

Neurobiological Foundations of Decision-Making under Uncertainty

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Contents

Acknowledgments	i
List of Figures	iii
List of Tables	iv
Overview of papers and co-authorship	v
1 Introduction	1
2 Skin conductance responses in anticipation of gains and losses	17
3 Sensitivity towards fear of electric shock in passive threat situations	32
4 The framing effect and skin conductance responses	34
5 Exposure to prenatal testosterone moderates financial loss aversion	36
6 Overconfidence, incentives and digit ratio	57
7 Gender differences in ambiguity aversion under different outcome correlation structures	59
8 Problem gambling and risk preferences	61
Erklärung zum selbständigen Verfassen der Arbeit	87

List of Figures

2.1	Experimental design	21
2.2	Averaged ISCRs during the anticipation phase	23
2.3	Averaged ISCRs during the anticipation phase for different ranges of gains and losses	24
2.4	Averaged ISCRs per Euro during the anticipation phase	26
5.1	Risk preferences in the gain domain by probability and country	44
5.2	Risk preferences in the loss domain by probability and country	45
5.3	Risk preferences for mixed prospects by country	46
8.1	Risk preferences in the gain domain by probability and group	70
8.2	Risk preferences in the loss domain by probability and group	73
8.3	Risk preferences for mixed prospects by group	76
8.4	Estimated parameters for the probability weighting function by Prelec in the gain domain by group	77
8.5	Estimated probability weighting function by Prelec for the PG and C group	78
8.6	Estimated parameters for the probability weighting function by Prelec in the loss domain by group	78
8.7	Estimated parameters for the probability weighting function by Lattimore et al. in the gain domain by group	85
8.8	Estimated probability weighting function by Lattimore et al. in the gain domain for the PG and C group	85
8.9	Estimated parameters for the probability weighting function by Lattimore et al. in the loss domain by group	86

List of Tables

5.1	Mean of digit ratios by sex and country	44
5.2	Regression analysis for gains	47
5.3	Regression analysis for losses	48
5.4	Regression analysis for mixed prospects	49
8.1	Demographic variables, alcohol and cigarette consumption, and SOGS-scores by group	66
8.2	Regression analysis for gains based on groups	71
8.3	Regression analysis for gains based on SOGS-scores	72
8.4	Regression analysis for losses based on groups	74
8.5	Regression analysis for losses based on SOGS-scores	75
8.6	Regression analysis for mixed prospects based on SOGS-scores	76

Overview of papers and co-authorship

This thesis consists of the following seven papers:

Ring, P. and Schmidt, U. (2016). Skin conductance responses in anticipation of gains and losses. *Mimeo*.

Ring, P. and Kaernbach, C. (2015). Sensitivity towards fear of electric shock in passive threat situations. *PLOS ONE*, 10(3):e0120989. doi:10.1371/journal.pone.0120989.

Ring, P. (2015). The framing effect and skin conductance responses. *Frontiers in Behavioral Neuroscience*, 9:188. doi:10.3389/fnbeh.2015.00188.

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Neyse, L., Bosworth, S., Ring, P., and Schmidt, U. (2016a). Overconfidence, incentives and digit ratio. *Scientific Reports*, 6:23294. doi:10.1038/srep23294.

Friedl, A., Ring, P., and Schmidt, U. (2016). Gender differences in ambiguity aversion under different outcome correlation structures. *Theory and Decision*. doi:10.1007/s11238-016-9565-9

Ring, P., Kaernbach, C., Neyse, L., Probst, C. C., van Eimeren, T., Wolff, S., and Schmidt, U. (2016). Problem gambling and risk preferences. *Mimeo*.

Each co-author contributed significantly to the concept, design, and content of the articles. All persons entitled to authorship have been so named. For published papers, abstracts and digital object identifiers (doi) are given within the thesis.

Chapter 1

Introduction

Individuals typically cannot foresee all consequences of their actions. This is due to the fact that the consequences of one's actions depend on numerous variables and a decision-maker has only limited control over them. Among other things, social components (e.g., the behavior of others) or natural components (e.g., the weather) shape the outcome of an individual choice and are therefore important determinants which are outside the individual's reach (Platt and Huettel, 2008). This implies that most human decisions are made under a state which behavioral scientists refer to as uncertainty (Knight, 1921). Basically all decisions in our lives are made under this state. This not only holds for decisions on the individual level, such as crossing a street (a car might hit you), but also for decisions on the global level, such as mitigating climate change or dealing with financial crises. The latter group of examples is characterized by a large impact on economic growth and welfare. A thorough understanding of individual and collective behavior under uncertainties is necessary to sufficiently address these challenges and consequently has been a major concern of (behavioral) economists (Güth et al., 1982; Ostrom et al., 1992; Simon, 1959).

As indicated above, evaluating the probabilities of uncertain events is fundamental for human decision-making. In order to assess the likelihood of uncertain outcomes, people often apply rules of thumb, so-called judgmental heuristics. On the one hand, heuristics might be advantageous by shortening the decision process or by shifting attention to important aspects of a choice problem. On the other hand, they can lead to discrepancies between an individual's assessment of a situation and objective measures (Tversky and Kahneman, 1974). For example, when people estimate the likelihood of an event, they are typically influenced by current news reports. Media coverage, however, is usually high for rare events, but low for common events, and therefore not representative of the probability of an event. Consequently, people tend to overestimate the probability of rare events,

such as airplane accidents, and underestimate the probability of common events, such as car accidents. This mental short-cut is known as the availability heuristic (Tversky and Kahneman, 1973). Studying judgmental heuristics is an important field of research for at least two distinct reasons. First, they suggest insights into the psychology underlying human judgment and thereby improve our understanding of individual decision-making (Tversky and Kahneman, 1983). These insights might provide more realistic foundations for models of human behavior (Kahneman and Tversky, 1979). Second, they can explain aggregate market results, e.g., overconfidence potentially explains excessive trading in stock markets (Barber and Odean, 2001). While traditionally it has been proposed that cognitive processes are the main driver for behavior, growing evidence stresses the importance of biological underpinnings (Angie et al., 2011; Lerner et al., 2015; Ochsner and Phelps, 2007; Phelps et al., 2014).

Damasio (1994), for example, argues that emotional body signals play an important role in decision-making. According to his theory, changes in the somatic state of an individual do not only accompany human behavior, but they have direct influence. This is supported by empirical evidence from studies using the Iowa Gambling Task. In the Iowa Gambling Task, patients with damage to the ventromedial sector of prefrontal cortices and healthy control participants choose repeatedly cards from four available decks. While two decks are advantageous because they have a positive expected value, the other two decks are disadvantageous in the sense that they have a negative expected value. In the course of the experiment, healthy participants learn to choose cards from the advantageous decks. At the same time they produce anticipatory skin conductance responses (SCRs) preceding disadvantageous decisions even before they are able to verbally express the rule underlying this task. In contrast to that, patients do not follow an optimal strategy and also lack the aforementioned body reactions. Some of them, however, are able to verbally identify the advantageous decks at the end of the experiment. Based on this finding, Damasio and colleagues conclude that overt reasoning might not be enough to make advantageous decisions and that emotional body reactions appear necessary (Bechara et al., 1996, 1997, 2000, 2005; Damasio, 1994). Besides emotions, many other biological factors have an impact on behavior, such as hormones (Bröder and Hohmann, 2003; Brunnelieb et al., 2016; Chavanne and Gallup, 1998; Cueva et al., 2015; Margittai et al., 2016) or genes (Kreek et al., 2005; Kuhnen and Chiao, 2009; Stoel et al., 2006).¹ Taken together with the work by Damasio and colleagues, these findings stress the importance of biological factors on decision-making.²

¹While there is evidence for a causal relation between hormones and decision-making, studies on genes and decision-making currently provide only evidence for a correlation.

²This, however, does not mean that other aspects have no influence on behavior. It is well known that cultural and social influences are important. For an overview, please refer to the Dual Inheritance Theory (Durham, 1991).

The motivation of this thesis is to study the connection between the two aforementioned strands of research. In particular, it focuses on well-known heuristics of individual decision-making and tries to find biological factors that accompany them. For this purpose, research methods from different scientific fields – including behavioral economics, psychology, neuroscience, biology, and anthropology – are applied. This interdisciplinary approach is supposed to provide holistic insights into processes underlying individual behavior. Thereby, this thesis contributes to the field of behavioral and neuroeconomics. The following four well-known characteristics of individual decision-making are addressed within this thesis:

Loss aversion

Loss aversion refers to a tendency that people give more weight to losses than to gains of equal size (Kahneman and Tversky, 1979). Numerous studies have provided an empirical basis for loss aversion on the behavioral level (Ganzach and Karsahi, 1995; Kahneman et al., 1990), the psychophysiological level (Hochman and Yechiam, 2011; Sokol-Hessner et al., 2009), the brain level (De Martino et al., 2010; Tom et al., 2007) and in self-reported feelings (McGraw et al., 2010). Based on the accumulated evidence, loss aversion has been used as an explanation for a variety of other empirical findings both from the laboratory and the field, among others are the endowment effect (Thaler, 1980) and the status quo bias (Samuelson and Zeckhauser, 1988). Furthermore, it is an integral part of prospect theory, the dominating theory of decision-making under risk (Kahneman and Tversky, 1979).

Framing

Framing describes a judgmental heuristic where individuals react systematically different to the same choice problem depending on how it is presented. For example, Tversky and Kahneman (1981) explore how framing affects participants' decisions in a hypothetical life and death situation. In their choice problem, participants choose between two treatments for 600 potential victims of a deadly disease. It is predicted that treatment A would lead to 400 deaths, whereas treatment B has a 33% chance that no one would die, but a 66% chance that everyone would die. This hypothetical choice is presented either in a positive frame emphasizing how many people would survive or in a negative frame emphasizing how many people would die. In a positive frame, 72% of the participants choose treatment A. In a negative frame, by contrast, only 22% of the participants opt for treatment A. In this example, participants are risk seeking in the loss domain but risk averse in the gain domain. This finding violates rational economic theory, which

assumes that changes in frames do not alter behavior in a systematic way. Framing effects are robust findings that are reported in different settings (Gächter et al., 2009; Johnson et al., 1993).

Overconfidence

Social comparison theory suggests that individuals make predictions in both social and individual contexts every day. For example, the decision to participate in a competition is driven by predictions about one's own abilities relative to the competitors' (Festinger, 1954; Niederle and Vesterlund, 2007). While under certain circumstances it appears beneficial to base such a decision on accurate judgments, in some situations it may be advantageous to be overconfident (Mannes and Moore, 2013). Among other things, overconfidence can have a positive impact on one's own motivation and a detrimental impact on competitors' motivation (Bénabou and Tirole, 2002; McKay and Dennett, 2009; Wrangham, 1999). If this is the case, overconfidence increases the probability of success and therefore could be seen as an adaptive survival strategy (McKay and Dennett, 2009). Empirically, overconfidence has a positive impact on success in academia (Stankov et al., 2012) and war (Johnson and Fowler, 2011). Additionally, it seems to promote human well-being by giving oneself a positive view of the future (Taylor and Brown, 1988, 1994). It does not, however, increase the chances of success in every situation, because overconfident beliefs are by definition inaccurate (Plous, 1993). Therefore, they can be exploited by rational agents (Della Vigna and Malmendier, 2006). For instance, overconfident investors trade too much and thereby reduce their earnings (Barber and Odean, 2001). Overly optimistic beliefs about the future potentially explain the high rates of business failure (Camerer and Lovallo, 1999). These findings suggest that the adaptiveness of overconfidence is highly sensitive to the strategic context in which it is deployed.

Ambiguity aversion

Ambiguity aversion describes the tendency that individuals prefer known probability distributions over unknown probability distributions. This behavior was first reported upon by Ellsberg (1961). Since then, it has become an important explanation for a variety of observed phenomena, among others the equity premium puzzle (Collard et al., 2011; Rieger and Wang, 2012) and the stock market participation puzzle (Dow and Werlang, 1992; Easley and O'Hara, 2009). One possible explanation for the bias towards ambiguity is that individuals prefer options about which they are best informed (Frisch and Baron, 1988).

In order to study the neurobiological foundations of the above described judgmental heuristics, the following research methods are applied:

Laboratory experiments

Laboratory experiments are an integral part of the behavioral and neuroeconomic toolbox. During an experiment, participants typically make a sequence of decisions in a controlled environment. This approach is supposed to reveal their preferences (Camerer and Loewenstein, 2004; Camerer et al., 2005). Besides behavior, brain activity or physiological responses can be recorded during the experimental procedure and subsequently integrated into the analysis. All experiments within this thesis are incentivized,³ but they apply different types of incentives. While the studies in Chapter 2, 5, 6, 7 and 8 use monetary payments as incentives, the studies in Chapter 3 and 4 are incentivized by means of unpleasant, but not painful, electric shocks. Due to ethical concerns, participants rarely put their own money at stake in an experiment, which makes it difficult to study decision-making in the loss domain. Therefore, unpleasant electric shocks are a commonly used tool in neuroeconomics to simulate real losses in a laboratory environment (Berns et al., 2008).⁴

Electrodermal activity

Electrodermal activity is a commonly used psychophysiological indicator for emotional arousal (Boucsein, 1992). It has been shown to be sensitive to monetary outcomes and cognitive biases (Bechara et al., 2005; Boucsein, 1992; Ring, 2015). Furthermore, it seems to have substantial impact on individual decision-making (Damasio, 1994). Within this thesis, electrodermal activity is analyzed by means of continuous decomposition analysis (Benedek and Kaernbach, 2010). This approach separates SCRs into a phasic (stimulus-driven) and a tonic (stimulus-independent) part by taking the characteristics of the underlying sudomotor nerve activity into account. The analysis of electrodermal activity within this thesis focuses on its phasic components.

³In contrast to psychological experiments, behavioral and neuroeconomic experiments are typically incentivized. The main argument for using incentives is that it makes laboratory experiments more comparable to real-world behavior (Ariely and Norton, 2007).

⁴The research design was approved by the Ethics Committee of the German Psychological Society and performed in agreement with the Declaration of Helsinki. The ethic statements are within the papers.

Digit ratio

The ratio between the lengths of the second and the fourth digits of hands (2D:4D digit ratio) has been proposed as bio-marker of prenatal testosterone exposure. Prenatal testosterone exposure is thought to affect the brain development and thereby subsequent behavior (Manning et al., 1998; Manning, 2002). The relationship between digit ratio and prenatal testosterone is negative, i.e., a low digit ratio indicates a high level of prenatal testosterone exposure and vice versa (Lutchmaya et al., 2004). Among other things, digit ratios are negatively correlated with physical fitness (Hönekopp et al., 2006) and facial attractiveness (Ferdenzi et al., 2011). For the measurement of the digit ratio, both hands are scanned with a high resolution scanner. Then, the length of the second and fourth digits are measured from the basal crease to the finger tip in a photo editor. Usually this task is performed by two independent raters and the mean of both rates are used for the subsequent analysis (Neyse and Brañas-Garza, 2014). This approach is supposed to reduce individual measurement errors.

Evolutionary theory

From a biological point of view, the human species is the result of an ongoing evolutionary process (Darwin and Wallace, 1858; Evans et al., 2005). Taking the evolutionary process and the resulting requirements into account can help to explain observed behavior and judgmental heuristics (Buss, 1989). One example is the idea that men and women had different biological requirements during the evolutionary past and that this might contribute to observed gender differences in behavior (Trivers, 1972). Schmidt et al. (2015) show theoretically and empirically that this framework can explain gender differences in risk taking behavior.

Special participant group: Problem gamblers

Research involving special participant groups – e.g., patients with psychiatric or neurological disorders – can provide insights into the decision-making processes of the general population (Damasio, 1994). For example, if patients with an identified brain lesion in region X show impaired decision-making abilities on a specific task, this might indicate that region X is used to do this task (Camerer et al., 2004). This thesis involves a study on problem gamblers' risk taking behavior. In general, gambling is a challenge for classical theories of decision-making under risk, because the odds are typically against the gambler. Still many people gamble and some continue with gambling although it has severe negative consequences for them, such as debt overload (Pietrzak et al.,

2005), involvement in criminal activities (Yeoman and Griffiths, 1996) or social isolation (Trevorrow and Moore, 1998). From this perspective, (problem) gambling can serve as a test case for new theories of decision-making under risk (Camerer et al., 2004).

Having outlined the research field and the applied methods, the next paragraphs give an overview of the content of the seven papers of this thesis and describe how they are related to each other.

The first paper studies SCRs during the anticipation of monetary gains and losses in a roulette task. Under the loss aversion hypothesis one might expect that the anticipation of a loss would lead to a higher level of emotional arousal than the anticipation of a gain of equal size. Contrary to this prediction, we found that SCRs during the anticipation phase were not significantly different between gains and losses of equal size. SCRs, however, were sensitive towards the magnitude of the bet size. This currently unpublished manuscript is a joint work with Ulrich Schmidt.

