Final Report

Neurobiological Foundations of Economic Decision Making under Uncertainty and Excessive Risk Taking

Leibniz-Institute: Kiel Institute for the World Economy
Reference number: SAW-2013-IfW-2 219
Project period: 01.06.2013-31.05.2017
Contact partner: Prof. Dr. Dr. Ulrich Schmidt
E-Mail: ulrich.schmidt@ifw-kiel.de, Tel: +49 (431) 8814-337

Members of the Project:

Grant Holders

Prof. Dr. Christian Kaernbach
Prof. Dr. Dr. Ulrich Schmidt
Prof. Dr. Thilo van Eimeren

Staff:

Dr. Levent Neyse	01.09.2013-31.05.2017
Dr. Catharina Probst	01.06.2013-30.09.2015
Dr. Patrick Ring	01.07.2013-31.05.2017

Student Assistants:

Lucie Kleefeld
Baiba Renerte
Milda Aleknonyte
Tom Erhart
Adrian T. Lehrke

Table of Contents

Executive Summary

Under uncertainty, decision makers lack precise knowledge about the consequences of their decisions as these consequences are influenced by numerous factors that cannot be entirely controlled. In fact nearly all of our decisions involve some degree of uncertainty. Decisions made under uncertainty are crucial in numerous domains, such as financial markets, insurance economics, economics of innovation or climate change. Therefore, modeling decision made under uncertainty is an important challenge for economists, who now interact with other disciplines such as psychology and neuroscience to gain a better understanding of human decision making processes. Of particular interest is excessive risk taking as this has been identified as major cause of the recent financial crisis.

To analyze excessive risk taking, this project compared the decisions and the decision making processes of extreme risk-seeking subjects (habitual and pathological gamblers) with normal ones. The methods included decision tasks, neuro-imaging (fMRI and EEG), skin conductance response analyses, psychological tests as well as 2D:4D methods to explore the possible role of prenatal testosterone exposure for decision making.

Results from the choice tasks show that problem gamblers systematically take more risks and are less sensitive towards changes in probabilities in the gain domain only. Interestingly, no differences in the loss domain were observed. Furthermore, they have a stronger present bias and at the same time a significantly smaller long-run discount factor than non-gambling controls. This means that problem gamblers are more impulsive in both the short and the long-run. Neural activity was measured in a task where subjects face the risk of receiving an electric shock. Here, increases in the punishment probability predicted activation in a network comprising bilateral insula, bilateral supplementary motor area, anterior cingulate cortex, left precentral gyrus, left inferior frontal gyrus and left rolandic operculum. In these areas activation increased almost linearly with probability – we found no inverted s-shaped pattern of probability distortion as is often seen in behavioral studies. We also found no differences between gamblers and healthy controls in neural responses. This is consistent with the results from the lottery choice task where no differences were observed in the loss domain (as receiving an electric shock should also be perceived as loss). Sensitivity for high versus low punishment probability correlated positively with risk taking and seeking/avoiding scores in the health domain. Endocrinological results showed that higher exposure to prenatal testosterone yields lower degrees of loss aversion.

1. Objectives of the Project

The main objective of this project was to investigate the decision making processes of individuals, in particular excessive risk taking, using various experimental, theoretical and empirical methods drawn from the disciplines of economics, psychology, neuroscience and physiology. To this end, we aimed at recruiting samples of extremely high risk taking groups from society. Hence, pathological gamblers, who would represent excessive risk takers, were our primary group of interest. Additionally, patients with Parkinson`s disease (PD) develop as side effect of their treatment often an impulse control disorder which may also results in excessive risk taking. The original design of the study included a sample of professional investors. Besides these groups, a healthy control group is required.

The interdisciplinary methodology of the project aimed to capture different aspects of decision making patterns. From the viewpoint of economics, several behavioral patterns and economic preferences are embedded in risky decisions. The most prominent theory of decision making, Cumulative Prospect Theory (Tversky and Kahneman, 1992) introduces reference dependence and underlines the fact that decision patterns differ for the domains of gains and losses. That is, decision makers are often more concerned about *losing* than winning. The economics methodology of the project adopted Cumulative Prospect Theory as its theoretical benchmark and employed experimental methods that build upon this theory.

The neurobiological methods consisted of functional magnetic resonance imaging (fMRI) and electroencephalography (EEG). Utilizing brain imaging techniques enabled us to capture neural activity during the decision making processes and also neural reactions to winning and losing during the gambling activity. In line with Cumulative Prospect Theory previous studies revealed that brain activation is more sensitive to the magnitude of losses than to the magnitude of gains (Tom et al., 2006).

While neural activity has a significant impact on the decision making process, decisions are also affected by emotional reactions and automatic processes. This is why the physiological reactions of decision makers were also investigated by skin conductance response analysis in the study.

2. The development of the work carried out and deviations from the original concept

The project was carried out sticking to the original research protocol with only slight changes. Following a meticulous design process, the pilot sessions were carried out with healthy student participants from the subject pool of Kiel University. Pilot sessions were first conducted separately for all the above-mentioned methods to test the appropriateness of the chosen methods, common decision patterns, timing and fatigue affects. After each method was confirmed, several more pilot sessions were conducted with the merged, complete protocol.

For efficient use of time, recruitment of the main study participants was carried out while the pilot sessions were underway. The call for participation was announced through various channels

such as local newspapers in Kiel, Germany, as well as flyers and posters in the local casino and the city. We aimed at maintaining a balance between gambler and control groups with regards to several aspects such as gender, age, drinking and smoking habits etc. Furthermore, we followed the strict protocol and selection criteria determined jointly with the ethical board of the University Hospital Schleswig Holstein (UKSH). The diagnosis stage of pathological gamblers prior to the experimental protocol provided us with an additional sample of habitual gamblers. The habitual gamblers group consists of participants who do not have as serious a gambling problem as pathological gamblers, yet regularly engage in gambling activities. This extra sample enabled us to introduce an additional risk taking group between our control and pathological gambler groups.

While the inclusion of the habitual gamblers enriched our subject pool and the study itself, the group of patients with PD had to be removed from the study due to the exhausting nature of the experimental protocol. The average duration of the protocol, which included numerous stages of data collection, two break times for participants to rest, short technical setups and re-locations in the building, was about four hours (Figure 1 shows the experimental protocol and average durations of each phase). In pilot studies with PD patients it turned out that they were not able to attend this procedure.

The initial design also included a few professional investors as a group which is experienced in dealing with risks. We aimed to cooperate with HSH Nordbank in this respect which promised its support at the time we prepared the project application. Due to severe financial problems the bank was restructured substantially and no professional investors were available in Kiel. Recruiting such subjects from other cities would have been only possible incurring unreasonably high costs. The professional investor group was therefore excluded.

