

Konstanze Albrecht: Brain Correlates of Cognitive Processes
Underlying Intertemporal Choice for Self and Other. Leipzig: Max Planck
Institute for Human Cognitive and Brain Sciences, 2009 (MPI Series in
Human Cognitive and Brain Sciences; 116)

Impressum

Max Planck Institute for Human Cognitive and Brain Sciences, 2009



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Coverpicture: Adapted from McClure et al. (2004)

Druck: Sächsisches Druck- und Verlagshaus Direct World, Dresden

ISBN 978-3-941504-00-4

**Brain correlates of cognitive
processes underlying intertemporal
choice for self and other**

Der Fakultät für Biowissenschaften, Pharmazie und Psychologie

der Universität Leipzig

eingereichte

D I S S E R T A T I O N

zur Erlangung des akademischen Grades

doctor rerum naturalium

Dr. rer. nat.

vorgelegt von

Diplom-Psychologin Konstanze Albrecht

geboren am 20. Juli 1980 in Torgau

Leipzig, den 15. März 2009

Acknowledgments

First and foremost, I am grateful to Professor von Cramon and Kirsten Volz for their invaluable knowledge and advice during many discussions, and their unconditional support of my work.

I want to thank Stefan Zysset and Jöran Lepsien, as well as the LIPSIA group for very interesting discussions and answers concerning data analyses.

I am very thankful to my roommates, Maria Golde, Joe King and Franziska Korb, with whom I frequently discussed research questions, designs, and analyses methods. It was fun working with them.

I am grateful to the whole EXEC group for valuable meetings and discussions during all stages of my thesis.

I also want to thank Matthias Sutter who provided very helpful comments on chapter 6 and 7 of this thesis. He very much supported the development of the studies presented.

For help in carrying-out the experiments, I thank Ramona Menger, Bettina Johst and all MTAs working at the fMRI scanner.

A great “thank you” also goes to Heike Schmidt and Stephan Liebig for their help in preparing the figures.

A last but not least “thank you” goes to Sarah Jessen, Derek Ott, Friederike Thiel, Maria Golde, Joe King, Emma von Essen, and Anke Becker, simply for their knowledge about grammar and style.

Moreover, I am very thankful to Friedl, Sarah, Derek, Maria, the after-work groups, the ice-skating group, and everyone else who made Leipzig an exciting and great place to do research, and to live.

Finally, I want to thank my family who supported me in every aspect of what I did.

Contents

1	Introduction	1
2	Intertemporal choice	3
2.1	Economic and psychological perspectives	3
2.1.1	Economic models of intertemporal choice	5
2.1.2	Dual processing theories in psychology	11
2.1.3	Influential factors on impulsive behavior	14
2.2	Brain correlates of intertemporal choice	15
2.2.1	Standard neuroanatomic nomenclature	16
2.2.2	Imaging intertemporal choice	16
2.2.3	Neural correlates of hot system processes	17
2.2.3.1	Ventral striatum	18
2.2.3.2	Cingulate cortex	20
2.2.3.3	Anterior cingulate cortex	20
2.2.3.4	Posterior cingulate cortex	21
2.2.3.5	Precuneus	22
2.2.4	Neural correlates of cool system processes	23
2.2.4.1	Lateral parietal cortex: The intraparietal sulcus	24
2.2.4.2	Lateral prefrontal cortex (LPFC) and lateral orbitofrontal cortex	25
2.2.5	Evidence against multiple systems in the brain	29
3	Decision making for self and other	31
3.1	Who am I? Theories of the self	31
3.1.1	James' classical theory of multiple selves	31
3.1.2	Social interactionists' theories of the self	32
3.1.3	Modern theories of the self and empirical evidence	33
3.1.4	The Parfitian theory of the self: Differences between present self, future self, and other persons	34
3.2	Decision making for self and other: empirical findings	35
3.2.1	Giving advice and making risky decisions for self and other	35
3.2.2	Intertemporal choice for self and other	36
3.2.3	Being the other: Observing choices being made	37
4	Open questions, hypotheses and implementation of present fMRI studies	39
4.1	Open questions and hypotheses	39

4.2	Implementation – fMRI	40
5	Methods: Functional magnetic resonance imaging (fMRI)	43
5.1	Physical basics of fMRI.....	43
5.2	Physiological basics of fMRI.....	44
5.3	Analysis of fMRI data	45
5.3.1	Preprocessing.....	45
5.3.2	Spatial transformation	45
5.3.3	Statistical analysis	46
6	Experiment 1.....	49
6.1	Introduction.....	49
6.2	Method.....	50
6.2.1	Participants	50
6.2.2	Behavioral task and stimuli	51
6.2.3	Imaging.....	53
6.2.4	Data analyses	53
6.3	Results	55
6.3.1	Behavioral results	55
6.3.2	Imaging results.....	57
6.3.2.1	Today trials > delay trials in SELF and OTHER	58
6.3.2.2	Interaction effect of temporal distance and receiver.....	58
6.3.2.3	Effects of “discounter type” on today trials > delay trials in SELF and OTHER	60
6.3.2.4	Effects of “discounter type” on the interaction of temporal distance and receiver.....	60
7	Experiment 2.....	63
7.1	Introduction.....	63
7.2	Method.....	64
7.2.1	Participants	64
7.2.2	Behavioral task and stimuli	64
7.2.3	Imaging.....	67
7.2.4	Data analyses	67
7.3	Results	68
7.3.1	Today trials > delay trials in SELF and OTHER and interaction effects	68
7.3.2	Comparison with results of experiment 1	70

8	General Discussion	73
8.1	Making intertemporal choices for self and other (experiment 1).....	73
8.1.1	Intertemporal choice for SELF	73
8.1.2	Intertemporal choice for OTHER	74
8.1.3	Strong and moderate discounters.....	75
8.2	Observing intertemporal choices for self and other (experiment 2) in comparison to making choices for self and other (experiment 1)	76
8.2.1	Activation accompanying immediate rewards	76
8.2.2	Activation accompanying immediate rewards when observing choices vs. when actively choosing in SELF	78
8.2.3	No activation differences when observing choices in SELF and OTHER	79
8.3	Conclusion	79
9	Limitations and future perspectives	81
9.1	Why was there a mismatch of behavioral and imaging data in experiment 1?	81
9.2	How to elicit different behavior for self and other?	82
9.3	The role of empathy on intertemporal choice behavior for self and other	84
9.4	Does concreteness of the other person matter?	85
9.5	Are immediate rewards special?	86
9.6	Conclusion	87
	Bibliography.....	89
	Supplementary Tables	105

1 Introduction

“For the good that I would do I do not: but for the evil which I would not, that I do“ (Romans 7:19, King James Version)

In this quote from the Bible, Paul struggles with the discrepancy between what he knows would be the right thing to do, and the things he wants to do. He realizes that what is wanted and what is right often are different things, and that the desire of the “flesh” has to be overcome to do the right thing. In an everyday example, this could be as simple as the question of eating a piece of chocolate cake or not eating it for the sake of long term health. (Not to mention the good body shape one can get keeping to a diet.)

This thesis will deal with a kind of choice similar to the one described above, also called intertemporal choice. Intertemporal choices in general are choices between a smaller, sooner reward (e.g. chocolate cake) and a larger, yet later reward (e.g. good body shape, future health). Theories concerning characteristics of such choices will be explained, and brain correlates of intertemporal choice will be described.

Intertemporal choice is well suited to investigate patience in human behavior. Why do people behave impatient, and more importantly for this thesis: Is there a way of framing choice options to make people behave less impatient? In the introductory part of this thesis, possible origins and factors influencing patience in intertemporal choice will be discussed. In the experimental part, it will be investigated whether intertemporal choices made for other persons is such a factor influencing patience, i.e., whether choices made for another person are made with more patience since the decision maker is less emotionally and personally engaged in such a choice. This finding would be crucial for topics as decision delegation, since it can contribute to the discussion why decisions are delegated and whether this leads to altered decision processes and outcomes than choices made for oneself.

Hence, two functional magnetic imaging studies will be presented in sections 6 and 7, which bring together intertemporal choice (section 2) and decision making for self and other (as discussed in section 3). In the first study, it was explored whether intertemporal choice for another person leads to different outcomes and relies on different processes (and brain

activation) than intertemporal choice for oneself. The second study investigated brain correlates of the “other” person while observing choices being made for her.

2 Intertemporal choice

2.1 Economic and psychological perspectives

Generally, intertemporal choices can be defined as decisions between a sooner (often immediate) gratifying option and a later, delayed but in the long run more rewarding option. Everyone makes such choices in everyday's life, for example when resisting the temptation of smoking a cigarette now in favor of long term health reasons, or when deciding to spend money on a fancy vacation this summer, instead of saving it for retirement, or when eating a piece of vegetable instead of a piece of chocolate cake.

Choices for smaller, sooner over larger, later rewards are usually termed “impulsive”, while waiting for the more rewarding alternative is often referred to as behaving “self-controlled”. Individuals try to behave self-controlled (e.g. keeping to their diet), which involves resisting temptations that lead to smaller outcomes in the short run (e.g. eating a piece of chocolate cake), and putting forward patience to receive larger outcomes in the long run (e.g. health, body shape). The terms “impulsive” and “self-controlled” are used in accordance with intertemporal choice behavior by numerous authors (Ainslie, 1975; Evenden & Ryan, 1996; Kalenscher, Ohmann, & Gunturkun, 2006). Hence, these terms will be used throughout this thesis to describe intertemporal choice behavior.

Mischel, Shoda and Rodriguez (1989) were interested in the development of intertemporal choice behavior. To this end, they investigated impulsive behavior in children and its impact on the children's later life. They offered snacks (e.g. marshmallows) to pre-school children, telling them that the experimenter would have to leave for some time, and that they would get two marshmallows when the experimenter returned. Alternatively, they could get one marshmallow immediately, without having to wait. Children were then left alone, knowing they could end their waiting period by giving a signal whenever they wanted, but with the consequence of receiving the smaller reward of only one marshmallow. They knew that they were awarded two marshmallows if they would not give the signal, but patiently wait until the experimenter returned. The authors found that more patient and self-controlled four-year-old children (i.e., children who could delay gratification longer), tended to be more intelligent, more achievement-oriented, and socially more engaged. These children further were reported to show higher cognitive and social skills by parents and teachers ten years later. Thus, the

degree of self-control that people can apply in intertemporal choices seems to be interconnected with other personal characteristics, and to be stable over time.

Many more recent studies tested intertemporal choices in the domain of monetary rewards. Such secondary rewards have a number of advantages compared to primary rewards such as food or water. First, they are considered useful in a similar way by at least a large part of the human population, as they can usually be exchanged for most primary rewards very easily and within almost no time. The subjective value of a certain primary reward instead varies much stronger with the condition the receivers temporarily are in (i.e., hungry or thirsty) and their individual preferences (i.e., liking marshmallows). Second, as monetary rewards can be used manifold and saved, their size offered can be varied much more. Most people offered the choice between 1000 marshmallows now and 1010 marshmallows tomorrow, might not have to think about their decision. They cannot eat 1000 anyway, then why wait for ten more? In comparison, choosing between € 1000 now and € 1010 tomorrow, might be a much harder choice, because money can be split up for buying different (primary) rewards, or it can alternatively be saved for a long time. In the studies discussed in this thesis, monetary rewards are used. It is nevertheless important to keep in mind that such secondary rewards also have a disadvantage, as their immediacy is influenced by them being only a means towards an end. They can be achieved sooner or later, i.e., immediately, but also after a delay, which could turn immediate secondary rewards into delayed primary rewards. For instance, immediately received money is not the same as an immediately received cake or book, which both can be consumed immediately. Immediately received money on the other hand can be turned into a cake or a book, but when this is going to happen (i.e., immediately after receiving the money or only days later), is usually not controlled for in experiments. Thus, immediacy in the domain of secondary rewards has to be handled with care, but is used in many studies, including the studies presented in this thesis, because of the aforementioned advantages.

Psychologists and economists have frequently been investigating intertemporal choice. For psychologists, the focus usually was on cognitive processes accompanying such choices, asking the question why people behave as they do, how this is related to personality traits, and which factors can influence the underlying processes (Ainslie, 1975; Ainslie & Haslam, 1992; Mischel, et al., 1989). Economists were mostly interested in the outcomes of such choices and how these outcomes can be modelled, but also influenced to lead to more foresighted behavior, for instance to higher savings for retirement, or a more healthy alimentation

(Laibson, 1997; Loewenstein & Prelec, 1993). Thus, psychologists and economists both were interested in finding out how to influence behavior, but they used different ways of investigating these possible influential factors. Recently, mostly due to the work of Kahneman and Tversky (e.g. Kahneman, 2003; Kahneman & Tversky, 1979, 1984), the work of psychologists and economists converges, as both disciplines start taking into account arguments and findings from each other (e.g. Kahneman & Frederick, 2002). For instance, economic models were and are changed according to empirical findings from economic and psychological research (e.g. Ainslie & Haslam, 1992; Laibson, 1997).

In the following, economic models of intertemporal choice, and empirical (psychological) findings leading to changes in these models, will be discussed.

2.1.1 Economic models of intertemporal choice

In traditional economic models, human decision makers were regarded as rational agents, whereas the term “rationality” can be defined as “internal consistency with manifest preference ordering” (e.g. Eisenführ & Weber, 2002; Hastie & Dawes, 2001). Rationality thus means conformity with a prescriptive, normative model, i.e., obeying all assumptions (axioms) the model is based on. One of these models, the discounted utility (DU) model (Fishburn & Rubinstein, 1982; Koopmans, 1960; Samuelson, 1937), was developed to model intertemporal choices. The term “discounted utility” thereby refers to the value of a future reward: The theory assumes that compared to immediate rewards, future rewards are devalued (i.e., discounted) by a certain amount depending on its delay and amount (Fishburn & Rubinstein, 1982; Koopmans, 1960; Samuelson, 1937). Hence, an amount of € 80 one can receive now has a larger value than the same amount available after two weeks.

