Independent Junior Research Group

Neurocognition of Decision Making

Contents

Scientific Staff (October 2005–September 2010)

Markus Bauer, Guido Biele, Isabel Dziobek, **Hauke R. Heekeren**

Predoctoral Research Fellows
Markus Bahnemann, Nikos Green, Lea Krugel, Katja Mériau (NaföG), Peter Mohr (LIFE), Kristin Prehn (NaföG), Sandra Preißler (BNIC), Christina Scheibe (NaföG), Hermine Wenzlaff

Research Agenda: Multimodal Approach to the Neurocognition of Decision Making

Decision making can be defined as the process of choosing a preferred option or course of action from among a set of alternatives. There is a long history of decision-making research in psychology and economics that has resulted in the development of formal models of behavior, which are inspired by behavioral data or the computational demands of a task. An example for the former are sequential sampling models of decison making, an example for the latter are reinforcement learning models for repeated choice tasks. However, cognitive functions, such as decision making, cannot be completely understood on the basis of mathematical models and behavioral data alone; we have to investigate how mental (cognitive) and neuronal processes map onto each other (cf. Schall, 2004). Therefore, a central goal of the independent junior research group "Neurocognition of Decision Making" is to explicitly link brain function and behavior using formal models of decision-making behavior.

In pursuit of this goal, we investigate decision making in different domains. First, at the basis of a number of different decisions we are facing in everyday life stands *perceptual decision making:* the process of translating sensory input into some kind of motor output (cf. Figure 1). Many of our decisions are influenced by the potential outcomes associated with different options, hence, *reward-based decision making* is another important topic for our group. *Decision making in social contexts* relies not only on perceptual and reward-related processes but also includes more complex cognitive processes and emotional aspects and the interaction between the two.

We believe that the investigation of the neurocognition of decision making requires a multimodal methodological approach that integrates information from an array of methods ranging from cognitive modeling based on behavioral data to simultaneous *functional Magnetic Resonance Imaging* (fMRI) and EEG experiments (cf. Figure 1).

On the following pages, we briefly describe research on the three topics in some more detail. Each section begins with a brief introduction, which is followed by short descriptions of individual projects.

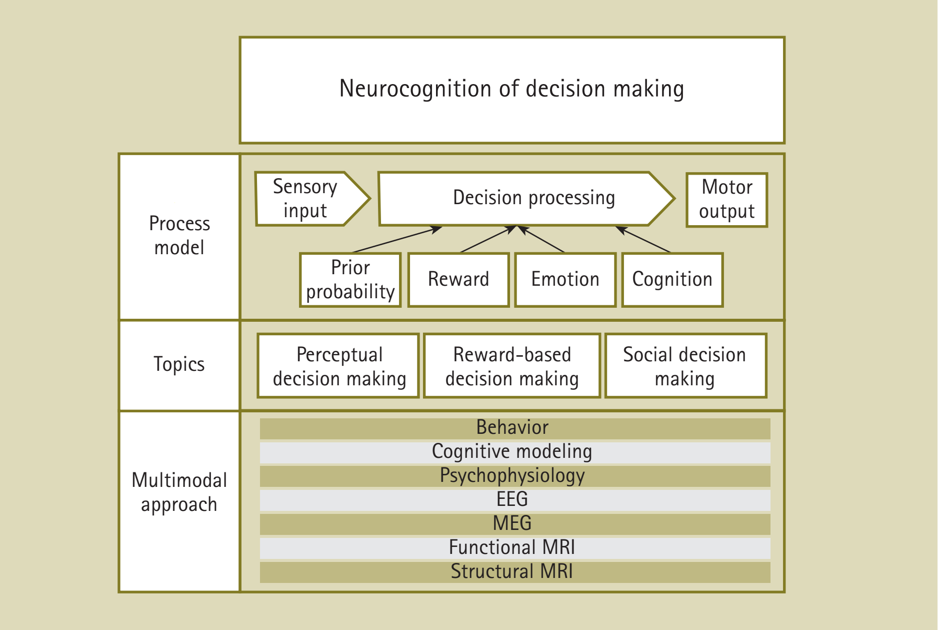


Figure 1. A multimodal approach to the neurocognition of decision making.

Neurocognition of Perceptual Decision Making

Perceptual decision making entails processing of sensory signals, formation of a decision, and the planning and execution of a motor response. For example, in a motion-direction discrimination task, motion signals need to be interpreted and translated into a saccadic eye movement. In a face-house discrimination task, degraded images of faces and houses have to be interpreted and translated into a button press with the right or the left hand.

Over the last 40 years, decision-making research in mathematical psychology has resulted in detailed mathematical models of the assumed underlying cognitive processes. Sequential sampling models are particularly successful in explaining response time data and accuracy in two-choice reaction time tasks, such as the ones described above. A prominent version of sequential sampling models are diffusion models, which assume that decisions are formed by continuously accumulating sensory information until one of the two response criteria is reached (e.g., Smith & Ratcliff, 2004; cf. Figure 2).

Given the well-described nature of perceptual decision-making tasks, such as face-house discrimination and the relatively well-known functional neuroanatomy of the subsystems involved, perceptual decision making has recently been used as paradigm to study simple decision processes in the brain of human and nonhuman primates.

Single-unit recordings in monkeys, and more recently neuroimaging studies in humans, have begun to investigate the neural mechanisms involved in these processes (e.g., Heekeren, Marrett, Bandettini, & Ungerleider, 2004, 2006; Mazurek et al., 2003; Romo & Salinas, 2003) and to model not only psychophysical data but also neurophysiological data as a diffusion-to-barrier process (e.g., Gold & Shadlen, 2002; Philiastides et al., 2006). Thus, perceptual decision-making tasks provide an ideal paradigm to pursue our goal to explicitly link brain function and behavior using formal models.

Studies in monkeys and humans performing sensory discrimination tasks suggest that perceptual decisions are made by integrating the sensory evidence represented by lower level sensory neurons (Gold & Shadlen, 2002; Heekeren et al., 2004). For example, when monkeys must decide whether a noisy field of dots is moving upward or downward, a decision can be formed by computing the difference in responses between lower level neurons sensitive to upward motion and those sensitive to downward motion. In this model, higher level brain regions computing decision variables thus have to accumulate evidence over time. The dynamics that are involved in the formation of these higher level representations are of core interest to systems and cognitive neuroscience. In ongoing projects, we build on our previous work and investigate how sensory systems infer the identity of real-world objects from their noisy neural representations, and how the outcome of such a process is signaled to the motor system. Furthermore, we want to elucidate how the brain uses contextual information (in particular prior probabilities about possible alternatives) that is integrated with stimulus

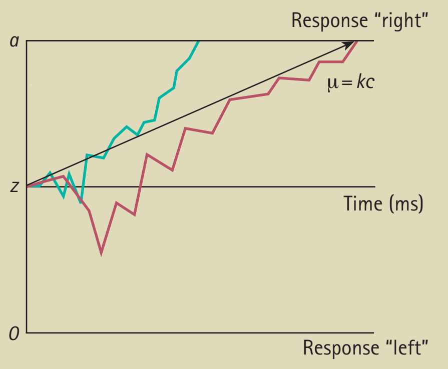


Figure 2. Stochastic diffusion models assume that a decision is the result of continuously accumulating noisy stimulus information from a starting point *z* until one of two response criteria, *a* and *0*, is reached. Once the boundary is reached, the decision process is concluded and a response is elicited. Moment-by-moment fluctuations in the sample path reflect noise in the decision process. The drift rate (μ) is related to the efficacy of information processing. μ is dependent on the ncrease in the decision variable (accumulation rate, *k*) quantifying how much evidence is accumulated per time interval as well as on the strength of the sensory signal *(c)* (e.g., Smith & Ratcliff, 2004).

inherent information, and thereby conveys additional information to improve decision making.

Perceptual Decision Making in the Somatosensory Domain

The project "Tactile Decision Making" investigates how sensory information is processed to make categorical judgments and aims at revealing the neural processes behind the accumulation of sensory evidence.