The second paper aims at a better understanding of how probabilities are perceived by individuals in terms of emotional body reactions. In order to analyze emotional body reactions preceding negative events with varying probability of occurrence, we have our participants play a two-stage card game. The first stage of the card game reveals the probability of receiving an unpleasant electric shock. The second stage applies the electric shock with the previously announced probability. SCRs increase monotonically with the probability of receiving an electric shock during the anticipation phase. This paper is a joint work with Christian Kaernbach and it is published as: Ring, P. and Kaernbach, C. (2015). Sensitivity towards fear of electric shock in passive threat situations. *PLOS ONE*, 10(3):e0120989. doi:10.1371/journal.pone.0120989.

Based on this finding, the third paper studies the framing effect and its emotional underpinnings. In this study, participants are exposed to different probabilities of receiving an unpleasant electric shock. Information about electric shock probabilities is either positively or negatively framed. I find evidence for a relationship between emotional body reactions and the framing effect. Under negative frames, participants show significantly higher SCRs while waiting for an electric shock to be delivered than under positive frames. This finding is important for behavioral and neuroeconomics, because it shows that framing effects occur in well-educated and well-informed individuals on a low emotional level. This is a single-author paper and it is published as: Ring, P. (2015). The framing effect and skin conductance responses. *Frontiers in Behavioral Neuroscience*, 9:188. doi:10.3389/fnbeh.2015.00188.

The fourth paper studies a potential relationship between digit ratio and risk taking. This study is motivated by empirical findings indicating gender differences in risk preferences.

Typically, it is reported that women are more risk and loss averse than men. This potentially indicates an underlying biological mechanism. One potential mechanism is prenatal testosterone, which is thought to have an impact on the brain development and thereby on subsequent sex-typical behavior. Our findings reveal that men with lower digit ratios (i.e., a higher level of prenatal testosterone) show lower degrees of loss aversion. This offers a potential explanation for the observed gender differences in risk taking. This currently unpublished manuscript is a joint work with Levent Neyse, Ulrich Schmidt, Ferdinand M. Vieider, Catharina C. Probst, Christian Kaernbach and Thilo van Eimeren.

The fifth paper contributes to a better understanding of the biological underpinnings of overconfidence by analyzing performance predictions in the Cognitive Reflection Test with and without monetary incentives. The main finding of this study is that men with low digit ratios are more sensitive towards different incentive structures. In the un-incentivized treatment, we find that males with low digit ratios, on average, are significantly more overconfident about their performance. In the incentivized treatment, however, we observe that males with low digit ratios, on average, are less overconfident about their performance. These effects are not observed in females. This paper is a joint work with Levent Neyse, Steven Bosworth and Ulrich Schmidt and it is published as: Neyse, L., Bosworth, S., Ring, P., and Schmidt, U. (2016). Overconfidence, incentives and digit ratio. *Scientific Reports*, 6:23294. doi:10.1038/srep23294.

The sixth paper studies the impact of different outcome correlation structures on gender differences in ambiguity aversion. From an evolutionary perspective, we expected that men would be more sensitive to changes in outcome correlation structures than women. In the evolutionary past, men had to be more concerned about relative outcomes, since their reproductive success mainly depended on their relative standing within society; women, by contrast, had to be more concerned about absolute outcomes, because their reproductive success was mainly linked to their access to resources for themselves and their children. This hypothesis was supported by the empirical evidence. This currently unpublished manuscript is a joint work with Andreas Friedl and Ulrich Schmidt.

Finally, the seventh paper studies financial risk preferences of problem gamblers including their risk attitudes in the gain and loss domain, their degree of loss aversion and their perception of probabilities. To our knowledge, this is the first study which provides a comprehensive analysis of their financial risk behavior. Our findings suggest that problem gamblers are systematically more risk taking and less sensitive towards changes in probabilities in the gain domain only. Neither their degree of loss aversion nor their risk attitudes in the loss domain are significantly different from the controls. These novel insights provide an explanation why some individuals persist in gambling

activities – despite their severe negative consequences – while the general population does not. Furthermore, we discuss potential medical applications of these findings. This currently unpublished manuscript is a joint work with Christian Kaernbach, Levent Neyse, Catharina C. Probst, Thilo van Eimeren, Stephan Wolff and Ulrich Schmidt.

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Chapter 2

Skin conductance responses in anticipation of gains and losses

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Mimeo

Abstract

Anticipating future outcomes is fundamental for decision-making. Traditionally, it has been proposed that the anticipation of a loss looms larger than the anticipation of a gain of equal size. This phenomenon has been referred to as loss aversion. Recent evidence, however, indicates that individuals often give similar weight to gains and losses, and thereby challenges the validity of the loss aversion hypothesis. We examine skin conductance responses – a psychophysiological marker for emotional arousal – during the anticipation of gains and losses in a roulette task. This approach is supposed to give insights into the emotional states that participants experience while they anticipate a gain or loss. In contrast to most previous research, gains and losses were separated from each other and symmetric in magnitude. We found that integrated skin conductance responses during the anticipation phase increased with the magnitude of both gains and losses. Contrary to the predictions of the loss aversion hypothesis, the anticipation of a loss did not elicit stronger reactions than the anticipation of a gain of equal size. By

an ex-post restriction of the loss domain, we found that participants were more aroused per Euro to losses relative to gains. This finding has previously been interpreted as an indicator of loss aversion. We show that it results from a smaller range of losses compared to gains rather than from a general aversion to losses.

Introduction

Loss aversion is a well-studied phenomenon in the behavioral sciences. It refers to a tendency that people give more weight to losses than to gains of equal size (Kahneman and Tversky, 1979). Numerous studies have provided an empirical basis for loss aversion on the behavioral level (Ganzach and Karsahi, 1995; Kahneman et al., 1990), the psychophysiological level (Hochman and Yechiam, 2011; Sokol-Hessner et al., 2009), the brain level (De Martino et al., 2010; Tom et al., 2007) and in self-reported feelings (McGraw et al., 2010).¹ Based on the accumulated evidence, loss aversion has been used as an explanation for a variety of other empirical findings both from the laboratory and the field, among others are the endowment effect (Thaler, 1980) and the status quo bias (Samuelson and Zeckhauser, 1988).² Furthermore, it is an integral part of prospect theory, the dominating theory of decision-making under risk (Kahneman and Tversky, 1979).

Recently, the validity of the loss aversion hypothesis has been challenged (Ert and Erev, 2013; Gal, 2006; Harinck et al., 2007; Morewedge et al., 2009; Walasek and Stewart, 2015; Yechiam and Hochman, 2013; Yechiam et al., 2014). While some authors fail to replicate its predictions (Erev et al., 2008; Harinck et al., 2007), others provide alternative explanations. Gal (2006), for example, describes a rejection of a lottery with equal chances of losing and winning as a status quo bias rather than an aversion to losses. Yechiam et al. (2014) explain loss aversion in self-reported feelings by a complaint bias, i.e., a tendency to complain more about losses than to praise gains. By incentivizing self-reported feelings they are able to reduce this bias.

Moreover, methodological concerns regarding experimental designs have been raised. In several studies, the magnitude of gains and losses was unbalanced (Sokol-Hessner et al., 2009; Tom et al., 2007). Typically, the range of losses was smaller than the range of gains (max. gain: 30\$ - max. loss: 24\$ in Sokol-Hessner et al. (2009); max. gain: 40\$ - max. loss: 20\$ in Tom et al. (2007)). Therefore, a diminishing sensitivity to increased bet sizes or a sensitivity to ranks within the set of alternatives could also explain the finding of a loss aversion (Hochman and Yechiam, 2011; Walasek and Stewart, 2015). Walasek and Stewart (2015) are able to reverse loss aversion by manipulating the range of gains and losses. In addition, previous studies supporting loss aversion are not able to differentiate an increased sensitivity to negative outcomes from an increased sensitivity to performance failure (Critchley et al., 2005).

¹Rick (2011) provides a summary of the literature on loss aversion covering all four areas.

²Camerer (2000, 2005) gives an overview on phenomena that potentially can be explained by loss aversion.

In the current study, we aimed to disentangle the emotional states that participants experience while they anticipate a potential gain or loss. To do so, participants played a roulette task while their skin conductance responses (SCRs) were recorded. Electrodermal activity (EDA) is a commonly used psychophysiological indicator for emotional arousal (Boucsein, 1992). It has been shown to be sensitive to monetary outcomes and cognitive biases (Bechara et al., 2005; Boucsein, 1992; Ring, 2015). Contrary to most previous studies, gains and losses were separated from each other and symmetric in magnitude. Furthermore, we focus on the anticipation phase rather than on the realization phase, and therefore exclude an increased sensitivity towards performance failure as a potential explanation for our findings.

Our analysis will proceed in two steps: Firstly, we analyze SCRs during the anticipation phase in a balanced design. Secondly, we restrict our data set ex-post such that maximal gains and maximal losses differ. This approach is supposed to make our results comparable to findings from previous studies with asymmetric ranges of gains and losses. We calculate the EDA per Euro for gains and losses. This procedure follows the protocol by Sokol-Hessner et al. (2009), which has been the main study reporting loss aversion in EDA.

Method

Participants

Thirty-five participants (gender: 18 female, 17 male, age: $M = 24.7$, $SD = 4.1$) were recruited from the student population of the Kiel University. Participants gave written informed consent and could decide to discontinue participation at any time. All participants had normal or corrected to normal vision and no participant reported any other sight defect.

Design

Participants attended a single session at the Psychology Department of the Kiel University. They played a roulette task on a 17-inch computer screen. At the beginning of each round, the participants saw a roulette wheel with four red and four green segments. Additionally, they were given information about the size of the following bet. Participants were asked to decide on the color on which they wanted to place the bet while the alternative color resulted always in an outcome of zero. The decision initiated the anticipation phase, which was characterized by a spinning wheel. Between the start of the anticipation phase and the decision was a 2-second (s) pause to exclude skin conductance (SC) artifacts

due to hand movement. The anticipation phase lasted 7 s. The wheel stopped on one of the eight segments and the result was displayed for 2 s. After 3 s with a fixation cross, the next trial started. Figure 2.1 gives a graphical representation of the experimental design.

Participants played bets with four different sizes (5, 10, 15 and 20 Euro). Each size appeared as a gain and a loss within a block. Each block was presented three times such that there was a total of 24 rounds. The order within a block and the outcome of each lottery were randomly determined.

Participants were first instructed in written form and then verbally. The average duration of one session was approximately 30 minutes. The software package Psychtoolbox-3 (www.psychtoolbox.org) running on Matlab 8.6 (MathWorks Inc., United States) was used for stimulus presentation and response acquisition.

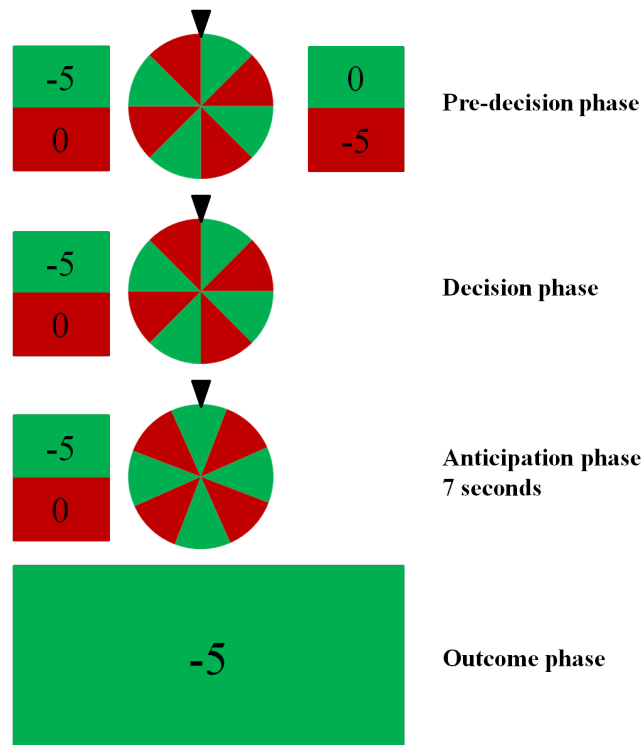


FIGURE 2.1: Experimental design.

Procedure

Participants were endowed with 20 Euro and asked to put this money into their pocket. Afterwards, they were informed that they would play 2 test rounds and approximately 20 payment relevant rounds of the aforementioned roulette task. No specific information about the total number of rounds was given, in order to remove the risk of a last round effect. At the end of the experiment, one round was randomly chosen to determine the

final payment. In the case of a loss, participants had to give (part of) their endowment back to the experimenter.

Skin conductance measurement

SC data were recorded with a 16-channel bioamplifier (Nexus-16, Mind Media B.V., the Netherlands) and the corresponding recording software Biotrace (Mind Media B.V.). Two flat AG-AGCL 10-mm-diameter electrodes were placed at the medial phalanges of digits II and III of the non-dominant hand. Following common recommendations (Boucsein et al., 2012), the electrode sites were prepared with an isotonic paste (TD-246, Discount Disposables, U.S.A.) and there was a 5-minutes pause between attaching the electrodes and starting recording. SC data were sampled at 32 Hz.

Data analysis

SC data were analyzed using Ledalab (www.ledalab.de) applying continuous decomposition analysis to disentangle phasic components from tonic activity. The integrated SCRs (ISCRs), which are defined as the time integrals of the phasic drivers, were used as measures for the phasic electrodermal responses to a given stimulus (Benedek and Kaernbach, 2010). Following the protocol by Sokol-Hessner et al. (2009), ISCRs at outcome in units of microsiemens \times seconds ($\mu S \times s$) were square-root transformed to reduce skewness ($\sqrt{(\mu S \times s)}$).

Symmetric range of gains and losses

For the first part of the analysis, we computed ISCRs for the 7-s time window during the anticipation phase. This measure was supposed to reflect the anticipatory reactions towards potential gains and losses.

Asymmetric ranges of gains and losses

For the second part of the analysis, we restricted the range of maximal gains and losses. This was done, because previous studies often used asymmetric ranges of gains and losses and we wanted to study the effect of these manipulations. In order to make the emotional reactions towards gains and losses comparable to each other in these settings, we normalize ISCRs by the size of the bet, giving each participant an average Gain ISCRs score and average Loss ISCRs score in units of $\sqrt{(\mu S \times s)}/Euro$. This approach also follows the protocol by Sokol-Hessner et al. (2009).

Statistical analysis

For ANOVA analysis, where necessary degrees of freedom were corrected by means of Greenhouse-Geisser (G-G) method and unless indicated otherwise Bonferroni post-hoc tests were used for pair-wise comparisons of means.

Results

Symmetric range of gains and losses

Figure 2.2 shows the averaged ISCRs for the anticipation phase for the different bet sizes and separately for the gain and loss domain. A Two-Way ANOVA for repeated measurements revealed a significant main effect for the size of the bet [G-G corrected ($\epsilon = 0.90$): $F(2.71, 92.31) = 7.82$, $p < 0.001$, $n_p^2 = 0.19$]. Post-hoc tests revealed a significant difference between a bet size of 5 and 20 Euro ($p < 0.001$) and between 5 and 15 Euro ($p = 0.02$). The domain of the bet, i.e., whether it was a loss or a gain, did not have a significant main effect: $F(1, 34) = 1.73$, $p = 0.20$, $n_p^2 = 0.05$. There was also no significant interaction between the bet size and the domain [G-G corrected ($\epsilon = 0.88$): $F(2.63, 89.47) = 0.50$, $p = 0.69$, $n_p^2 = 0.01$].

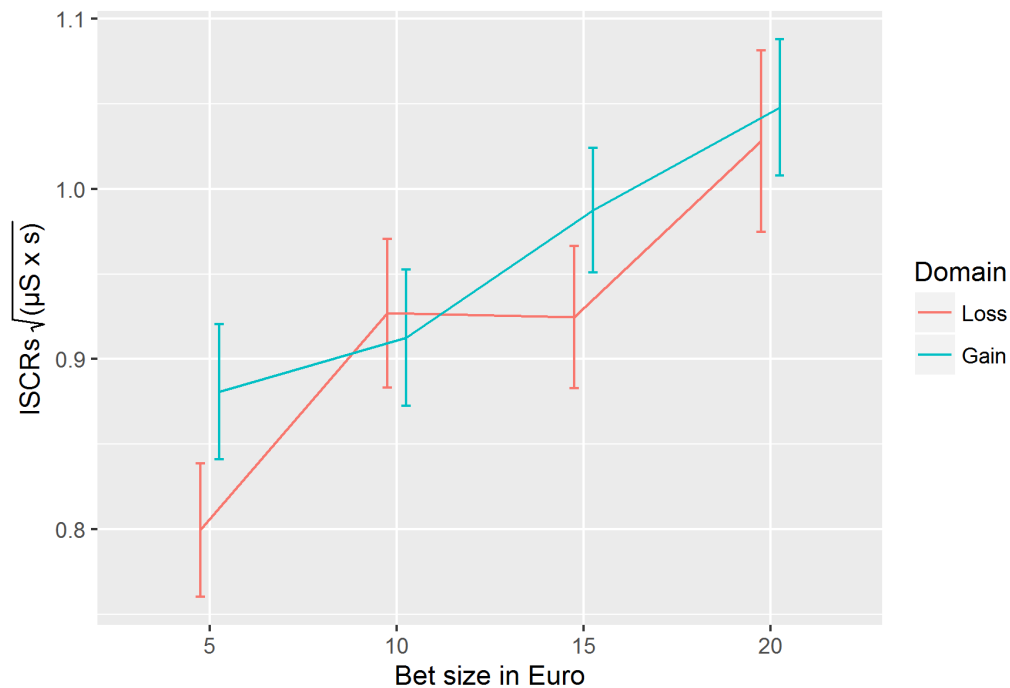


FIGURE 2.2: Averaged ISCRs during the anticipation phase. Error bars indicate the within-participant standard errors of the means.

