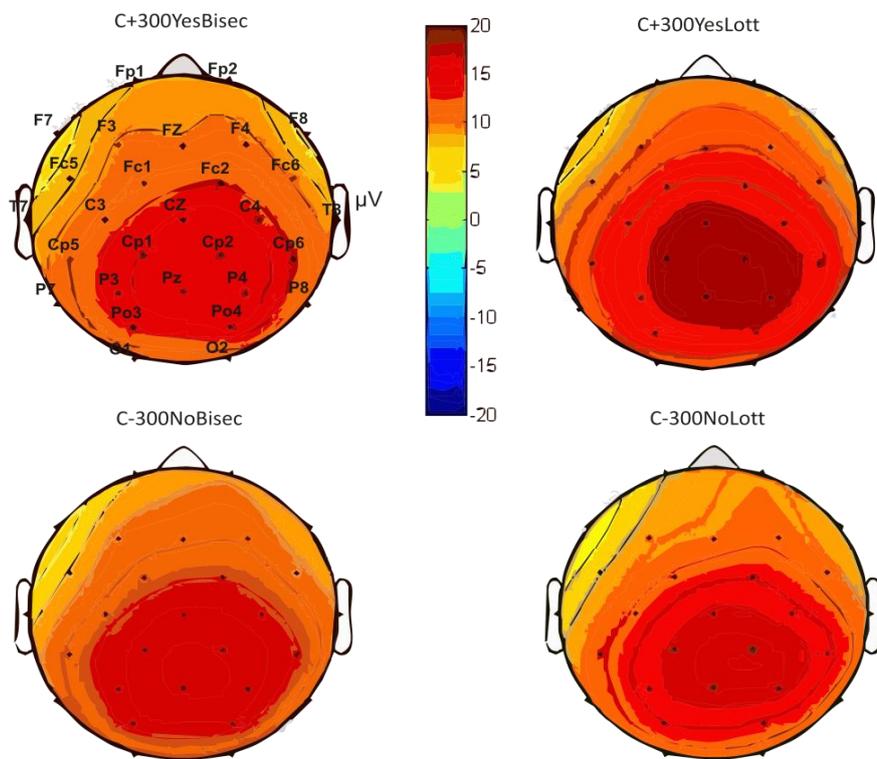


Figure 8: Voltage scalp distribution of the extreme categories

Depending on the stimulus event of the colored frame presentation, the ERPs are not distinguishable, as seen in figure 9. Based on this identical pattern no further statistical test was deemed necessary.

CZ

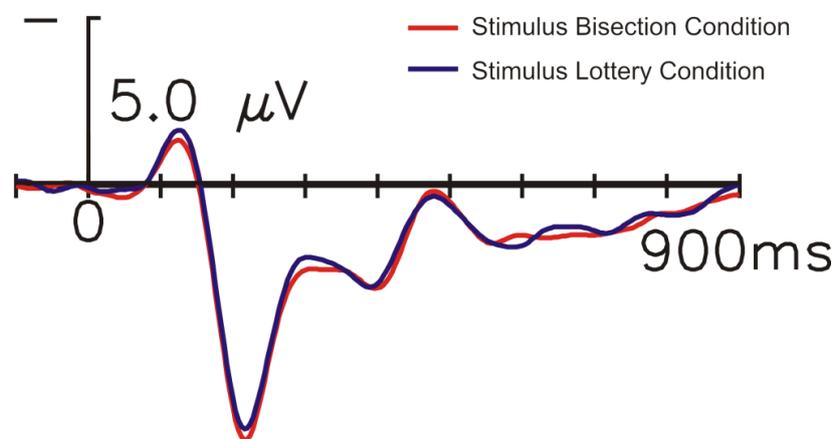


Figure 9: ERPs of the colored frame stimulus

Conclusion

The experimental analysis shows three considerable results. First, there are no obvious differences between the bisection method and the CE method at the presentation of risk as well as for the behavioral data. Second, differences appear in the ERPs concerning the inner number categories. Third, the category C+300 in particular produces a high positive potential for the YES answers under the lottery condition.

The characteristic of the evoked ERPs within the time period of 450-600 ms poststimulus shows that a P3 is existent. Given the assumption that a P3 reflects a task-related attention, the statement can be made that a higher positive potential represents higher attention on that stimulus.