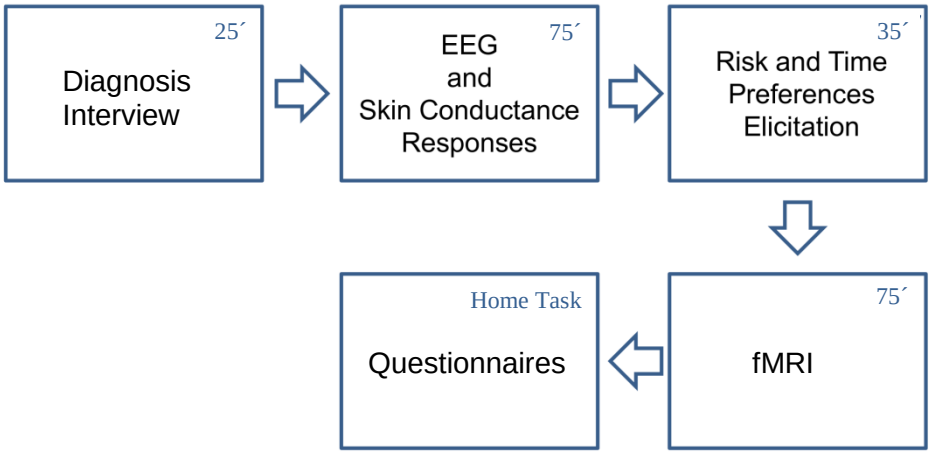

Figure 1: Experimental protocol and phase durations in minutes

We thus have results from 25 pathological and 23 habitual gamblers, as well as 26 control subjects, complemented by a set of student samples from the pilot sessions. Details on the main

sample a given in Table 1. The last column shows that all three subject groups differ significantly only for their gambling behavior as measured by the standards SOGS score.

Table 1: The main sample

	C group N=26	HG group N=23	PG group N=25	p.overall
Age	40.46±15.22	37.57±14.16	38.48±15.13	0.703
Income	1778.08±1533.34	1603.17±1195.96	1323.00±813.52	0.946
Alcohol	4.47±5.34	3.72±3.73	5.41±9.64	0.347
Smoking	37.88±70.75	32.05±41.36	46.28±47.19	0.254
Education	12.96±2.24	12.52±2.39	12.28±1.95	0.495
SOGS	0.42±0.99	3.96±2.96	8.36±3.82	<.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.

3. Results

The project results are given in separate subsections. Each section is readable on its own. A part of these findings have already been published and some others are contained in papers which are currently still in the submission stage. All papers are available upon request.

3.1. Risk preferences of pathological gamblers

In Ring et al. (2017a) we study risk preferences of problem gamblers including their risk attitudes in the gain and loss domain, their weighting of probabilities, and their degree of loss aversion. Subjects had to perform binary choice tasks between lotteries and a sure outcome in the price list format. These tasks were composed of three groups: gains only lottery, losses only lotteries and mixed lottery. Responses allowed us to derive certainty equivalents for varying probabilities in the gain and loss domains as well as the degree of loss aversion. Moreover we fitted probability weighting functions for the single domains.

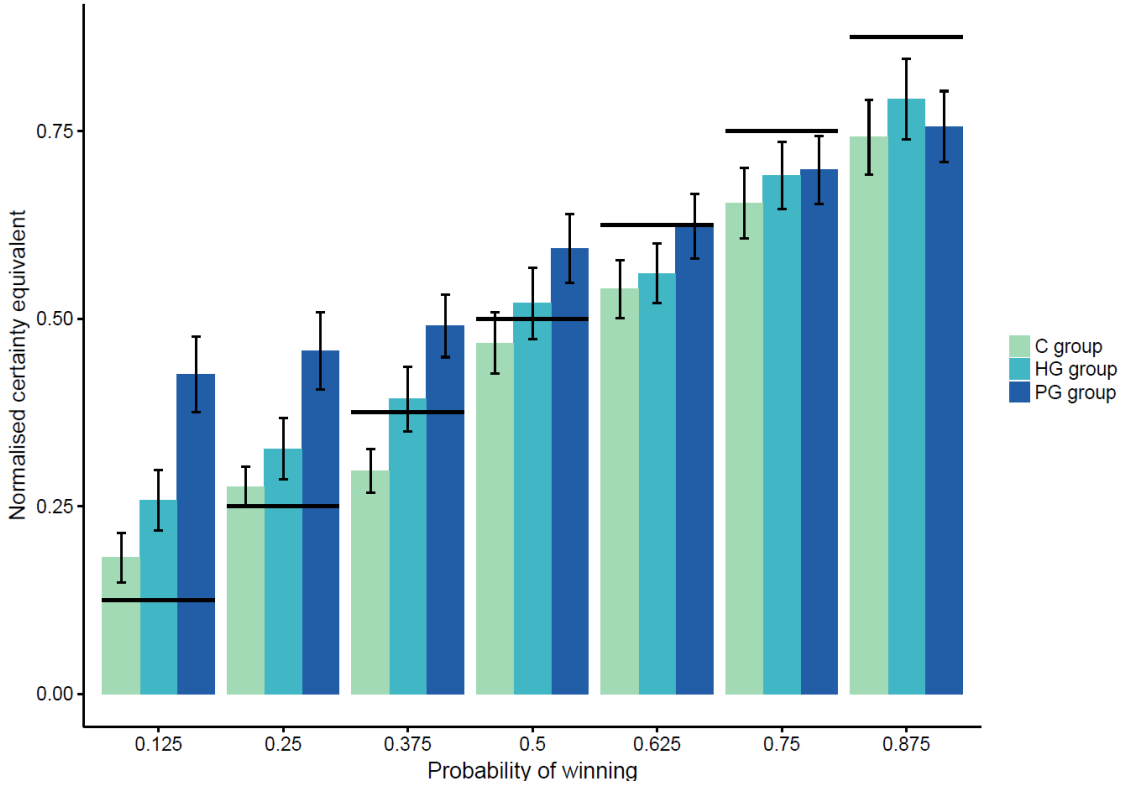

Figure 2: Certainty equivalents in the gain domain

Figure 2 shows the certainty equivalents in the gain domain for the control group (C), habitual gamblers (HG), and pathological gamblers (PG). We see the usual pattern that small probabilities are overweighted whereas large ones are underweighted. The figure reveals that gamblers are significantly more risk seeking for small winning probabilities whereas for large probabilities no differences occur. Figure 3 shows the same data for the loss domain. Here it turns out that no significant differences between gamblers an controls can be observed. The same holds for the degree of loss aversion.