Asymmetric ranges of gains and losses

For this part of the analysis, we restricted the ranges of gains and losses. In previous studies, gains and losses were not symmetric in magnitude. This could be an explanation for diverging findings. Using data sets where the maximal gain was larger than the maximal loss, we found that losses on average were more arousing per Euro than gains ([+20:-10 Euro]: Loss - Gain = $0.03 \sqrt{(\mu S \times s)}/Euro$, $t(34) = 5.23$, $p < 0.001$; [+20:-15 Euro]: Loss - Gain = $0.01 \sqrt{(\mu S \times s)}/Euro$, $t(34) = 2.13$, $p = 0.04$, paired t-Tests, uncorrected). Using data sets where the maximal gain was smaller than the maximal loss, we found that losses on average were less arousing per Euro than gains ([+10:-20 Euro]: Loss - Gain = $-0.04 \sqrt{(\mu S \times s)}/Euro$, $t(34) = -7.08$, $p < 0.001$; [+15:-20 Euro]: Loss - Gain = $-0.02 \sqrt{(\mu S \times s)}/Euro$, $t(34) = -4.63$, $p < 0.001$, paired t-Tests, uncorrected). These findings are illustrated Figure 2.3.

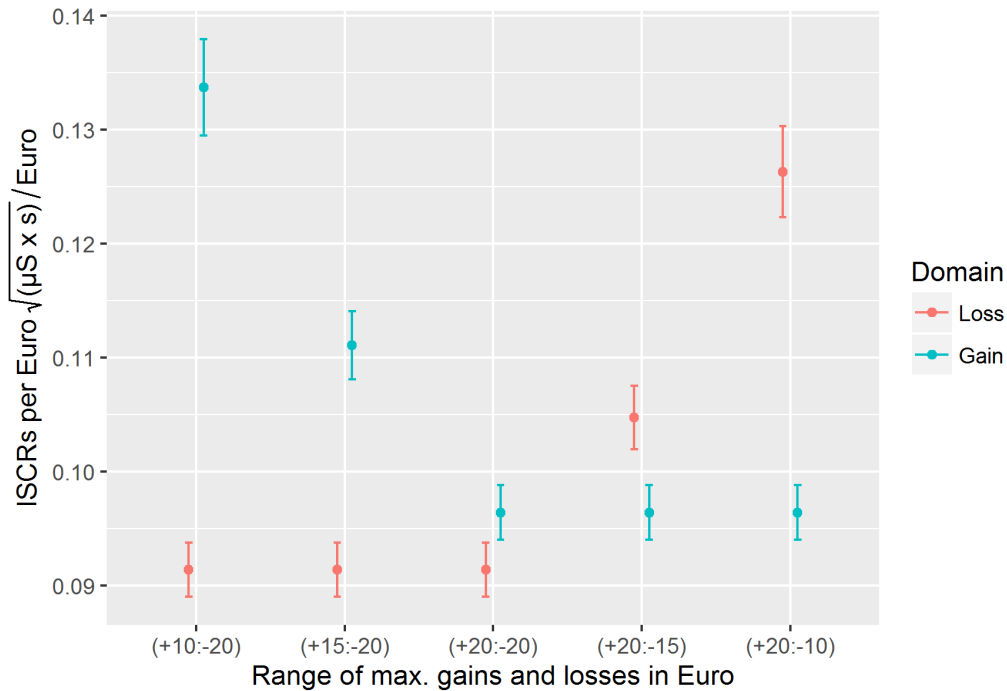


FIGURE 2.3: Averaged ISCRs during the anticipation phase for different ranges of gains and losses. Error bars indicate the within-participant standard errors of the means.

Discussion

We find that anticipatory ISCRs increase with the magnitude of the bet size for both gains and losses. We, however, do not find significant differences between gains and loss of equal size. When the maximal gain is larger than the maximal loss, we are able to replicate a finding which has commonly been taken as an indicator for loss aversion in

EDA. When the maximal gain is smaller than the maximal loss, this finding is reversed. In the following part of the paper, both results are discussed. Finally, limitations of our research approach are described.

Symmetric range of gains and losses

In the first part of the analysis, we found that anticipatory ISCRs increase with the magnitude of the bet size in the gain and loss domain. This finding extends previous research showing increased sensitivity towards bets with larger magnitudes (Studer and Clark, 2011). To our knowledge, we are the first to show that this sensitivity exists for both gains and losses. This sensitivity appears relevant for several theories on judgment and decision-making.

First of all, our finding relates to the somatic marker hypothesis (Bechara et al., 1997, 2005; Damasio, 1994). The somatic marker hypothesis states that emotional body signals have a behavior guiding functioning. In the Iowa Gambling Task (IGT), participants show increased EDA preceding disadvantageous decisions. This finding is not directly comparable to ours, because we study EDA after the decision. Moreover, the magnitude of potential gains and losses was explicitly presented in our task. This is not the case in the IGT. Importantly, disadvantageous decisions in the IGT were associated with gains and losses of a higher magnitude compared to the advantageous decisions. Our findings are compatible because we also find that an increase in the bet size leads to higher anticipatory EDA.

Secondly, in the anticipatory affect model by Knutson and Greer (2008), the anticipation of uncertain gains increases positive arousal (e.g., excitement) and thereby approaching behavior. Uncertain losses trigger negative arousal (e.g., anxiety) and thereby avoiding behavior. In contrast to the somatic marker hypothesis, no mediating body loop is required. In line with the predictions of this model, we find an increase in EDA for both gains and losses. EDA is generally insensitive towards positive and negative arousal and therefore no conclusive statement is possible as to whether we indeed observe two separate systems (Boucsein, 1992).

Asymmetric ranges of gains and losses

In the second part of our results section, we were able to replicate a finding by Sokol-Hessner et al. (2009). The finding that losses elicit larger EDA per Euro than gains – under the restriction of the loss domain – has commonly been interpreted as an indicator for loss aversion. In our experiment, we do not find a tendency that losses are more

severe than gains in terms of ISCRs if we consider the whole data set. Figure 2.4 shows the average ISCRs per Euro for the different bet sizes. For illustrative purposes gains and losses were averaged. EDA per Euro is smaller for higher bets, because a line through the ISCRs for different bet sizes has an intercept larger than zero (see Figure 2.2). A normalization of EDA by the size of the bets necessarily implies higher EDA per Euro for smaller bet sizes. If gains and losses are unbalanced such that average gains are larger than average losses, a finding in favor of the loss aversion hypothesis is obtained. The square-root transformation of EDA, as described in the Method section above, adds to this finding.

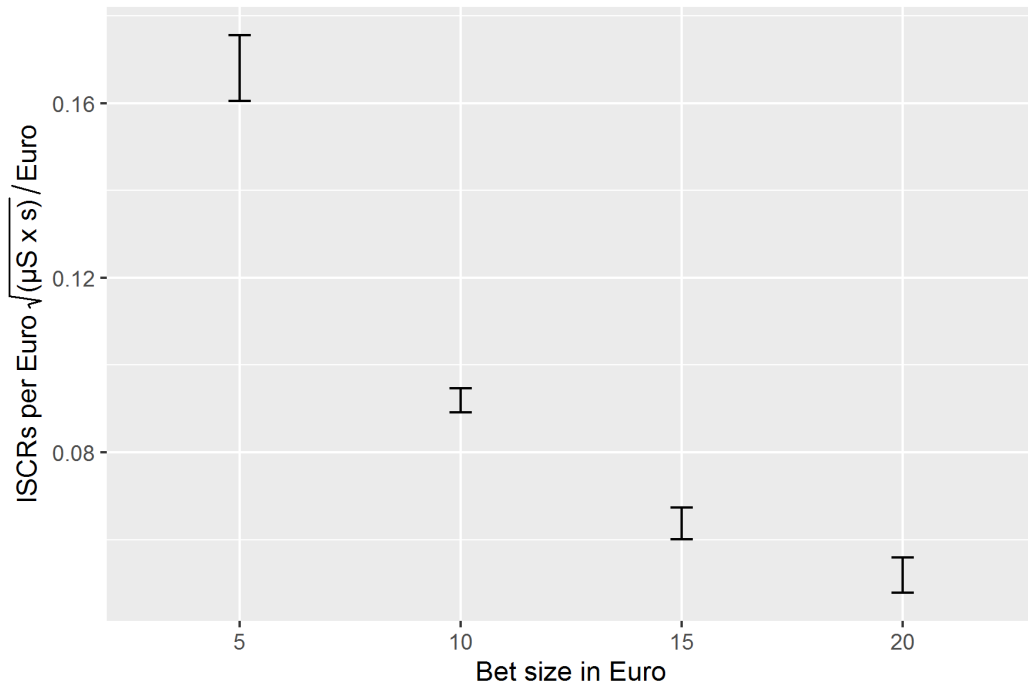


FIGURE 2.4: Average ISCRs per Euro during the anticipation phase for different ranges of gains and losses. Error bars indicate the within-participant standard errors of the means.

While we found a general sensitivity of EDA towards gains and losses, we did not find that gains weight more than losses. This finding is in line with recent evidence on the behavioral level indicating that losses do not loom larger than similar gains. To our knowledge, we are the first study reporting this finding on the psychophysiological level.

Contrary to our results, Hochman and Yechiam (2011) found increased activation of the autonomic nervous system – measured by pupil dilation and increased heart rate – after losses compared to similar gains. Because this finding can also be explained by a sensitivity to performance failure, they include a control condition without losses. This approach was supposed to rule out that a participant’s loss of a bet explains an increased activation of the autonomic nervous system. A relative loss (i.e., winning the smaller

amount of money) had no effect on the autonomic nervous system. This control condition, however, does not necessarily provide an argument in favor of the loss aversion hypothesis. If the autonomic nervous system is sensitive towards the magnitude of gains and losses – as it is in our study – then finding no difference between the smaller and the bigger gain in the control condition, can be the result of a sensitivity towards performance failure. Therefore, it can not be taken as a proof in favor of the loss aversion hypothesis.

Limitations

In the following part of the paper, potential limitations of our study are discussed. First of all, at the beginning of the experiment, participants were endowed with money. This money could be lost in the roulette task. It is possible that participants did not feel attached to this money and therefore losing it might not have felt like a real loss. This is a general problem of studying the loss domain in laboratory settings and it is a limitation which other studies on loss aversion face as well (Berns et al., 2008). One possible solution could be to let the participants work for their endowment (Gill and Prowse, 2012). This potentially increases their sense of ownership (Gneezy and Potters, 1997).

Furthermore, we are not able to make any statement to which extend the observed arousal impacts consequent choices. Recent theories on judgment and decision-making stress that arousal or the observed emotional body reactions should have an impact on behavior. We restricted ourselves to a passive situation, in order to avoid any contagion of the recorded emotional body reactions due to active decision processes. As indicated by the anticipatory affect model, it might be possible that we observe two different types of arousal in the gain and loss domain. It does not, however, necessarily imply that they are directly comparable to each other in terms of the observed EDA. Therefore, more research is needed in order to understand the underlying mechanisms and to verify whether a unique or two separate systems are at work.

Most studies focus on the realization phase rather than on the anticipation phase. One important debate within the literature on loss aversion, however, is whether losses are actually experienced more intensely than comparable gains or whether just the anticipation matters. Kermer et al. (2006) found that people rated the hedonic impact of an experienced loss as being nearly equal to an experienced gain. Without the real experience, ratings for losses were about twice as strong as for gains. It appears natural to assume that a loss aversion should manifest itself in the anticipation phase rather than in the realization phase. Therefore, we focus on the anticipation phase in our study.

Moreover, we study gains and losses separately in order to disentangle their impact on emotional arousal. McGraw et al. (2010) claim that loss aversion is more likely to appear,

if gains and losses are directly compared with each other. Without this direct comparison, loss aversion might be reduced. In our design, gains and losses do not appear together in one screen, which might hinder a direct comparison. Still, by using monetary incentives in a repeated design, it seems unlikely that participants fail to make a direct comparison.

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Chapter 3

Sensitivity towards fear of electric shock in passive threat situations

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Abstract

Human judgment and decision-making (JDM) requires an assessment of different choice options. While traditional theories of choice argue that cognitive processes are the main driver to reach a decision, growing evidence highlights the importance of emotion in decision-making. Following these findings, it appears relevant to understand how individuals assess the attractiveness or riskiness of a situation in terms of emotional processes. The following study aims at a better understanding of the psychophysiological mechanisms underlying threat sensitivity by measuring skin conductance responses (SCRs) in passive threat situations. While previous studies demonstrate the role of magnitude on emotional body reactions preceding an outcome, this study focuses on probability. In order to analyze emotional body reactions preceding negative events with varying probability of occurrence, we have our participants play a two-stage card game. The first stage of the card game reveals the probability of receiving an unpleasant

electric shock. The second stage applies the electric shock with the previously announced probability. For the analysis, we focus on the time interval between the first and second stage. We observe a linear relation between SCRs in anticipation of receiving an electric shock and shock probability. This finding indicates that SCRs are able to code the likelihood of negative events. We outline how this coding function of SCRs during the anticipation of negative events might add to an understanding of human JDM.

Chapter 4

The framing effect and skin conductance responses

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Abstract

Individuals often rely on simple heuristics when they face complex choice situations under uncertainty. Traditionally, it has been proposed that cognitive processes are the main driver to evaluate different choice options and to finally reach a decision. Growing evidence, however, highlights a strong interrelation between judgment and decision-making (JDM) on the one hand, and emotional processes on the other hand. This also seems to apply to judgmental heuristics, i.e., decision processes that are typically considered to be fast and intuitive. In this study, participants are exposed to different probabilities of receiving an unpleasant electric shock. Information about electric shock probabilities is either positively or negatively framed. Integrated skin conductance responses (ISCRs) while waiting for electric shock realization are used as an indicator for participants' emotional arousal. This measure is compared to objective probabilities. I find evidence for a relation between emotional body reactions measured by ISCRs and the framing effect. Under negative frames, participants show significantly higher ISCRs

while waiting for an electric shock to be delivered than under positive frames. This result might contribute to a better understanding of the psychological processes underlying JDM. Further studies are necessary to reveal the causality underlying this finding, i.e., whether emotional processes influence JDM or vice versa.

Chapter 5

Exposure to prenatal testosterone moderates financial loss aversion

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Mimeo

Abstract

Prenatal testosterone exposure is associated with financial risk preferences in numerous studies. Although decision-making under risk and uncertainty is a complex cognitive process, most of these studies apply basic risk elicitation tasks and yield mixed evidence. According to prospect theory, risk preferences may differ between gains, losses and mixed prospects, as well as for different probability levels. Thus, we investigate the association between prenatal testosterone and the aforementioned aspects of risk taking by using the second to fourth digit ratio method in two samples from Germany and Vietnam.

By doing this, we control for potential ethnicity effects, which have been reported to be a significant determinant of biological differences in the literature. We show that lower exposure to prenatal testosterone yields higher loss aversion in men in our German sample, but not in the Vietnamese. This provides a potential explanation for observed gender differences in risk taking behavior. We find no differences for pure gains, pure losses or probabilistic sensitivity.

Introduction

The biological basis of risk preferences is an intensively discussed topic in several disciplines, including economics, psychology, neuroscience, and human biology (Cesarini et al., 2009; Coates et al., 2009; Dreber et al., 2009; Kandasamy et al., 2014; Kuhnen and Chiao, 2009; Pearson and Schipper, 2012, 2013; Zethraeus et al., 2009; Zhong et al., 2009). One prominent issue in this literature is the impact of prenatal testosterone exposure (PTE) on risk taking behavior. PTE has been shown to have an organizational effect on the development of the brain and thereby it has a systematic influence on subsequent decision-making patterns (see Manning (2002) for an overview). In empirical studies the ratio between the lengths of the index and ring fingers (2d:4d ratio or digit ratio) is usually employed as a marker of PTE (Goy and McEwen, 1980; Lutchmaya et al., 2004; Hönekopp et al., 2007; Zheng and Cohn, 2011). A smaller digit ratio is associated with higher PTE, where men in general have lower ratios than women (Hönekopp and Watson, 2010).