To date, it is unclear whether the accumulation of evidence by a diffusion process as found in the visual domain (see above) generalizes to other sensory modalities and stimulus materials with only brief exposure. Furthermore, the precise neuronal mechanisms behind such accumulation of evidence remain unclear. In a first study, we therefore investigated whether there is evidence for temporal integration in the somatosensory system using a tactile decision task. Previous research from Bauer, Oostenveld, Peeters, and Fries (2006) has shown that in a two-alternative decision task, very brief exposure (35 ms) to tactile pattern stimuli leads to *sustained* high-frequency oscillations in primary somatosensory cortex when subjects have to report the identity of these patterns. On the contrary, when stimuli are presented, but subjects are not required to make a decision, only a brief burst of oscillatory activity occurs. These sustained oscillatory responses are accompanied by rather long reaction times (~500 ms) suggesting that time-enduring internal computational processes are necessary to distinguish between the two patterns to make a decision. A central question inherent to the project presented here will be whether these sustained oscillations are instrumental to the decision process and reflect the accumulation of evidence.

In a recent experiment, three pattern pairs were presented varying in difficulty level operationalized by the spatial separability of the patterns of a pair. Subjects had to discriminate between two tactile stimuli of a pair. Response times as well as error rates increased with increasing difficulty, indicating that temporal integration (accumulation) of evidence seems to occur (see Figure 3).

In ongoing studies, we are investigating whether, similar to neurophysiological studies in monkeys, human EEG and MEG data provide neurophysiological evidence for a "diffusion to boundary process" determining the elicitation of a response.

Future directions of this project will include simultaneous EEG and fMRI experiments to study the interactions between higher level cortical structures, such as the *DorsoLateral PreFrontal Cortex* (DLPFC; which is known to

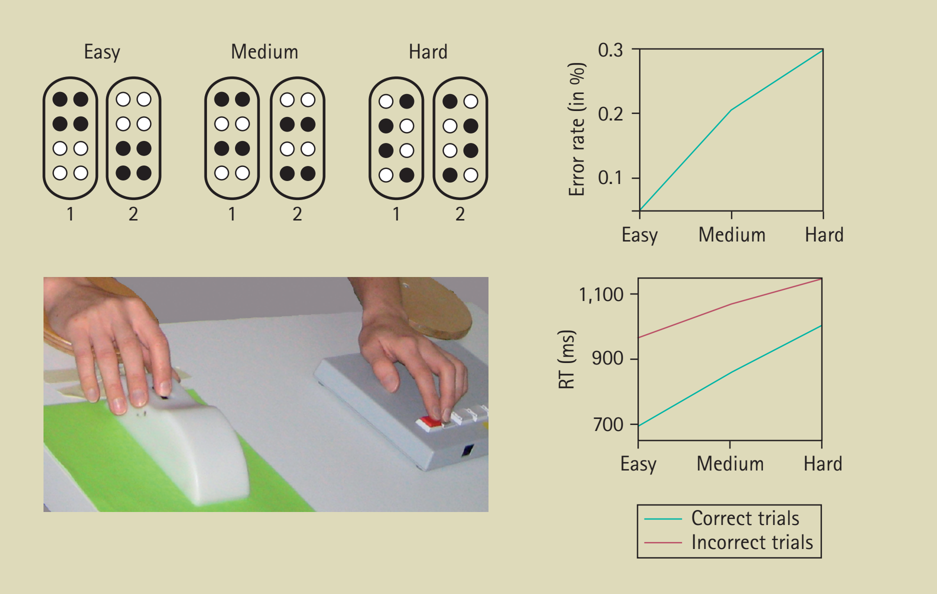


Figure 3. Three different Braille pairs (varying in spatial similarity) were presented to subjects' right index fingers (left). Discrimination of these pairs resulted not only in substantially different performance levels, but also longer reaction times (right).

Key Reference

Scheibe, C., Ullsperger, M., Sommer, W., & **Heekeren, H. R.** (2007). *Spatiotemporal dynamics munderlying the integration of prior probability information in decision making.* Conference of Cognitive Neuroscience, New York. Abstract.

be involved in somatosensory decision making, cf. Preuschhof, Heekeren, Taskin, Schubert, & Villringer, 2006, but difficult to map with EEG/MEG) and sensory cortices (which are more easily localizable with EEG/MEG, cf. e.g., Bauer et al., 2006). Furthermore, it will be of interest to show how information from different sensory modalities is combined to make decisions about external objects. Parts of this project are realized in collaboration with Driver (Institute of Cognitive Neuroscience/Wellcome Trust Centre for Neuroimaging, UCL, London) as well as von Oertzen (Center for Lifespan Psychology at MPI for Human Development).

The Influence of Prior Probability on Decision Making

The prior probability of the occurrence of an event is a critical variable in decision-making processes. The response time in two-alternative forced choice tasks is speeded by prior probability. Single cell recordings in monkeys revealed a modulation of the firing rate of motor-related neurons by prior probability. Furthermore, modeling studies suggest that the motor system is an integral component of decision-making processes. However, it is unclear at which stage of the decision-making process in the human brain prior probability is integrated. In a recent experiment, we used *Event-Related Potential* (ERP) components as proxies for different processing stages of the decision-making process. In this context, the *Contingent Negative Variation* (CNV) reflects higher level response selection and abstract motor programming at a more central level while the *Lateralized Readiness Potential* (LRP) is an index for lower level motor preparatory processes. To investigate the influence of prior probability, we used a number comparison task as a modified precue paradigm. Our data revealed that the CNV during the foreperiod is parametrically modulated by prior probability, indicating an integration of prior probability at an early stage of response selection and premotor preparation (cf. Figure 4) (Scheibe, Schubert, Sommer, & Heekeren, 2006). In contrast, the LRP was modulated in a binary fashion, that is, it only distinguished between certain (100% prior probability) and uncertain information (<100% prior probability).

Based on these results, we recently conducted an fMRI experiment with simultaneous EEG recordings (in cooperation with Ullsperger and von Cramon, MPI for Human Cognitive and Brain Science, Leipzig) to examine the neural correlates of the integration of prior probability in the decision process. Despite the EEG-adverse environment in the scanner, we replicated the increasing CNV amplitude with increasing prior probability. The fMRI data revealed that areas in the prefrontal cortex, particularly the dorsolateral and frontomedial regions, seem to play a crucial role in preparatory processes based on prior probability (Scheibe et al., 2007). In a further EEG-informed analysis, we will relate the CNV amplitude and *Blood Oxy-*

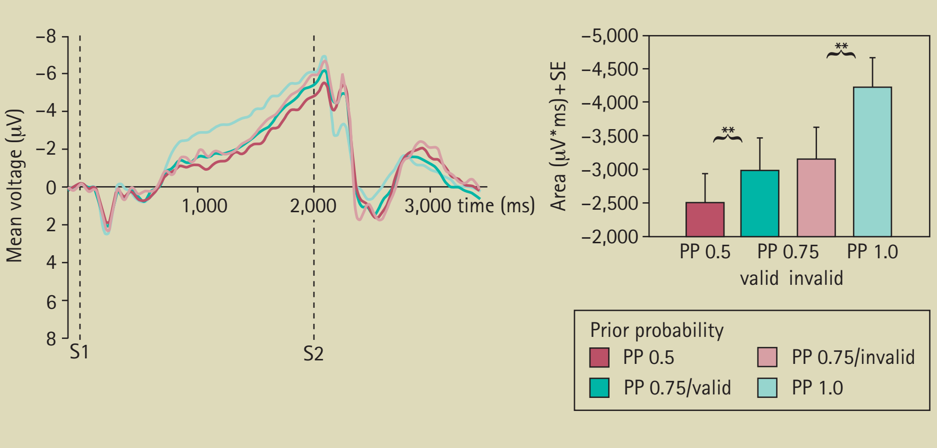


Figure 4. EEG component at the electrode position Cz for the different conditions. The CNV between S1 and S2 (foreperiod) increases parametrically with increasing prior probability.

genation Level Dependent (BOLD) correlates at a single-trial level. Thereby, we want to identify brain regions that are associated with the development of the CNV and the integration of prior probability into the decision process.