Certainty equivalents were used to fit probability weighting function. The functions are usually inverted-S shaped, a shape which reflects the underweighting of small and overweighting of large probabilities. This pattern is also called probabilistic insensitivity. A second feature of weighting functions is their elevation: A higher elevation reflects a general more optimistic attitude towards risk. Figures 4 and 5 show the weighting functions in the gain and loss domains respectively. We can see from Figure 4 that there is a clear difference between pathological gamblers and the two other groups: pathological gamblers have both a higher degree of probabilistic insensitivity and elevation. Figure 5 shows that there are no differences in the loss domain between our three subject groups.

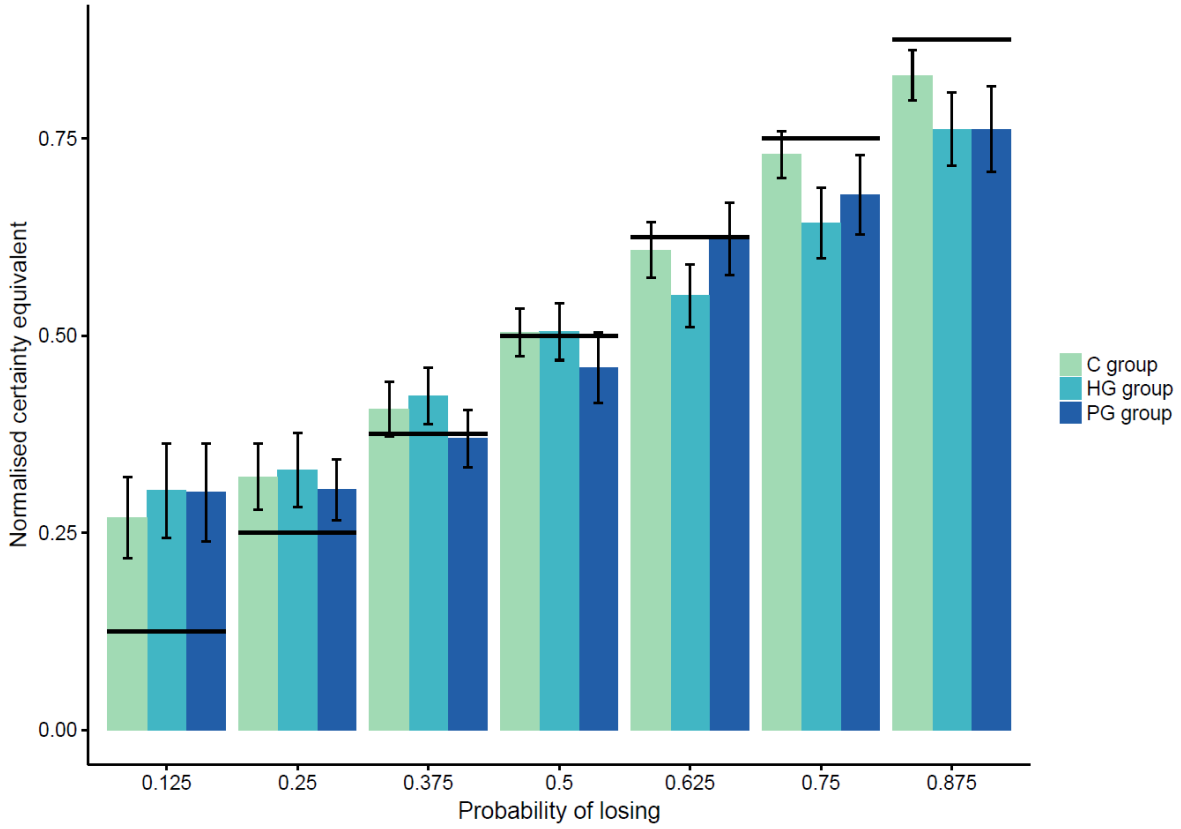

Figure 3: Certainty equivalents in the loss domain

In order to reconfirm that there are no differences between gamblers and controls in the loss domain, we also recorded their skin conductance responses in a task were they face the shock of receiving an electric shock which should be clearly in the loss domain. Skin conductance responses measure the emotional arousal of participants. In particular, we were interested in the differences of arousal for high and low shock probabilities. The results from the choice task suggest that patterns for gamblers and controls should not differ systematically. Figures 6 and 7 show that this is indeed the case leading to our conclusion that risk preferences between gamblers and control differ in the gain domain only.