Discounted utility theory (DUT), (Fishburn & Rubinstein, 1982; Koopmans, 1960; Samuelson, 1937), like all economic utility theories, makes assumptions (i.e., axioms) about a decision maker’s preferences. In the case of DUT, these are assumptions about preferences in intertemporal choices. They involve the assumption of completeness, monotonicity, intertemporal transitivity, consumption independence, and stationarity.

Completeness states that all time-dependent outcomes (rewards) can be ordered and thus compared, so that either outcome R1 is preferred to outcome R2, or R2 to R1, or that there is an indifference between the two; i.e., either $R1 > R2$ or $R1 < R2$ or $R1 \sim R2$.

Monotonicity simply implies, that the same reward (R) available at different points in time ($t1, t2$) should be preferred on the earlier available date, i.e., if $t1 < t2$ then $(R, t1) > (R, t2)$. Further, DUT posits that a reward R1 preferred over a reward R2 at t is also preferred at any other time point d ; i.e., if $(R1, t) > (R2, t)$, then $(R1, d) > (R2, d)$.

Intertemporal transitivity states that if a reward R1 delivered at time $t1$ is preferred to a reward R2 delivered at time $t2$, and R2 delivered at $t2$ is preferred to a third reward R3 delivered at time $t3$, then R1 delivered at $t1$ should be preferred to R3 delivered at $t3$; i.e., if $(R1, t1) > (R2, t2)$ and $(R2, t2) > (R3, t3)$, then $(R1, t1) > (R3, t3)$.

Consumption independence means that a preference for a reward R should stay the same over different consumption periods, independently of an experience of this reward in the past or future. Especially for primary rewards, this axiom obviously might be of limited validity, as probably everyone can imagine a change in preferences towards a less preferred food after having consumed a usually preferred food for days in a row.

Stationarity states that being indifferent between two rewards R1 and R2 delivered at time points t and $t+x$, respectively, means being indifferent between these two rewards being delivered at two other time points with the same temporal distance x (i.e., d and $d + x$): If $(R1, t) \sim (R2, t + x)$, then $(R1, d) \sim (R2, d + x)$.

DUT further assumes a constant discount rate (i.e., that future rewards are discounted at a constant rate when compared to current rewards) and a maximization of utility. The term utility can thereby be considered as “gratification”, and is thus not solely based on objective utility (like monetary gains) but can also reflect the subjective pleasure (i.e., subjective value) the decision maker receives from choosing one option over another (Fishburn & Rubinstein, 1982; Koopmans, 1960; Samuelson, 1937).

The assumption of constant discount rates is important to warrant time-consistency, as stated by the stationarity axiom. These assumptions are best described by an exponential function (Fishburn & Rubinstein, 1982; Lancaster, 1963; Samuelson, 1937).

$$V = R \cdot e^{-c \cdot D},$$

with V being the current subjective value or utility of a future reward R , delivered after a time interval D , and discounted by an individual constant (discount rate) c (Figure 2.1A). For instance, consider a participant with a subjective value (or utility) of $u(t) = € 80$ of a reward $R = € 100$, delivered after $D = 2$ weeks. This participant can be considered indifferent between receiving € 80 now and receiving € 100 in 2 weeks, discounting future rewards at a discount rate of $c = .111$. Since c is an individual discount rate, the same reward can be discounted differently by different persons. For instance, another, less impulsive person who is indifferent between € 80 now and € 90 in two weeks, would possess a smaller exponential discount rate of $c = .053$.

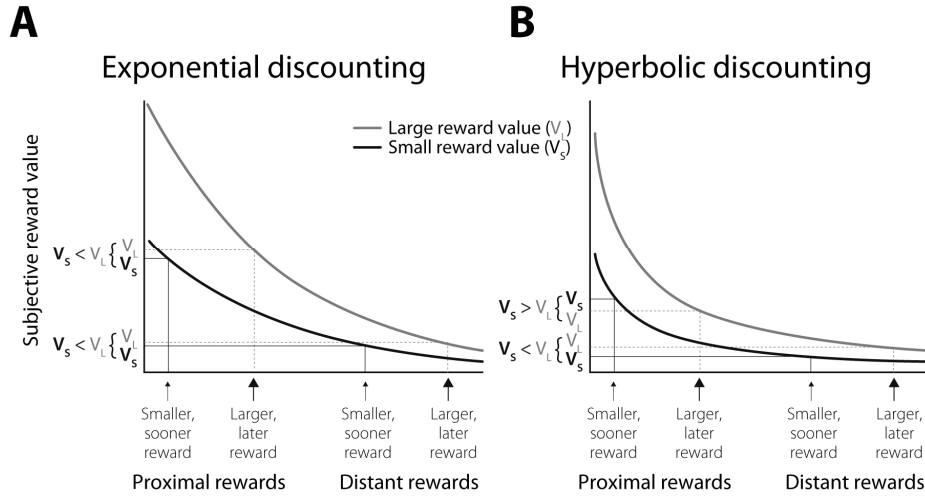


Figure 2.1: Depicted are exponential and hyperbolic discount functions. The x-axis plots the temporal delay whereas the y-axis represents the subjective discounted reward value V of a reward. The black and grey lines represent the value of the smaller, sooner and larger, later rewards of an individual, respectively. Slim arrows indicate the reception time of a smaller, sooner reward, while fat arrows indicate the reception time of a larger, later reward. (A) In the exponential discounting model, constant discounting takes place and hence the larger reward V_L is always preferred over the smaller reward V_S irrespectively of when it occurs in time. (B) In the hyperbolic discounting model, the values of the smaller and larger rewards reverse when rewards are deferred into the future, as it can be empirically observed in most studies on intertemporal choice. From Kalenscher & Pennartz (2008).

Soon, the assumptions of DUT, an economic model, were challenged by psychological research (Ainslie, 1975; Rachlin & Green, 1972). Psychological mechanisms that are underlying intertemporal choices have been empirically investigated, and violations of the stationarity axiom as well as the assumption of a constant discount rate were reported.

For instance, when given the choice between € 10 today and € 12 in two weeks, many people prefer to select the smaller but immediate reward. But when given the same choice delayed in time offering € 10 in a year and € 12 in a year and two weeks, most people's preferences switch and they select to wait for the larger, later reward. Although the temporal as well as the monetary difference is the same in both choices, humans do not choose the same option in both cases, which is violating the stationarity axiom.

The violation of this axiom was replicated in numerous empirical studies with humans (McClure, Ericson, Laibson, Loewenstein, & Cohen, 2007; Rohde, 2005), pigeons (Ainslie, 1974; Green, Fisher, Perlow, & Sherman, 1981), and rats (Ito & Asaki, 1982), all showing that organisms prefer a sooner reward over a later reward much more if it was available immediately and not only after a delay.

The violation of the stationarity axiom are closely related to violation of the assumption of a constant discount rate. A constant discount function cannot explain preference reversals as the ones observed (Benzion, Rapoport, & Yagil, 1989; Green, Fristoe, & Myerson, 1994; Rohde, 2005). Rather, shortly delayed rewards are discounted more steeply than rewards with long delays. Hence, other kinds of economic discount models were proposed. Here, only two of the most famous ones will be introduced. First, a hyperbolic discounting model will be discussed, since this function fits behavioral data better (Ainslie, 1974, 1975):

$$V = \frac{R}{(1+k \cdot D)}$$

As in the exponential function, V stands for the subjective value or utility of a reward R , delivered after a time interval D , and discounted by an individual constant (discount rate) k (Figure 2.1B). Using the same example as above, a participant who is indifferent between an offered reward $R = € 100$, delivered after $D = 2$ weeks, and a reward of € 80, delivered now, discounts future rewards at a discount rate $k = .125$. As in the exponential function, discount rates differ individually depending on how impulsive a person is. In contrast to the exponential discount rate c , the hyperbolic k accounts for empirically observed preference reversals.

Figure 2.1 depicts the exponential and hyperbolic discount functions with regard to the violations of stationarity and constancy in the exponential function, a problem solved by fitting behavioral data with a hyperbolic function instead.

Recently, a quasi-hyperbolic discount function was proposed (Laibson, 1997). This function fits experimental data as well as the hyperbolic model (Angeletos, Laibson, Repetto, Tobacman, & Weinberg, 2003; McClure, et al., 2004), additionally proposing the participation of distinct processes (modelled by two parameters instead of one) when intertemporal choices are made.

In general, the quasi-hyperbolic discount model proposes two distinct processes, a present-oriented and a future-oriented one (Berns, Laibson, & Loewenstein, 2007), and can be described by the following formula:

$$V = R \cdot \beta \cdot \delta^D$$

V and D are the utility/subjective value and delay of/to a reward R , respectively, and β and δ are discounting parameters, with β representing the special weight placed on immediate rewards and δ being a general discounting parameter discounting future rewards irrespectively of when they occur. As the formula shows, the quasi-hyperbolic discount function is only hyperbolic in the sense that it depicts the qualitative characteristic of the hyperbolic function by modelling a faster decline in the short run than in the long run (Figure 2.2).

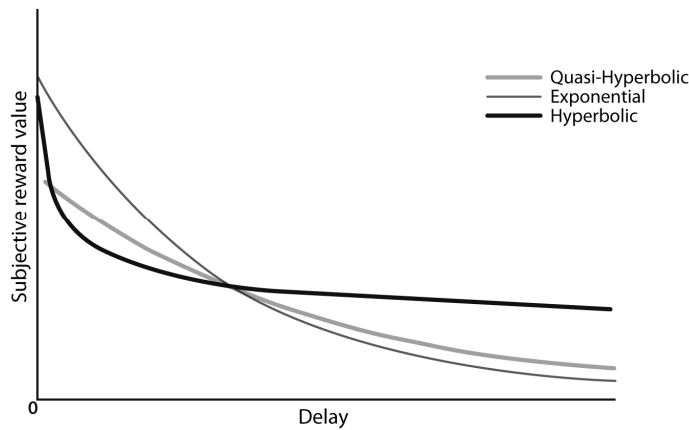


Figure 2.2: *Depicted is an example of a quasi-hyperbolic discount function in relation to an exponential and a hyperbolic discount function. The course of the quasi-hyperbolic function mostly follows the course of the exponential function, but since the quasi-hyperbolic model uses two parameters, the empirically found steeper devaluation of monetary rewards in the short compared to the long term is reflected. From Angeletos et al. (2003).*

The quasi-hyperbolic model takes into account distinct processes investigated mostly in psychological research (Epstein & Pacini, 1999; Kahneman, 2003; Kahneman & Frederick, 2002; Metcalfe & Mischel, 1999; Stanovich & West, 2000). This economic model hence incorporates psychological findings and theories, which were supported by a large number of studies (McClure, et al., 2007; McClure, et al., 2004; Metcalfe & Mischel, 1999; Mischel,

Ayduk, & Mendoza-Denton, 2003; Whalen, 1998), and which we suppose to be involved differently in intertemporal choices made for oneself (see also Metcalfe & Mischel, 1999) and for another person.

In the following section, theories of and empirical evidence for distinct cognitive processes (or systems) the quasi-hyperbolic model corresponds to, will be discussed. Their relation to intertemporal choice for self and other will be discussed later on, in section 3.

2.1.2 Dual processing theories in psychology

The quasi-hyperbolic discount model uses two parameters to model the special value placed on immediate rewards independently of a general discounting mechanism of future rewards. This corresponds to so-called dual-processing models proposed in psychology. These models, proposed by a great number of authors, suggest that there are two processing modes, commonly labeled as System 1 and System 2 processes (Epstein & Pacini, 1999; Kahneman, 2003; Kahneman & Frederick, 2002; Metcalfe & Mischel, 1999; Stanovich & West, 2000). Most theories posit a distinction between processes that are fast, automatic, unconscious, intuitive, and impulsive (System 1 or “hot system” processes), and processes that are slow, effortful, conscious, and deliberately controlled (System 2 or “cool system” processes; Table 2.1).

Table 2.1: Example for characteristics of the two systems put forward in dual-processing theories. From Metcalfe & Mischel (1999).

hot system (System 1)	cool system (System 2)
emotional	cognitive
“go”	“know”
simple	complex
reflexive	reflective
fast	slow
develops early	develops late
accentuated by stress	attenuated by stress
stimulus control	self-control

It is beyond the scope of this thesis to discuss the wide range of dual-processing theories. Yet, it is important to note that many have been proposed in different fields of psychology such as reasoning, judgement, decision making, and social cognition. I will restrict myself to discussing one dual-processing theory in more detail, namely the hot-cool model suggested by Metcalfe and Mischel (1999). This model provides the basis for numerous assumptions made about impulsive and self-controlled behavior, and can be used to model processes underlying intertemporal choice.

The hot-cool model, also called “the interface between affect and cognition” (Mischel, et al., 2003), proposes an emotional, or “hot” system (cp. System 1) and a cognitive, or “cool” system (cp. System 2), interacting with each other (Table 2.1).