Reward-Based Decision Making

Many of our decisions are influenced by the potential outcomes associated with different options. For instance, consumers test different brands of a particular product to identify their favored brand, or investors first learn about the past performance of investments and then decide about the allocation of their funds. The project "reward-based decision making" examines how people use information to achieve rewarding outcomes.

To examine reward-based decision making, we abstract basic features from real-life decisions, such as the type of information and feedback available, and implement them in simpler tasks, which are amenable for the application in an fMRI environment and to precise modeling. Conducting fMRI experiments allows us to test models and theories with variables, such as the prediction error in temporal difference learning models that are usually not accessible with exclusively behavioral experiments.

Reward-based decision making has been tackled by different disciplines, therefore, our theoretical approach combines elements from these: *Economics and Machine Learning* describe procedures which aim to maximize the decision maker's outcome (Markowitz, 1952; Sutton & Barto, 1998), psychological theories describe how people learn from feedback (Erev & Barron, 2005), and neuroscientific research describes which kind of information is represented, and how it is manipulated to reach a decision (e.g., Frank & Claus, 2006). While it is a challenging endeavor to examine reward-based decision making across these different levels, we believe that a solid understanding of reward-based decision making needs to describe and understand decision making on different theoretical levels (Marr, 1982). Understanding how goals can be achieved in an optimal way allows deriving hypotheses about the information that needs to be represented and manipulated to make good decisions. Knowledge about how the brain represents information, and about the type of connections between different brain regions, constrains theories about which information is used, and how it is manipulated.

Guided by this general approach, a typical project starts with one or several behavioral theories of reward-based decision making, which are compared in their ability to predict behavioral data. In a second step, the theories are tested on the neuronal level. Testing theories on a neuronal level amounts, for instance, to investigating if a representation of information that is essential to that theory can be found on the neuronal level, or if a representation of a behaviorally unobservable variable predicted by a theory can be identified. Due to our multilevel approach to reward-based decision making, the projects are usually interdisciplinary, and involve cooperation with other research institutions. The remainder will introduce some ongoing projects.

Neural Representation of Decision Thresholds

One question that is particularly interesting for the fields of both perceptual decision making and reward-based decision making is how decision makers adjust their decision criterion to obtain optimal rewards. One kind of model addressing this question are sequential sampling models because they successfully explain response times and percentage of correct decisions in tasks as different as perceptual decision making and short-term memory tasks (Ratcliff & Smith, 2004). The common idea of sequential sampling models is that the decision maker accumulates information in favor of the different decision options, and that the decision is made in favor of the option for which the accumulated evidence first exceeds a decision threshold (see above). Recent research attempted to test sequential sampling models by identifying neurons that accumulate evidence over time, and by correlating EEG parameters with the accumulation gradient in sequential sampling models. From a reward-based learning perspective, the decision

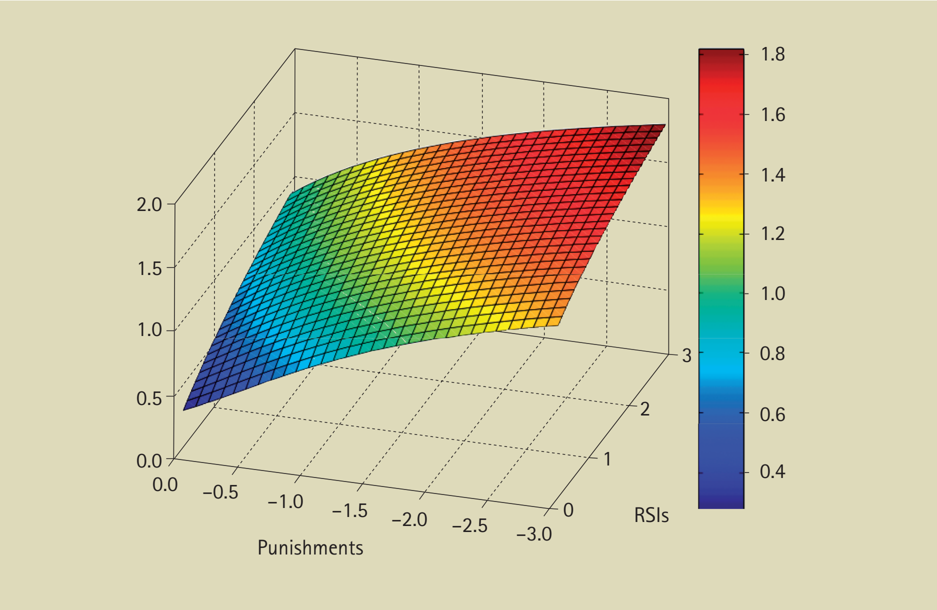


Figure 5. Decision thresholds: Speed-accuracy trade-off can be manipulated by the *Response Stimulus Interval* (RSI) and by punishment for incorrect decisions. The figure depicts optimal thresholds (Y-axis) for a sequential sampling decision model. The payoff for a correct decision is fixed to 1, the parameter for the drift rate is .5, the residual decision time is set to empirically realistic 0.4.

threshold is an especially interesting parameter because it is under the influence of the decision maker. Therefore, in this project, we investigate the neural correlates of the decision threshold. Specifically, we plan to conduct experiments on perceptual (visual) decision making, in which we systematically modify payoffs, so that participants have a strong incentive to adjust their decision threshold. For instance, increasing the punishment for a wrong decision for one alternative in a two-alternative forced choice task should increase the decision threshold for that alternative (Figure 5). In a first behavioral study, we investigate how people respond to changing payoff structures. The first goal of the behavioral study is to identify payoff matrices leading to different thresholds. The second goal is to evaluate which sequential sampling model explains the data best. In an fMRI study, we will then record brain activation during perceptual decision making under different payoff conditions identified in the behavioral study. Here, the objective is to identify how the decision threshold parameter of the best sequential sampling model is represented in connectivity between different brain regions. This project is realized in collaboration with Galesic and Olsson from the Center for Adaptive Behavior and Cognition (ABC) at the MPI for Human Development.

Is Ambiguity Aversion Caused by Pessimism or Dislike?

An observation of considerable interest to economists and psychologists alike is that people prefer risky situations over ambiguous situations with the same expected outcome. For example, most subjects would prefer a gamble with a 50 % chance to win 10 Euros and to win nothing otherwise, over a gamble with unknown probabilities to win either 10 Euros or nothing. The aim of this experiment is to test the hypothesis that ambiguity aversion can be explained by a pessimistic attitude toward ambiguous situations, that is, that people assign the worse outcome a higher likelihood than justified by the available information (Gilboa & Schmeidler, 1989). To test this hypothesis, we use a new variant of the monetary incentive delay task, which has previously been used to elicit representations of event probabilities (Knutson et al., 2005). During the task, participants first receive information about the difficulty of a shortly following face-house discrimination task (see Figure 6). Crucially, the participants' payment depends on the performance in this task, where the correct response needs to be