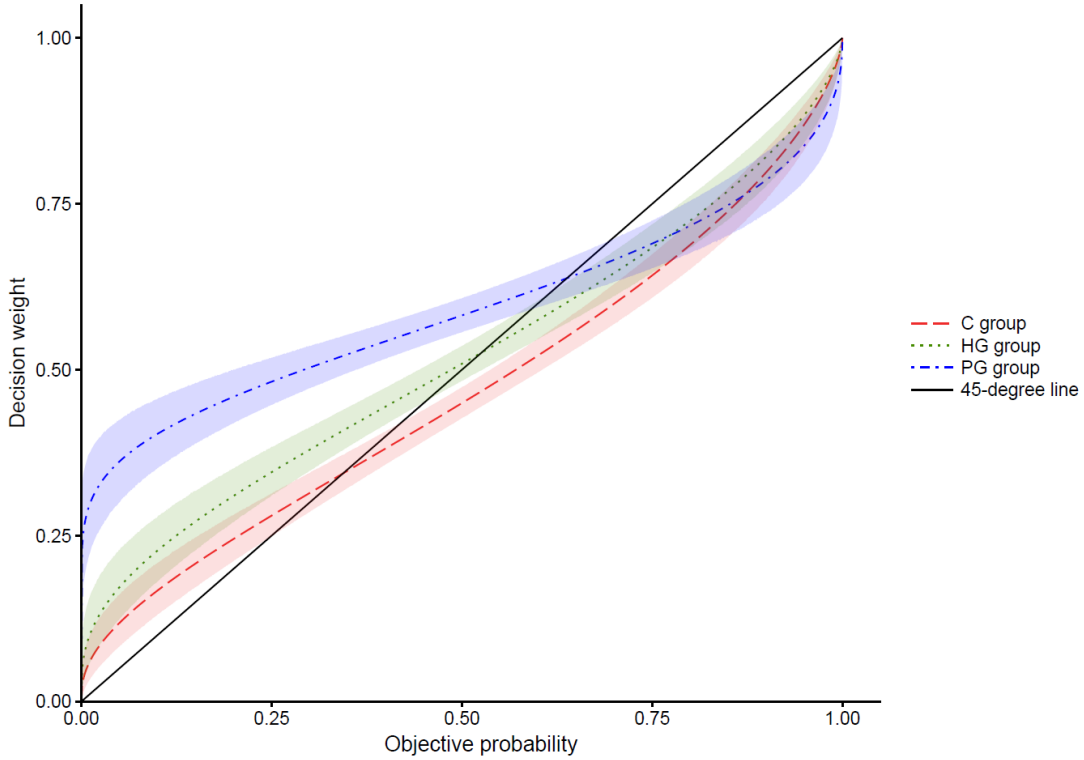

Figure 4: Weighting funtions in the gain domain

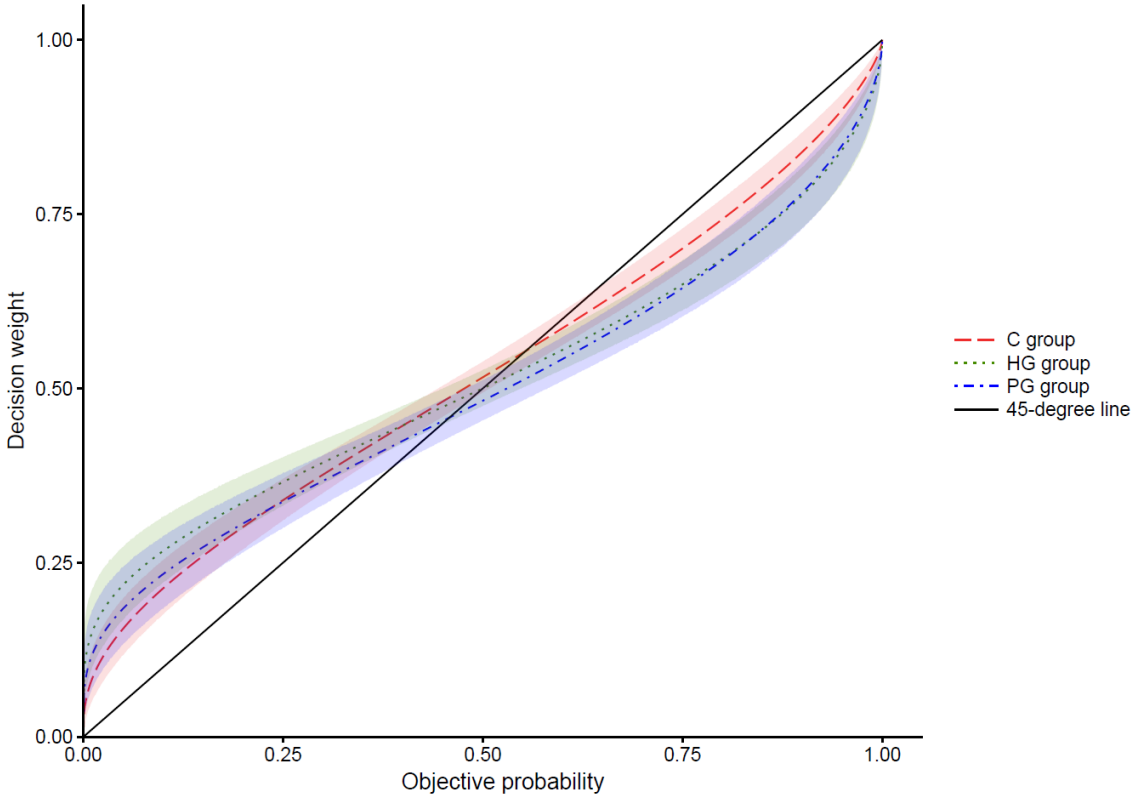

Figure 5: Weighting funtions in the loss domain

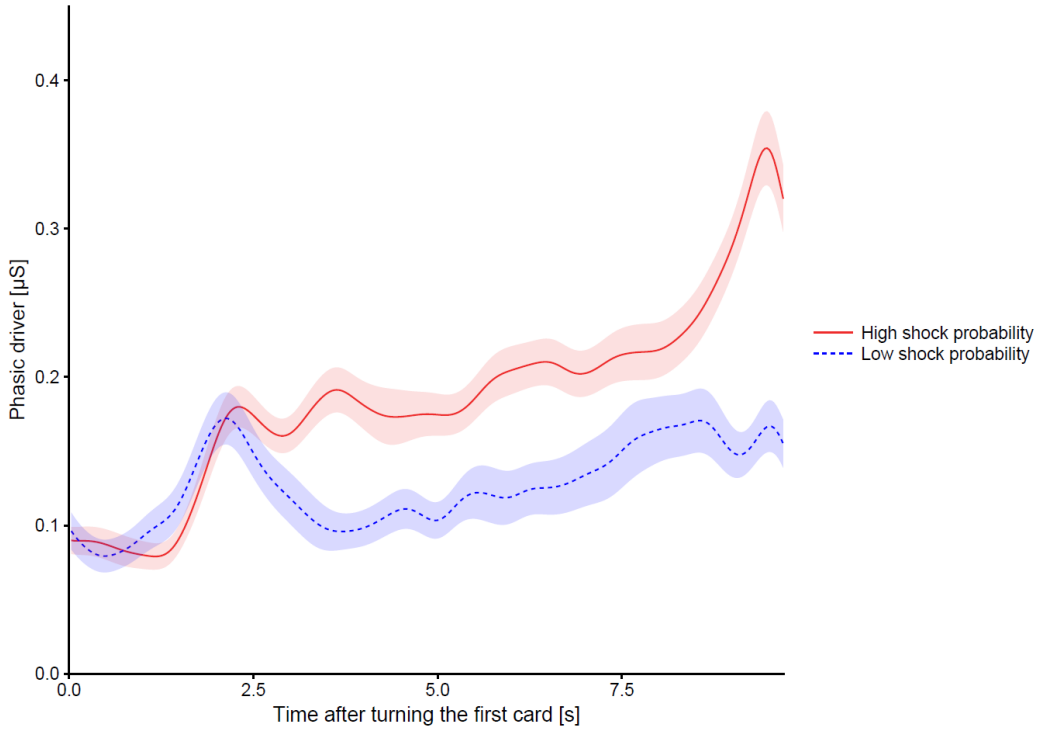

Figure 6: Skin conductance responses of pathological gamblers

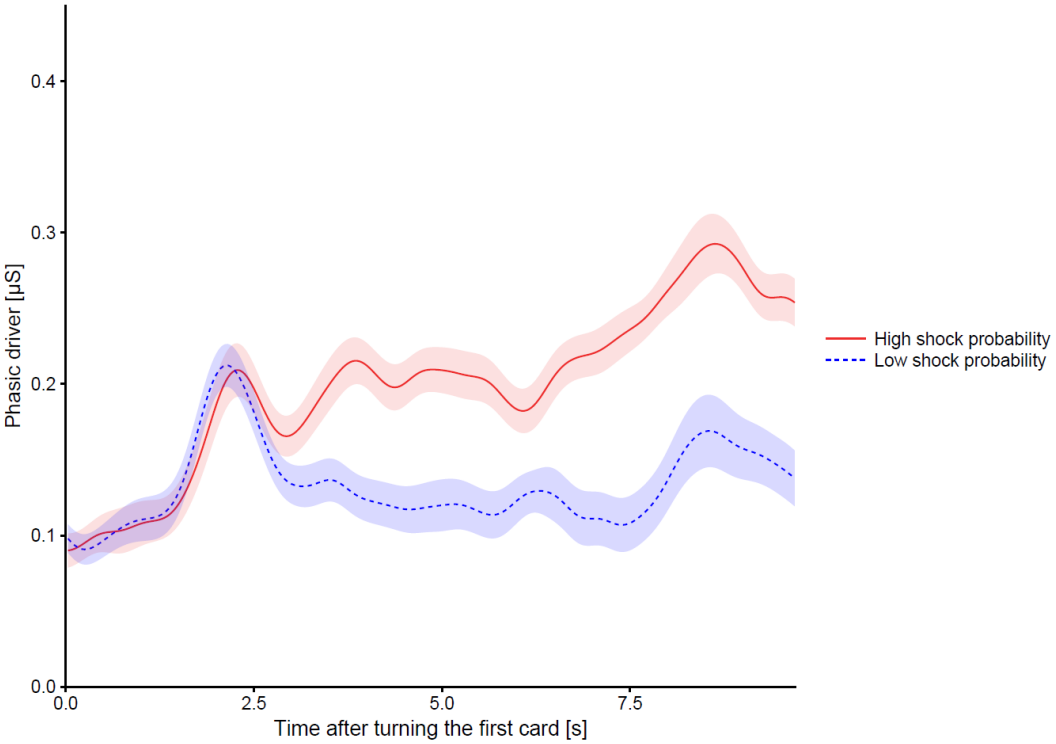

Figure 7: Skin conductance responses of controls

3.2. Time preferences of pathological gamblers

Time preferences were elicited by standard price lists given the choice between a smaller soon award and a larger delayed reward. An example of such a choice list is given in Table 2. We employed several of such choice list most of them including an upfront delay, i.e. also Option A involves a delay. The row where a subject switches from choosing Option A to Option B allows to assess the future equivalent of Option A (i. e. 10 Euro in the example of Table 1).

Table 1: Example of a price list for eliciting time preferences

Option	Option A: Today	Option B: Tomorrow	Preferred alternative	