The fact that women have often been found to be more risk and loss averse than men (Charness and Gneezy, 2012; Croson and Gneezy, 2009; Eckel and Grossman, 2008) suggests a possible relation between risk taking behavior and sex hormones, in particular testosterone. Existing studies on the impact of PTE on risk preferences are, however, not entirely conclusive. While some studies find a positive relation (Brañas-Garza and Rustichini, 2011; Dreber and Hoffman, 2007; Garbarino et al., 2011; Ronay and Von Hippel, 2010), several others do not find a significant effect (Apicella et al., 2008; Aycinena et al., 2014; Drichoutis and Nayga, 2015; Sapienza et al., 2009; Schipper, 2012).

An obvious reason for this conflicting evidence may be differences in the elicitation of risk preferences. The majority of studies use the method of Holt and Laury (2002) (HL method) whereby subjects have to choose between safe and risky lotteries which involve gains only. Interestingly, all studies which use this HL method under real monetary incentives (Aycinena et al., 2014; Drichoutis and Nayga, 2015; Sapienza et al., 2009; Schipper, 2012) did not find a correlation between risk attitudes and digit ratio. Brañas-Garza and Rustichini (2011) observed low digit ratio males to be less risk averse under the HL method. Their design, however, involved only hypothetical payments. As there is evidence that digit ratio has a strong impact on the reaction to monetary incentives (Neyse et al., 2016) their result should be taken with some caution. The fact that digit ratio has no impact on the risk preferences elicited with the HL method is in some sense consistent with the meta study of Filippin and Crosetto (2016) which shows that under this method no significant gender differences can be observed.

The HL method relies on expected utility theory and has been designed to elicit only one parameter measuring the degree of relative risk aversion. Risk attitudes, however, are known to be far more complex than modeled in expected utility theory. There is substantial evidence that behavior differs between gains and losses, as evidenced by the reflection effect of Kahneman and Tversky (1979). Moreover, subjects tend to be more risk averse over prospects involving both gains and losses than in either pure outcome domain – a phenomenon known as loss aversion (Markowitz, 1952; De Martino et al., 2010). Finally, people tend to be insensitive to variations of probabilities, leading to subjective probability distortions (Abdellaoui et al., 2007; Kandasamy et al., 2014; Preston and Baratta, 1948). All these effects are integral components of prospect theory (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992; Wakker, 2010), which is currently the most prominent descriptive theory of decision-making under risk. The elicitation of risk attitudes in previous PTE studies could not address this complexity of risk attitudes as in most cases only gains and/or 50% probabilities were involved.

The goal of the present paper is to comprehensively study the impact of PTE on the different facets of risk attitudes incorporated in prospect theory. We employ the method of Vieider et al. (2015), in which certainty equivalents for only gains, only losses, and for mixed gain-loss lotteries are elicited while systematically varying the probabilities. This procedure allows us to analyze whether PTE is associated with (i) risk attitudes in the domain of gains, (ii) risk attitudes in the domain of losses, (iii) the degree of loss aversion, and (iv) probabilistic insensitivity. As women are typically more loss averse than men (Andersson et al., 2016; Booij et al., 2010; Brooks and Zank, 2005), one can hypothesize that increased PTE leads to lower degrees of loss aversion. It could also be argued that probabilistic insensitivity should be related to PTE, as numerous cognitive skills like numerical intelligence (Luxen and Buunk, 2005), cognitive reflection test scores (Bosch-Domènech et al., 2014) and exam marks (Hopp et al., 2012) are positively affected by PTE. Such cognitive skills have in turn been found to be associated with increased probabilistic sensitivity and lower loss aversion (L'Haridon and Vieider, 2016).

The ethnicity of respondents constitutes an important factor in PTE studies. According to Manning (2002), the variation of digit ratio between ethnic groups, and even between Caucasians of different European origin, is larger than the variation between sexes within an ethnic group. In order to address possible effects of ethnicity, we run our experiment with two samples, a group of German students and a Vietnamese student sample. While our study is motivated by prospect theory, our analyses and tests do not rely on this theory. By just comparing certainty equivalents, our analysis is entirely non-parametric and valid for any theory which is based on standard definitions of risk aversion.

Before discussing the experimental design in more detail in Section 3, the next section introduces the theoretical background. Results are presented in Section 4 and Section 5 contains our conclusions.

Theoretical background

To formalize decision-making under risk we consider a set of monetary outcomes X . A lottery P assigns a real number $P(x)$ to each $x \in X$ such that $P(x) \geq 0 \quad \forall x \in X$ and $\sum_{x \in X} P(x) = 1$. \mathcal{P} denotes the set of all lotteries. We consider a binary preference relation \succeq defined on \mathcal{P} where \succ indicates strict preference and \sim indifference.

The certainty equivalent of a lottery P , denoted by $CE(P) \in X$, is defined by $CE(P) \sim P$. A decision maker is risk averse if $CE(P) \leq E(P) \quad \forall P \in \mathcal{P}$. Moreover, decision maker A is more risk averse than decision maker B if $CE_A(P) \leq CE_B(P) \quad \forall P \in \mathcal{P}$ (Pratt, 1964). Consequently, if lower digit ratio leads to less risk aversion, digit ratio and certainty equivalents should be negatively correlated. This is the basic hypothesis for the analyses in the present paper.

In expected utility theory (von Neumann and Morgenstern, 1944), preferences of the decision maker are represented by

$$EU(P) = \sum_{x \in X} u(x)P(x), \quad (5.1)$$

where u is called von Neumann-Morgenstern utility function. In expected utility theory the degree of risk aversion depends solely on the curvature of u , i.e., (a higher degree of) risk aversion is equivalent to a (more) concave u . Empirical applications often rely on the specification $u(x) = x^\alpha$ where $\alpha > 0$ is the degree of relative risk aversion. The method of Holt and Laury (2002) which is employed in the majority of digit ratio studies on risk aversion has been specifically designed to elicit the parameter α . Some other studies analyzing the correlation of digit ratio and risk aversion employ the portfolio method of Gneezy and Potters (1997). Also this method relies, in principle, on expected utility as it neither separates the gain and loss domain nor varies probabilities.

Starting with the famous paradoxes of Allais (1953), a large body of evidence has been gathered that subjects often violate expected utility when choosing between risky lotteries. This research has revealed that risk attitudes are far more complex than modeled in expected utility theory and has motivated the development of alternative theories which are in line with observed choice behavior. Prospect theory has nowadays become the most prominent of these alternatives. In prospect theory, outcomes are evaluated relative

to a reference point r such that positive deviations from r are coded as gains and negative ones as losses.¹ Our experimental design is based solely on lotteries with two outcomes. We denote these outcomes by x and y such that $|x| > |y| \geq 0$. Now if x and y are either both gains or both losses the utility of lottery P with $P(x) := p$ in prospect theory is given by

$$PT(P) = w(p)v(x) + [1 - w(p)]v(y). \quad (5.2)$$

Compared to expected utility, the evaluation of lotteries in prospect theory differs by two aspects:

(i) Outcomes in prospect theory are evaluated by a value function v which satisfies diminishing sensitivity and loss aversion. Diminishing sensitivity means that the marginal value is decreasing if one moves further away from the reference point (i.e., zero) implying a concave (convex) value function in the gain (loss) domain. This assumption accommodates the reflection effect of Kahneman and Tversky (1979) which summarizes empirical evidence that people are typically risk averse (seeking) for gains (losses). Loss aversion indicates that a given loss has a higher impact on the attractiveness of a lottery than a gain of equal size and is captured by a value function which is steeper for losses than for gains. Numerous studies have provided an empirical basis for loss aversion on the behavioral level (Ganzach and Karsahi, 1995; Kahneman et al., 1990), the psychophysiological level (Hochman and Yechiam, 2011; Sokol-Hessner et al., 2009), the brain level (De Martino et al., 2010; Tom et al., 2007) and in self-reported feelings (McGraw et al., 2010).

(ii) Probabilities in prospect theory are transformed by a weighting function $w : [0, 1] \rightarrow [0, 1]$ which is strictly increasing and satisfies $w(0) = 0$ and $w(1) = 1$. Originally, this value function was proposed to capture the tendency of people to overweight small and underweight large probabilities. Nowadays, there is ample evidence (Abdellaoui et al., 2011; Tversky and Fox, 1995; Wu and Gonzalez, 1996) that the weighting function is inverse-S shaped for most subjects, which implies, besides the overweighting (underweighting) of small (large) probabilities, a relative insensitivity towards probability changes for medium sized probabilities. A typical inverse-S shaped weighting functions is depicted in Figure 5.1.

A central empirical finding in the context of prospect theory is the fourfold pattern of risk attitudes: People are risk averse for high probability gains and low probability losses while they are risk seeking for low probability gains and high probability losses (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992). Evidence in favor of this pattern has been reported in several experimental studies (Cohen et al., 1987; Harbaugh et al., 2010; Tversky and Kahneman, 1992; Wehrung et al., 1989). Prospect theory directly

¹In the following, we normalize r without loss of generality to zero.

implies the fourfold pattern if the influence of probability weighting is large relative to the curvature of the value function, e.g., if the value function is linear. Assuming a linear value function, we get according to equation 5.2

$$CE(P) = w(p)x + (1 - w(p))y. \quad (5.3)$$

For $y = 0$ this equation immediately shows that $w(p) > (<)p$ implies risk seeking (aversion) in the gain domain and risk aversion (seeking) in the loss domain such that the fourfold pattern of risk attitudes is equivalent to the overweighting of small and the underweighting of large probabilities. Solving equation 5.3 for $w(p)$ yields

$$\frac{CE(P) - y}{x - y} = w(p). \quad (5.4)$$

In the following we will call $(CE(P) - y)/(x - y)$ a normalized certainty equivalent. The normalized certainty equivalent equals p in the case of risk neutrality (i.e., $w(p) = p$) whereas it is less than (exceeds) p in the case of risk aversion (seeking). For illustrative purposes, the analyses of the present paper will rely on normalized certainty equivalents instead of regular certainty equivalents.² This has the advantage of making our measures directly comparable across outcomes, which is its great advantage in our setup. We can then further control for the effect of probabilities in our regression to detect variations in probabilistic sensitivity.

Materials and methods

Participants

In Germany, we ran the experiment with 122 students at the Kiel University. The experiment was organized and recruited with the software hroot (Bock et al., 2012). Students met in groups of 15 and were randomly assigned to seats in a classroom. At the beginning of the experiment, participants were given general instructions about the experimental procedure, which were followed by the decision task. Subsequently, they were asked to fill out self-report questionnaires. After the experiment, participants were invited one by one to a separate room for receiving their payment and scanning of their both hands. The gender distribution was almost equal.

In Vietnam, we ran the experiment with 243 students. The students were recruited at the Economics University of Ho-Chi-Minh city using flyers. The average age of the

²Since a higher regular certainty equivalent implies a higher normalized certainty equivalent, this procedure does not involve any assumptions or restrictions.

students was 20.67 years, and 52% of participants were female. The hands of students were photocopied after the experiment. For 12 students, the photocopy of the right hand digit ratio could not be measured due to quality issues. The same is the case for 16 students for the left hand digit ratio. This reduces our subject pool for the analysis to 231 and 227 respectively.

Experimental design

In the experimental task by Vieider et al. (2015), participants decide between binary monetary lotteries and different sure monetary payments (the whole task can be found in Vieider et al. (2015)). In the gain domain, participants typically prefer the lottery for low sure payments, but switch as the sure payment rises. This behavior is reversed in the loss domain. The point where participants switch from the lottery to the sure payment is called the certainty equivalent. At the certainty equivalent a participant is just indifferent between the lottery and the sure payment. In the loss domain, outcomes were realized by subtraction from an initial endowment. There were a total of 39 decision tasks including 14 for gains, 13 for losses and 2 for mixed outcomes (i.e., gains and losses). In Vietnam, only one task over mixed outcomes was included in the design.³

In Vietnam, the orders of the experiment were counter-balanced. We found no order effects in our data, and using a fixed order was found to reduce the cognitive burden for our subjects. We thus decided to present the task in a fixed order in Germany. For the individual payment, one choice was randomly selected and realized for each participant. This is the standard type of compensation mechanism in this literature. The possible payments for this task ranged from €0 to €44 in purchasing power parity, including a fixed participation payment of €4.

Digit ratio

In Germany, both hands were scanned with a high-resolution scanner (Epson V370 Photo). To determine 2D:4D, we measured the lengths of the index and ring digits on both hands from basal crease to the finger tip. In Vietnam, the hands were photocopied, and the digit ratios were calculated from a subsequent scan of these photocopies.

We find significant differences in digit ratios by sex and ethnicity. Table 5.1 shows the average digit ratio by sex and country, separately for the left and the right hand. The means are tested against each other using Mann-Whitney tests.

³One task is sufficient to clearly identify loss aversion. The additional task in Germany was added to address an issue specific to structural econometric parameter estimations, which will not be used in this paper. We will nevertheless present results for both tasks, and use the second one as a stability check.

TABLE 5.1: Mean of digit ratios by sex and country

	left hand digit ratio			right hand digit ratio		
	Germany	Vietnam	difference	Germany	Vietnam	difference
male	0.964	0.944	$p < 0.001$	0.959	0.949	$p = 0.029$
female	0.962	0.964	$p = 0.859$	0.965	0.974	$p = 0.102$
difference	$p = 0.872$	$p < 0.001$		$p = 0.287$	$p < 0.001$	

Results

Descriptive analysis of risk preferences

We start from a descriptive analysis of risk preferences elicited across the different decision domains. In particular, we compare normalized certainty equivalents to winning and losing probabilities (see Section 2). For mixed prospects, we use the ratio of the elicited loss, ℓ , that makes the decision maker indifferent between playing the prospect and the status quo, to the prize. The point of risk neutrality is given by a ratio of 1, so that any smaller value can be directly interpreted as a measure of risk aversion over mixed prospects.

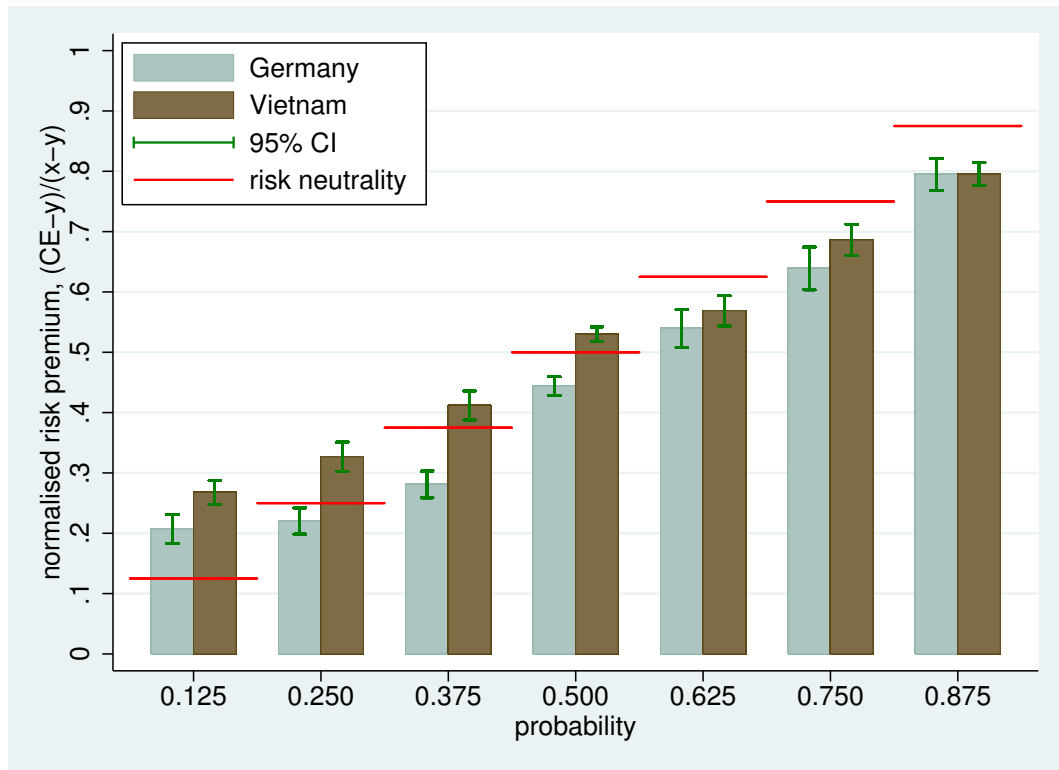


FIGURE 5.1: Risk preferences in the gain domain by probability and country.