As most dual-processing theories, the hot-cool model proposes the cool system having a guiding and monitoring function, allowing people to keep their goals in mind and working towards the fulfillment of these goals. Further, it was suggested that the cool system consists of a network of interconnected “cool nodes”. These interactions lead to complex relations between the nodes, making complex thoughts possible. The hot system is also supposed to consist of nodes, or “hot spots”, also called “fragments of feelings” (Metcalfe & Mischel, 1999). Since here, according to the model, less interaction is necessary, hot spots are not interconnected, which leads to less cycling and less complexity, and thus allows a faster response. The occurrence of a stimulus or event may be represented by both, hot spots and cool nodes. While the activation of a hot spot results in an affective reaction to that stimulus, activation of a cool node makes information available about the stimulus, its context and its consequences, allows self-reflection, and provides information about interconnections to other concepts and characteristics. Connections between hot spots and cool nodes exist, and allow for an interaction between the two systems, if both are activated. Metcalfe and Mischel (1999) propose that the default state is an activation in the hot system, which happens automatically when a stimulus or event occurs. Mental effort (i.e., activation of nodes in the cool system) is required to overcome response tendencies connected to this hot system activation. In ontogenesis, the hot system is believed to be fully developed at birth, whereas the cool system develops later on (Metcalfe & Mischel, 1999; Mischel, et al., 1989; Perner & Lang, 1999; Zelazo & Muller, 2002).

The assumptions of the hot-cool model can be easily applied to explain preference reversals in intertemporal choice behavior.

In intertemporal choice, the hot system builds upon a “here-and-now principle” whereas the cool system is responsible for a “long term perspective” (Mischel, et al., 2003). The cool system deliberately processes a choice by evaluating the alternatives with regard to their usefulness, comparing and calculating the expected utility of the two options. When an intertemporal choice between an immediate, but smaller and a later, but larger reward is presented, the hot system will impulsively go for the immediate gratification, while the cool system will usually opt for the later, larger option, since this delayed reward is larger and can be considered the greater gain in the end. As uncertainty and prospect are also taken into account by the cool system (i.e., “Will I live to receive the delayed reward?” or “Will I need the money as desperately later as I need it now?”), it might not per se opt for the larger reward but calculate whether it is worth waiting. In the end, if the cool system does not opt for the larger reward, the smaller reward will be chosen. Otherwise, the more highly activated system will win. It depends on different internal and external factors which system wins, i.e., whether a person will wait for the larger reward or go for immediate gratification (Mischel, et al., 2003; Mischel, et al., 1989). One such factor is shifting the choice forward in time, i.e. instead of letting people choose between € 10 today and € 12 in two weeks, letting them choose between € 10 in a year and € 12 in a year and two weeks. As mentioned before, preferences usually reverse; while people choose the smaller reward when it is immediate, they choose the larger reward when both rewards are delayed. The hot-cool model explains such reversals with its greater engagement of the hot system in choices with a possible immediate gratification compared to choices without this possibility. In terms of the quasi-hyperbolic discount function (which has been discussed in section 2.1.1), the hot system is integrated by the β parameter, whereas the cool system is explained by the δ parameter.

More factors influencing intertemporal choices (i.e., the differential activation of the hot and cool systems) will be discussed in the next section.

2.1.3 Influential factors on impulsive behavior

It has been shown in numerous studies that intertemporal choice behavior is influenced by a number of factors, leading to impulsive versus self-controlled decisions. In the following, some influential factors will be discussed.

One important factor is attention. When attending to a reward, i.e., seeing it, people act more impulsively by going for it immediately instead of waiting for more of it. Accordingly, when rewards are not within view, people act less impulsively and are more prepared to wait for a promised later, larger reward (Mischel & Ebbesen, 1970). The hot-cool model explains this by assuming a higher activation of the hot system by the sight of an immediate available reward, as the salience and hence the “consummatory representation” is higher (Mischel, et al., 2003). Hence, preventing the activation of the hot system is supposed to prevent impulsive choices, advancing more patient choices (Mischel, et al., 2003).

Applying distraction can also help to control one’s impulsiveness. Distraction, no matter if applied externally (i.e., generated by another person) or internally (i.e., self-generated), can also lead to the choice of a later, larger reward over immediate gratification (Mischel, Ebbesen, & Raskoff Zeiss, 1972). This can be best achieved through “hot” (affective) distraction (Mischel & Baker, 1975) which means to think about rewarding things other than the reward (e.g. about a salty pretzel when the actual reward waited for are sweet marshmallows). According to the hot-cool model, this should activate irrelevant hot spots, and hence lead to less engagement of the hot system in the actual choice (Mischel, et al., 2003).

Abstraction is another way of influencing patience in intertemporal choice. When participants were asked to focus on the (abstract) cool features (e.g. round, cloud-shaped objects) instead of the hot features (e.g. sweet, chewy taste) of a reward (e.g. marshmallows), they were more able to wait for the later, larger reward (Mischel & Baker, 1975). In the case of secondary rewards like money, hot features could be thoughts about what to buy immediately after receiving the reward, whereas cool features could be the shape and size of a note or coin.

The aforementioned factors all demand a certain cognitive effort in order to suppress hot system activation. But also the cool system can be influenced in such a (here usually not intended) way. Negative, stressful thoughts seem to negatively influence the cool system and lead to a decreased waiting time, suggesting the cool system to be busy with these thoughts,

being unable to “fight” against impulsiveness (Mischel, et al., 1972). Cognitive load can be considered having similar effects: When cognitively otherwise engaged during intertemporally choosing, participants chose the immediate reward more often, suggesting that the cool system was occupied similarly as with the aforementioned stressful thoughts. For example, participants who were engaged in a cognitively demanding task, like high number calculations or keeping in mind several digit numbers, behaved more impulsively, as cool system processes were applied to solve this task and hence had fewer free capacities for establishing self-control and suppressing hot system processes. (Mischel, et al., 2003; Shiv & Fedorikhin, 1999). Take for instance the following task: “A bat and a ball cost € 1.10 in total. The bat costs € 1 more than the ball. How much does the ball cost?” (adapted from Kahneman, 2003). According to the two-systems-theory, in such a paradigm, the wrong answer (here: € 0.10) will be given more often, if a participant is put under cognitive load (Kahneman, 2003). Accordingly, also a dieter trying to forgo food is less able to keep to this resolution if under cognitive load or in a stressful situation (Shiv & Fedorikhin, 1999). This might explain why many people are especially unable to keep to resolutions such as losing weight or stop smoking in more stressful times of their lives.

Attention, distraction, abstraction, and stress/cognitive load hence seem to have a great influence on intertemporal choice towards making more or less patient choices. As described before, in this thesis another important “factor” shall be investigated: In the experimental part (sections 6 and 7), the person the choice is made for (self or other) will be varied. We ask whether this factor has an influence on hot system processes, i.e., whether these processes play no or only a minor role in choices made for another person, making choices for this other person more patient.

But before discussing this new factor in detail, neural correlates of intertemporal choice (for oneself) will be discussed. Further, the extent to which these findings from neuroscientific studies support dual-processing theories will be addressed in the following section.

2.2 Brain correlates of intertemporal choice

Before specific correlates will be discussed, an international convention of neuroanatomical nomenclature will be introduced.

2.2.1 Standard neuroanatomic nomenclature

A widely used standard nomenclature for a division of the cerebral cortex into discrete regions is based on the “Brodman map” (Brodmann, 1909). These so-called Brodmann Areas (BA) are separated by changes in the laminar patterns of the cortex. Brodmann showed that the cerebral cortex consists of six layers, and developed a numbering system on the basis of the relative size of the different layers. The Brodmann map divides the cortex into 52 (Brodmann) areas. Other cytoarchitectonic divisions of the cortex were introduced (e.g. Petrides & Pandya, 1994; von Economo & Koskinas, 1925), partly based on that by Brodmann. Since Brodmann’s nomenclature still is the most widely used, it will also be used throughout this thesis.

The co-planar stereotactic atlas by Talairach and Tournoux (1988) retains the systematic division into BAs, providing a proportional grid (coordinate system) to which individual fMRI data can be aligned, thus allowing the comparison of different brains. The upper rim of the anterior commissure (AC) forms the origin of the coordinate system, with the y-axis being the line connecting the zero-point with the lower boundary of the posterior commissure (PC). Perpendicular to this (so-called AC-PC) line, a horizontal line through the AC constitutes the x-axis. Perpendicular to both axes, also passing through the AC, is the z-axis (Talairach & Tournoux, 1988).

Together, the coordinates given by the stereotactic atlas and BAs offer an adequate terminology for the precise localization of activation found in functional imaging studies.

2.2.2 Imaging intertemporal choice

Several studies investigated which brain regions are involved in the processing of rewards in general, and in intertemporal choice in particular. McClure et al. (2007; 2004) tested the hypothesis, that there are two systems in the brain (relying on the characteristics of dual processing theories discussed in section 2.1.2), with certain brain areas involved in the processing of immediate rewards and other brain areas involved in the processing of intertemporal choices in general, but especially when a delayed reward is chosen. In their study, a series of choices between a sooner, smaller and a later, larger rewards were presented. Some of the sooner rewards were available immediately, whereas all other sooner rewards were delayed by a certain period of time (Figure 2.3). McClure and colleagues (2007; 2004)

could confirm their hypothesis. “Limbic” subcortical areas and paralimbic cortical structures were active during choices including immediate rewards only, whereas a network of lateral fronto-parietal areas was activated during all choices. They hence inferred, that these two neural systems resemble the two systems proposed by most dual processing theories (Kahneman & Frederick, 2002; Metcalfe & Mischel, 1999; Stanovich & West, 2000), (as proposed in section 2.1.2).

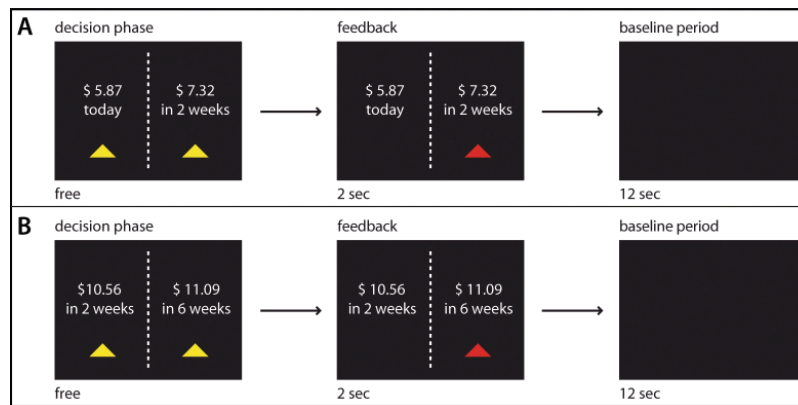


Figure 2.3: The decision phase presenting the two choice options was followed by a short feedback phase (2 sec), indicating the choice the participant had made. Then a black screen was presented (12 sec) before the next trial started. Trials either contained (A) an immediate and a delayed option or (B) two delayed options. Adapted from McClure et al. (2004).

Since the activated brain regions McClure and colleagues (2007; 2004) found are very important for the work presented in this thesis, I will describe these regions and processes they were found to be engaged in in more detail in the following.

2.2.3 Neural correlates of hot system processes

McClure and colleagues (2004) found the following areas to be more highly activated in choices containing an immediate reward option (today trials) compared to choices exclusively containing delayed options (delay trials): Medial orbitofrontal cortex (MOFC), ventral striatum, pregenual anterior cingulate cortex (pACC)/medial prefrontal cortex (MPFC), posterior cingulate cortex (PCC), and posterior hippocampus (Figure 2.4). Most of these areas

had formerly been found to be engaged in reward processing, e.g. in lotteries or gambles with monetary outcomes. Further, in their study concerning primary rewards, McClure and colleagues (2007) found activation in the precuneus, which will also be discussed in detail in the following.

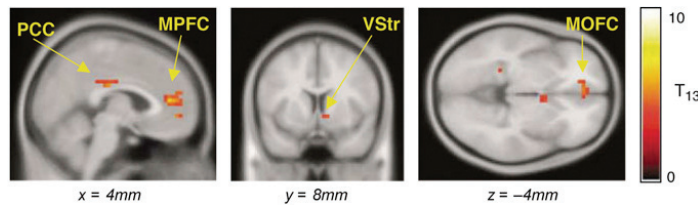


Figure 2.4: Activated brain regions when making intertemporal choices containing an immediate reward compared to choices containing exclusively delayed rewards. These activation differences were observed in the medial prefrontal cortex (MPFC), ventral striatum (vStr), posterior cingulate cortex (PCC), and medial orbitofrontal cortex (MOFC), ($p < .001$, uncorrected). From McClure et al. (2004).

2.2.3.1 Ventral striatum

The striatum consists of the caudate nucleus, putamen, and nucleus accumbens, and is located subcortically. The ventral parts of the caudate nucleus and putamen, together with the nucleus accumbens, constitute the ventral striatum.

The ventral striatum has connections to cortical structures, e.g. the MPFC, but also to subcortical structures like the thalamus and the midbrain's substantia nigra (Haber, 2003). Particularly, the ventral striatum is known to have strong reciprocal connections to the midbrain's dopaminergic neurons (Breiter, Aharon, Kahneman, Dale, & Shizgal, 2001; Schultz, Dayan, & Montague, 1997), which have been shown to play a crucial role in reinforcement learning (Schultz, et al., 1997).

As early as in the 17th century, lesions of ventral striatum were associated with lowered motivation (whereas lesions more dorsal in the striatum were assumed to influence motor behavior), (Finger, 1994). Behavioral changes during of Parkinson's Disease (PD) and other conditions that influence the striatum's dopaminergic input also allow inferences about the function of the ventral striatum. In PD, dopaminergic cells in the substantia nigra degenerate,

leading to a depletion of dopamine in the striatum, which leads to alterations of both, motor and cognitive skills. It is believed that dorsal striatal dopamine deficits lead to impaired movement control and initiation, whereas ventral striatal dopamine depletion affects reinforcement learning (Packard & Knowlton, 2002).