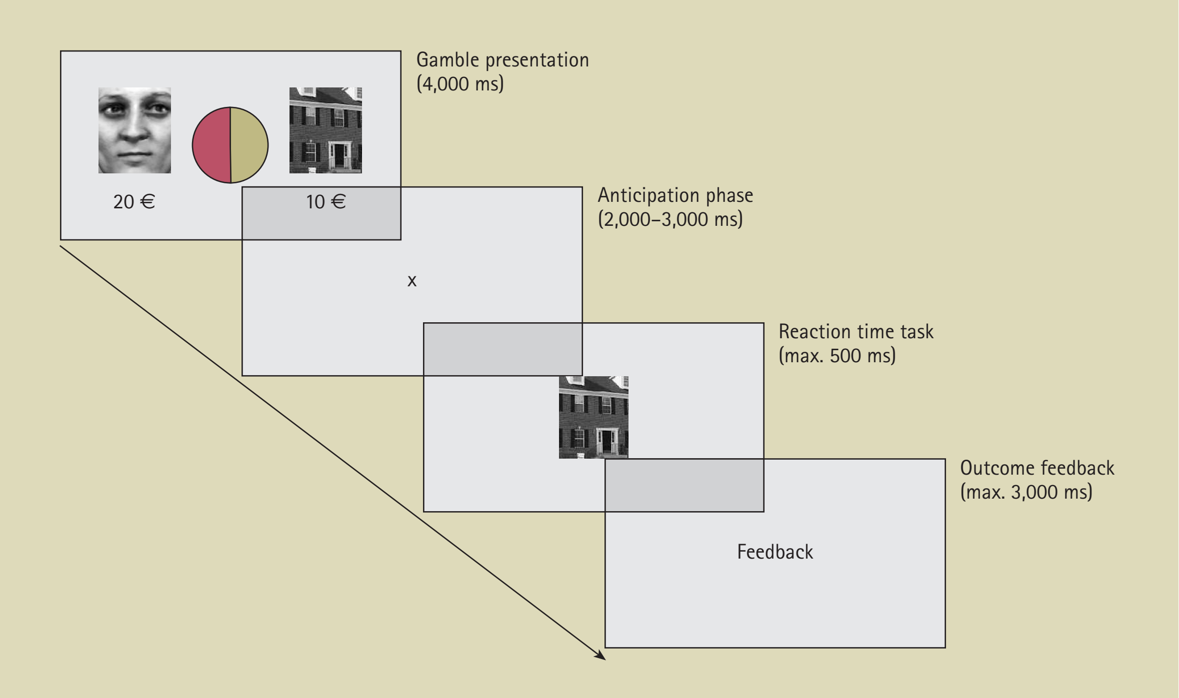


Figure 6. Modified delayed incentive task. Participants are first presented with a gamble, which also predicts the probability of a house-target or a face-target in the reaction time task. If participants are ambiguity averse due to pessimism, this increases their expected probability to react fast enough after presentation of an ambiguous lottery, compared to an 50 %-50 % lottery. Neural corralates of this expected probability, measured in the anticipation phase, have been identified in earlier studies.

made in limited time. After a brief delay (2,000-3,000 ms), participants perform the reaction time task, and finally receive feedback about their success. Previous studies showed that activation in the medial prefrontal cortex correlates with the success probability in the reaction time task. We modified the task so that participants first receive probabilistic or ambiguous information about which of two different stimuli (i. e., face or house) they will see in the face-house discrimination task. The two pictures represent the two possible outcomes of a gamble (high and low), which is only paid out to the participants if they make the correct response fast enough. The ambiguity aversion from pessimism hypothesis predicts on the behavioral level that reaction times for the low-outcome picture are slower in the 50 %-50 % condition compared to the ambiguous condition. On the neuronal level, the medial prefrontal cortex should signal a higher likelihood of success in the ambiguous decision compared to the 50 %-50 % condition because pessimistic participants will expect the low-outcome object with a high certainty. This likelihood of success is a direct function of the probability with which a participant expects a specific face, importantly, the participant's expectation is difficult to assess in a purely behavioral experiment.
This project is a collaboration with Rieskamp from the ABC group at MPI for Human Development, Gerhardt from the Humboldt University Berlin, and Mechtenberg from the Technical University Berlin.

Integration of Possible Gains and Losses in a Go-No-Go Task

How do people integrate possible gains and losses when they decide for or against a particular action? So far, this seemingly simple but also important question has stimulated little research in the field of neuroscience. While extensive research has examined the representation of experienced rewards and punishments, or anticipated reward, less is known about how potential gains and losses are represented and integrated before a decision is reached. Simple weighted additive models, which are often used to describe multiattribute choices, predict that benefits and costs of a particular action are weighted to generate a final evaluation. Translated into a hypothesis for an fMRI experiment, the weighted additive model suggests that people represent gains and losses in two different neural populations, whereas a third population might integrate this information. To gain insight in the neuronal processes of gain-loss integration, we designed an experiment in which participants first learn cues that signal monetary gains and losses of different amounts. After the learning phase, a decision condition follows in which people are confronted simultaneously with two cues representing possible losses and gains, and then have to decide if they want to receive the outcome of this gamble or not. The main goal of the study is to investigate which regions represent the gains and losses signaled by the cues. Whereas the *OrbitoFrontal Cortex* (OFC) is a natural candidate for this (Kringelbach, 2005), recent results about the function of the OFC are still so diverse that this hypothesis deserves empirical examination. A second goal consists in identifying the neuronal processes that generate the final evaluation of the gamble, for example, by integrating information from brain regions representing reward and punishment, respectively. This project is realized in collaboration with Basten and Fiebach (University of Heidelberg).

Neural Correlates of Risk-Value Models for Financial Investment Decisions

When people can choose between different choice options, the option with the highest expected value is often also the riskiest option. One domain in which this is particularly true is financial decision making, where investments with higher expected returns are usually also more volatile. Economic theory suggests that people should trade off expected return and risk in such cases, that is, they should subtract some measure of risk from the expected return to generate an integrated evaluation of an option (Markowitz, 1952). The aims of this project are (a) to model how people evaluate the expected return and the risk of an investment, (b) to identify the neural representations of these attributes, and, crucially, (c) to test if the representations are also present when people have to choose between two investments. In the experiment used to investigate these questions, participants first see a sequence of ten past returns of a risky investment and then have to either predict the expected return, judge the subjective risk, or choose between the presented investment and an investment with a known fixed return of 5 %. On the behavioral level, we test if risk-value models predict choices better than alternative models, like simple decision heuristics (Brandstätter, Gigerenzer, & Hertwig, 2006) or sequential sampling models (Busemeyer & Townsend, 1993). On the neuronal level, we will use fMRI to test if representations for both expected return *and* risk (see Figure 7) can be found when people choose between two investments, or if dif-

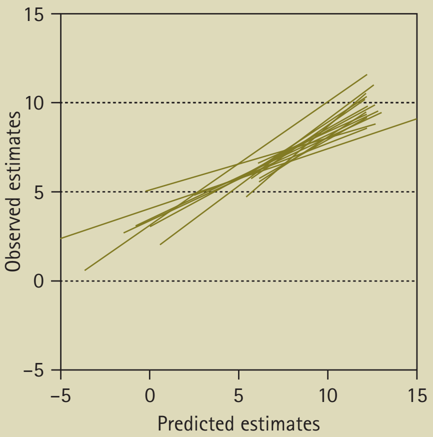


Figure 7. Modeling estimates of expected return. We selected for each participant the model that best predicts his/her estimates in the estimation trials. Most participants were best described by a model calculating the mean of the presented returns while putting higher weights on returns below 5 %. The figure shows the regression lines for estimated and modeled estimations of the expected return, indicating a good agreement of both ($n = 16$). It therefore seems justified to use modeled estimates as predictors of expected returns in the decision trials.

ferent kinds of information are represented. Finally, we aim to validate the behavioral tests of the models by investigating if the integrated evaluation of the risky option, as predicted by the best model, is also represented in the brain.

The Influence of Advice on Reinforcement Learning

The final project in this section makes the link between reward-based decision making and decision in social contexts. Starting point for the project is the observation that people often do not learn based on experienced rewards alone but also receive advice from other people. For example, when moving for a new job to a new city, one will probably get some advice about the best way to get to the office but also experiment with other alternatives. To examine the influence of advice on reinforcement learning, a first behavioral study by Biele, Rieskamp, and Gonzalez compared different computational models describing the integration of advice and own experience. The main result was that one model, which assumed that people evaluate payoffs from the recommended option more positively than the same payoff from alternative options, described people's behavior best. The current fMRI project examines in more detail how the evaluation of payoffs differs. One hypothesis is that people are not only rewarded by the monetary payoffs but also intrinsically for following advice. This hypothesis can be derived from early theoretical work on the development of imitative capacities (Miller & Dollard, 1941) and from more recent work highlighting the rewarding capacity of cooperative behavior (Decety et al., 2004). The fMRI prediction derived from the intrinsic reward hypothesis is that reward from the recommended options leads to greater activation in the OFC than reward from an alternative option. To test this and alternative hypotheses, we have collected fMRI and behavioral data from participants who first received a recommendation about which deck to choose from in a multiple-armed bandit task. We employed an event related design, which allows to separately examine the decision, the anticipation, and the feedback phases. First results indicate that outcomes from recommended options might indeed be evaluated differently than outcomes from alternative options (Biele, Krugel, Rieskamp, & Heekeren, 2007).