Figure 5.1 and 5.2 show normalized certainty equivalents by probability of winning or losing. We start from the results for gains, shown in Figure 5.1. For the smallest probability of $p = 0.125$, the normalised certainty equivalent is significantly higher

than the objective probability of winning the prize, indicating risk seeking behavior. This changes as probabilities increase. Already at $p = 0.25$, subjects in Germany are significantly risk averse on average, and risk aversion increases further with probabilities. For subjects in Vietnam, we observe a similar tendency, except that they become risk averse only at the much larger probability of $p = 0.625$. The pattern of risk aversion increasing in probability is consistent with probabilistic insensitivity and implied by the fourfold pattern of risk attitudes (see Section 2). The Vietnamese students are more risk taking on average than the German students ($z = -5.14, p < 0.001, N = 365$, Mann-Whitney test on average normalized certainty equivalents for gains). This result corresponds closely to previous comparative studies, which found risk aversion to increase in GDP per capita for gains (Rieger et al., 2014; Vieider et al., 2012).

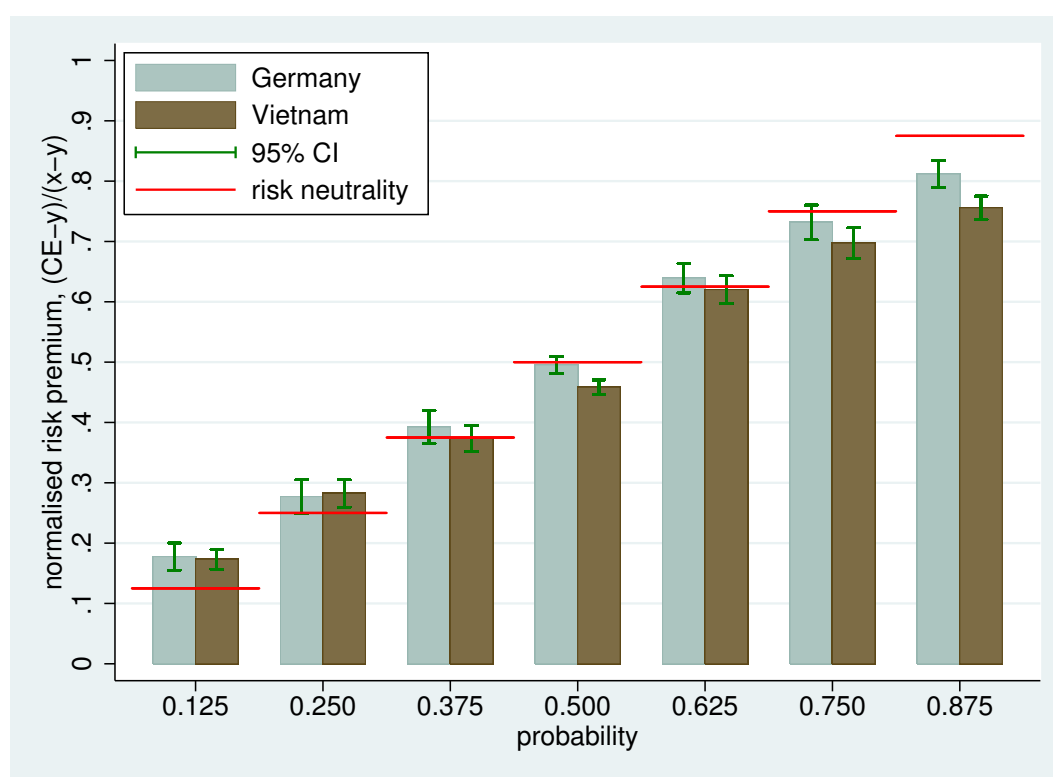


FIGURE 5.2: Risk preferences in the loss domain by probability and country.

An equivalent graph for losses is shown in Figure 5.2. We can now think of these values as insurance premia, since they are the absolute amounts paid to avoid playing a given prospect. The interpretation is thus reversed relative to gains, with values higher than the probability indicating risk aversion, and lower values indicating risk seeking. For the lowest probability, we now find risk aversion in both countries. As the probability increases, this risk aversion decreases and gives way to risk seeking for the highest probability level. As implied by prospect theory, this trend thus mirrors the one found for gains. While Germany and Vietnam exhibit very similar patterns of risk preferences for low probabilities, our Vietnamese subjects are more risk seeking than our German

subjects for large probabilities. On average, our Vietnamese subjects are thus again more risk seeking than our German subjects ($z = 2.35, p = 0.019, N = 365$, Mann-Whitney test on average normalized certainty equivalents for losses). This again corresponds to patterns found using the same tasks by Vieider et al. (2012), but it contradicts a correlation with GDP per capita in the opposite direction found by Rieger et al. (2014) using hypothetical willingness to pay for lotteries.

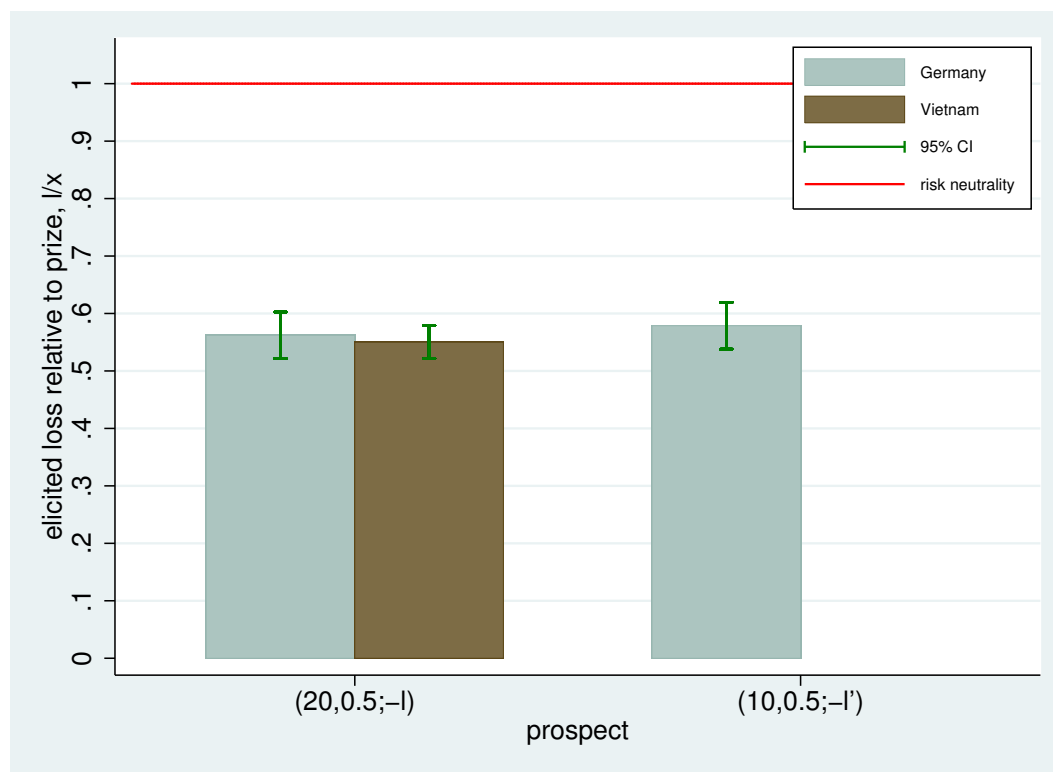


FIGURE 5.3: Risk preferences for mixed prospects by country.

Finally, Figure 5.3 shows the normalised risk preferences for the mixed prospects. For the first prospect, there is no significant difference between Germany and Vietnam in terms of risk aversion ($z = -0.401, p = 0.689, N = 365$). For Vietnam we did not have a second mixed prospect (we added the second prospect to the German study to address an unrelated question). Using the second prospect as a stability check for Germany, we find no difference in risk preferences according to the prospect used ($z = 1.205, p = 0.228, N = 122$). On average, we find that the prospect becomes acceptable over the status quo of not playing once the loss is close to half the gain. This matches the popular adage that losses loom about twice as large as gains. It also means that we find considerably more risk aversion over mixed prospects than for either gains or losses, where we found risk preferences close to risk neutrality for the same probability (although with some differences across countries and decision domains, as discussed above). This is again quite typical, as loss aversion is thought to account for most of risk aversion over small stakes (Köbberling and Wakker, 2005; Rabin, 2000).

Digit ratios and risk preferences

We can now regress our measures of risk preferences on the independent variables of interest. We present the regression separately by decision domain and by hand (left and right hand). Since we are particularly interested in differential effects by sex, this avoids difficult-to-interpret triple interactions. Table 5.2 shows the results for gains. All regressions are random effects OLS regressions, with robust standard errors clustered at the subject level. This allows us to enter the probability level as an independent variable capturing within-subject variance in risk preferences. The differing number of subjects across regressions is due to some unreadable hand scans, as outlined above.

TABLE 5.2: Regression analysis for gains.

Dep. var: norm. CE	Germany				Vietnam			
	I	II	III	IV	V	VI	VII	VIII
probability	0.802*** (0.028)	0.806*** (0.028)	0.803*** (0.028)	0.803*** (0.028)	0.701*** (0.022)	0.702*** (0.022)	0.701*** (0.022)	0.701*** (0.022)
LDR	-0.002 (0.019)	0.009 (0.023)			-0.008 (0.012)	-0.013 (0.018)		
LDR x female	-0.002 (0.024)	-0.002 (0.024)			0.019 (0.018)	0.019 (0.018)		
LDR x probability		-0.021 (0.033)				0.011 (0.022)		
RDR			0.012 (0.022)	0.033 (0.021)			-0.000 (0.016)	0.013 (0.021)
RDR x female			-0.024 (0.024)	-0.023 (0.024)			-0.003 (0.019)	-0.003 (0.019)
RDR x probability				-0.043 (0.027)				-0.027 (0.021)
female	-0.009 (0.020)	-0.009 (0.020)	-0.010 (0.020)	-0.010 (0.020)	-0.072*** (0.020)	-0.072*** (0.020)	-0.071*** (0.020)	-0.071*** (0.020)
constant	0.057*** (0.016)	0.055*** (0.016)	0.057*** (0.017)	0.057*** (0.017)	0.206*** (0.019)	0.205*** (0.019)	0.208*** (0.019)	0.208*** (0.019)
Obs.	1692	1692	1706	1706	3178	3178	3234	3234
Subjects (clusters)	121	121	122	122	227	227	231	231
R^2 within	0.55	0.55	0.55	0.55	0.46	0.46	0.47	0.47
R^2 between	0.00	0.00	0.01	0.01	0.07	0.07	0.07	0.07

robust standard errors in parentheses; *, **, *** indicate significance at the 10, 5 and 1 % level respectively
norm. CE is the normalised certainty equivalent
LDR (RDR) is the left (right) digit ratio; digit ratios are entered as z-scores
female is a dummy variable with 1 for women

The probability of winning is included in all the regressions to capture within-subject variance in risk preferences. The measure is always significantly lower than 1, indicating the probabilistic insensitivity already discussed above (a coefficient lower than 1 indicates that the certainty equivalent varies less than proportionately with the expected value). The coefficient is generally lower for Vietnam, indicating lower probabilistic sensitivity in Vietnam. This single variable captures 55% of the within-subject variance in Germany, and 47% in Vietnam.⁴ Regression I examines the effect of the left digit ratio and its interaction with the female dummy. We find no significant effect of the digit ratio either

⁴The remaining variance could be due to stakes and/or noise. We do not address stake effects here, as the latter are typically of second-order importance for typical experimental tasks (Fehr-Duda and Epper, 2012; Prelec, 1998)

for males (indicated by the digit ratio variable, which indicates a main effect for males only) or for females (as captured by the interaction effect). We also find no significant gender effect in Germany (this is consistent with the absence of a gender effect for digit ratios – see above). Regression II adds an interaction between the left digit ratio and the probability coefficient, i.e., it analyzes whether probabilistic insensitivity is related to digit ratios. There are no significant effects. Regressions III and IV repeat the analysis of regressions I and II respectively using the digit ratio of the right hand instead of the left. The conclusions remain very similar in the sense that we find now significant effects. For Vietnam we also do not find any significant results for our digit ratio variables. We do, however, find a strong gender effect, going in the expected direction of women being more risk averse than men. This is again consistent with the gender difference in digit ratios found in Vietnam.

TABLE 5.3: Regression analysis for losses.

Dep. var: norm. CE	Germany				Vietnam			
	I	II	III	IV	V	VI	VII	VIII
probability	0.861*** (0.028)	0.864*** (0.026)	0.863*** (0.027)	0.863*** (0.027)	0.788*** (0.023)	0.791*** (0.023)	0.792*** (0.023)	0.791*** (0.022)
LDR	-0.010 (0.016)	-0.002 (0.020)			-0.008 (0.010)	-0.024* (0.013)		
LDR x female	0.019 (0.022)	0.019 (0.022)			0.007 (0.014)	0.007 (0.014)		
LDR x probability		-0.017 (0.027)				0.032* (0.019)		
RDR			-0.007 (0.018)	0.015 (0.023)			-0.006 (0.014)	-0.017 (0.017)
RDR x female			-0.004 (0.021)	-0.004 (0.021)			0.015 (0.017)	0.015 (0.017)
RDR x probability				-0.044 (0.028)				0.023 (0.024)
female	-0.013 (0.019)	-0.013 (0.019)	-0.008 (0.019)	-0.008 (0.019)	0.014 (0.017)	0.014 (0.017)	0.010 (0.017)	0.010 (0.017)
constant	0.076*** (0.020)	0.074*** (0.020)	0.072*** (0.020)	0.072*** (0.020)	0.067*** (0.015)	0.066*** (0.015)	0.066*** (0.015)	0.066*** (0.015)
Observations	1573	1573	1586	1586	2951	2951	2951	2951
Subjects (clusters)	121	121	122	122	227	227	227	227
R ² within	0.68	0.68	0.68	0.68	0.55	0.55	0.55	0.55
R ² between	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01

robust standard errors in parentheses; *, **, *** indicate significance at the 10, 5 and 1 % level respectively
norm. CE is the normalised certainty equivalent
LDR (RDR) is the left (right) digit ratio; digit ratios are entered as z-scores
female is a dummy variable with 1 for women

Table 5.3 shows the same regression table as above for losses. The results are very similar to those observed for gains. We again observe probabilistic insensitivity in Germany and in Vietnam, but with a more pronounced effect (i.e., a smaller coefficient) in Vietnam. The within-subject variance explained by this is somewhat higher than for gains. For Germany, we do not find any significant effects in terms of digit ratios. For Vietnam, we find a marginally significant effect of left digit ratios in regression VI. Since that regression includes an interaction term with the probability of losing, the effect must be interpreted as an effect occurring when the probability is equal to zero, and hence as

a lower intercept. This effect is compensated by a marginally significant effect of the interaction with the probability level. The latter indicates that probabilistic sensitivity is somewhat higher for higher left digit ratios. Since the two effects compensate each other and are only marginally significant to begin with, they could easily be due to chance and we do not want to over-interpret them. We find no effects of the right hand digit ratio in regressions VII and VIII.

Table 5.4 shows the regression of the normalized loss equivalent on the usual independent variables. A smaller loss equivalent now indicates increased risk aversion (i.e., our outcome variable is an index of risk tolerance for mixed prospects). Since we do not have repeated observations, we now use regular OLS regressions with robust standard errors. Regression I finds that higher digit ratios of the left hand result in decreased risk tolerance. Since this is a main effect, this means that men with higher left hand digit ratios are significantly more loss averse than men with lower ratios. In other words, men with a *higher* exposure to prenatal testosterone are significantly *less* loss averse. There is no such effect for women, as shown by the insignificant interaction effect between the digit ratio and the female dummy, with the large coefficient compensating for the main effect found for men. There is also no main gender effect, which is again consistent with the absence of a gender difference in digit ratios.

TABLE 5.4: Regression analysis for mixed prospects.

Dep. var: norm. LE	Germany (20, 0.5; ℓ)		Germany (10, 0.5; ℓ)		Vietnam	
	I	II	III	IV	V	VI
LDR	-0.081** (0.037)		-0.053* (0.030)		0.022 (0.022)	
LDR x female	0.083 (0.050)		0.017 (0.043)		-0.017 (0.029)	
RDR		-0.100*** (0.033)		-0.094*** (0.032)		-0.004 (0.025)
RDR x female		0.113*** (0.043)		0.094* (0.048)		0.004 (0.031)
female	-0.041 (0.040)	-0.024 (0.040)	0.006 (0.041)	0.012 (0.040)	-0.146*** (0.030)	-0.135*** (0.030)
constant	0.586*** (0.028)	0.568*** (0.027)	0.581*** (0.029)	0.569*** (0.027)	0.629*** (0.024)	0.619*** (0.023)
Subjects	121	122	121	122	227	231
R^2	0.05	0.07	0.03	0.05	0.10	0.09

robust standard errors in parentheses; *, **, *** indicate significance at the 10, 5 and 1 % level respectively
norm. LE is the normalised loss equivalent
LDR (RDR) is the left (right) hand digit ratio; digit ratios are entered as z-scores
female is a dummy variable with 1 for women

Regression II examines the same effects for the right hand digit ratios. Once again, we find an effect going in the direction of larger digit ratios resulting in lower risk tolerance (or in other words, higher testosterone exposure resulting in reduced loss aversion). This effect is once again significant for men only, with the opposite and significant effect of the interaction term indicating that there is no effect for women. The effects are generally stronger and more highly significant than for the left hand. Regressions III and IV examine the stability of these effects to using the second mixed prospect, involving half

the stake levels. All effects discussed are confirmed and remain stable to using this second prospect. Finally, regressions V and VI examine the same correlations for Vietnam. Here we find no effects in terms of digit ratios, either for the left or the right hand. We do, however, find a gender effect in the expected direction of women being less risk tolerant or more loss averse than men. We now proceed to discussing these results.