Furthermore, electrophysiology studies showed that dopaminergic neurons responded to appetitive stimuli presented to monkeys (Mirenowicz & Schultz, 1996), and that rats, when given the possibility to stimulate their own dopaminergic systems through implanted electrodes, preferred this apparently rewarding stimulation even over food or sex (Phillips, Mora, & Rolls, 1979; Wise & Rompre, 1989). Further monkey studies demonstrated reward receipt being associated with firing of dopaminergic neurons, which could be shifted to a formerly neutral stimulus after classical conditioning (e.g. ringing of a bell seconds before reward delivery). Activity during reward receipt itself was no longer increased (Schultz, 1998).

Findings in human imaging studies supported these results, suggesting that the ventral striatum is activated by reward anticipation and receipt (Knutson, Fong, Adams, Varner, & Hommer, 2001; Schultz, Tremblay, & Hollerman, 2000). When investigated systematically, it could be found that reward anticipation was accompanied by ventral striatal activation more robustly than reward receipt (Berridge & Robinson, 1998). Activation was found to be high during the reward delivery period only when it occurred unexpectedly, i.e., when it was not anticipated (Knutson, et al., 2001; cp. Schultz, 1998). Contrarily, when a reward was anticipated but not delivered, activation was decreased at the point of expected receipt (Knutson, et al., 2001; cp. Schultz, 1998). This phenomenon was termed “reward prediction error”, and suggested to play a crucial role in reinforcement learning (Schultz, 1998). Further studies revealed the sensitivity of the nucleus accumbens of the ventral striatum for magnitude of anticipated rewards (Knutson, Taylor, & Kaufman, 2005), while it is still unclear whether the probability of gaining a reward is coded in nucleus accumbens activity, too (Ablner, Walter, Erk, Kammerer, & Spitzer, 2006; Knutson, et al., 2005). The ventral striatal/nucleus accumbens’ activation in intertemporal choice has been shown to be higher for immediately available rewards compared to delayed rewards (Hariri, et al., 2006; McClure, et al., 2007; McClure, et al., 2004).

Together, the above reported findings suggest the ventral striatum to play a role in reward processing, especially when rewards are anticipated. Activation seems to correspond to the magnitude of the rewards as well as the time to reward receipt.

2.2.3.2 Cingulate cortex

The cingulate cortex is located in the medial aspect of the forebrain, surrounding the corpus callosum. From anterior to posterior, it comprises BAs 25, 24/32, and 23. Based on cytoarchitectural, lesion, electrophysiological and imaging studies, the cingulate cortex was divided into subregions, with the ventral ones being responsible for the processing of emotions (Bush, Luu, & Posner, 2000; Vogt, 2005). Grossly, the cingulate cortex can be separated into an anterior (ACC), midcingulate (MCC), and posterior (PCC) part. Vogt further divides the ACC in subgenual ACC (sACC) and pregenual ACC (pACC), the MCC into anterior MCC (aMCC) and posterior MCC (pMCC), and the posterior PCC into dorsal PCC (dPCC) and ventral PCC (vPCC). The MCC is regarded the dorsal/caudal part of the ACC by a number of authors (Bush, et al., 2000; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004; Ullsperger & von Cramon, 2004).

2.2.3.3 Anterior cingulate cortex

Like the ventral striatum, the ACC receives rich dopaminergic innervations, which suggests its involvement in reward-related processes (Gaspar, Berger, Febvret, Vigny, & Henry, 1989; Schultz, 1998). Among other areas, the ventral part of the ACC (i.e., sACC and pACC) has connections to the nucleus accumbens and to the orbitofrontal cortex (Devinsky, Morrell, & Vogt, 1995), both also found to be activated by reward-related stimuli (Knutson, et al., 2001; Winstanley, Theobald, Cardinal, & Robbins, 2004).

Large, bipolar cells called Von Economo Neurons (VENs) were found to be located in the ACC (Allman, Watson, Tetreault, & Hakeem, 2005). Their high affinity dopamine receptors also suggest that they may be involved in reward-processing (Allman, et al., 2005).

Contrary to the MCC (also called dorsal ACC by some authors, e.g. Bush, et al., 2000), which was usually reported to be involved in performance monitoring and executive control processes (Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004; Ullsperger & von Cramon, 2004), the sACC was implicated in classical conditioning and visceral integrative

processes (Buchanan & Powell, 1993). Lesions in this region led to a dysregulation of autonomic functions and apathy (e.g. Tow & Whitty, 1953). The pACC, which is located anterior to the genu of the corpus callosum, was proposed to be involved in processing positive emotions (Vogt, 2005; Whalen, 1998). In an experimental task in which participants had to count words, the pACC showed activation when the words were emotionally valenced (e.g. “murder”), whereas the MCC/dorsal ACC (dACC) was involved when words were neutral (e.g. “three”), (Whalen, 1998). Hence, the ventral part of the ACC was termed “affective division” of the ACC (Whalen, 1998). In a gambling task, activation in this region was reported to be higher for gambles involving high rewards than for gambles possibly yielding only small rewards (Rogers, et al., 2004), which suggests the pACC to be sensitive to reward magnitude. The prospect of a high reward could be connected to positive emotions, which in turn are accompanied by pACC activation.

The activation in the pACC observed by McClure et al. (2007; 2004) further extended into the medial prefrontal cortex, a region anterior to the pACC, strongly interconnected with the precuneus (see below, section 2.2.3.5), and well-known for its engagement in self-related judgments (Craig, et al., 1999; Kelley, et al., 2002; Ochsner, et al., 2004) and self-focused attention (Gusnard & Raichle, 2001).

2.2.3.4 Posterior cingulate cortex

The PCC has extensive connections to the inferior parietal cortex, connections to the thalamus, precuneus, hippocampus, and is also interconnected with the sACC (De Luca, Beckmann, De Stefano, Matthews, & Smith, 2006; Greicius, Krasnow, Reiss, & Menon, 2003; Gusnard & Raichle, 2001).

Like the pACC, the PCC was reported to be active when emotions were processed; but in contrast to the pACC, it was also observed to be involved when non-emotional events were experienced (Vogt, 2005). Findings of emotional processing were investigated in a meta-analysis (Maddock, 1999), indicating the role of the PCC and nearby areas (such as the precuneus and retrosplenial area) in emotional processing to be related to episodic memory processes. The authors argue that emotional processing could influence memory processes the PCC was reported to be involved, as for instance, emotionally salient stimuli had been

reported to be recalled much better than neutral stimuli (Cahill & McCaugh, 1998; Maddock & Buonocore, 1997; Reisberg & Heuer, 1995; Rubin & Friendly, 1986).

Especially the vPCC was further observed to play a role in spatial orientation and representation (Greicius, et al., 2003; Gusnard & Raichle, 2001; Ries, et al., 2006; Whishaw & Wallace, 2003). Additionally, self-reflection and internal monitoring were observed (Ries, et al., 2006). Self-reflection (i.e., thinking about one's own personal characteristic traits) was reported to be accompanied by higher activation in the vPCC than reflections about other persons' characteristics (D'Argembeau, et al., 2008). In line with these findings, the vPCC was previously also found to be engaged in episodic memory retrieval (Maguire & Mummery, 1999; Wagner, Shannon, Kahn, & Buckner, 2005).

Together with its connections to the sACC, this suggests that the vPCC possesses a self-processing role, assessing the self-relevance of stimuli (Vogt & Pandya, 1987). The vPCC hence could serve as a pre-processor of emotional information, allowing this information to pass on to more anterior regions of the cingulate cortex (Vogt, 2005).

2.2.3.5 Precuneus

The precuneus, a large part of the medial aspect of the posterior parietal lobe, was also found to be activated when participants faced immediate rewards (Kable & Glimcher, 2007; McClure, et al., 2007). The precuneus is bordered by subparietal sulcus, pars marginalis of the cingulate sulcus, and parietal occipital sulcus. It corresponds to the mesial extent of BA 7. Brodmann (1909) further divided this area in two subareas, called 7a and 7b. However, no clear border was defined between these areas (Zilles, Eickhoff, & Palomero-Gallagher, 2003).

Concerning its connectivity, the precuneus possesses widespread connections to many cortical and subcortical areas. Within the parietal cortex, it is reciprocally interconnected with the caudal parietal operculum, the inferior and superior parietal lobules, and the intraparietal sulcus (IPS), (Leichnetz, 2001). Main connections outside the parietal lobe were found between the precuneus and the frontal lobes. BAs 8, 9, and 46 of the prefrontal cortex as well as the ACC show strong interconnections with the precuneus (Leichnetz, 2001; Petrides & Pandya, 1984). Subcortical connections involve the caudate nucleus and putamen among others (Leichnetz, 2001; Petrides & Pandya, 1984). Since no direct connections with primary

sensory areas could be observed, it is suggested that the precuneus does not directly process stimuli, but influences structures processing associative and integrated information (Cavanna & Trimble, 2006).

Functionally, the precuneus was observed to be active during different tasks. In their review article, Cavanna and Trimble (2006) suggest four main fields the precuneus might play a role in: Visuo-spatial imagery, consciousness, episodic memory retrieval, and self-processing. We found activation in the posterior part of the precuneus, which was mostly associated with episodic memory retrieval processes. Hence, we will focus here on findings of the precuneus' involvement in such episodic memory retrieval.

The term “episodic memory” refers to the memory of self-experienced events. Contrarily, “semantic memory” refers to acquired knowledge irrelevant of how and when it was acquired (Tulving, 1983). Imaging studies found activation related to successful episodic memory retrieval mostly in the posterior precuneus (e.g. Addis, McIntosh, Moscovitch, Crawley, & McAndrews, 2004; Naghavi & Nyberg, 2005; Zysset, Huber, Ferstl, & von Cramon, 2002). Activation in the anterior part of the precuneus was rather found in memory-related visual imagery (Fletcher, et al., 1995), suggesting that the precuneus plays a role in visual imagery during episodic memory recall (Buckner, et al., 1995; Fletcher, Shallice, Frith, Frackowiak, & Dolan, 1996).

While the ventral striatum and pACC were reported to be involved mostly in affective evaluation of rewards, the precuneus/vPCC and MPFC were mostly reported to be involved in self-related memory and thought. Hence, all of these structures are likely to play a role in intertemporal choice for oneself, but not for other. All the described structures fit in building a neural system which could be responsible for hot system processes, described by dual-processing theories (cp. section 2.1.2). In terms of the quasi-hyperbolic discount function, these brain structures were called β areas (McClure, et al., 2007; McClure, et al., 2004).

2.2.4 Neural correlates of cool system processes

During intertemporal choice irrespectively of delay (compared to phases in which participants were seeing a black screen), McClure and colleagues (2004) found activations within the visual cortex, premotor cortex, supplementary motor cortex, posterior parietal

cortex/intraparietal sulcus, dorsal lateral prefrontal cortex (DLPFC), ventral lateral prefrontal cortex (VLPFC), and lateral orbitofrontal cortex (LOFC), (Figure 2.5). But only the parietal and prefrontal areas showed enhanced activation in difficult compared to easy decisions, suggesting that only these areas were engaged in intertemporal choice, whereas the visual and motor areas were engaged in more general features of the task, such as seeing a stimulus and responding to that stimulus by button press.

Easy decisions were defined as choices in which the monetary difference between the sooner and the later reward was either very small (1-3%) or very large (35-50%), whereas difficult choices were defined as choices with medium reward differences (5-25%).

Hence, I will further focus on the parietal and prefrontal areas. These areas have been commonly found to be engaged in higher order cognitive tasks, such as attentional processes (Coull, Frackowiak, & Frith, 1998; Ishai, et al., 2002; Tamm, Menon, & Reiss, 2006) and memory retrieval processes (Henson, et al., 1999; Ishai, et al., 2002; Takahashi, Ohki, & Kim, 2008).

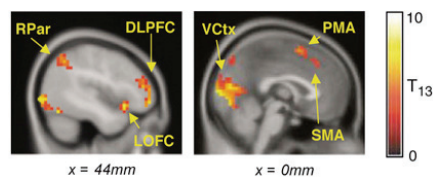


Figure 2.5: Brain regions active during intertemporal choice compared to presenting a black screen. Activation differences reached significance ($p < .001$, uncorrected) in the intraparietal cortex, dorsolateral prefrontal cortex, lateral orbitofrontal cortex, visual cortex, premotor area, and supplementary motor area. From McClure et al. (2004).

2.2.4.1 Lateral parietal cortex: The intraparietal sulcus

The intraparietal sulcus (IPS, BA 7) is located in the posterior lateral parietal cortex, separating the superior from the inferior parietal lobule.

The IPS posits connections to the precuneus (mesial BA 7), the fusiform and lingual gyrus, and to lateral prefrontal areas involved in memory processes (Cavanna & Trimble, 2006; Henson, et al., 1999; Takahashi, et al., 2008).

In human imaging, lesion, and animal studies, the cortex deep within the IPS was found to be largely involved in number processing (Dehaene, et al., 1996; Kiefer & D., 1997; Roland & Friberg, 1985), with more difficult tasks like multiplying large numbers being associated with stronger activations in that area (Kiefer & D., 1997). But also in studies asking for less complex mathematical operations, such as number comparison or number detection, are often accompanied by activation in the IPS, suggesting this region to play a crucial role also on basic levels of quantity representation (Eger, Sterzer, Russ, Giraud, & Kleinschmidt, 2003; Pinel, Dehaene, Riviere, & LeBihan, 2001). Further, the numerical distance of numbers which had to be compared corresponded to activation in the IPS, whereas notation (i.e., spoken or written numbers, in Arabic notation or spelled-out) did not affect activation (Pinel, et al., 2001).