Decision Making in Social Contexts

Decision making processes during social interactions are highly complex, unstructured, and often intuitive. For example, when we have to make a decision about the trustworthiness of a stranger, a variety of information, such as facial expression, tone of voice, and the pragmatics of language, have to be interpreted simultaneously. Although part of those interpretations are accomplished through cognitive (i. e., conscious and analytical) processes, given the velocity with which social decisions have to be made, the faster and mostly unconscious emotional processes (e. g., intuition) are likely to be involved as well (Adolphs, 2006). Thus, any social decision will be the result of social cognitive as well as socioemotional processes. The common goal of our subprojects within the topic of decisions in social contexts is to elucidate the unique as well as combined contributions that these cognitive and emotional processes have on social decision making. Given the complexity of social interactions, identification of brain correlates for social decisions poses a great challenge. By putting emphasis on the development of psychological paradigms that focus on subcomponents of social decisions, we are trying to reduce this complexity, and to make it more controllable for research settings while aiming for ecological validity at the same time. Using structural and functional MRI as well as psychophysiological measures, such as skin conductance and pupillometry, our group is trying to elucidate how and where in the brain of healthy individuals social decisions are processed. Moreover, to complement our understanding of the "social brain," we are studying neuropsychiatric patients with socioaffective impairments, such as Borderline personality disorder and autism. We expect that, in turn, our studies will inform future research and intervention efforts in these and other conditions with deficient decision making.

Sociotopy of the Posterior Superior Temporal Sulcus

Social tasks, such as judging another person's movements (*biological motion,* BM), mental states (*theory-of-mind,* ToM), and norm-congruency of behavior (*normative judgment,* NJ), lead to the recruitment of a network of brain areas that consistently includes the *posterior superior temporal sulcus* (pSTS). The goal of the present fMRI study was to elucidate the specific function of the pSTS region within the social cognitive network. Based on a meta-analysis of previous imaging studies, we hypothesized that subregions within the pSTS would be differentially activated by the three different tasks (BM, ToM, NJ). For our fMRI study, we developed a new set of animated stimuli, which depicts two persons in social interactions (Figure 8).

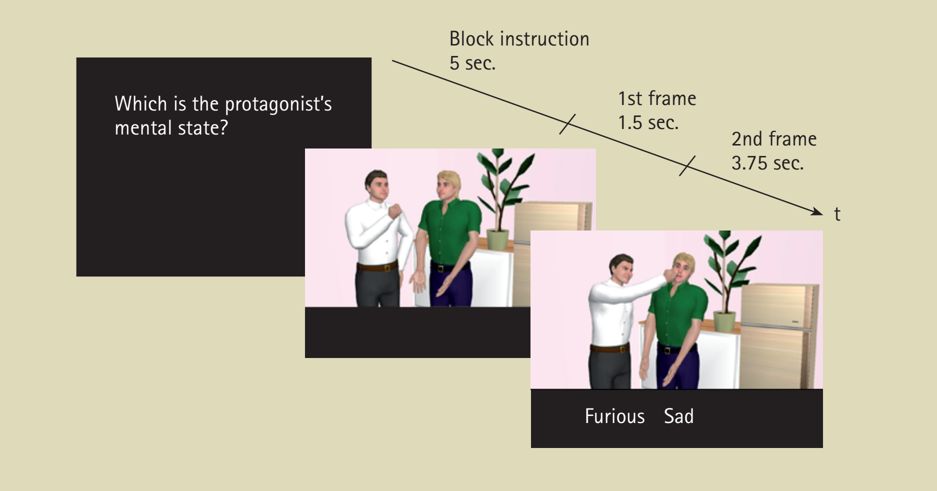


Figure 8. Sample stimulus for the ToM condition with timeline of presentation. The protagonist was marked by the white shirt. The same two frames were used for the BM and NJ conditions, only the block instruction and the response choice pair were adapted accordingly. BM: In which direction is the protagonist moving? (left or right). NJ: Is the protagonist committing a norm violation? (yes or no).

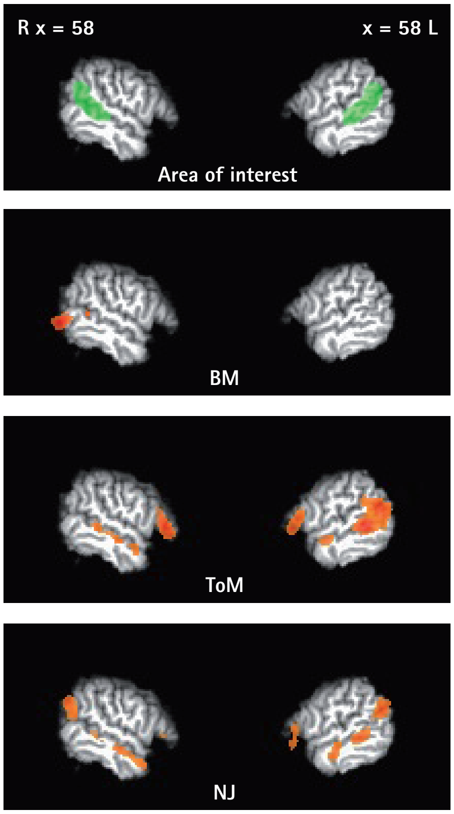


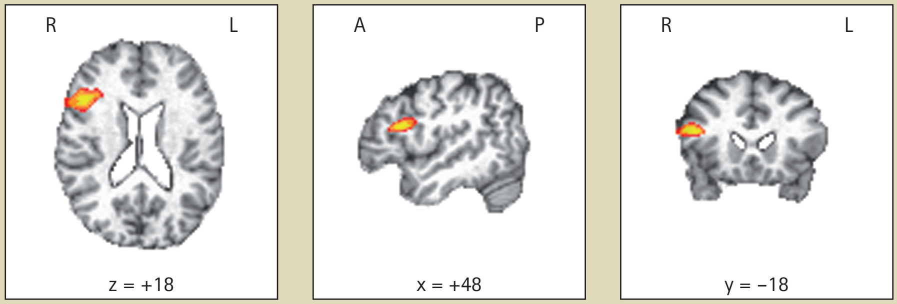
Figure 9. Sagittal view of the pSTS in the right and left hemisphere for BM, ToM, and NJ, $p < 0.001$, uncorrected. The area of interest is highlighted in green in the uppermost panel.

Each stimulus includes the display of a person's movements and mental states, and the depicted behavior could clearly be judged concerning a possible violation of social norms. Importantly, the material was kept constant for all three conditions, and only task instructions were manipulated. The fMRI results reproduced task-specific activation patterns for each task, as reported by previous studies ($Z = 3.1$, uncorrected) (e.g., Allison et al., 2000; Gallagher & Frith, 2003; Goodenough & Prehn, 2004; Heekeren, Wartenburger, Schmidt, Schwintowski, & Villringer, 2003; Heekeren et al., 2005). With respect to the pSTS, the activity evoked by the BM task was strongly right-lateralized, while that evoked by the ToM task was left-lateralized. The NJ task led to bilateral activation. There was a significant overlap of activity of the ToM and NJ tasks (Figure 9). The distinctive pattern of activation during the BM task in relation to the ToM and NJ tasks suggests the involvement of different cognitive processes. In contrast, the considerable overlap between activations evoked by the ToM and NJ tasks indicates that the two functions engage a common cognitive process, such as an automated inference of thoughts/feelings or intentions, even if not explicitly demanded by the task. Currently, we are preparing the adaptation of the paradigm for use with *Near InfraRed Spectroscopy* (NIRS) and its use in a study with subjects with Asperger Syndrom.