1	10	11	A	B
2	10	12	A	B
3	10	13	A	B
4	10	14	A	B
5	10	15	A	B

Responses were analyzed within the framework of quasi-hyperbolic discounting. In this model an immediate payment of X has utility U(X) whereas the same payment at a later point of time t has utility $\beta\delta$tU(X). Whereas δ is the usual discount rate, β measures the present bias.

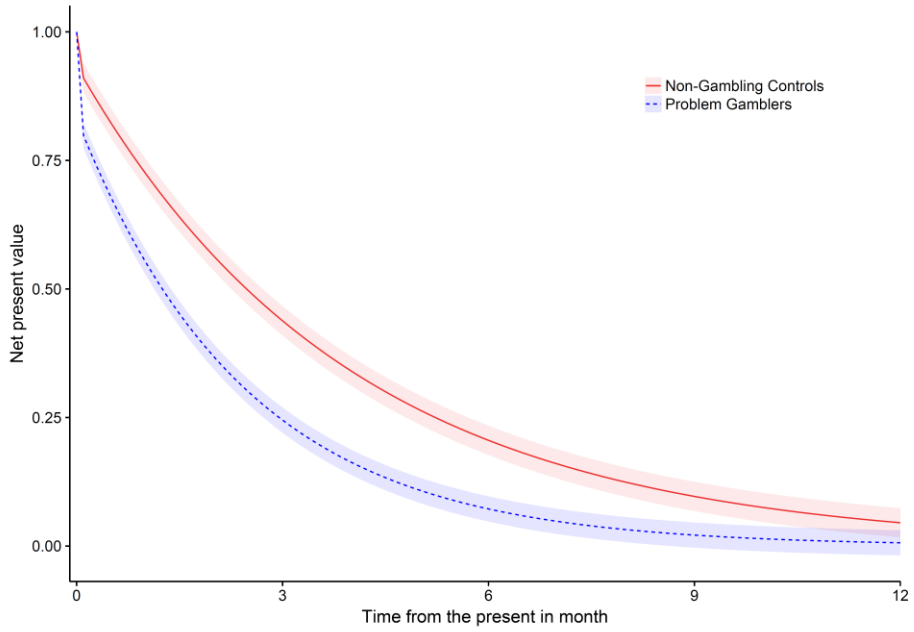

Figure 8: Net present values of gamblers and controls

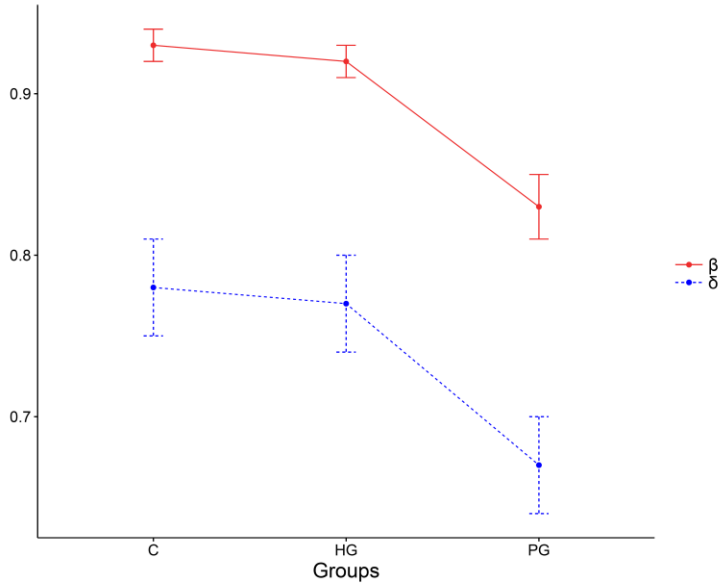

Figure 9: Hyperbolic discounting

Our results show clearly that gamblers are more impatient than controls. Figure 8 shows the net present value, i.e. the future equivalent of X divided by X, for different time horizons. The net present value of gamblers is always less than that of controls indicating higher impatience. Figure 9 decompose these results in the hyperbolic discounting model. The Figure reveals clearly that both β and δ are significantly lower for pathological gamblers than for the other subject groups.