Further, the IPS has been found to be engaged in memory processes (Takahashi, et al., 2008) with connections to the DLPFC and the lateral temporal cortex, which are both known for their involvement in memory processing (Henson, et al., 1999; Takahashi, et al., 2008). These memory processes were proposed to support more complex calculation processes, in which numbers have to be kept in mind while calculating (Dehaene, et al., 2004).

2.2.4.2 Lateral prefrontal cortex (LPFC) and lateral orbitofrontal cortex

The lateral prefrontal cortex consists largely of the superior, medial, and inferior frontal gyri, whereas the lateral orbitofrontal cortex consists of the more ventrally and rostrally situated lateral orbitofrontal gyri.

The LPFC can be further distinguished in dorsal LPFC, ventral LPFC, and inferior frontal junction (IFJ), (Derrfuss, et al., 2004; Owen, et al., 1999; Ridderinkhof, van den Wildenberg, et al., 2004). The DLPFC corresponds to BA 46, BA 9/46, BA 8, whereas the VLPFC was proposed to correspond to BA 44 and BA 45. The IFJ is situated at the junction of the inferior frontal sulcus and the inferior precentral sulcus, i.e., at the junction of BA 9, BA 6, and BA 44 (Brass & von Cramon, 2002; Ridderinkhof, van den Wildenberg, et al., 2004).

Dorsal lateral prefrontal cortex

The DLPFC can be further divided into a middorsolateral PFC (mDLPFC; BA 9/46 and BA 46) and a posterior dorsolateral PFC (pDLPFC; area 8a and b, after the nomenclature of Petrides and Pandya), (Petrides & Pandya, 1994).

The DLPFC is interconnected with other PFC regions, such as the VLPFC, dACC, OFC, and motor areas (premotor cortex, SMA, pre-SMA), (Barbas & Pandya, 1989; Carmichael & Price, 1995; Koski & Paus, 2000). Its interconnections are not limited to the PFC, but also involve connections to the parietal cortex and IPS (Cavanna & Trimble, 2006; Henson, et al., 1999; Takahashi, et al., 2008).

The DLPFC, especially the middorsolateral part (mDLPFC), was reported to be engaged in maintaining and monitoring ongoing working memory processes (Henson, et al., 1999; Petrides, 2000; Takahashi, et al., 2008), helping to keep in mind under which conditions (i.e., delays and reward differences) which options were chosen in previous trials. The DLPFC further was reported to play a role in decision making, since it has been found to be sensitive to difficulty in response selection (Jiang & Kanwisher, 2003; Ridderinkhof, van den Wildenberg, et al., 2004; Schumacher, Elston, & D'Esposito, 2003). In a study using transcranial magnetic stimulation (TMS) to inhibit the DLPFC while participants were playing a game in which they could accept or reject unfair offers from another person, it could be shown that the DLPFC inhibition led to less self-controlled behavior: Participants were less likely to reject unfair offers from other persons when their DLPFC activation was disturbed (Knoch, Pascual-Leone, Meyer, Treyer, & Fehr, 2006). Hence, the DLPFC seems to play a crucial role in higher order cognitive processes such as response selection.

Ventral lateral prefrontal cortex

The VLPFC receives information for instance from the inferotemporal cortex, OFC, midbrain, and amygdala (Barbas & De Olmos, 1990). It is further strongly interconnected with the DLPFC and projects to the pre-motor cortex (Petrides & Pandya, 2002), which suggests its involvement in translating received information into precursors for a motor response (Sakagami & Pan, 2007).

The VLPFC was reported to be involved in response inhibition (Aron, Robbins, & Poldrack, 2004), task switching (Braver, Reynolds, & Donaldson, 2003), associative learning (Passingham, Toni, & Rushworth, 2000), category learning (Freedman, Riesenhuber, Poggio, & Miller, 2001), memory encoding (Bor, Duncan, Wiseman, & Owen, 2003) and episodic memory retrieval (Buckner & Wheeler, 2001). These findings show that there is a partly overlap with functions of the DLPFC, suggesting these structures to be involved in similar tasks on the one hand, but also to possess a certain functional specialization on the other hand (cp. Ridderinkhof, van den Wildenberg, et al., 2004). For instance, Petrides (1996) suggested that the general role of the VLPFC was that of maintaining information in working memory, whereas the DLPFC was suggested to be mostly involved in monitoring actions. There are other proposals for the functional specialization of VLPFC and DLPFC, but to which extent any of these theories holds still has to be investigated in more detail.

Inferior frontal junction

The IFJ is located at the border between the DLPFC and VLPFC. Since connectivity data exists mostly from monkeys, connections in the macaque cortex will be discussed here. The macaque cortex in the arcuate sulcus is cytoarchitectonically similar to that of the IFJ, hence this region might be considered a homologue of the human IFJ (Barbas & Pandya, 1989; Barbas & Pandya, 1987; Derrfuss, et al., 2004; Matelli, Luppino, & Rizzolatti, 1985). Connections of the arcuate sulcus were observed to the pre-SMA (Barbas & Pandya, 1987; Matelli, Camarda, Glickstein, & Rizzolatti, 1986), anterior IPS (Deacon, 1992; Matelli, et al., 1986; Petrides & Pandya, 1984), and the insula (Barbas & Pandya, 1987; Deacon, 1992; Matelli, et al., 1986).

The IFJ was observed to play a role in tasks usually ascribed to the mDLPFC (Derrfuss, Brass, Neumann, & von Cramon, 2005) or inferior frontal sulcus (Zysset, Muller, Lohmann, & von Cramon, 2001). These tasks involve task switching, n-back, and Stroop tasks (Derrfuss, et al., 2005). In the Stroop task, for instance the color of the letters (e.g. green) a word (e.g. the word “yellow”) is made of, has to be named. When the word names a different color than the color it is written in, this interferes with the correct response (which is the color of the letters), and hence response inhibition is necessary (e.g. L. Mead, et al., 2002). In an n-back task, participants are required to compare items they are presented with in a series of items, with the item being n items ago. Studies found IFJ activation in such a task for $n > 1$ and linked it to working memory (Konishi, et al., 1999) and rehearsal processes (Jonides,

Schumacher, & Smith, 1998). Hence, the IFJ's function can be termed as "updating task representations" in interference control and working memory tasks (Derrfuss, et al., 2005).

Lateral orbitofrontal cortex

The LOFC extends into BA 47/12 and BA 10.

The LOFC receives information from areas involved in taste and visual associations, as well as from somatosensory and temporal cortices (Barbas, 1995; Petrides & Pandya, 1988). It was further reported to be interconnected with the amygdala, thalamus, insula, and DLPFC (Barbas, 1995; Fuster, 1997; Goldman-Rakic, 1987; Yeterian & Pandya, 1988).

The LOFC was reported to play a role in decision making since response inhibition was found to be impaired when the monkey's LOFC was lesioned (Iversen & Mishkin, 1970). In a fMRI study, a stimulus was presented, followed by the presentation of two stimuli after a delay, one being identical to the previously presented stimulus, one being novel (Elliot & Dolan, 1999). In the matching task, participants were asked to select the stimulus they had previously seen, in the non-matching task they were asked to select the novel stimulus (Elliot & Dolan, 1999). While the MOFC showed higher activation when the matching task was performed, the LOFC showed higher activation when the non-matching task was performed (Elliot & Dolan, 1999). This result was explained with the MOFC being responsible for monitoring familiarity, whereas the LOFC might have been responsible for inhibiting the more natural selection of the matching stimulus (Elliott, et al., 2004). This interpretation of the LOFC as being responsible for response inhibition was supported for instance by a PET study's results, showing that the presence of invalid cues in a cued orientation task led to higher activation in the LOFC than the exclusive presence of valid cues (Posner, 1980). Further, the involvement of the LOFC in decision making was supported by lesion studies in humans (Bechara, Damasio, Damasio, & Anderson, 1994) and rodents (Fuchs, Evans, Parker, & See, 2004), indicating higher impulsivity (in accordance with lower response inhibition) when the LOFC is lesioned.

A recent fMRI study by Goldstein et al. (2007) showed that the LOFC as well as the LPFC play an important role in self-control. While healthy control participants showed reward-related activation within the lateral prefrontal and lateral orbitofrontal cortex, substance

abusers did not. Further, control participants' task performance correlated with their own reports of task engagement. This was not the case in substance abusers, and suggests that these participants might be less able to perceive inner drives and hence show strong self-control deficits (Goldstein, et al., 2007). The authors argue, that frontal networks might not be able to communicate in a proper way and thus lead to inappropriate behavior in substance abusers.

In a recent review on decision making and the OFC in rodents, it was proposed that drug addiction leads to impairments in the LOFC and to the inability to rapidly adjust learned behavior (Schoenbaum, Roesch, & Stalnaker, 2005). Hence, the authors conclude that the LOFC is involved in value signaling. Lesions accordingly lead to an impairment in evaluating outcomes appropriately, which might in turn lead to inappropriate, impulsive behavior.

Thus, the LOFC can be considered to play a crucial role in response selection, selecting the "correct" response, and inhibiting "wrong" responses.

The lateral orbitofrontal, prefrontal, and parietal areas thus were labeled cool system or (according to the quasi-hyperbolic discount function) δ areas, and proposed to deliberately represent general discounting processes, irrespective of delay (McClure, et al., 2004).

2.2.5 Evidence against multiple systems in the brain

Researchers arguing against a multiple systems approach criticize that the study by McClure et al. (2004) did not use short delays to the smaller rewards and thus did not investigate if immediate gratification was special compared to all delayed gratification, or whether it is also possible that there was a gradual decrease with increasing delay. Further, one study found that participants preferred the sooner over the later option independently of when the sooner option was available (Glimcher, Kable, & Louie, 2007). Kable and Glimcher (2007) report that activation in the aforementioned reward- and emotion-related brain areas did not solely depend on immediate rewards, but varied as a function of reward size and delay to the later reward. They could show that the neural activity tracks the subjective value of rewards. Kalenscher and colleagues (2005) investigated intertemporal choice in pigeons and similarly found that activation in single neurons in the Nidopallidum Caudolaterale (NCL; which is supposed to be the pigeon's homologue to the human prefrontal cortex) integratively code

reward amount AND delay. Kalenscher and Pennartz (2008) hence propose a neural integrative theory of intertemporal choice based on reinforcement learning. The model by Kalenscher and Pennartz (2008) assumes that reward features (such as delay) are reversely replayed after a choice, i.e., so that the stimulus/event most proximal to a reward is replayed first. A decaying (reward amount coding) reinforcement signal coincides with this replayed reward information, so that temporally proximal and/or higher rewards are valued higher than temporally distant and/or lower rewards. The authors suggest that a Hebbian learning rule then converts these temporal couplings of the different stimuli/events into neural weight changes. This model needs further testing, as it is necessary to investigate whether reverse replay really happens in target regions as the ventral striatum, and whether the reinforcement signal actually coincides with a replay of the stimuli representation. But this model challenges the view of multiple systems and should be considered a candidate model for an alternative explanation of the neural basis of intertemporal choice. Hence, it remains unclear, whether the two-system approach will really hold in the long term. But as Kalenscher and colleagues (2005) did not investigate humans but pigeons, and as results by Kable and Glimcher (2007) are based on choices that always involved an immediate option, much more research will be necessary to learn about the real nature of the basis of human discounting in intertemporal choice. Given the empirical findings so far, it seems a two-systems approach is very likely (Hariri, et al., 2006; McClure, et al., 2007; McClure, et al., 2004). Hence, cognitive processes and brain areas were labelled as hot system or cool system processes and areas throughout this thesis, since this provides short expressions for relatively clearly defined processes and structures.

As already posed in section 2.2.3, the question we want to investigate is whether hot system processes, and thus activation in β areas, are special for choices made for oneself, or are also present in choices made for another person. To investigate this question theoretically and on the background of existing empirical research, the next chapter will introduce theories of self and other, and give an overview of literature about decision making for self and other. It will be discussed to which extent and why choices made for another person might deviate from choices made for oneself, and whether it can be better to delegate decisions under certain circumstances.

3 Decision making for self and other

The distinction between multiple systems can be found not only in the economic quasi-hyperbolic discount model and psychological dual process theories described in the section above, but also in philosophical, psychological, and economic self-theories postulating the existence of multiple selves. In the following section, theories of the self and how they apply to dual processing will be described, and links of these theories to the perception of other persons will be introduced.

The second part of this chapter (section 3.2) contains a discussion of empirical findings on decision making for self and other.

3.1 Who am I? Theories of the self

“Not only our selves are conditional, but they die. Each day, we wake slightly altered, and the person we were yesterday is dead.” (John Updike, , American novelist)

3.1.1 James’ classical theory of multiple selves

Although the self is perceived as a temporally and spatially continuous entity, it is widely considered to be composed of many parts. In social and personality psychology, theories assume that the self is multiple and dynamic, i.e., that there are many selves and that these selves change over time and influence each other. Already in 1890, William James (1890) postulated two distinct functions of the self: The “self as knower” (“I”) and the “self as known” (“me”). Whereas the “I” is a subjective perceiver and actor, the “me” is considered the object of what the “I” perceives and knows. Hence, the “me” contains the self’s empirical knowledge (James, 1890). James further distinguished between a material, spiritual, social, and bodily “me” or self. While the spiritual self contains all non-material aspects of the self, such as feelings and thoughts, the material self contains all material aspects, such as personal possessions, but also family members. Closely related to this, the bodily self contains the image of one’s own body. The social self again splits into many selves. According to James, there can be as many social selves as important relationships a person has to other individuals

or groups. These social selves are integrated and interdependent, so that the self can be experienced in a coherent way (James, 1892).