Discussion

The present paper aims at contributing to the growing literature on the impact of PTE on risk preferences. So far this literature does not come to conclusive results, since some studies find a positive correlation between digit ratio and risk aversion while others did not. Our design is motivated by prospect theory and analyzes the relation of digit ratio to (i) risk attitudes in the domain of gains, (ii) risk attitudes in the domain of losses, (iii) the degree of loss aversion, and (iv) probabilistic insensitivity. To our knowledge no previous study distinguishes between the gain and loss domain, and no study takes either loss aversion or probabilistic insensitivity into account. Focusing first on our German sample, we did not find an effect of digit ratio on risk attitudes in both the gain and loss domains. Also probabilistic insensitivity is not significantly related to digit ratio. We, however, find for males a significant effect of digit ratio on the degree of loss aversion, i.e., males with lower digit ratio are less loss averse. Given that women are more loss averse than men (Brooks and Zank, 2005) this effect seems plausible and was hypothesized beforehand.

The effect of digit ratio on loss aversion may also have influenced the results of previous studies. Although they did not consider losses explicitly in their design many experiments create a reference point for participants simply due to framing effects. For instance the expected earnings for participation in an experiment could well serve as a reference point and earning less than expected could therefore be experienced as a loss. A theory which explicitly proposes that expectations create reference points in this way has been proposed by Köszegi and Rabin (2006, 2007). The conflicting results of previous studies may, therefore, have resulted from a different salience of such reference points in the execution of experiments.

The role of ethnicity for digit ratio has been stressed in several previous studies. Similarly, in our study results for the German and Vietnamese sample differ substantially. While our main effect on loss aversion cannot be observed in the Vietnamese sample, here lower digit ratio leads to decreased risk aversion for losses. Similar to the effect on loss aversion, this result is significant for males only.

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Chapter 6

Overconfidence, incentives and digit ratio

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Abstract

This paper contributes to a better understanding of the biological underpinnings of overconfidence by analyzing performance predictions in the Cognitive Reflection Test with and without monetary incentives. In line with the existing literature we find that the participants are too optimistic about their performance on average; incentives lead to higher performance; and males score higher than females on this particular task. The novelty of this paper is an analysis of the relation between participants' performance prediction accuracy and their second to fourth digit ratio. It has been reported that the digit ratio is a negatively correlated bio-marker of prenatal testosterone exposure. In the un-incentivized treatment, we find that males with low digit ratios, on average, are significantly more overconfident about their performance. In the incentivized treatment, however, we observe that males with low digit ratios, on average, are less overconfident

about their performance. These effects are not observed in females. We discuss how these findings fit into the literature on testosterone and decision-making and how they might help to explain seemingly opposing evidence from the literature.

Chapter 7

Gender differences in ambiguity aversion under different outcome correlation structures

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Abstract

This paper studies the impact of different outcome correlation structures on gender differences in ambiguity aversion. We conducted an investment game with two separate treatments. In the uncorrelated treatment, the outcomes of the investment game were determined individually. In the correlated treatment, the outcomes of the investment game were determined collectively within a reference group. From an evolutionary perspective, men should be more concerned about relative outcomes, because their reproductive success mainly depended on their relative standing within society. Women, by contrast, should be more concerned about absolute outcomes, because their reproductive success

was mainly linked to their access to resources for themselves and their children. Therefore, we predict that the type of outcome correlation structure has a larger impact on men than on women. In particular, we hypothesize that men are less ambiguity averse under an uncorrelated outcome structure. In this situation, the ambiguous alternative should be more attractive, because it potentially reduces inequality and thereby improves men's relative standing within society. Women's choices should not be significantly affected by different outcome correlation structures. Both hypotheses are supported by evidence from laboratory experiments.

Chapter 8

Problem gambling and risk preferences

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Abstract

Problem gambling is a serious socio-economic problem with an average prevalence ranging from 0.5 to 7.6% worldwide. Reported consequences include debt overload, social isolation, depression, and suicide. In this paper, we study financial risk preferences of problem gamblers including their risk attitudes in the gain and loss domain, their degree of loss aversion and their perception of probabilities. To our knowledge, this is the first study that provides a comprehensive analysis of their financial risk behavior in an incentivized task. Our findings indicate that problem gamblers are systematically more risk taking

and are less sensitive towards changes in probabilities in the gain domain only. Neither their degree of loss aversion nor their risk attitudes in the loss domain are significantly different from the controls. These novel insights provide an explanation for why some individuals persist in gambling activities – despite their severe negative consequences – while the general population does not.

Introduction

Problem gambling is characterized by an inability to control one's urge to gamble. Gambling in this context is a deliberate act to put valuables at stake that an uncertain event happens in the future (Wildman, 1998). The inability to control this desire typically leads to negative psycho-social consequences, such as debt overload (Pietrzak et al., 2005), involvement in criminal activities (Yeoman and Griffiths, 1996), social isolation (Trevorrow and Moore, 1998), depression (Clarke, 2006), and suicide (Ledgerwood and Petry, 2004). Nowadays, problem gambling is considered to be a public health concern with an average prevalence of 0.5 to 7.6% worldwide (Williams et al., 2012).

In this paper, we compare risk preferences of problem gamblers to two types of controls – habitual gamblers and non-gambling controls. By comparing these three groups, we aim at identifying behavioral underpinnings of gambling addiction. Before we outline different theories which have been brought up to explain this type of behavior, we give a brief overview of prospect theory, which is currently the most prominent descriptive theory of decision-making under risk (Kahneman and Tversky, 1979). This will be the starting point for our analysis and we will discuss hypotheses for gambling addiction and differences among the three groups within this framework. While our study is motivated by prospect theory, the general part of our analysis does not rely on this theory, but is valid for any theory that is based on standard definitions of risk aversion.

Prospect theory by Kahneman and Tversky (1979) has three main components: First, outcomes are evaluated relative to a reference point r such that positive deviations are coded as gains and negative ones as losses. Second, outcomes in prospect theory are evaluated by a value function v which satisfies diminishing sensitivity and loss aversion. Diminishing sensitivity means that the marginal value is decreasing if one moves further away from the reference point implying a concave (convex) value function in the gain (loss) domain. This assumption accommodates the reflection effect, which summarizes empirical evidence that people are typically risk averse (seeking) for gains (losses). Loss aversion indicates that a given loss has a higher impact on the attractiveness of a lottery than a gain of equal size and is captured by a value function which is steeper for losses than for gains. Finally, probabilities in prospect theory are transformed by a weighting function $w : [0, 1] \rightarrow [0, 1]$ which is strictly increasing and satisfies $w(0) = 0$ and $w(1) = 1$. Originally, this value function was proposed to capture the tendency of people to overweight small and underweight large probabilities. Nowadays, there exists ample evidence that the weighting function is inverse-S shaped for most participants, which implies, besides the overweighting (underweighting) of small (large) probabilities, a relative insensitivity towards probability changes for medium-sized probabilities (Abdellaoui et al., 2007; Fox and Tversky, 1995).

Having outlined prospect theory as an empirically motivated model for decision-making under risk, we will now discuss different theories on how gambling addiction might arise from a behavioral point of view. This discussion is grounded within the framework of prospect theory: First of all, gambling is typically associated with small probabilities of winning (e.g., the probability of winning in the German state lottery is only 3.13%). Therefore, it has been proposed that gambling addiction arises from a systematic distorted probability perception, such that small winning probabilities are more strongly overweighted. This distortion would make gambling more attractive and thus offers an explanation for a continuous urge to gamble (Camerer, 2000; Trepel et al., 2005). Within the framework of prospect theory, this so-called probability distortion hypothesis¹ would be reflected in a more distorted probability weighting function in the gain domain (Kahneman and Tversky, 1979). Among other things, our approach enables us to study the weighting function in the gain domain and thus allows a direct test of this hypothesis.

Secondly, gambling addiction might arise from a general upward shift in risk preferences (Ligneul et al., 2012). This theory is supported by empirical evidence showing increased risk taking behavior in problem gamblers in many other domains besides gambling (Potenza, 2008; Powell et al., 1999; Slutske et al., 2005). This so-called probability elevation hypothesis² would imply that problem gamblers, in general, overestimate (underestimate) the probabilities of gains (losses) over the whole probability range. Within the framework of prospect theory, this hypothesis would express itself in an upward (downward) shifted probability weighting curve in the gain (loss) domain. Because we elicit risk preferences in the gain and loss domain, we can directly test this hypothesis. Ligneul et al. (2012) found empirical support for this hypothesis. Their results, however, should be taken with caution, because they used an unincentivized risk elicitation task. The general population makes decisions differently under real rather than under hypothetical payments (Grether and Plott, 1979). Together with studies showing different brain activation during the anticipation and realization of real monetary outcomes in problem gamblers (Balodis et al., 2012; Linnet et al., 2010), it appears unclear how their behavior changes in comparison to non-gambling controls.³ In order to make our laboratory experiments more comparable to real-world behavior (Ariely and Norton, 2007), we apply an incentive-compatible risk elicitation task in the current study.

Finally, problem gamblers might be significantly less averse towards losses relative to gains (Tom et al., 2007). This would imply that their value function is steeper for gains than for losses compared to the controls. We elicit the degree of loss aversion for each participant, which allows us to test this loss aversion hypothesis. Recently, Takeuchi et al.

¹Ligneul et al. (2012) have introduced this term.

²Ligneul et al. (2012) have introduced this term.

³To our knowledge, this has not been directly addressed in the literature.

(2015) compared pathological gamblers' degree of loss aversion with non-gambling controls and did not find significant differences. They observed, however, that the distribution of the loss aversion parameters were significantly different between the two groups. Again, this study was not incentive-compatible, which raises the same concerns as outlined above.

Materials and methods

Participants

Seventy-six participants (mean age = 38.9 years, standard deviation = 14.7 years) took part in the current study. One participant was excluded because of dyscalculia, which severely impacts the understanding of the mathematical task instructions. Another participant was excluded due to pharmaceutical treatment. All participants gave written informed consent and could decide to discontinue participation at any time. The research protocol was approved by the local ethics committee of the University Hospital in Kiel.

Participants were recruited via advertisements in local newspapers. First, a telephone interview was conducted to inform participants about the general experimental procedure and to exclude participants based on the following criteria:

- problematic (illegal) drug consumption, i.e., drug consumption at least once a week.
- a history of psychiatric or neurological disorder.
- standard MRI exclusion criteria.

Then, participants were invited to the University Hospital in Kiel for a semi-structured interview in order to evaluate their medical history and their gambling behavior. The interviews were conducted by psychologists and took approximately 30 minutes. Nineteen participants fulfilled five or more criteria of the DSM-IV-TR criteria for pathological gambling and therefore can be classified as pathological gamblers (American Psychiatric Association, 2013). Six participants fulfilled more than three but less than five criteria and therefore can be classified as compulsive gamblers (Weintraub et al., 2009). These two sub-groups build our problem gambling group (PG group, four females). Furthermore, 23 participants were classified as habitual gamblers (HG group, three females). These participants fulfilled less than three criteria of the DSM-IV-TR criteria, but were gambling at least once per week. The motivation of including habitual gamblers as an additional control group is that this group is more similar to the problem gambling group – e.g.,

in their experience with gambling activities – than non-gambling controls. They differ, however, in the attribute of interest, i.e., the medically diagnosed addiction to gambling. Additionally, 26 participants were recruited as a non-gambling control group (C group, five females).

Besides the DSM-IV-TR criteria, participants answered the South Oaks Gambling Screen (SOGS) (Lesieur and Blume, 1987) in order to obtain a continuous variable for their gambling behavior. Higher values indicate a higher probability for a gambling addiction. As expected, the groups differed significantly in their SOGS-scores with the PG group having the highest average score (see Table 8.1). Both the classification based on the DSM-IV-TR criteria and the SOGS-scores will be used as independent variables in our analysis.

All three groups were matched based on important demographic variables (age, income, education), and their alcohol and cigarette consumption. Results are displayed in Table 8.1.

TABLE 8.1: Demographic variables, alcohol and cigarette consumption, and SOGS-scores by group. Groups were compared by means of independent t-tests (two tailed).

	C N=26	HG N=23	PG N=25	p -value C vs. HG	p-value C vs. PG	p-value HG vs. PG
Age	40.5±15.2	37.6±14.2	38.5±15.1	0.494	0.643	0.830
Income	1778±1533	1603±1196	1323±813	0.656	0.191	0.353
Alcohol	4.5±5.3	3.7±3.7	5.4±9.6	0.569	0.670	0.422
Smoking	37.9±70.7	32.0±41.4	46.3±47.2	0.723	0.619	0.271
Education	13.0±2.2	12.5±2.4	12.3±1.9	0.511	0.251	0.704
SOGS	0.4±1.0	4.0±3.1	8.4±3.8	<0.001	<0.001	<0.001

Age in years; Income per month in €; Alcohol in units (0.33 l beer, 0.2 l wine or 0.02 l liquor) per week; Smoking in cigarettes per week; SOGS, South Oaks Gambling Screen.

After the psychological interview, participants took part in the risk elicitation task, which is described in the next subsection. This was followed by fMRI and EEG experiments, which are not reported here.

Experimental design

In the experimental task by Vieider et al. (2015), participants make repeated decisions between binary monetary lotteries and different sure monetary outcomes. The task elicits risk preferences for gain-only, loss-only and for mixed lotteries. In the pure gain (loss) domain, one outcome is positive (negative) while the other outcome is always zero. The

magnitude of the first outcome and the winning (losing) probabilities are manipulated over different choice situations. In the gain domain, participants typically choose the lottery for low sure payments. When the sure payment rises, participants switch and start to prefer the sure payment at a certain point. This is the so-called certainty equivalent, i.e., the point where the individual is just indifferent between the sure payment and the lottery. In the loss domain, this behavior is reversed, i.e., the participants typically prefer a small sure loss over the lottery and switch as the small sure loss is increasing. In order to cover potential losses, participants received an initial endowment, which was as large as the largest possible loss. The task has a total of 29 choice situations (14 for gains, 13 for losses and 2 for mixed outcomes). In the mixed prospects, participants state a loss that makes them indifferent between playing a 50/50 lottery involving a certain price and the stated loss, or the status quo.

This approach allows us to study (i) risk attitudes in the gain domain, (ii) risk attitudes in loss domain, (iii) the degree of loss aversion, and (iv) probability perception. These four measures will be compared across the three groups and tested according to the above-outlined theories on gambling addiction.

For the individual payment, one decision was randomly selected and realized for each participant. This is the standard protocol in this literature (Cox et al., 2015). The possible payments for this task ranged from €0 to €40.

Non-parametric data analysis

For the analysis, we normalise certainty equivalents such that values below (above) the objective probability indicate risk aversion (risk seeking) in the gain domain. In the loss domain, this characteristic is reversed. The normalisation can be derived mathematically as follows:

Our experimental design is based solely on lotteries with two outcomes. We denote these outcomes by x and y such that $|x| > |y| \geq 0$. Now if x and y are either both gains or both losses the utility of lottery P with $P(x) := p$ in prospect theory is given by

$$PT(P) = w(p)v(x) + [1 - w(p)]v(y). \quad (8.1)$$

Assuming a linear value function where $v(x) = x$, according to the previous equation we get

$$CE(P) = w(p)x + (1 - w(p))y. \quad (8.2)$$

For $y = 0$ this equation immediately shows that $w(p) > (<)p$ implies risk seeking (aversion) in the gain domain and risk aversion (seeking) in the loss domain. Solving equation 8.2 for $w(p)$ yields

$$\frac{CE(P) - y}{x - y} = w(p). \tag{8.3}$$

In the following we will call $(CE(P) - y)/(x - y)$ a normalised certainty equivalent. The normalised certainty equivalent equals p in the case of risk neutrality (i.e., $w(p) = p$) whereas it is less than (exceeds) p in the case of risk aversion (seeking). The analysis of the present paper will rely on normalised certainty equivalents instead of regular certainty equivalents.⁴ This allows us to enter the probability of winning and losing into the regression analyses.