The ANOVAs of the inner number stimulus revealed a very high significance for the time period of 450-600 ms, with the consequence that this stimulus will probably cause differences. ERPs of categories near the center position have a lower positive peak than categories further away from this center position, which is specifically category C+300 in the lottery condition. Thus, this stimulus induces a very high attention. Since in this category the sure payoff seems to be very attractive compared to the offered lottery, this potential could reflect the attractiveness of money or a pleasant surprise concerning the following sure payoff.

The statistical analysis of the behavioral data shows no difference between the results of the CE method and the bisection method. It can be assumed that the perceived center of 'joy' equals the certainty equivalent, $CU \approx CE$ accordingly. Hence, the utility of both is $u(CU) = u(CE) = \frac{1}{2}$ and not $u(CU) > u(CE)$. There is no evidence that probabilities in risky choices are underweighted, as stated in the Prospect Theory. The EEG data shows no different attention on both methods at the presentation of risk. Thus, a distinct process of probability weighting or risk evaluation cannot be found.

APPENDIX

Table 2: ANOVA for behavioral data

	Df	F-value	p-value
Condition (Cond)	1	0.307	0.588
Scaled Factors (Pot)	1.313	6.762	0.012
Inner Number Category (Diff)	1.771	71.087	0
Cond*Pot	1.39	0.221	0.722
Cond*Diff	2.544	2.012	0.137
Pot*Diff	5.593	0.87	0.515
Cond*Pot*Diff	5.064	0.84	0.527

Values corrected by Greenhouse-Geisser.

Table 3: Paired t-test for behavioral data

	t-value	Df	p-value
C-300: Lottery Condition Bisection Condition	1.367	15	0.192
C-150: Lottery Condition Bisection Condition	1.006	15	0.33
C-50: Lottery Condition Bisection Condition	0.723	15	0.481
Center: Lottery Condition Bisection Condition	-0.38	15	0.709
C+50: Lottery Condition Bisection Condition	-1.227	15	0.239
C+150: Lottery Condition Bisection Condition	-1.199	15	0.249
C+300: Lottery Condition Bisection Condition	-1.306	15	0.211

Table 4: ANOVAs of ERPs of inner number stimulus for YES-answers

Parasagittal locations	300-450 ms	450-600 ms	600-750 ms	750-900 ms
Anterior-Posterior (Ant)	F(1.56)=8.34 ^c	F(1.62)=7.71 ^c	F(1.78)=4.83 ^a	F(1.89)=3.35 ^a
Inner Number Category (Diff)		F(2.02)=12.17 ^d	F(2.62)=2.91 ^a	
Condition (Cond)				
Hemisphere (Hem)				
Diff*Cond				
Ant*Diff				F(4.59)=3.24 ^a
Ant*Cond	F(2.56)=3.73 ^a	F(1.93)=3.75 ^a		F(2.43)=4.41 ^a
Hem*Diff				
Hem*Cond				
Ant*Diff*Cond				
Hem*Diff*Cond	F(2.46)=3.97 ^a	F(2.26)=3.34 ^a		
Lateral locations	300-450 ms	450-600 ms	600-750 ms	750-900 ms
Anterior-Posterior (Ant)	F(1.42)=13.24 ^d	F(1.45)=12.89 ^d	F(1.64)=9.16 ^c	F(1.89)=7.16 ^c
Inner Number Category (Diff)		F(1.97)=9.44 ^d		
Condition (Cond)				
Hemisphere (Hem)				
Diff*Cond				
Ant*Diff		F(4.47)=4.85 ^d	F(4.29)=3.04 ^a	F(3.70)=2.96 ^a
Ant*Cond				
Hem*Diff				
Hem*Cond				
Ant*Diff*Cond				
Hem*Diff*Cond		F(2.25)=3.24 ^a		
Midline locations	300-450 ms	450-600 ms	600-750 ms	750-900 ms
Anterior-Posterior (Ant)	F(1.18)=7.71 ^b	F(1.19)=11.54 ^c	F(1.31)=10.28 ^c	F(1.44)=7.63 ^b
Inner Number Category (Diff)	F(2.52)=3.62 ^a	F(2.02)=13.15 ^d	F(2.77)=3.31 ^a	
Condition (Cond)				
Diff*Bed	F(2.10)=4.19 ^a	F(2.45)=2.92 ^a		
Ant*Diff	F(3.08)=3.11 ^a			
Ant*Bed				
Ant*Diff*Bed				

Values inside cells correspond to F values and df. ^ap<0.05; ^bp<0.01; ^cp<0.005; ^dp<0.001.