3.1.2 Social interactionists' theories of the self

James' (1890, 1892) multiple selves approach was incorporated by many other researchers. For instance, social interactionists, who believe in an interdependent relationship between self and society, and hence in an inseparable unit of self and other, became interested in the "self as known". Cooley (1902) thought of the self as a "looking glass", as he supposed people to see themselves like other people saw them. The self concept, i.e., the concept and theory a person has about herself, is hence formed by feedback learning from social interactions with other individuals or groups. Mead (1934) further developed Cooley's (1902) theory. Mead's theory states that individuals learn from the reactions of others to anticipate these reactions and to adjust their own behavior. Mead (1934) considered both a "me" and an "I" in his theory, stating that the former is emphasized in social interactions with other individuals, whereas the latter is important when the self wants to distinguish herself from others. Contrary to James' (1890) theory, the "I" is considered an impulsive agent, whereas the "me", which develops over time and with experience, gives directions on how to behave appropriately in social interactions. Hence, this approach parallels dual processing theories in stating that an individual's behavior arises from the combined influence of two cognitive systems: A fast and automatic one, which is impulsively striving for self gratification (hot system), and a slow and reflective one, which deliberately argues for rational behavior (cool system; for a discussion of these systems see section 2.1.2). Hence, in Mead's (1934) theory such rational behavior would be to behave socially appropriate. For instance, take a repeated Ultimatum Game. In this game, two individuals play together: The proposer and the responder. The proposer gets a certain amount of money, say €10, from the experimenter, and now has to split this amount between herself and the responder. The amount offered to the responder can range between €0 and €10. The responder then can either accept or refuse the offer. If she refuses, none of the two players gets any money, but the whole amount goes back to the experimenter. If she accepts, they both get their share. In the beginning of a series of such games, the proposer might offer very small shares to the responder, as her "I" or hot system opts for keeping the money to herself, but when the responder keeps rejecting these low offers, the proposer learns to adapt her behavior and develops a strategy (through the "me" or cool system), which allows her to make appropriate offers that the responder accepts,

but that also satisfy her own needs as far as possible. The responder's "I" or hot system, on the other hand, might go for very small offers in the beginning, as every offer larger than zero is rewarding. But when her "me" or cool system tunes in, the responder might reason that rejecting small offers possibly leads to larger offers in the next rounds, and hence to an overall larger outcome for the responder.

3.1.3 Modern theories of the self and empirical evidence

Modern self theories are based on these dynamic theories, mostly conceptualizing multiple selves (Harre, 1998; Markus & Nurius, 1986; Neisser, 1988). For instance, Markus and Nurius (1986) argue that possible future selves play an important role in a self-concept, which regulates behavior and hence decision making. A choice can be made taking into account not only "what I want now", but also "what I might want later". The authors argue that these selves (present and future selves) can be discrepant and in conflict with each other. Consequently, it can be assumed that preference reversals could arise from such discrepancy: Choices with immediate outcomes are made on a "what I want now" basis, whereas choices with delayed outcomes are made on the basis of "what I might want later". Again, this is similar to dual-processing theories, suggesting that the hot system corresponds to the present self, whereas the cool system corresponds to a future (more patient) self. Based on this temporal distinction, Kivetz and Tyler (2007) divided the self into two main parts: The pragmatic and idealistic selves. Whereas the pragmatic self is action oriented, the idealistic self is oriented towards values and principles.

Regarding the temporal perspective, the authors argue that a pragmatic self will be activated by a proximal time perspective, while a distal time perspective activates an idealistic self. Indeed, when asked about preferred course attributes for a (proximal) course starting in a few days or a (distal) course starting next year, participants preferred distant courses described by identity attributes such as respectful treatment and serious consideration of the students' points of view, and proximal courses described by instrumental attributes such as easily earned high grades and looking good on the resume. These preference changes are similarly described as a function of multiple selves by Thaler and Shefrin (1981), who consider a person to be a planner and a (myopic) doer at the same time, introducing a "two-self economic man". While the doer myopically goes for immediate gratification, the planner is more farsighted, trading off immediate gratification for higher, long term gratification. The conflict between these (economic) selves resembles that between the pragmatic and idealistic

selves, and even more closely, that between (psychological) System 1 and System 2. Thus, dual-processing theories can be considered the cognitive basis of many multiple selves theories, like the ones described here.

3.1.4 The Parfitian theory of the self: Differences between present self, future self, and other persons

Parfit (1984) argues in favor of a multiple selves approach over time: Today one is another person than one will be tomorrow. Parfit (1984) further argues that these temporal differences are of the same significance as spatial differences, i.e., the difference between oneself and another person might be comparable to the difference between oneself today and oneself next year. Therefore, as it can be assumed that people care less about the utility of other persons, they accordingly also care less about their own future utility (Parfit, 1984). This theory hence assumes that choosing for another person would be the same as choosing for a future self. Or, in other words, making intertemporal choices for another person would cause no preference reversals, but yield the same outcome as intertemporal choices made for oneself when only future outcomes are available. This would assign a special status to the present self: Choice options containing immediate rewards for oneself should lead to more impulsive choices than choice options containing no immediate reward for oneself or choice options irrespective of delay for another person. I will come back to this crucial assumption, as it is central to the research presented in this thesis.

In summary, the multiple selves approach is in accordance with the assumption of multiple processes involved in decision making. Based on this assumption, hypotheses about the relation of present self, future self, and (present and future) other in decision making can be made, as proposed by Parfit (1984). Behavioral evidence for such decision making will be presented in the next section, followed by the proposal of hypotheses (section 4.1) based on this evidence as well as on the theories introduced in this section.

3.2 Decision making for self and other: empirical findings

Imagine a politician being sent as a middleman to negotiate with a representative of another country, a physician deciding about a treatment for a patient, or a lawyer deciding how to defend a client. Of course, these people usually are recruited because they have a certain expertise in their field, but apart from this, they are also supposed to be more objective and thus more rational in their decisions than the patient or client themselves, because they are less personally involved (Moran, et al., 2006). Hence, differences in decision making for self and other have been investigated in order to support or contradict this view.

3.2.1 Giving advice and making risky decisions for self and other

Kray (2000) and Kray and Gonzalez (1999) found that when giving advice to another person, participants rather rely on the most important aspect of a decision problem instead of considering a multitude of aspects as they would do when choosing for themselves. These findings show that self-other discrepancies do not occur because of motivation problems when other persons are concerned, but because of differential processing of information. These results support those from Hsee and Weber (1997) who found that predicting what other persons would choose differs from what participants themselves would choose. Participants predicted others to be less risk averse and hence more risk neutral than they were themselves. The fact that this only applied when the other person was abstract (e.g., a U.S. citizen) compared to concrete (e.g., the person sitting at the table next to you), supports a risk-as-feelings hypothesis (Hsee & Weber, 1997), suggesting that emotions influence choices, and that participants are more emotionally distant from abstract than concrete other persons. Hence, participants rely on risk neutrality rather than their own feelings when predicting choices of others. Results from Stone, Yates, and Caruthers (2002), who investigated risk taking for self and other by letting participants choose between sure outcomes and gambles of the same expected value for themselves and for a concrete (i.e., vivid) other, further supported these findings. There were no differences in the choices made for oneself and for concrete other persons. As participants did not choose for abstract others, it is difficult to say whether making predictions (as in the study by Hsee and Weber) and actually choosing for another abstract person would yield different results.

A study by Beisswanger, Stone, Hupp, and Allgaier (2003) yielded no differences between giving advice and choosing for another concrete person in an experiment investigating risk taking in social relationships. But importantly, it yielded differences between choices made for oneself and advice given to or choices made for this other person. The choices made concerned social events, such as asking an unknown but attractive girl to dance, or going out with someone one does not know well. These results seem to contradict the findings by Hsee and Weber (1997), and Stone and colleagues (2002), but as Beisswanger et al. (2003) used social instead of monetary risks, this difference might be due to the involvement of these different domains. Beisswanger and colleagues (2003) hypothesize that the personal emotional involvement in a task might play a role. Participants are believed not to be highly emotionally involved in choices made for others, hence choice outcomes between decisions for self and other will differ only if participants are highly emotionally involved in choices made for themselves. For most people, when making monetary decisions for oneself, emotional involvement is supposed to be lower than when making social decisions, concerning relationships to other persons.

3.2.2 Intertemporal choice for self and other

The aforementioned studies investigated the field of risk taking, but intertemporal choice has also been explored. A recent study investigating intertemporal choice for self and other was done by Prencipe and Zelazo (2005). They investigated developmental aspects, similar to Mischel et al. (1989), but added the dimension of perspective taking. Children did not only choose between smaller, sooner rewards (candy) and larger, later rewards (more candy) for themselves, but were also asked to make intertemporal choices for the experimenter. Three-year-olds acted highly impulsively when choosing for themselves, but patiently when choosing for the experimenter. Four-year-olds acted less impulsively when choosing for themselves, but more impulsively than the younger group when choosing for the experimenter. The authors concluded that while three-year-olds seem unable to emotionally empathize with the other person, four-year-olds do so and accordingly choose not significantly different for themselves than for the experimenter. This finding is in line with results from false belief tasks in which it is investigated at what age children understand that other persons can have knowledge, thoughts, and beliefs that differ from their own (Baron-Cohen, Leslie, & Frith, 1985; Premack & Woodruff, 1978). It is believed that children from about the age of four years on can discriminate their views from other persons' views and

hence have a “Theory of (other) Mind(s)”, (Wellman, Cross, & J., 2001). The results of Prencipe and Zelazo (2005) are also in line with the findings by the aforementioned studies on risk taking which did not find differences in decision making for self and a concrete other. Interestingly, when adults were tested in a different, hypothetical scenario, preferences for self and other differed: While for themselves participants were choosing impulsively to immediately sell an inherited business, for another person they more often chose to rent it out and hence, to receive less money immediately, but more money in the long run (Borresen, 1987). The contradictory results in these two studies could have different reasons. The age of the participants could play an important role, of course. Comparing adults and four-year-olds might be critical as only older participants might be able to infer what is generally better (i.e., waiting for the delayed, but larger reward), and choose accordingly for the other person. Moreover, there are two critical differences between the two studies: First, the “other person” was concrete for the children in Prencipe and Zelazo’s study (2005), while it was probably rather abstract in the study by Borresen (1987). (It is not explained, what exactly participants had been told about the “other person” in Borresen’s study.) Second, rewards were real in the study by Prencipe and Zelazo (2005), but hypothetical in Borresen’s study (1987). It remains to be clarified in future studies whether this fact could influence decision outcomes. What can be inferred is that when making intertemporal choices for another person, human adults act less impulsively compared to making such choices for themselves. Thus, delegating a decision to another person, instead of deciding oneself, can lead to less impulsive and in the end more rewarding choices. It can be concluded that amongst the factors influencing intertemporal choice listed in section 2.1.3, the person the choice is made for also plays an important role. The experiment that will be discussed in section 6 will investigate whether intertemporal choice behavior and hemodynamic activation during such choices differ according to the person the choices are made for: oneself or another person.

3.2.3 Being the other: Observing choices being made

Another interesting self-other related question is: What is going on in the mind of the person the choice is made for? Does observing choices being made influence the perception of the choice options? Merlo and Schotter (2003) investigated choice behavior after participants had either made choices themselves or observed other participants making choices. Choices were made between different numbers; choosing larger numbers led to a higher probability of winning a reward, but to lower rewards than smaller numbers. Hence, an optimal choice

strategy existed. Afterwards, all participants made a choice of the same kind they either just made for themselves (doers) or observed being made by the doer for herself (observers). In this concluding choice, former observers on average received higher outcomes than doers. For observers, being in a more abstract and distant situation while having observed choices being made might have led to a reinforcement of all possible choices, whereas for doers, only chosen actions might have been reinforced, preventing them from learning what outcomes non-chosen options might have yielded (Camerer & Ho, 1999; Merlo & Schotter, 2003). The experiment discussed in section 7 will investigate the brain activation of observers during intertemporal choice, in order to identify which brain regions are involved and whether these regions differ from the regions involved when making intertemporal choices oneself (as in the experiment discussed in section 6). The precise research questions asked in these experiments will be discussed in more detail in the following section.

4 Open questions, hypotheses and implementation of present fMRI studies

4.1 Open questions and hypotheses

Open questions arising from the research presented above are 1) Does intertemporal choice yield different (i.e., dynamically consistent) outcomes when choices are made for another person than when they are made for oneself?, and 2) Do brain correlates of intertemporal choice differ accordingly when choices are made for self and other?

Further, it can be asked what brain activation accompanies the observation of intertemporal choice: 3) Does immediacy play a special role also when observing intertemporal choices?, and 4) Do brain correlates of observing intertemporal choices being made differ between choices observed being made for oneself and for another person? These questions concern what is going on in the mind of a person choices are made for. Are these assumingly the same or different processes than the processes going on in a decision maker's mind?

Question 1 draws upon dual-processing models and models of the self explained earlier (in sections 2.1.2 and 3.1). If another person in general is considered similar to a future self (Parfit, 1984), then choices for another present and future person should be made in the same way as for a future self. In terms of dual-processing, the hot system should not be engaged when no immediate gratification is possible or when immediate gratification is possible for other persons only (Mischel, et al., 2003). According to studies on decision making for self and other reported in section 3.2, a concrete present other seems to be treated more similarly to the present self than to the future self (Hsee & Weber, 1997; Prencipe & Zelazo, 2005). Hence, aforementioned differences should be true for abstract other persons only, as here choices should be less based on own feelings (i.e., hot system processes) and more on what yields the objectively higher outcome.