For the mixed gambles, we calculate the ratio between the gain and the elicited loss that makes the participant just indifferent between playing the lottery or the status quo. The point of loss neutrality would be indicated by a ratio of unity, smaller values indicate loss aversion, and higher values indicate loss seeking. Since we have two mixed lotteries, we average the two ratios for each participant to get a more stable estimate of their degree of loss aversion.

Parametric data analysis

Having provided a non-parametric analysis of our data, the next step will be to fit functional forms to our data. This approach takes the repeated observations into account and thereby allows us a more precise separation of noise from underlying preferences (Vieider et al., 2015). This approach is motivated by prospect theory. In particular, we will use the probability weighting function developed by Prelec (1998):

$$w(p) = e^{-\delta(-\ln p)^\gamma} \tag{8.4}$$

where δ measures the elevation of the weighting function. Smaller values of δ shift the weighting function upwards. γ measures the degree of curvature. Smaller values of γ indicate a more pronounced inverse-S shape of the weighting function (Fox and Poldrack (2013) illustrate this graphically). We will use the confidence intervals of the estimates to see differences among the groups. The algorithm was initialized with values of 0.7 for both δ and γ (Vieider et al., 2015). No additional boundary conditions were applied.

In order to make our a study comparable to a study by Ligneul et al. (2012) on problem gamblers' risk preferences, we also estimate the probability weighting function

⁴Since a higher regular certainty equivalent implies a higher normalised certainty equivalent, this procedure does not involve any assumptions or restrictions.

by Lattimore et al. (1992):

$$w(p) = \frac{\delta p^\gamma}{\delta p^\gamma + (1-p)^\gamma} \quad (8.5)$$

where δ measures the elevation of the weighting function. Smaller values of δ shift the weighting function downwards. γ measures the degree of curvature. Smaller values of γ indicate a more pronounced inverse-S shape of the weighting function (Fox and Poldrack (2013) illustrate this graphically). The algorithm was initialized with values of 0.6 and 0.8 for δ and γ respectively (Ligneul et al., 2012). No additional boundary conditions were applied. The conclusions from this analysis will be the same as from Prelec's probability weighting function and therefore the analysis is displayed in the appendix.

Results

Non-parametric results

In the first part of the analysis, we provide a non-parametric analysis of the risk preferences. To do so, we compare the normalised certainty equivalents of the three different groups across decision domains. We directly compare the three groups with each other, but we also provide an analysis that is based on the SOGS-scores as a continuous variable of gambling behavior.

Figure 8.1 shows normalised certainty equivalents by probability of winning for the three different groups. At the smallest probability of winning ($p = 0.125$) all three groups have a normalised certainty equivalent which is larger than the objective probability (the objective probability is marked by a grey line). This suggests risk seeking behavior at this particular probability level. With increasing objective probabilities of winning, participants, on average, become risk neutral and finally risk averse. The points where the different groups, on average, switch from risk neutral to risk avoiding behavior are different (C group: $p > 0.25$; HG group: $p > 0.5$; PG group: $p > 0.625$).

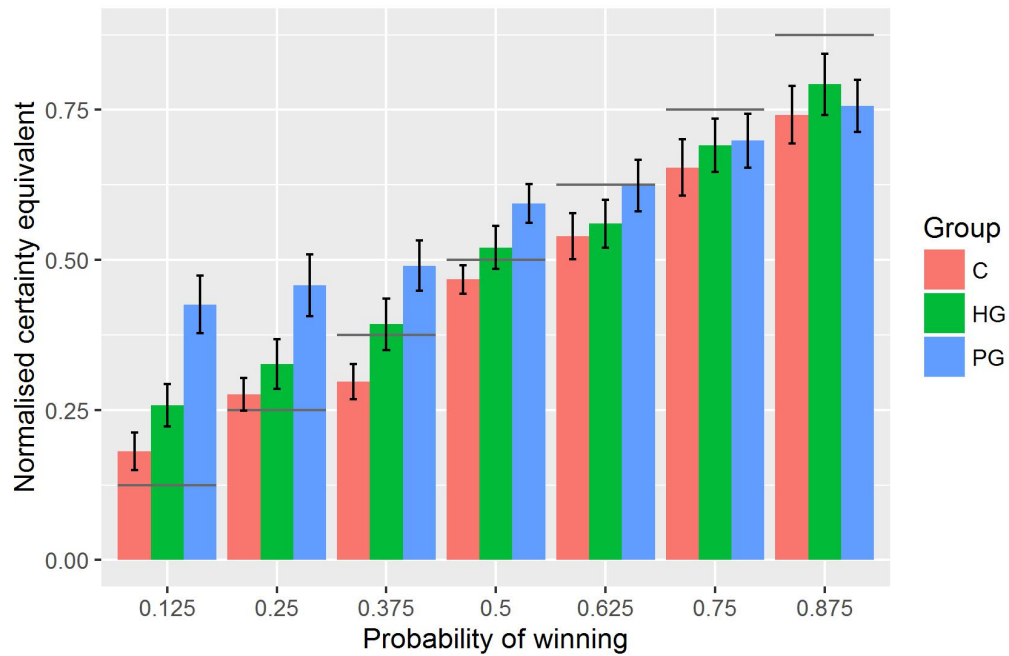


FIGURE 8.1: Risk preferences in the gain domain by probability and group. Error bars indicate the standard errors of the means.

Now we can test whether the elicited certainty equivalents are different between the three groups and whether there are differences in the perception of probabilities. To do so, we run random effects ordinary least squares regressions. This approach allows us to enter the probability levels as an independent variable and thereby to control for within-subject differences in probability perception (Vieider et al., 2015). Table 8.2 displays the result for an analysis where we compare the PG and HG group to the C group. As displayed in regression I, the PG group is significantly more risk taking than the control group, which is indicated by a positive and significant regressor for GroupPG. The regressor for GroupHG is also positive, but smaller than the regressor for GroupPG and not significant. Furthermore, the analysis shows that the significant probability coefficient is smaller than unity indicating probability insensitivity in the C group. This finding was expected and also previously reported (Vieider et al., 2015). In order to test whether there are differences in probability perception among the three groups, regression II adds an interaction term for the group classification and probability. The interaction term for the PG group is negative and significant indicating that the PG group is significantly more insensitive towards changes in probabilities than the C group. For the HG group the interaction term is negative, but not significant. Altogether this analysis shows that the PG group is both *more risk taking* and *less sensitive* towards changes in probability than the C group in the gain domain.

TABLE 8.2: Regression analysis for gains based on groups.

Dep. var: Norm. CE	I	II
prob	0.646*** (0.027)	0.766*** (0.044)
GroupHG	0.051 (0.042)	0.077 (0.053)
GroupPG	0.125*** (0.041)	0.278*** (0.052)
Age	0.000 (0.001)	0.000 (0.001)
Male	0.057 (0.047)	0.057 (0.047)
Prob:GroupHG		-0.051 (0.064)
Prob:GroupPG		-0.307*** (0.063)
Constant	0.086 (0.074)	0.026 (0.076)
Num. obs.	518	518
Num. groups	74	74
Marginal R ²	0.413	0.429
Conditional R ²	0.672	0.689

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Norm. CE is the normalised certainty equivalent.

Marginal R² describes the proportion of variance explained by the fixed factors alone. Conditional R² describes the proportion of variance explained by both the fixed and random factors (Nakagawa and Schielzeth, 2013)

In Table 8.3 we regress the normalised certainty equivalents on the SOGS-scores. Regression I reveals that individuals with higher SOGS-scores are more risk taking, which is indicated by a positive and significant regressor for SOGS-scores ($p = 0.01$). Furthermore, regression II includes an interaction term for SOGS-scores and probability ($p = 0.01$). The regressor is significant and negative, which suggests that individuals with higher SOGS-scores are less sensitive towards changes in probabilities. In a nutshell, this analysis reveals that individuals with higher SOGS-scores are *more risk taking* and *less sensitive* towards changes in probability. The analysis on the group level and the analysis based on SOGS-scores support each other. This was somehow expected, because SOGS-scores and a classification based DSM-IV-TR criteria have a high positive correlation (Stinchfield, 2002).

TABLE 8.3: Regression analysis for gains based on SOGS-scores.

Dep. var: Norm. CE	I	II
Prob	0.646*** (0.027)	0.646*** (0.027)
SOGS	0.043** (0.018)	0.077*** (0.022)
Age	0.000 (0.001)	0.000 (0.001)
Male	0.064 (0.048)	0.064 (0.048)
prob:SOGS		-0.068** (0.027)
Constant	0.138* (0.071)	0.138* (0.071)
Num. obs.	518	518
Num. groups	74	74
Marginal R ²	0.402	0.406
Conditional R ²	0.670	0.675

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Norm. CE is the normalised certainty equivalent.

SOGS-scores are entered as z-scores.

Marginal R² describes the proportion of variance explained by the fixed factors alone. Conditional R² describes the proportion of variance explained by both the fixed and random factors (Nakagawa and Schielzeth, 2013)

Figure 8.2 shows normalised certainty equivalents by probability of losing for the three different groups. The normalised certainty equivalents can be understood as insurance premia, because they are payments to avoid playing a lottery with a potential monetary loss. The interpretation in the loss domain is thus reversed relative to the gain domain, i.e., normalised certainty equivalents which are above (below) the objective probabilities now indicate risk avoiding (risk seeking) behavior. As Vieider et al. (2015), and consistent with the reflection effect of Kahneman and Tversky (1979), we find for the lowest probability $p = 0.125$ now risk aversion in all three groups. As the probability of losing increases, this risk aversion decreases and at some point each group, on average, is risk seeking. A visual inspection of the data does not indicate systematically different patterns among the groups.

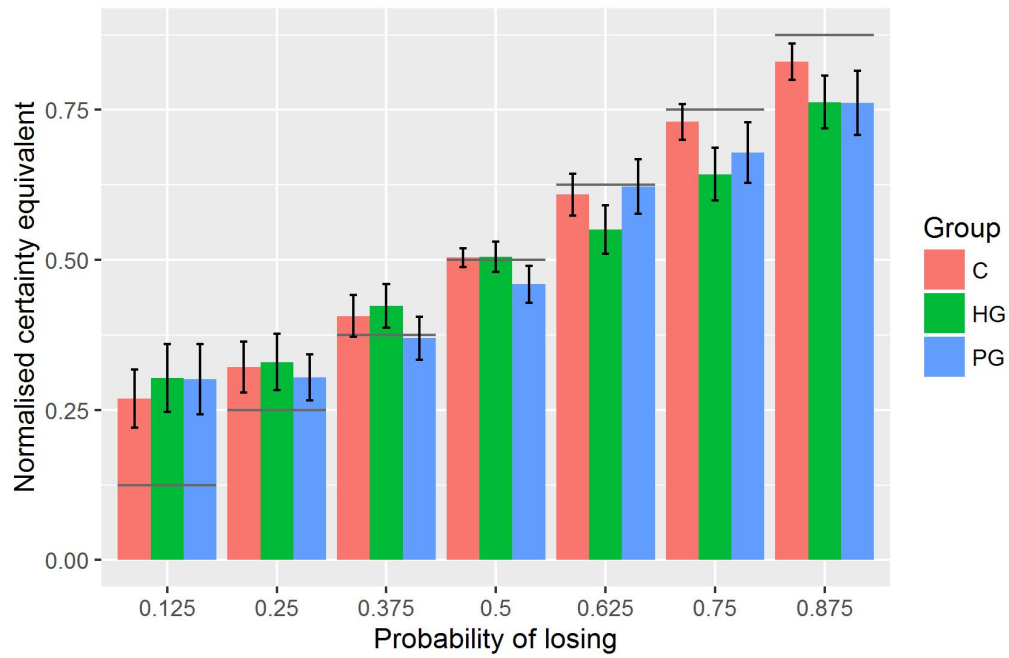


FIGURE 8.2: Risk preferences in the loss domain by probability and group. Error bars indicate the standard errors of the mean.

Table 8.4 displays the result for an analysis where we compare the PG and HG group to the C group in the loss domain. In regression I, we observe a general insensitivity towards changes in probability in the C group. This is revealed by a significant coefficient for probability which is smaller than unity. Neither the PG nor the HG group is significantly different in terms of their risk attitudes, which is indicated by non-significant regressors for PGGroup and HGGroup. Again, we observe probabilistic insensitivity in the C group by a significant regressor of probability which is smaller than one. In regression II, an interaction term is added for group classification and probability. The PG group is not significantly different in terms of their probability perception than the C group, while the HG group is. We do not want to overinterpret this finding, however, because if it were a component of gambling addiction, we would expect a more pronounced effect in the PG group, which we do not observe.

TABLE 8.4: Regression analysis for losses based on groups.

Dep. var: Norm. CE	I	II
Probability	0.692*** (0.030)	0.772*** (0.050)
GroupHG	-0.025 (0.038)	0.054 (0.053)
GroupG	-0.027 (0.037)	0.019 (0.052)
Age	-0.001 (0.001)	-0.001 (0.001)
Male	0.043 (0.043)	0.043 (0.043)
Probability:GroupHG		-0.159** (0.073)
Probability:GroupG		-0.091 (0.071)
Constant	0.165** (0.068)	0.125* (0.071)
Num. obs.	517	517
Num. groups	74	74
Marginal R ²	0.419	0.422
Conditional R ²	0.607	0.610

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Norm. CE is the normalised certainty equivalent.

Marginal R² describes the proportion of variance explained by the fixed factors alone. Conditional R² describes the proportion of variance explained by both the fixed and random factors (Nakagawa and Schielzeth, 2013)

This analysis is repeated using SOGS-scores as a continuous variable of gambling addiction. While we observe a general pattern of probability insensitivity, normalised certainty equivalents are neither affected by SOGS-scores nor by the interaction of SOGS-scores and probability. Altogether we do not observe systematic differences in risk attitudes in the loss domain among the three groups of interest.

TABLE 8.5: Regression analysis for losses based on SOGS-scores.

Dep. var: Norm. CE	I	II
Probability	0.692*** (0.030)	0.692*** (0.030)
SOGS	-0.022 (0.015)	-0.019 (0.021)
Age	-0.001 (0.001)	-0.001 (0.001)
Male	0.040 (0.042)	0.040 (0.042)
Probability:SOGS		-0.006 (0.030)
Constant	0.152** (0.063)	0.152** (0.063)
Num. obs.	517	517
Num. groups	74	74
Marginal R ²	0.424	0.424
Conditional R ²	0.605	0.605

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Norm. CE is the normalised certainty equivalent.

SOGS-scores are entered as z-scores.

Marginal R² describes the proportion of variance explained by the fixed factors alone. Conditional R² describes the proportion of variance explained by both the fixed and random factors (Nakagawa and Schielzeth, 2013)

Finally, Figure 8.3 shows the normalised risk preferences for mixed prospects. The average ratio of the potential loss to the potential gain is smaller than unity which indicates loss aversion in all three groups. We do not observe significant differences between the groups based on Wilcoxon Rank-Sum Test (C vs. HG: $W = 205.5$, $p = 0.15$; C vs. PG: $W = 287.5$, $p = 0.40$; HG vs. PG: $W = 297$, $p = 0.45$). The conclusion remains the same when we look at the ordinary least squares regression based on SOGS-scores in Table 8.6.

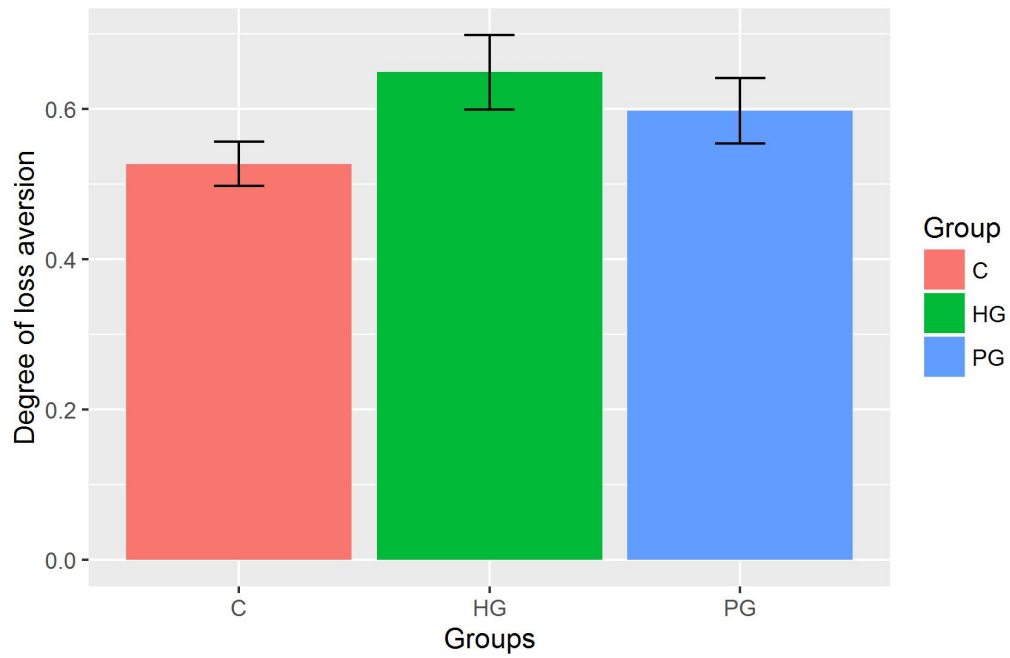


FIGURE 8.3: Risk preferences for mixed prospects by group. Error bars indicate the standard errors of the means.