Blank cells were not significant (p>0.05). Values corrected by Greenhouse-Geisser.

Ant*Hem*Diff. Ant*Hem*Bed. Ant*Hem*Diff*Bed had no significant values

Table 5: ANOVAs of ERPs of inner number stimulus for NO-answers

Parasagittal locations	300-450 ms	450-600 ms	600-750 ms	750-900 ms
Anterior-Posterior (Ant)	F(1.45)=7.48 ^b	F(1.43)=6.88 ^b	F(1.61)=4.38 ^a	F(1.82)=3.26 ^a
Inner Number Category (Diff)		F(2.16)=6.28 ^c	F(2.27)=3.03 ^a	
Condition (Cond)				
Hemisphere (Hem)				
Diff*Cond				
Ant*Diff		F(3.50)=2.68 ^a		
Ant*Cond				
Hem*Diff				
Hem*Cond				
Ant*Diff*Cond			F(4.66)=2.87 ^a	F(5.30)=2.30 ^a
Hem*Diff*Cond				
Lateral locations	300-450 ms	450-600 ms	600-750 ms	750-900 ms
Anterior-Posterior (Ant)	F(1.51)=11.31 ^d	F(1.46)=11.51 ^d	F(1.52)=9.22 ^c	F(1.72)=8.47 ^c
Inner Number Category (Diff)		F(2.33)=4.39 ^b		
Condition (Cond)				
Hemisphere (Hem)				
Diff*Cond				
Ant*Diff		F(5.30)=2.41 ^a	F(5.59)=2.89 ^a	
Ant*Cond				
Hem*Diff			F(2.35)=4.19 ^a	
Hem*Cond				
Ant*Diff*Cond				F(5.57)=2.59 ^a
Hem*Diff*Cond			F(2.11)=3.67 ^a	
Midline locations	300-450 ms	450-600 ms	600-750 ms	750-900 ms
Anterior-Posterior (Ant)	F(1.25)=6.41 ^a	F(1.21)=10.77 ^c	F(1.28)=10.06 ^c	F(1.25)=8.07 ^b
Inner Number Category (Diff)		F(2.08)=7.19 ^c	F(2.24)=3.58 ^a	
Condition (Cond)				
Diff*Bed				
Ant*Diff	F(3.20)=2.78 ^a			
Ant*Bed				
Ant*Diff*Bed				

Values inside cells correspond to F values and df. ^ap<0.05; ^bp<0.01; ^cp<0.005; ^dp<0.001.

Blank cells were not significant (p>0.05). Values corrected by Greenhouse-Geisser.

Ant*Hem*Diff. Ant*Hem*Bed. Ant*Hem*Diff*Bed had no significant values

Table 6: Paired t-test for CZ and PZ electrode at C+300 and C-300

	t-value	Df	p-value
CZ 450-600 ms. C+300 Lottery Condition C+300 Bisection Condition	-2.192	15	0.045
CZ 450-600 ms. C-300 Lottery Condition C-300 Bisection Condition	0.092	15	0.928
PZ 450-600 ms. C+300 Lottery Condition C+300 Bisection Condition	-2.389	15	0.03
PZ 450-600 ms. C-300 Lottery Condition C-300 Bisection Condition	-0.167	15	0.869

Table 7: Correlation of behavioral data

	N	R	p-value
C-300: Lottery Condition Bisection Condition	16	0.879	0
C-150: Lottery Condition Bisection Condition	16	0.768	0.001
C-50: Lottery Condition Bisection Condition	16	0.683	0.004
Center: Lottery Condition Bisection Condition	16	0.623	0.01
C+50: Lottery Condition Bisection Condition	16	0.675	0.004
C+150: Lottery Condition Bisection Condition	16	0.593	0.015
C+300: Lottery Condition Bisection Condition	16	0.706	0.002

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