3.3. Peripheral somatic markers associated with behavior under uncertainty

In two studies, we analyzed skin conductance responses (SCRs) – a psychophysiological marker of emotional arousal – during the anticipation of unpleasant, but not painful, electric shocks with a varying probability of occurrence. Thereby, we studied how individuals perceive probabilities in terms of emotional bodily reactions and whether probability distortions, which exist at the behavioral level, also manifest at the somatic level. Our main findings show that during the anticipation of electric shocks SCRs increase linearly with the probability, i.e., we did not observe probability distortions in SCRs (Ring, 2015). Moreover, we were able to show that framing effects occur in well-educated and well-informed individuals at a low emotional level (Ring and Kaernbach, 2015). Framing effects are an important topic in both psychology and economics and we have directly contributed to the current discussion on the robustness of these effects. Based on the previous findings, we applied EEG source analysis to identify the sources of afference and targets of reafference of threat-sensitive SCR-events (Ring et al. 2017c). Due to the potentially behavior guiding function of somatic markers (as stated in Damasio's somatic marker hypothesis), these findings appear to be relevant across behavioral science literature.

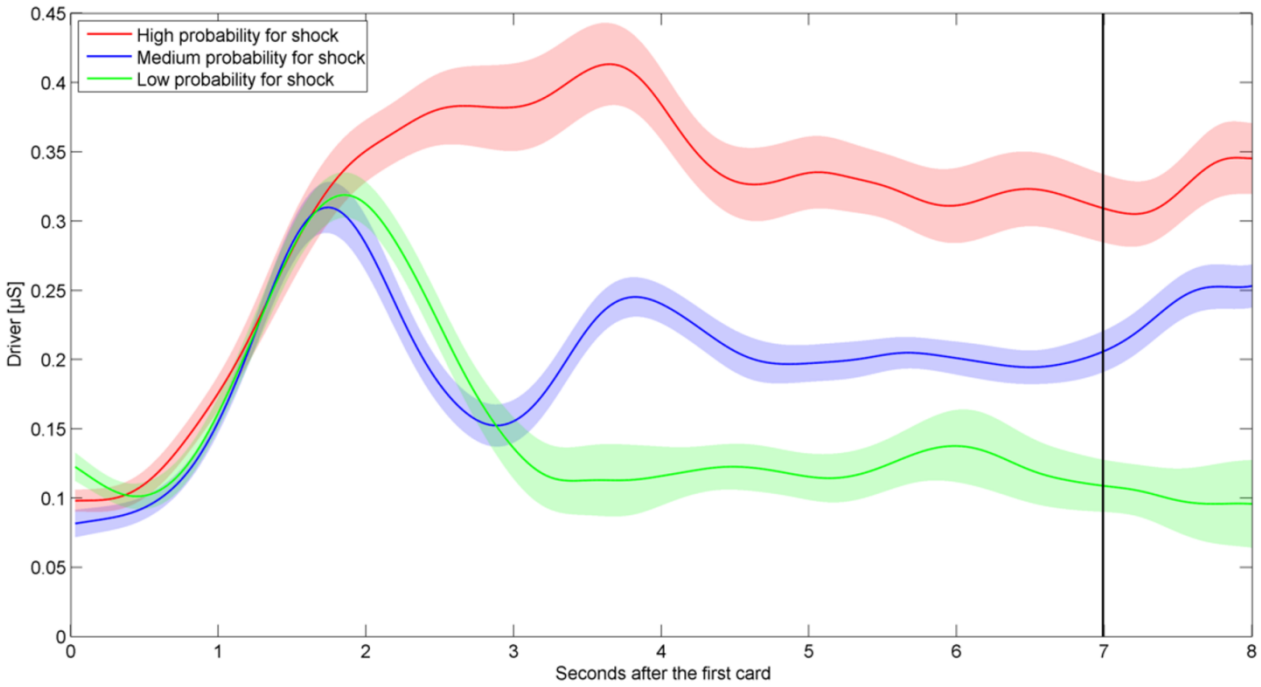

Figure 10: Phasic (driver) information after the first card for three cases (8 s). Shaded areas indicate the within-participant standard errors of the mean.

3.4. Neural activity

Results on neural activity are reported in Probst et al. (2017). Our sample of 25 pathological and 23 habitual gamblers, as well as the 26 control subjects were scanned with blood oxygenation level-dependent (BOLD) functional magnetic resonance imaging and engaged in a card game in which unambiguous situations of various risk levels for punishment (unpleasant, but not painful electric shocks) were created. As shown in Figure 11, participants were to choose one out of ten cards shown on a monitor. The card value together with information about the bet type (↑= higher card wins, ↓=lower card wins) indicated the probability of receiving an electric shock after an anticipation phase of ~ 8 s. The electric shock was applied when the second card was revealed. Subsequently, participants were asked to answer a control question to control for loss of attention. With this procedure, our design comprised 10 conditions differing in probability of pending physical punishment.

Apart from neural responses to punishment, our paradigm therefore allowed us to measure how neural activity is modulated in expectation of punishment by the probability of being punished (risk) or the certainty of the outcome (certainty).