TABLE 8.6: Regression analysis for mixed prospects based on SOGS-scores.

Dep. var: LA.	
SOGS	0.018 (0.024)
Male	0.056 (0.069)
Age	0.000 (0.002)
Constant	0.521*** (0.099)
R ²	0.017
Adj. R ²	-0.027
Num. obs.	72

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

LA is the degree of loss aversion

SOGS-scores are entered as z-scores.

Number of observations is reduced due to missing loss aversion scores for two participants.

Parametric results

In the next step, we show the results for the parametric estimations based on Prelec’s probability weighting function (see Figure 8.4). The results for our C group are within the expected range, with an average value of 1.06 (95% CI [0.96, 1.16]) for δ and an average value of 0.68 (95% CI [0.56, 0.81]) for γ (Fox and Poldrack, 2013). By looking at the 95% confidence intervals, we see that the PG group has a smaller average value of δ (mean = 0.65, 95% CI [0.59, 0.72]) than the HG and C group. This indicates that the weighting function in the gain domain is shifted upwards. There seems to be a decreasing trend from the C group over the HG group to the PG group as displayed in Figure 8.4. The γ value is also smaller for the PG group than for the HG and C group which reflects a more pronounced inverse-S shape of the weighting function, i.e., a more distorted probability perception.

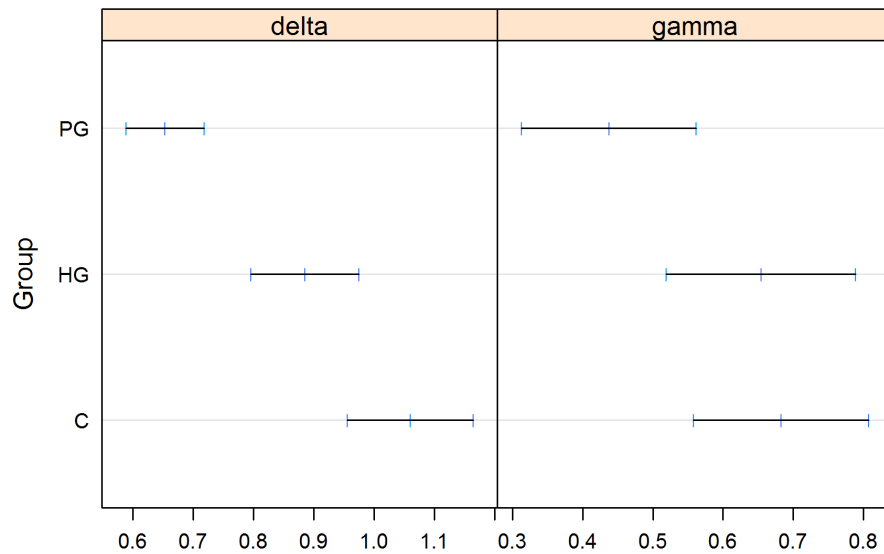


FIGURE 8.4: Estimated parameters for the probability weighting function by Prelec in the gain domain by group. Error bars indicate the 95% confidence intervals.

In Figure 8.5 we show a graphical representation of Prelec’s probability weighting function based on the estimated parameters for the C and PG group. Both the upward shift and the more distorted probability perception are visible.

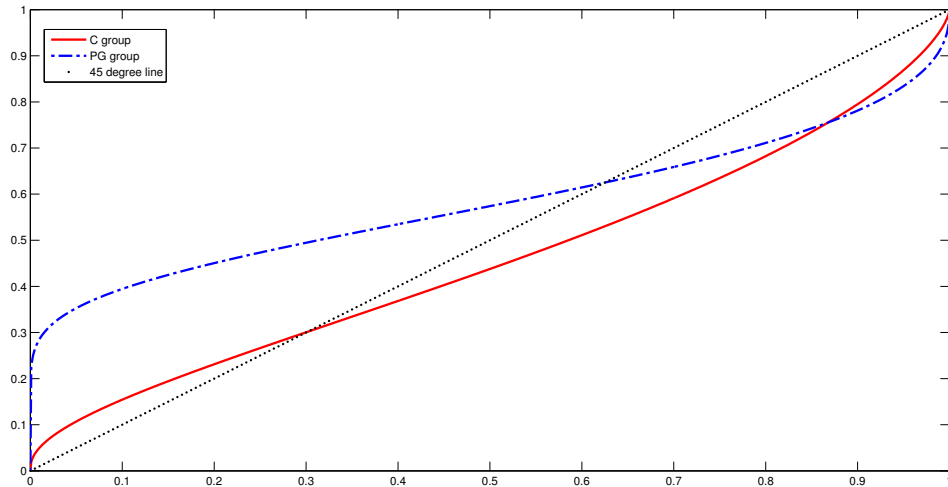


FIGURE 8.5: Estimated probability weighting function by Prelec for the PG and C group.

We repeat this analysis for the loss domain. As expected based on the non-parametric analysis, we observe large overlaps of the confidence intervals for both the value of δ and γ among the three groups (see Figure 8.6). This indicates that also in this analysis no systematically different patterns of risk preferences in the loss domain can be observed. Therefore, we spare showing a graphical representation of Prelec’s probability weighting function in the loss domain.

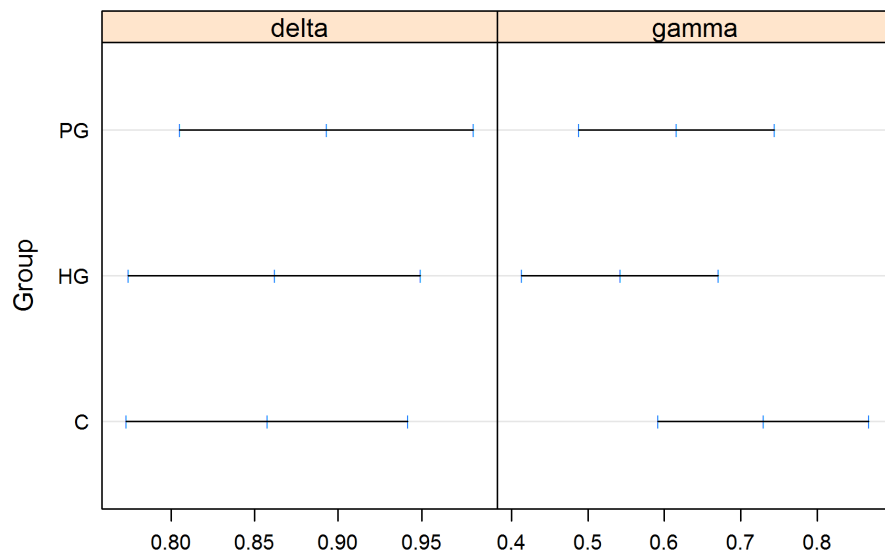


FIGURE 8.6: Estimated parameters for the probability weighting function by Prelec in the loss domain by group. Error bars indicate the 95% confidence intervals.

Discussion

In a nutshell, our data reveals that problem gamblers in the gain domain are systematically more risk taking and less sensitive towards changes in probabilities than the control group. This finding holds for a non-parametric comparison of these two groups – based on a group comparison and based on SOGS-scores – but it is also supported by a parametric approach. Neither in the loss domain nor for mixed prospect we find systematically different patterns. In the following part of the paper these results are discussed. First, we relate these findings to the previously outlined hypotheses on gambling addiction. Secondly, we describe differences among our paper and previous studies on problem gamblers' risk preferences. Finally, we give an outlook on how our findings might provide a basis for future treatments of gambling addiction.

We outlined three hypotheses which have been brought up in the literature to explain gambling addiction. According to the probability distortion hypothesis, problem gamblers have a distorted perception of winning probabilities, which makes them overly optimistic. The probability elevation hypothesis, by contrast, argues that risk preferences in the gain (loss) domain are generally shifted upwards (downwards), which makes gambling more attractive but also many other risky activities. Finally, the loss aversion hypothesis states that problem gamblers are less sensitive towards losses relative to gains. Our findings support both the probability distortion and the probability elevation hypothesis, while we do not find any empirical evidence for the loss aversion hypothesis. We observe an upward shifted and more distorted probability weighting function, however, only in the gain domain. In the loss domain, by contrast, we do not find significantly different patterns in risk attitudes. These findings are robust, in the sense that they hold for a non-parametric group comparison, a non-parametric analysis based on SOGS-scores and also for parametric approaches based on probability weighting functions by Prelec (1998) and Lattimore et al. (1992).

A limited number of studies have analyzed risk preferences of problem gamblers (Takeuchi et al., 2015; Ligneul et al., 2012). The results from these two studies are similar to ours. The first study did not find significant differences in the loss aversion parameter between problem gamblers and non-gambling controls. We found the same. The second study reported differences in the elevation parameter, but not in the distortion parameter. We found that both parameters are systematically different between the PG and C group in the gain domain. By looking at the two briefly outlined studies, we observe three fundamental differences compared to our study. First, we explore risk preferences for gain-only, loss-only and mixed prospects. The other two studies focus on single aspects of the risk attitudes space. While Takeuchi et al. (2015) focus on mixed gambles, Ligneul et al. (2012) focus on the gain domain. Secondly, we apply an incentive-compatible task

in order to make our findings more comparable to the real-world. The other two studies use hypothetical incentives. Thirdly, we include habitual gamblers as an additional control group. This approach allows us to treat gambling addiction as a continuous variable (Strong and Kahler, 2007).

Finally, we will give an outlook to which extent our findings might have a medical application. Recent studies indicate that hormonal mechanisms or interference with hormonal mechanisms through drugs can have a selective impact on financial risk preferences. Sokol-Hessner et al. (2015), for example, show that propranolol, a beta-blocker, has an effect on loss aversion, but not on risk attitudes. While this is not the only study suggesting an impact of hormones on decision-making (Bröder and Hohmann, 2003; Brunlieb et al., 2016; Chavanne and Gallup, 1998; Cueva et al., 2015; Margittai et al., 2016), it reveals that hormonal mechanisms potentially affect only specific aspects of risk behavior. Within the context of our study, this appears as highly relevant, if one thinks about a medical treatment for gambling addiction, because we show that problem gamblers have a selectively affected risk behavior in the gain domain only.

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Appendix

Here, we repeat the parametric analysis for the probability function by Lattimore et al. (1992), which has also been used in a study by Ligneul et al. (2012) on problem gamblers' risk preferences. Smaller values of δ shift the weighting function downwards in this parametrization. Therefore, the conclusion remains the same as the one based on Prelec's probability weighting function.

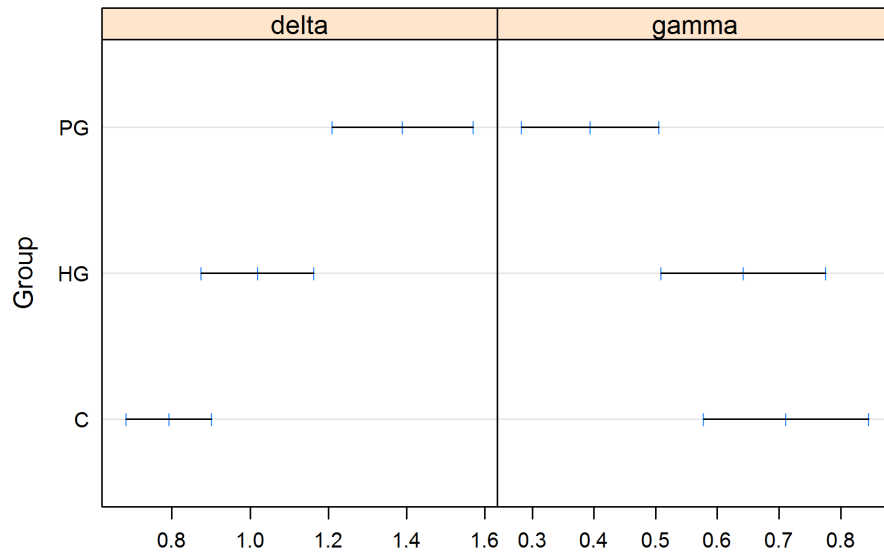


FIGURE 8.7: Estimated parameters for the probability weighting function by Lattimore et al. in the gain domain by group. Error bars indicate the 95% confidence intervals.

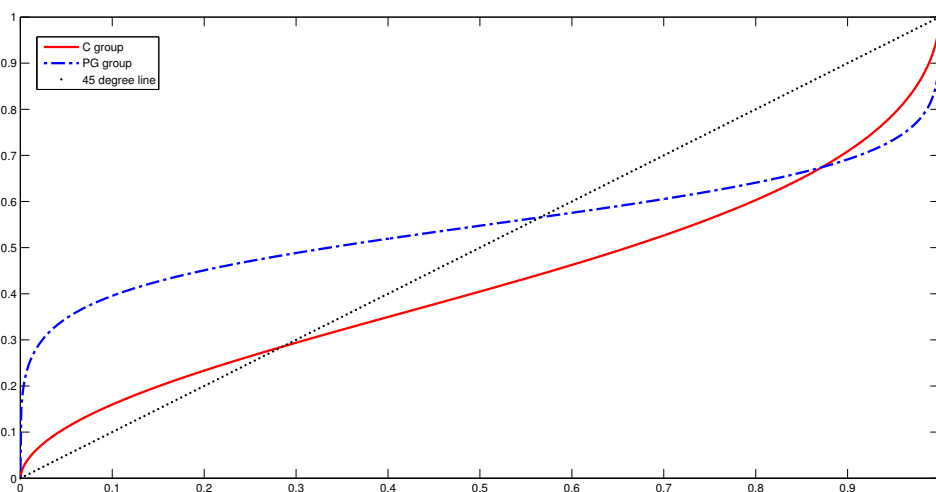


FIGURE 8.8: Estimated probability weighting function by Lattimore et al. in the gain domain for the PG and C group.

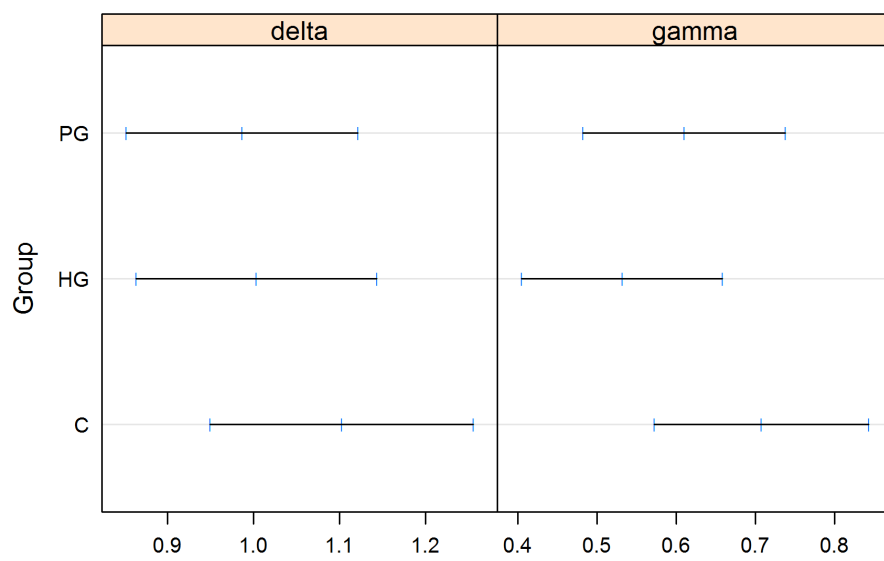


FIGURE 8.9: Estimated parameters for the probability weighting function by Lattimore et al. in the loss domain by group. Error bars indicate the 95% confidence intervals.

Erklärung zum selbständigen Verfassen der Arbeit

Ich erkläre hiermit, dass ich meine Doktorarbeit "Neurobiological Foundations of Decision-Making under Uncertainty" selbstständig und ohne fremde Hilfe angefertigt habe und dass ich als Koautor maßgeblich zu den weiteren Fachartikeln beigetragen habe. Alle von anderen Autoren wörtlich übernommenen Stellen, wie auch die sich an die Gedanken anderer Autoren eng anlehnenden Ausführungen der aufgeführten Beiträge wurden besonders gekennzeichnet und die Quellen nach den mir angegebenen Richtlinien zitiert.

Ort, Datum

Patrick Ring