Given that hot system processes are suggested to draw on activation in emotion- and reward-related brain areas such as the ventral striatum and pACC/MPFC (McClure, et al., 2007; McClure, et al., 2004), then, according to dual-processing theory, activation in these areas should be enhanced only when choices containing immediate rewards for oneself are made.

Hence, the answer to question 2 should be: When choices are made between two delayed rewards or for abstract other persons irrespective of delay, less activation is expected to be observed in these brain areas.

With respect to question 3, observing choices being made could lead to less emotional involvement, as the observer is more distant and not in control. Merlo and Schotter (2003) could show that after observing choices being made, observers were able to choose gambles that yielded more rewarding outcomes than active decision makers, indicating that observing choices puts one in a more abstract situation, making one able to choose more optimally. Thus, it is assumed that brain correlates of observing choices should reflect deliberative processes like working memory, while keeping in mind what the other has chosen in previous trials, as well as evaluation, calculation, and control processes. Hence, lateral prefrontal and lateral parietal brain areas could be found involved (Dehaene, et al., 2004; Derrfuss, et al., 2004). If immediacy plays a special role, activation in these areas should be higher when immediately available rewards compared to delayed rewards are involved, as immediacy should be considered special (like when actively choosing for oneself), but on a non-emotional level (unlike when actively choosing for oneself). On the other hand, it is also possible that immediacy might play no special role at all without hot system processes involved, and hence no activation differences between these two kinds of choices might be found.

Further assumptions (cp. question 4) can be made about differences depending on the beneficiary of the outcome: oneself or another person. The outcome in the study by Merlo and Schotter (2003) was not for the observer but received by the decision maker. Hence, it remains unclear whether the observer can take a view as distant as when she herself receives the chosen rewards. Thus, this question needs a rather explorative investigation, varying the receiver of the outcome as well as the temporal distance (delay).

4.2 Implementation – fMRI

To investigate the open questions listed above, we conducted two fMRI-experiments.

In the first experiment we used a modified version of the design by McClure and colleagues (2004), (Figure 2.3). Participants faced 80 choices, each between a smaller, sooner and a

larger, later reward. 32 of these choices contained an immediate reward and a delayed reward, whereas the remaining 48 choices contained two delayed rewards, with the sooner one either available after two or after four weeks. Trials in which participants chose between an immediate and a delayed reward are referred to as “today trials” in the following, and choices not containing an immediate reward will be referred to as “delay trials”. Participants made 40 choices for themselves, and 40 choices for another, unknown person. The independent within-subject variables hence were: 1) receiver type (SELF and OTHER) and 2) temporal distance (today trials and delay trials). This first experiment investigated the questions: 1) Does intertemporal choice yield different (i.e., dynamically consistent) outcomes when choices are made for another person than when they are made for oneself? and 2) Do brain correlates of intertemporal choice differ when choices are made for self and other?

In the second experiment, participants observed intertemporal choices being made by others. They viewed the same screen as in the first experiment, but now they were not allowed to choose themselves, but a choice was indicated to them as being made by another person. To realistically implement the choices made by the other person, we averaged responses from the first experiment, and hence determined which of the two alternatives was indicated as chosen. The same was true for the response times (2.6 to 3.4 seconds), i.e., presentation times of the two alternatives before the choice was indicated. Independent within subject variables were the same as in the first experiment: 1) receiver type (SELF and OTHER) and 2) temporal distance (today trials and delay trials). The second experiment aimed at investigating the following questions: 3) What brain activation accompanies the observation of intertemporal choice? and 4) Do brain correlates of observing intertemporal choices being made differ between choices observed being made for oneself and for another person?

5 Methods: Functional magnetic resonance imaging (fMRI)

Functional magnetic resonance imaging (fMRI) was used to investigate the above mentioned research questions (posed in section 4.1). This method makes it possible to non-invasively investigate the brain correlates of cognitive processes with a high spatial resolution. A more detailed introduction to fMRI can be found in the books by Huettel and colleagues (2004) or Jezzard and colleagues (2001).

5.1 Physical basics of fMRI

Spatial information can be acquired with MRI because protons of water molecules possess a spin about themselves, which means they rotate around their own axis. Furthermore, these protons also possess a charge which means that their spins generate electrical currents. When placed in a magnetic field, such a current induces a torque referred to as magnetic moment. If no strong external magnetic field is applied, spins cancel each other out, because they are oriented randomly. But magnetic moments of protons align with an external magnetic field if such a field is applied. Thereby, a higher proportion of the moments align in parallel with the field, as this is their more stable, low-energy state. The magnetic moments of these few more protons sum up to a net magnetization in direction of the external field. But the protons are not perfectly aligned with the field, since their axes of spin perform rotations themselves (i.e., they precess) with a certain frequency called Larmor frequency, which is directly proportional to the strength of the external field. If a so-called excitation pulse is applied with the same frequency, protons will absorb energy and turn into the direction of their high-energy state (i.e., the antiparallel direction). Spins can be turned by 90 degrees, so that they are perpendicular to the external field. Protons spin in phase with each other now, and hence their vectors can be summed up and measured. When the pulse is turned off, the protons begin to turn back to their low-energy state and dephase. The returning to the low-energy state is described by the relaxation parameter T1 (longitudinal relaxation), while T2 (transverse relaxation) describes the dephasing of the protons. Due to these processes, a signal from the returning and dephasing spins can be received. T1 depends on the magnetic field and the tissue in which the protons are situated. If a new excitation pulse is applied, spins will be turned again. The excitation of the spins depends on their relaxation: If more spins are aligned

in a longitudinal direction again, then more excitation is possible. Since more excitation leads to a higher measurable signal, the interval between two excitation pulses (also called repetition time, TR) is crucial. $T2^*$ is a parameter also important to fMRI, as it (in addition to dephasing) describes the effect of magnetic field inhomogeneities caused by physiological parameters to which I will come back in the next section. In order to localize the measured signal, gradients are superimposed on the external magnetic field. The external field varies spatially in a linear fashion and hence, superimposing gradients in three dimensions makes it possible to localize the signal. The spatial resolution of fMRI is about 2 to 3 mm.

5.2 Physiological basics of fMRI

The spin dephasing described in the previous section is the key to relate the obtained spatial information to functional information. The speed of dephasing depends on the properties of the environment. The environmental properties can be changed by the amount of oxygen carried by hemoglobin. Hemoglobin is diamagnetic (i.e., does not have a magnetic moment) when it carries oxygen, but paramagnetic (i.e., possesses a magnetic moment) when it does not. Spins dephase faster when oxygen is present, and less signal is emitted when protons are close to deoxyhemoglobin (i.e., hemoglobin not carrying oxygen). Oxyhemoglobin (i.e., hemoglobin carrying oxygen) can be found around active neurons, as those need energy which can be obtained from oxygen. Hence, when neurons become active, more oxygen will be delivered to them, whereby the amount of oxygen delivered to these neurons is higher than the amount of oxygen that is actually needed. Thus, more oxyhemoglobin is present around active neurons. With more oxyhemoglobin present, the measured fMRI signal increases during neural activity. $T2^*$ -weighted images are used here as they are most sensitive to environmental properties, i.e., to the amount of deoxyhemoglobin present. The measured variable is called the blood oxygenation level dependent (BOLD) response. A BOLD response usually peaks after 4 to 6 seconds after its beginning. Using BOLD contrasts, neural activation is measured only indirectly. However, a study with monkeys reported that synaptic activity is indeed reflected by the BOLD response (Logothetis, Pauls, Augath, Trinath, & Oeltermann, 2001).

5.3 Analysis of fMRI data

The goal of fMRI data analysis is to obtain statistical parametric maps (SPMs) depicting brain areas that respond to experimental manipulations, i.e., that are “activated”. In order to create these maps, several steps of preprocessing and statistical analyses are necessary.

5.3.1 Preprocessing

fMRI data can be considered to consist of volume elements (voxels). Within these voxels, sequences of two-dimensional images are taken every 2 to 4 seconds.

Several preprocessing steps are necessary to reach the final goal of obtaining SPMs. Apart from preparing the data for the analyses, a main goal of preprocessing is to remove uninteresting variability in order to increase the signal-to-noise ratio. Preprocessing includes motion correction, slice time correction, and baseline correction. Since slices are measured sequentially, a sinc-interpolation can be used to correct for the temporal offset between slice acquisitions. In the course of data acquisition, signal drifts may occur due to technical and physiological reasons. To correct such baseline drifts, temporal high pass filters are used. Further, spatial smoothing can be applied in order to reduce noise.

5.3.2 Spatial transformation

Structural data of each participant have to be rotated and scaled so that they can be geometrically aligned with a three-dimensional, subject specific structural reference scan in a stereotactic coordinate system (Talairach-system; Talairach & Tournoux, 1988). Rotational and translational parameters are acquired on the basis of the Modified Driven Equilibrium Fourier Transform slices (MDEFT; Norris, 2000; Ugurbil, et al., 1993) to achieve an optimal match between these slices and the individual reference data set. Further, a transformation of the two-dimensional functional data into three-dimensional space is necessary. Data is usually interpolated to receive output data with a resolution of 3mm x 3mm x 3mm per voxel. This normalization procedure can be performed linearly and non-linearly.

5.3.3 Statistical analysis

To determine which voxels are significantly activated by certain conditions, a least-squares estimation using a general linear model (GLM) can be performed (Friston, Holmes, Poline, et al., 1995; Friston, Holmes, Worsley, et al., 1995; Worsley & Friston, 1995). With this method, a linear combination of experimental conditions ($X\beta$) and the error term ε is assumed: $Y = X\beta + \varepsilon$. The parameters (β) are estimated using a least-squares estimations. The general linear regression performs a ‘precoloring’ of the data, i.e. it applies a temporal Gaussian smoothing with a user-specified kernel width given by the parameter FWHM. The smoothing imposes a temporal autocorrelation that determines the degrees of freedom.

Blocked, event-related, and mixed fMRI designs can be used. In a blocked design, trials of the same condition are presented in blocks usually lasting 40 to 60 s each. Many repetitions are possible in a block design, leading to high statistical power. A Gaussian function is used to model the different periods. Since predictability is high while randomization possibilities are low, event-related designs are often used instead. Here, hemodynamic responses to individual stimuli (events) are recorded and can be compared. Stimuli can be presented in a random, non-predictable order. In an event-related design, synthetic hemodynamic response functions are used and modeled for each stimulus depending on the experimental treatment (Friston, et al., 1998). In a mixed design, both types of functions are used, depending on the period to be modeled.

Contrast images, i.e., images of the raw-score differences between specified conditions are generated for each participant. Contrast images can then be entered into a second-level analysis, using t-statistics. Alternatively, a second-level analysis based on Bayesian statistics can be applied (Neumann & Lohmann, 2003). In this approach, posterior probability maps and maps of the effect size are calculated on the basis of the resulting least-squares estimates of parameters for the GLM. The output of the Bayesian second-level analysis is a probability map showing the probability for the contrast to be larger than zero. This approach has the advantage of being less sensitive to outliers than traditional t-statistics. Furthermore, since probabilities of the contrasts are calculated, but no significance tests are performed, corrections for multiple comparisons or calculations of effect sizes are not necessary.

Areas of interest can be subjected to a further post hoc analysis. It can be tested whether the activation strength in ‘regions of interest’ (ROIs) differs between hemispheres and/or

conditions (Bosch, 2000). For all voxels of a ROI, a contrast value (i.e., parameter from the GLM) is generated for each contrast and participant. These data are then submitted to statistical group analyses.

Conjunction analyses are another important method. Here, a logical AND is used to compare two group contrasts. With this method, it is possible to determine whether regions are commonly or differentially activated in two groups or tasks (Joseph, Partin, & Jones, 2002; Nichols, Brett, Andersson, Wager, & Poline, 2005). Regions activated above a certain threshold in both contrasts, in one contrast only, or in none of the contrasts can be identified.

6 Experiment 1

6.1 Introduction

It is believed that the subjective value of reward and thus the degree to which choice behavior is impulsive or self-controlled emerges from an interplay of competitive emotional and cognitive processes (Kalenscher, et al., 2006; McClure, et al., 2007; Metcalfe & Mischel, 1999). Consistently with this distinction, McClure, Botvinick, Yeung, Greene, and Cohen (2006) identified two different neural systems involved in intertemporal decision making: An 'impulsive' limbic one and a 'reasoning' prefrontal one (as discussed in section 2.2)

A question arising from these findings is, whether there are situations in which humans can reduce this limbic activation, and thus some emotional involvement, when making decisions. In our opinion, decision delegation is closely related to this issue, because here one relies on less personally involved agents to make more rational and thus better decisions for another person. Persons like lawyers and physicians are usually recruited because they have a certain expertise on their field, but apart from this, they are also supposed to be more objective because they are hardly emotionally and personally involved (Moran, et al., 2006).

Empirical evidence for differential effects in decision making for self and other revealed inconsistent evidence (cf. Beisswanger, et al., 2003; Stone, et al., 2002). Some studies suggest that there is no difference between decision making for self and other (Prencipe & Zelazo, 2005; Stone, et al., 2002), while others support the assumption that less personal involvement leads to more rational decision making and thus yields more appropriate outcomes, at least when making choices for an abstract other person (Borresen, 1987; Hsee & Weber, 1997). This leads to our hypothesis that people should decide more patiently by relying more on deliberative than on emotional processes when they are not affected by their decision's outcome themselves, but are choosing for another, abstract person. Applying an intertemporal choice paradigm, we thus hypothesize that in choices including an immediate reward, participants will choose less impulsively for other persons and hence more often the delayed over an immediate reward than for themselves. Thus, we expect them to decide more consistently when choices for others are made, i.e. that there will be no preference reversals.