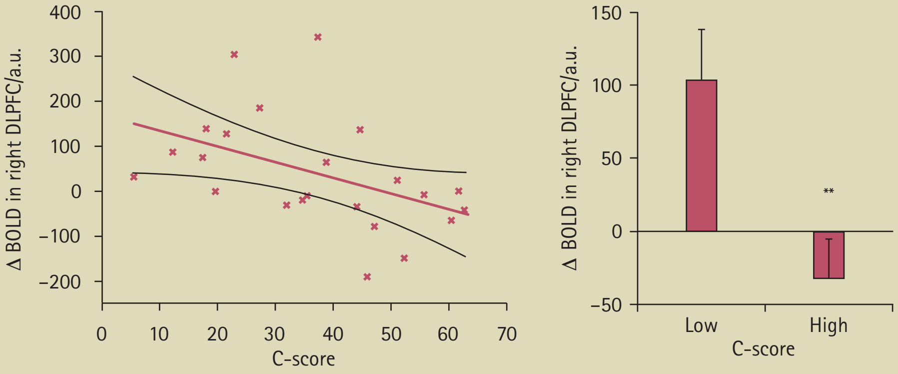
Interaction of Emotional and Cognitive Processing in Decision Making

To address the question, how emotional and conceptual processes interact in decision making, we developed an analogical reasoning task. In this task, word pairs were presented simultaneously, and participants had

(a) Covariation of C-scores with BOLD responses in right DLPFC



(b) Socio-normative judgments



(c) Grammatical judgments

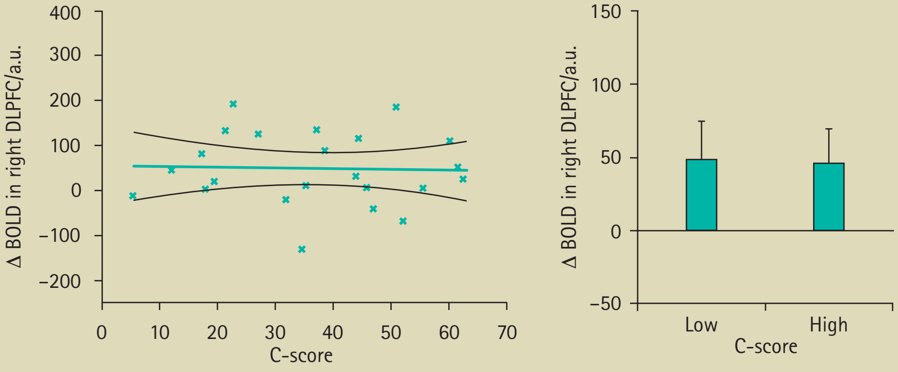


Figure 10. Neural correlate of individual differences in moral judgment competence.

to decide whether they corresponded in their emotional as well as in their conceptual relations. Response times, error rates, and pupillary responses were recorded. Response time data showed that emotional processing is faster than conceptual processing. Pupillary responses as a proxy for the processing load, however, clearly indicated that semantic processing is consuming as many cognitive resources as emotional processing. This result suggests that both cognitive and emotional aspects are processed in parallel (Prehn et al., 2005). In a next step, we will identify the network of brain regions that mediates emotional and conceptual processing using fMRI and concurrent psychophysiological monitoring. In another project, we continue our previous work on the neural correlates of moral judgment processes (Goodenough & Prehn, 2004; Heekeren et al., 2003, 2005). Moral judgment as a higher cognitive function entails a number of processes implemented by a network of brain regions that are involved in cognitive as well as in emotional processing. People differ with respect to their competence to make moral judgments. We used fMRI and skin conductance recording to investigate how individual differences in this domain modulate neural correlates of normative judgments. We found that individual moral judgment competence (assessed with the Moral Judgment Test; Lind, 2005) was reflected in BOLD activity in right DLPFC during socio-normative judgments relative to grammatical judgments. Participants with lower moral judgment competence recruited the right DLPFC more than those with higher competence in this domain (Figure 10), indicating higher processing demands (Prehn et al., 2006).

Neural Correlates of Individual Differences in Cognitive Processing of Emotions

People differ in the extent to which they experience emotions. These individual differences affect even simple perceptual decisions, and influence the psychophysiological and neural correlates of emotion processing. In a first fMRI study, we investigated how individual differences in cognitive processing of emotions influence perceptual decisions on the gender or the emotional expression of faces (Figure 11). We found that those individual differences were associated with increased activity of the left dorsal anterior cingulate cortex and altered connectivity of this region with prefrontal areas (cognitive processing) and limbic regions (emotional processing). We argue that differences in functional integration of this neural network

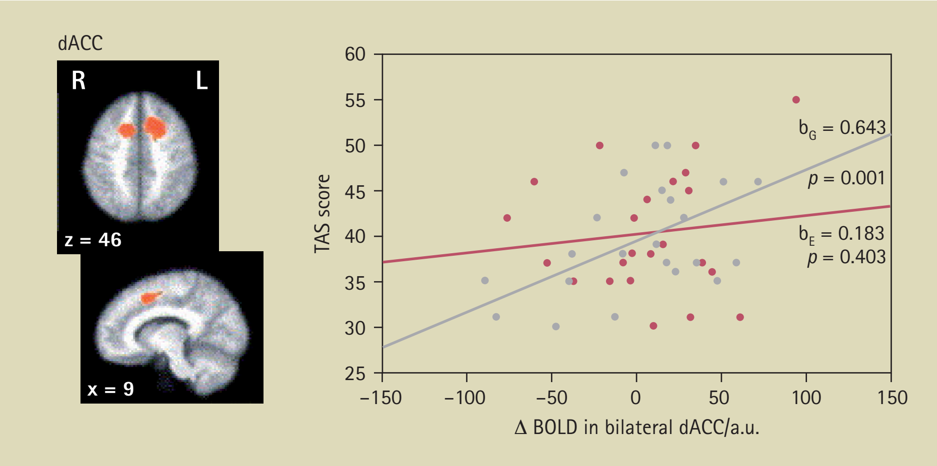


Figure 11. Covariation of BOLD responses with TAS score. Left panel: TAS score covaried significantly with BOLD responses in the bilateral dACC during gender decisions. The figure shows activations from higher level analysis thresholded at $Z > 3.1$, corresponding to $p = 0.001$, uncorrected, that were used as a mask for subsequent PPI analyses. Right panel: Covariation of TAS score and BOLD responses (*arbitrary units*, a.u.) during emotion decisions (red dots) and gender decisions (grey dots) (b_E and b_G represent regression slopes for emotion decisions and gender decisions, respectively; $p = p$ value).

may give rise to individual differences in the ability to cognitively process emotions. Moreover, we present neurophysiological evidence for a theoretical model which posits that discommunication of the neocortex with limbic areas impairs cognitive processing of emotions (Mériau, Wartenburger et al., 2006). In another study, we combined psychophysiological and fMRI measurements to investigate how individual differences in *negative affect* (NA) are reflected in changes in BOLD responses and *Skin Conductance Level* (SCL) during passive viewing of emotional stimuli. Our data show differential insular activity as a function of individual differences in NA when passively viewing aversive stimuli. Furthermore, this finding was independent of autonomic arousal.

The insula has been implicated in interoceptive processes and in the integration of sensory, visceral, and affective information, thus contributing to subjective emotional experience. Therefore, the greater recruitment of the insula in response to aversive stimuli in subjects with high NA may indicate increased interoceptive sensitivity to internal changes independent of autonomic arousal, and may contribute to greater self-reported NA (Mériau, Kazzer et al., 2006).

Social Cognition and Cortical Thickness in Asperger Syndrome

Asperger Syndrome (AS) represents the cognitively higher functioning end of the autism spectrum with selective deficits in social perception and cognition. Thus, brain imaging research in AS can provide important information on the neuronal structures, which are crucially involved in social cognitive processes in healthy individuals. In a previous study, we have found some evidence for amygdala abnormalities and impaired social cognitive functions in adults with AS (Dziobek, Rogers, Fleck, Wolf, & Convit, 2006). In the present study, in collaboration with researchers from the New York University School of Medicine, we investigated whether social cognitive impairments in AS are selective, and how they are related to neuroanatomical differences. We compared a group of individuals with AS (n = 27) with a group of well-matched *Normal Controls* (NC) (n = 29) in tests of social cognition, memory, attention, executive functioning, and cortical thickness measures. Neuropsychological results showed that differences between the diagnostic groups were restricted to social perception and cognition (facial emotion recognition and theory of mind [as assessed using the *Movie for the Assessment of Social Cognition*, MASC; Dziobek, Fleck et al., 2006]). Imaging analyses revealed that the AS group had thicker cerebral cortex in the left fusiform gyrus and the right *Temporo-Parietal Junction* (TPJ). Interestingly, there was a negative association between cortical thickness of the fusiform *Region of Interest* (ROI) and facial emotion recognition in the AS, but not in the NC group (due to later inclusion in the study, data on facial emotion recognition was available only for a subset of study participants [*n:* AS = 18; NC = 13]), (Figure 12).