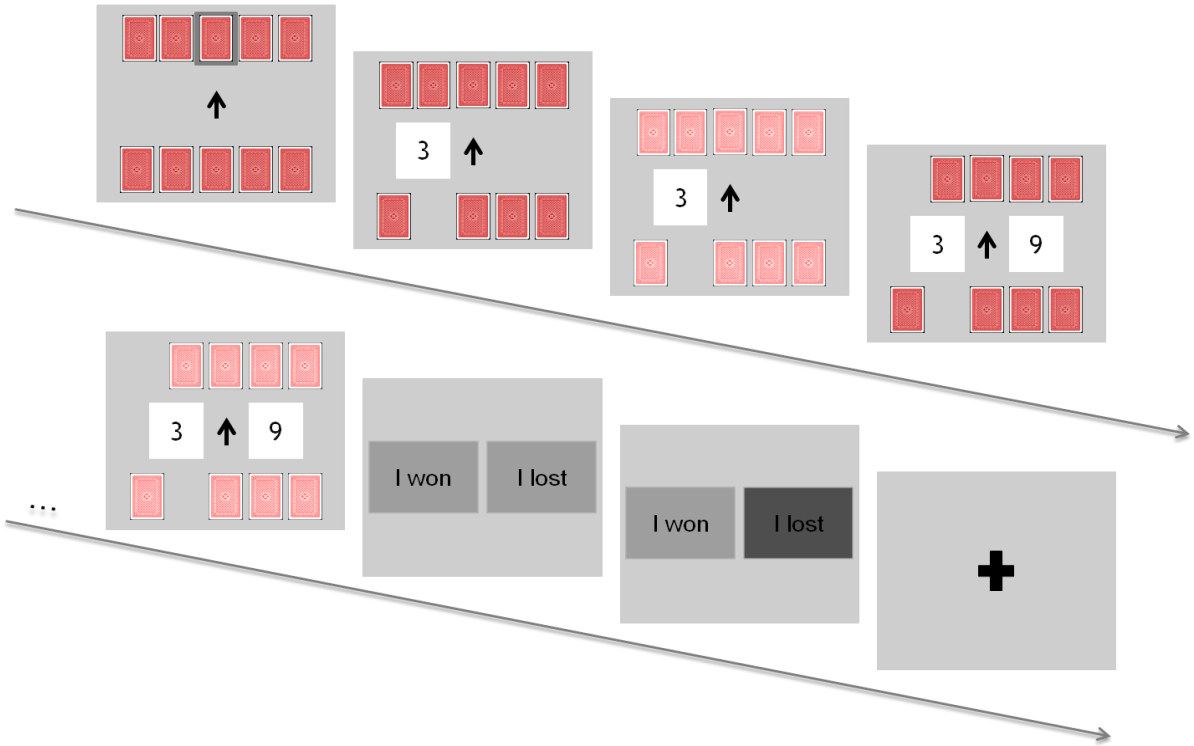

Figure 11: Experimental design. Participants chose one out of ten cards. The card value together with information about the bet type (↑= higher card wins, ↓=lower card wins) indicated the probability of receiving an electric shock after an anticipation phase of ~ 8 s. The electric shock was applied when the second card was revealed. Subsequently, participants were asked to answer a control question.

fMRI data processing

Data was analyzed using Statistical Parametric Mapping 8 (SPM8, Wellcome Department of Cognitive Neurology, London, the United Kingdom) software implemented in Matlab 14a (Mathworks Inc.). T1 images were segmented to white matter, grey matter and cerebrospinal fluid and the EPI images were coregistered to the bias corrected T1 image. EPIs and T1 were then normalized to MNI space. The normalized fMRI images were spatially smoothed with a Gaussian kernel of 8 mm (full-width at half-maximum) in the x, y, and z axes.

We set up a first level analysis that contained all probability levels revealed on card one as separate conditions. The onset of the second card was divided in 10 conditions depending on the outcome probabilities of the trial. The second level comprised a flexible factorial model containing the ten contrasts for all probability levels as factors of interest. We were especially interested in areas activated by increasing punishment probability and thus set up a contrast for a linear increase of loss probability from the lowest loss probability greater than zero (i.e. p=0.12) to the highest probability. Furthermore, we were interested in non-linear (u-shaped, or inverted u-shaped) functions, correlating with outcome certainty (from certain win to maximum uncertainty - 4/5 or 5/4 - to certain loss of the trial).

We also computed a one sample t-Test at the second level including the linear and non-linear contrast. Further, we tested between-group differences using two-sample t-Tests.

The results, as shown in Figure 12, were corrected for multiple comparisons using family-wise error (FWE) corrected with p=0.05 for clusters with >10 contingent voxels.

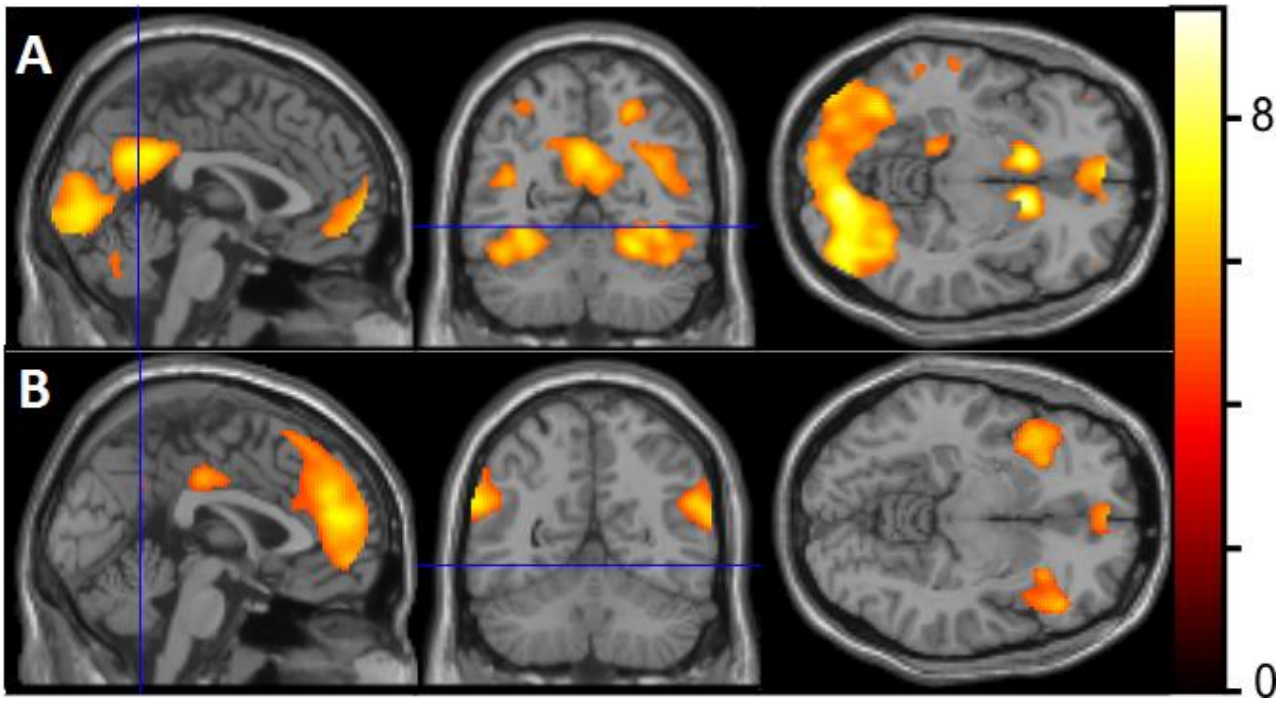

Figure 12: [X Y Z] = [0 -56 -8] fMRI activation for all participants modelled with A: the linear increase for the chance to win a trial. B: the nonlinear increase for the chance to win and lose a trial (U-shape)

Preliminary Conclusion: Our results support the notion that economic decision making contains both linear and nonlinear cognitive processes that broadly follow contingencies for risk and certainty and provide evidence that these cognitive processes are represented in different sets of brain regions. Correlates for the risk for punishment were found in areas known to be involved in dopaminergic reinforcement learning, while regions known to subserve decision making, conflict monitoring and punishment exhibit a correlation with the certainty of the outcome. While there is ample evidence for altered neural processing of reward in pathological gamblers, we found no evidence for changes in the neural processing of punishment. This is consistent with our results from the choice task where we found differences between gamblers and controls in the gain domain but not in the loss domain.