One of the most consistent findings in autism spectrum conditions is increased head and brain size (e. g., Redcay & Courchesne, 2005). In addition, both the fusiform gyrus and the TPJ have previously been identified as crucial for face processing and social cognitive functions in typically developed individuals, as has also been shown by our previous research (see Bahnemann, Dziobek, Prehn, Wolf, & Heekeren, 2007; Prehn et al., 2006). Thus, our data represent convergent neuroanatomical and neuropsychological evidence for specific social perceptive and social cognitive impairments in AS. The results may be important in the understanding of yet unknown brain behavior relationships in autism spectrum conditions.

Differentiating Cognitive and Emotional Empathy in Asperger Syndrome

Empathy is a multidimensional construct entailing cognitive (understanding others' mental states, theory of mind) and affective (emotional reaction to the observed experiences of another) components. Despite a lack of research, deficient empathy is considered a central characteristic of AS. In a preliminary study, we profiled empathy multidimensionally in individuals with AS using question-

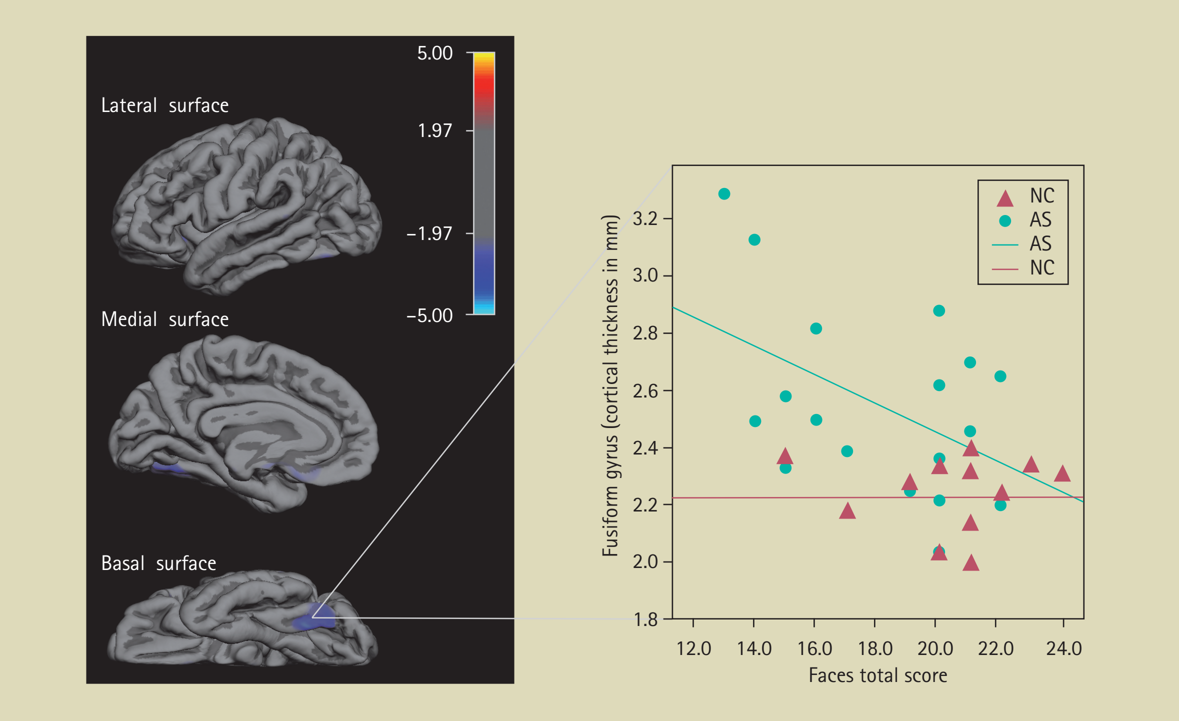
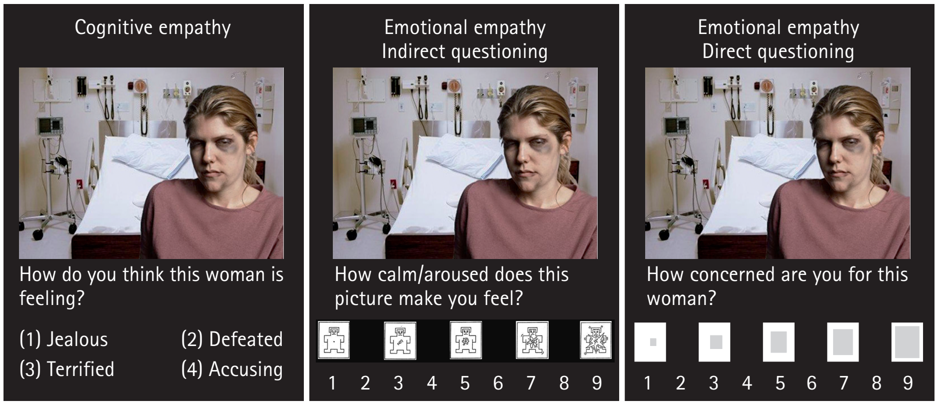


Figure 12. Left: Areas of increased cortical thickness of the AS group were restricted to the fusiform gyrus ($p < 0.001$). Right: Associations between fusiform gyrus cortical thickness and facial emotion recognition for the AS ($r = -.47$, $p = 0.048$) and NC ($r = .00$, $p = 0.99$) groups.

naires (Rogers, Dziobek, Hassenstab, Wolf, & Convit, 2006). In a next step, to further characterize empathic abilities, we used in-house developed empathy paradigms that allow separate assessment of emotional and cognitive components, while also aiming at ecological validity. The MASC (Dziobek, Fleck et al., 2006) is a video-based measure of cognitive empathy that requires a subject to infer mental states of movie characters. The *Multifaceted Empathy Test* (MET) (Dziobek, Rogers, Fleck, Bahnemann et al., 2006) allows simultaneous assessment of cognitive and affective empathy, asking study participants to rate their emotional reaction to social picture stimuli (Figure 13).

Our data showed that while individuals with AS seem to have impairments in inferring others' mental states (cognitive empathy), they are as empathically concerned for others (emotional empathy) as control subjects. In a next step, we will test the hypothesis that

Figure 13. MET example item depicting the various conditions.



healthy controls and individuals with AS recruit dissociable brain networks during cognitive, but not emotional empathy tasks. We developed fMRI compatible adaptations of the MASC and MET and will be using them with a combination of structural (brain volumetrics) and fMRI measures.

An important goal of our work is to make it applicable for clinical cognitive neuroscience questions. In pursuit of this goal, we started investigating empathic abilities in clinical populations: In collaboration with the Department of Psychiatry and Psychotherapy of the Charité—University Medicine, Campus Benjamin Franklin in Berlin (Prof. Heuser), we are evaluating patients with narcissistic and Borderline personality disorder. In collaboration with the Department of Social Pedagogy of the Free University Berlin (Prof. Körner), we are currently examining delinquent adolescents and school children with behavioral deviances.

The Independent Research Group in March 2007

From left to right: Sonali Beckmann, Philipp Kazzer, Markus Bauer, Hauke Heekeren, Isabel Dziobek, Christina Scheibe, Katja Mériau, Nikos Green, Jenny Kirchner, Kristin Prehn, Guido Biele, Hermine Wenzlaff, Peter Mohr, Sandra Preißler, Janine Bayer, Ulrich Reinacher, Lea Krugel, Markus Bahnemann, Flora von Randow, Ingo Wolf.