3.5. Biological markers associated with behavior under uncertainty

Another line of the team research focuses on the role of biological markers – in particular the digit ratio – of decision making under uncertainty. The second to fourth digit ratio is thought to be

a negatively correlated marker of prenatal exposure to testosterone, which has an impact on brain development and subsequent sex-typical behavior. Several findings from behavioral economics indicate that certain types of behavior are more pronounced in one gender than in the other and such gender differences. For example, males tend to be less loss averse and more overconfident than females. Our findings also indicate that low digit-ratio men (indicating high prenatal testosterone exposure) show higher overconfidence in a cognitive task (Neyse et al., 2016) when they are monetarily incentivized (Figure 13). Without monetary incentives, no significant relationship between digit ratio and overconfidence was observed. Further analysis also shows that low digit ratio men are also less loss averse (Neyse et al., 2017). These findings suggest that the above-outlined gender differences in decision making are to some extent biologically determined.

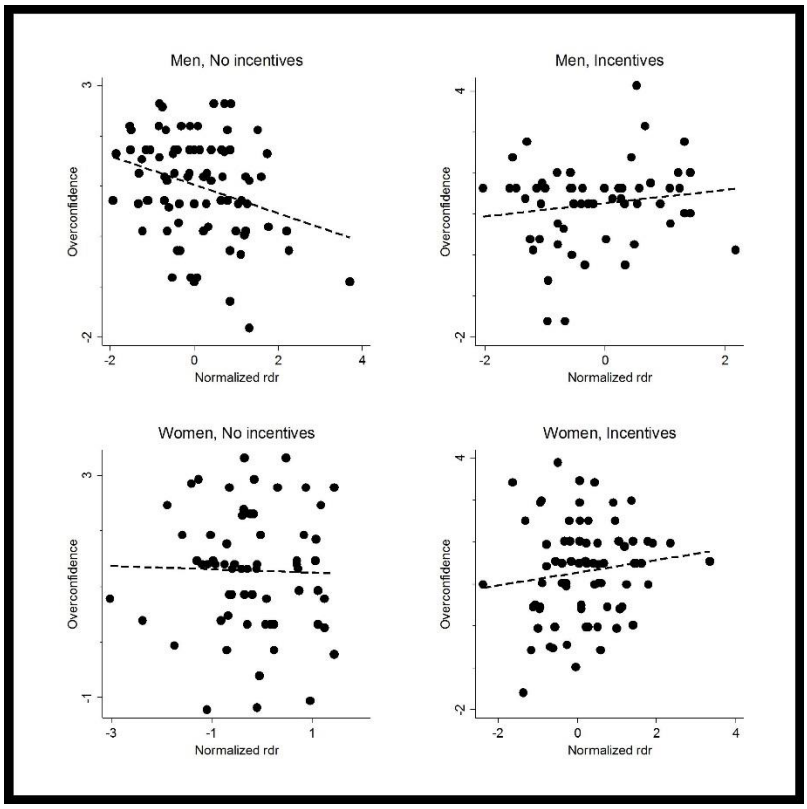

Figure 13: Scatterplots for the relationship between digit ratio and overconfidence

4. Research Output

4.1. Published Articles

Friedl, A., Ring, P., & Schmidt, U. (2017). Gender differences in ambiguity aversion under different outcome correlation structures. *Theory and Decision*, *82*(2), 211-219.

Neyse, L., Bosworth, S., Ring, P., & Schmidt, U. (2016). Overconfidence, incentives and digit ratio. *Scientific Reports*, *6*.

Espín, A. M., Exadaktylos, F., & Neyse, L. (2016). Heterogeneous motives in the trust game: a tale of two roles. *Frontiers in Psychology*, *7*.

Ring, P., & Kaernbach, C. (2015). Sensitivity towards fear of electric shock in passive threat situations. *PloS One*, *10*(3), e0120989.

Ring, P. (2015). The framing effect and skin conductance responses. *Frontiers in Behavioral Neuroscience*, *9*.

Ring, P., Neyse, L., David-Barett, T., and Schmidt, U. (2016). Gender Differences in Performance Predictions: Evidence from the Cognitive Reflection Test. *Frontiers in Psychology*, *7*.

Sandnes, F. E., Neyse, L., & Huang, Y. P. (2016). Simple and practical skin detection with static RGB-color lookup tables: A visualization-based study. In *Systems, Man, and Cybernetics (SMC), 2016 IEEE International Conference on* (pp. 002370-002375). IEEE.

4.2. In Submission

Neyse L, Brañas-Garza P (2014) Digit ratio measurement guide. Munich Personal RePEc Archive 54134.

Neyse, L., Probst, C. C., Ring, P., Wolff S., Vieider, F., Kaernbach C., van Eimeren T., Schmidt, U. (2017) Exposure to prenatal testosterone reduces loss aversion in Caucasian men.

Ring, P., Probst, C. C., Neyse, L., Wolff S., Kaernbach C., van Eimeren T., Camerer, C. F., Schmidt. U. (2017a) It`s all about gains: Risk preferences in problem gambling.

Ring, P., Probst, C. C., Neyse, L., Wolff S., Kaernbach C., van Eimeren T., Schmidt, U. (2017b) Quasi-hyperbolic discounting in problem gamblers

Ring, P., Muthuraman, M., Probst, C. C., Neyse, L., Wolff, S. Schmidt, U., van Eimeren, T., Kaernbach, C. (2017c) Brain networks associated with skin conductance responses in the context of risk

Probst, C. C., Ring, P., Neyse, L., Lehrke A., Kaernbach C., van Eimeren T., Schmidt, U. (2017) Neural correlates of probabilistic punishment anticipation and health related risk taking

4.3. Doctoral Theses

Probst, C. C. (May 2017), [Components and neural correlates of the decision making process] (Summa Cum Laude)

Ring, P. (2016) [Neurobiological Foundations of Decision-Making under Uncertainty] (Summa Cum Laude)

5. References

Neyse, L., Bosworth, S., Ring, P., & Schmidt, U. (2016). Overconfidence, incentives and digit ratio. *Scientific Reports*, *6*.

Ring, P. (2015). The framing effect and skin conductance responses. *Frontiers in behavioral neuroscience*, *9*.

Ring, P., & Kaernbach, C. (2015). Sensitivity towards fear of electric shock in passive threat situations. *PloS one*, *10*(3), e0120989.

Tversky, A., & Kahneman, D. (1992). Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and uncertainty*, *5*(4), 297-323.

Tom, S. M., Fox, C. R., Trepel, C., & Poldrack, R. A. (2007). The neural basis of loss aversion in decision-making under risk. *Science*, *315* (5811), 515-518.