Publications 2005–2006

(last update: May 2007)

Bahnemann, M., Dziobek, I., Prehn, K., Wolf, I., & **Heekeren, H. R.** (2007). Sociotopy of the superior temporal sulcus: Searching for dissociable representations of judgments on movements, mental states and norm-congruency of behavior. *Human Brain Mapping.* Abstract.

Bauer, M., Oostenveld, R., Peeters, M., & Fries, P. (2006). Tactile spatial attention enhances gamma-band activity in somatosensory cortex and reduces low-frequency activity in parieto-occipital areas. *Journal of Neuroscience, 26* (2), 490–501.

Biele, G., Krugel, L., Rieskamp, J., & **Heekeren, H. R.,** (2007). The influence of advice on reward based decision-making and learning. *Human Brain Mapping.* Abstract.

Dziobek, I., Gold, S., Wolf, O. T., & Convit, A. (2007). Hypercholesterolemia in Asperger syndrome: Independence from lifestyle, obsessive-compulsive behavior, and social anxiety. *Psychiatry Research, 149* (1–3), 321–324.

Dziobek, I., Wolf, I., **Preißler, S.,** Kirchner, J., **Bahnemann, M.,** Convit, A., & **Heekeren H. R.** (2007). Neuropsychological and neuroanatomical evidence for social perceptive and social cognitive impairments in adults with Asperger syndrome. *Human Brain Mapping.* Abstract.

Dziobek, I., Fleck, S., Kalbe, E., Rogers, K., Hassenstab, J., Brand, M., Kessler, J., Woike, J., Wolf, O. T., & Convit, A. (2006). Introducing MASC: A movie for the assessment of social cognition. *Journal of Autism and Developmental Disorders, 36* (5), 623–636.

Dziobek, I., Rogers, K., Fleck, S., **Bahnemann, M., Heekeren, H. R.,** Wolf, O. T., & Convit, A. (2006). Differenzierung kognitiver und affektiver Emapthie bei Menschen mit Asperger Syndrom: erste Ergebnisse des Multifaceted Empathy Test (MET). Kongress der Deutschen Gesellschaft für Psychiatrie, Psychotherapie und Nervenheilkunde (DGPPN), Berlin November 2006. *Der Nervenarzt, 77* (Suppl. 3), S343:0095.

Dziobek, I., Rogers, K., Fleck, S., Wolf, O. T., & Convit, A. (2006). The amygdala theory of autism revisited: Linking structure to behaviors. *Neuropsychologia, 44* (10), 1891–1899.

Dziobek, I., Rogers, K., Fleck, S., Hassenstab, J., Gold, S., Wolf, O. T., & Convit, A. (2005). In search of "master mindreaders": Are psychics superior in reading the language of the eyes? *Brain and Cognition, 58* (2), 240–244.

Gold, S. M., **Dziobek, I.,** Rogers, K., Bayoumy, A., McHugh, P. F., & Convit, A. (2005). Hypertension and hypothalamo-pituitary-adrenal axis hyperactivity affect frontal lobe integrity. *Journal of Clinical Endocrinolgy and Metabolism, 90* (6), 3262–3267.

Goodenough, O. R, & **Prehn, K.** (2004). A neuroscientific approach to normative judgment in law and justice. *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences, 359,* 1709–1726.

Hassenstab, J., **Dziobek, I.,** Rogers, K., Wolf, O. T., & Convit, A. (2007). Knowing what others know, feeling what others feel: A controlled study of cognitive and affective empathy in psychotherapists. *Journal of Nervous and Mental Disease, 195,* 277–281.

Heekeren, H. R., Wartenburger, I., Mell, T., Marschner, A., Villringer, A., & Reischies, F. M. (in press). Role of ventral striatum during reward-based decision-making. *NeuroReport.*

Heekeren, H. R., Marrett, S., Bandettini, P. A., Ungerleider, L. G. (2006.) Involvement of human left dorsolateral prefrontal cortex in perceptual decision-making is independent of response modality. *Proceedings of the National Academy of Sciences of the United States of America, 103* (26), 10023–10028.

Heekeren, H. R., Wartenburger, I., Schmidt, H., **Prehn, K.,** Schwintowski, H. P., & Villringer, A. (2005). Influence of bodily harm on neural correlates of semantic and moral decision-making. *NeuroImage, 24* (3), 887–897.

Heekeren, H. R., Marrett, S., Bandettini, P. A., Ungerleider, L. G. (2004). A general mechanism for perceptual decision-making in the human brain. *Nature, 431*, 859–861.

Marschner, A., Mell, T., Wartenburger, I., Villringer, A., Reischies, F. M., & **Heekeren, H. R.** (2005). Reward-based decision-making and aging. *Brain Research Bulletin, 67* (5), 382–390.

Mell, T., **Heekeren, H. R.,** Marschner, A., Wartenburger, I., Villringer, A., & Reischies, F. M. (2005). Effect of aging on stimulus-reward association learning. *Neuropsychologia, 43* (4), 554–563.

Mériau, K., Kazzer, P., Wartenburger, I., **Prehn, K.,** Villringer, A., van der Meer, E., & **Heekeren, H. R.** (2006). Insular activity reflects individual differences in negative affect independent of autonomic arousal. *Human Brain Mapping.* Abstract.

Mériau, K., Wartenburger, I., Kazzer, P., **Prehn, K.,** Lammers, C.-H., van der Meer, E., Villringer, A., & **Heekeren, H. R.** (2006). A neural network reflecting individual differences in cognitive processing of emotions during perceptual decision-making. *NeuroImage, 33*, 1016–1027.

Pachur, T., & **Biele, G.** (2007). Forecasting from ignorance: The use and usefulness of recognition in lay predictions of sports events. *Acta Psychologica, 125,* 99–116.

Prehn, K., Heekeren, H. R., Raisig, S., Schiemann, T., Villringer, A., & van der Meer, E. (2005). Integration of emotional and conceptual processing in decision-making: Evidence from pupillometry. *Journal of Cognitive Neuroscience* (Suppl.), 169–169.

Prehn, K., Wartenburger, I., **Mériau, K., Scheibe, C.,** Goodenough, O .R., Villringer, A., van der Meer, E., & **Heekeren, H. R.** (2006). Influence of individual differences in moral judgment competence on neural correlates of normative judgments. *Human Brain Mapping.* Abstract.

Preuschhof, C., **Heekeren, H. R.,** Taskin, B., Schubert, T., & Villringer, A. (2006). Neural correlates of vibrotactile working memory in the human brain. *The Journal of Neuroscience, 26,* 13231–13239.

Rogers, K., **Dziobek, I.,** Hassenstab, J., Wolf, O. T., & Convit, A. (2006). Who cares? Revisiting empathy in Asperger syndrome. *Journal of Autism and Developmental Disorders,* Aug. 12 [Epub ahead of print].

Scheibe, C., Ullsperger, M., Sommer, W., & **Heekeren, H. R.** (2007). *Spatiotemporal dynamics munderlying the integration of prior probability information in decision making.* Conference of Cognitive Neuroscience, New York. Abstract.

Scheibe, C., Schubert, R., Sommer, W., & **Heekeren, H. R.** (2006). *Integration of prior probability in the process of decision making.* Human Brain Mapping Conference, Florence. Abstract.

Scheibe, C., Wartenburger, I., Wüstenberg, T., Villringer, A., & **Heekeren, H. R.** (2005). Neural correlates of the interaction between transient and sustained processes—A mixed blocked/

event-related fMRI study. *Human Brain Mapping,* Sep. 2 [Epub ahead of print].

de Wit, T. C., **Bauer, M.,** Oostenveld, R., Fries, P., & van Lier, R. (2006). Cortical responses to contextual influences in amodal completion. *NeuroImage, 32* (4), 1815–1825.

Wolf, O. T., **Dziobek, I.,** McHugh, P. F., Sweat, V., Javier, E., de Leon, M. J., & Convit, A. (2005). Subjective memory complaints in aging are associated with elevated cortisol levels. *Neurobiology of Aging, 26,* 1357–1363.