Concerning the neural basis of intertemporal choices made for another person, we expect less limbic activation (McClure, et al., 2007; McClure, et al., 2004) when choices including an immediate option are made for other persons compared to choices made for oneself. It is hypothesized that this will be the case because of less personal involvement (Moran, et al., 2006) and thus no reward expectation (Knutson & Peterson, 2005) and emotional involvement (Grezes, Berthoz, & Passingham, 2006) when making decisions for other, abstract persons. A further hypothesis is, that accordingly there will be no neural activation differences for choices including an immediate option (i.e., today trials) and choices that do not include an immediate option (i.e., delay trials), when these are made for another person.

Based on the finding by McClure et al. (2004), that choices and amount of neural activation are linked, we further hypothesize that participants who choose more impulsively by discounting future rewards more strongly will show stronger activation differences in the critical brain regions between choices made for themselves and others. Applying the quasi-hyperbolic discount function (Laibson, 1997), we assume that participants with lower β values (i.e., participants who value immediate rewards highly) will show stronger differences in the neural activation accompanying choices made for themselves and others, and that these choices will thus behaviorally differ more than for participants who discount less. We believe this to be the case as due to a high engagement of the hot system, choices that these participants make for themselves should be highly impulsive. On the contrary, a choice made for another person should not be influenced by the hot system, as we suppose it only to be engaged when decisions are made for oneself. Further, there is evidence that in domains in which people are more emotionally involved, differences are stronger between decisions made for oneself and for another person (Beisswanger, et al., 2003).

6.2 Method

6.2.1 Participants

Twenty-eight right-handed, healthy volunteers (14 females) were recruited to participate in the study. The mean age was 24.6 years (range 18-30), with a standard deviation of 2.8 years. All participants gave informed consent before participating. The experimental standards were approved by the local ethics committee of the University of Leipzig. Data were handled anonymously.

6.2.2 Behavioral task and stimuli

Before starting the experiment, participants were instructed that the experiment consisted of two parts, and that the instructions for the (at this point not further explained) second part would be presented on the display in the fMRI-scanner only after the first part was completed. Then half of the participants were instructed that they were going to face a series of 40 intertemporal choices, each between two rewards, and that they were supposed to make these choices for themselves. They were told that in the end one of their choices would be randomly selected and actually paid to them at the corresponding time. The other half of the participants was initially instructed that they were going to face a series of intertemporal choices, each between two rewards, and that they were to make these choices for another person. They were told that this person was another participant they would never get to know, and that in the end one of their choices would be randomly selected and actually paid to this person at the corresponding time, whereas they themselves would receive a flat amount of € 5 for making decisions for the other person. Instructions were standardized by presenting them in written form.

After completing the first 40 choices, participants were instructed about the second part of the experiment inside the fMRI-scanner. Instructions differed from the first part (see above) insofar, as participants who had chosen rewards for themselves in the first part were now instructed to choose for another, unknown person. Participants choosing for another person in the first part were told that they would now choose for themselves. Payment conditions paralleled those of the first part: Participants who chose for themselves were told that one of their choices would be randomly selected at the end of the experiment and actually paid to them at the corresponding time, while participants who chose for another person were told that this other person would receive the chosen reward of a randomly selected trial while they themselves would receive a flat amount of €5.

All choices were presented on a screen with the smaller, sooner reward always shown on the left-hand side (see Figure 6.1). Participants were given as much time as they needed to respond. Responses were made by pressing one of two buttons, each spatially corresponding to one of the two stimulus locations on the screen. To confirm the chosen response, during a period of two seconds the yellow triangle underneath each of the reward/time pair changed its color to red for the chosen option and to black for the option not chosen in this trial. A

baseline period of twelve seconds followed, presenting a fixation cross in the center of the black screen. Then the next trial was presented.

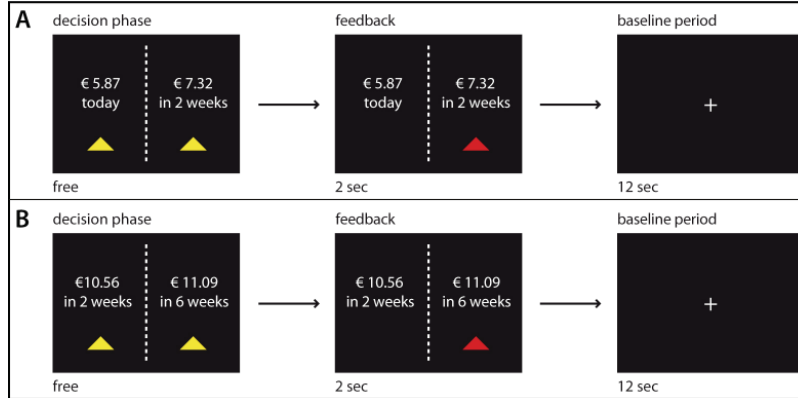


Figure 6.1: Design adapted from McClure et al. (2004), see Figure 1.3. Example of a presented choice in (A) a today trial and in (B) a delay trial are shown.

The presentation of the choices was pseudo-randomly arranged for every participant and part. Depending on the duration of the response time, each of the two tasks was supposed to be completed in 10 to 15 minutes.

The 40 sooner, smaller rewards (r_1) were randomly drawn from a Gaussian distribution (mean: €20, standard deviation: €10, minimum: €5, maximum: €40). The corresponding later, larger rewards (r_1') were calculated by adding a percentage (x) of either 1, 3, 5, 10, 15, 25, 35, or 50% to the sooner reward, i.e. $r_1' = (1+x)*r_1$. The assignments of percentages to the sooner rewards were implemented pseudo-randomly, so that every percentage rate was used five times. The sooner reward was available either 'today', 'in two weeks', or 'in four weeks'. These three options denote period t . The delay for receiving the later, but larger reward was either two weeks or four weeks, and this delay was added to period t at which the sooner reward was available. All combinations of sooner rewards and delays were used eight times each, except for the combination of 'in four weeks' and 'in eight weeks', which was eliminated completely. Each combination was then assigned to all available percentage rates and thus pseudo-randomly to the rewards connected to these rates. In the second part of the experiment, the whole procedure was repeated with another 40 sooner, smaller rewards (r_2) that were randomly drawn from the Gaussian distribution mentioned above. The assignment of the two sets of forty choices (r_1/r_1' or r_2/r_2') to either the first or the second part of the

experiment was balanced across all participants. (See Supplementary Tables S1 and S2 for the two sets of forty trials, reward sizes, and the availability of the rewards.)

At the end of the experiment one trial of each part was randomly selected and paid at the corresponding time. The reward chosen when deciding for themselves was delivered in cash to the participants on the particular day. The chosen reward of the choice made for another person was delivered in the same manner to another participant of the study, but only after this person had finished the experiment. Note that participants were not informed during the experiment about the opportunity of receiving money from choices made by other participants. Delayed rewards were delivered to the participants' homes, or any other place they chose. Apart from this, every participant was paid an additional amount of €5 for making decisions for another person, immediately after the experiment.

6.2.3 Imaging

Imaging was performed on a 3 Tesla scanner (Siemens TRIO, Erlangen, Germany). 22 axial slices (4mm thickness, 20% spacing, field of view (FOV) 19.2cm, data matrix of 64x64 voxels, and in-plane resolution of 3mm x 3mm) parallel to the bi-commissural plane (AC-PC), covering the whole brain, were acquired using a single-shot echo-planar imaging (EPI) sequence (TR 2s, echo time (TE) 30ms, flip angle 90°). Two functional runs with 450 time points each were run with each time point sampling over the 22 slices. Prior to functional runs, 22 anatomical T1-weighted modified driven equilibrium Fourier transform images (data matrix 256x256, TR 1.3s, TE 10ms; MDEFT; Norris, 2000; Ugurbil, et al., 1993) were acquired as well as 22 T1-weighted EPI images with the same spatial orientation as the functional data. The latter were used to co-register the functional scans with previously acquired high-resolution full-brain 3D brain scans.

6.2.4 Data analyses

The MRI data were processed using the software package LIPSIA (Lohmann, et al., 2001). Functional data were motion-corrected offline with the Siemens motion correction protocol (Siemens, Erlangen, Germany). To correct for the temporal offset between the slices acquired in one scan, a cubic-spline-interpolation was applied. A temporal highpass filter with a cut-off frequency of 1/120 Hz was used for baseline correction of the signal and a spatial Gaussian

filter with 5.65mm full width half-maximum (FWHM) was applied. The anatomical slices were co-registered with the high-resolution full-brain scan that resided in the stereotactic coordinate system and then transformed by linear scaling to a standard size (Talairach & Tournoux, 1988). The transformation parameters obtained from this step were subsequently applied to the preprocessed functional slices so that the functional slices were also registered into the stereotactic space. This linear normalization process was improved by a subsequent processing step that performed an additional nonlinear normalization known as ‘demon matching’. In this type of non-linear normalization, an anatomical 3D data set, i.e. the model, is deformed such that it matches another 3D anatomical data set, i.e. the source, that serves as a fixed reference image (Thirion, 1998). This 3D reference data set was acquired for each participant during a previous scanning session. The MDEFT volume data set with 160 slices and 1mm slice thickness was standardized to the Talairach stereotactic space (Talairach & Tournoux, 1988). The voxel size was interpolated during the co-registration from 3mm x 3mm x 4mm to 3mm x 3mm x 3mm. The statistical evaluation was based on a least-squares estimation using the general linear model (GLM) for serially autocorrelated observations (random effects model; Friston, Holmes, Poline, et al., 1995; Friston, Holmes, Worsley, et al., 1995; Worsley & Friston, 1995). The general linear regression performs a ‘precoloring’ of the data, i.e. it applies a temporal Gaussian smoothing with a user-specified kernel width given by the parameter FWHM. The smoothing imposes a temporal autocorrelation that determines the degrees of freedom.

The design matrix included the following conditions: Today trials (T), delay trials (D), response confirmation/feedback (FB), and baseline period (NULL). The duration of T and D depended on participants’ response times, particularly the time between the appearance of the stimulus and the participant’s choice. FB was presented for 2 seconds and NULL for 12 seconds. Conditions were modeled separately for SELF and OTHER, and then concatenated.

A mixed design was used: The baseline periods were modeled as a block of 12 seconds, using a Gaussian function, whereas for all other conditions a synthetic hemodynamic response function was utilized (Friston, et al., 1998). The model equation including the observation data, the design matrix, and the error term, was convolved with a Gaussian kernel of dispersion of 4 seconds FWHM to deal with the temporal autocorrelation (Worsley & Friston, 1995).

Contrast images, i.e., estimates of the raw-score differences between specified conditions were generated for each participant. The single subject contrast images were entered into a second-level analysis on the basis of Bayesian statistics (Neumann & Lohmann, 2003; see also section 2.3.3 for advantages of this approach). For visualization, a threshold of 99 % was applied to the resulting probability maps, which means that any activation (difference) above this threshold occurred with a probability of more than 99%.

Areas of interest that were found to be activated above the threshold were subjected to a further post hoc analysis. More specifically, we tested whether the activation strength in ‘regions of interest’ (ROIs) differed between hemispheres and/or conditions (Bosch, 2000). For all voxels of a ROI, a contrast value (i.e. parameter from the GLM) was generated for each contrast and participant.

6.3 Results

Behavioral results revealed no order effect, both as measured by response time ($F(1, 26)=0.219$, $p=.644$) and choice for the sooner over the later reward ($F(1, 26)=0.007$, $p=.932$). Likewise, imaging results did not reveal any order effects, i.e., group comparisons yielded no neural activation differences of today and delay trials between the two parts of the experiment. Accordingly, order is not further considered in the analyses of the behavioral and imaging data.

6.3.1 Behavioral results

A median split of the sample by the extend to which participants discounted future rewards when choosing for themselves was performed (using the choices from the SELF-condition). Specifically, a maximum likelihood logit estimator was used to estimate the value β of the quasi-hyperbolic discount function (Laibson, 1997). We then split the sample into two groups, separating the strong discounters (with β s below the median) from the moderate discounters (with β s above the median; see Supplementary Table S3 in the Supplementary Material).

To test the behavioral hypotheses, a repeated-measurement analysis of variance (ANOVA) for *choice* (percentage of times the sooner, but smaller option was chosen), including the two-level inner-subject variables *receiver* (SELF vs. OTHER) and *temporal distance* (today vs.

delay trials) as well as the between-subject variable *type* (moderate vs. strong discounters) was carried out. The analysis yielded a main effect of *temporal distance*, with the sooner option chosen significantly more often in today than in delay trials ($F(1, 26)=34.93, p<.001$; Figure 6.2A). Beyond, the comparison revealed a main effect of the between-subject variable *type* ($F(1, 26)=9.12, p=.005$), in that strong discounters chose the sooner option more often than moderate discounters. This finding supports our division of participants into strong and moderate discounters. We did not find a main effect of *receiver* ($F(1, 27)=0.481, p=.494$), but a significant interaction of *type* and *receiver* ($F(1, 26)=5.61, p=.026$). Paired-sample t-tests revealed that only participants who strongly discounted future rewards chose the sooner option for themselves more often than for the other person ($t(13)=-2.34, p=.036$, Figure 6.2B). A further analysis showed that this difference was significant, though, only for today trials: In line with our hypothesis, strongly discounting participants became more patient in the OTHER-condition by choosing more frequently the larger, but later reward in today trials ($t(13)=3.18, p=.007$). There were no such choice differences between SELF and OTHER in delay trials ($t(13)=1.45, p=.170$, Figure 6.2C).

Using the same independent variables as above, a repeated-measurement ANOVA of *response time* confirmed a main effect of *temporal distance*, with participants choosing faster when an immediate reward was available ($F(1, 26)=12.33, p=.002$; Figure 6.2D).

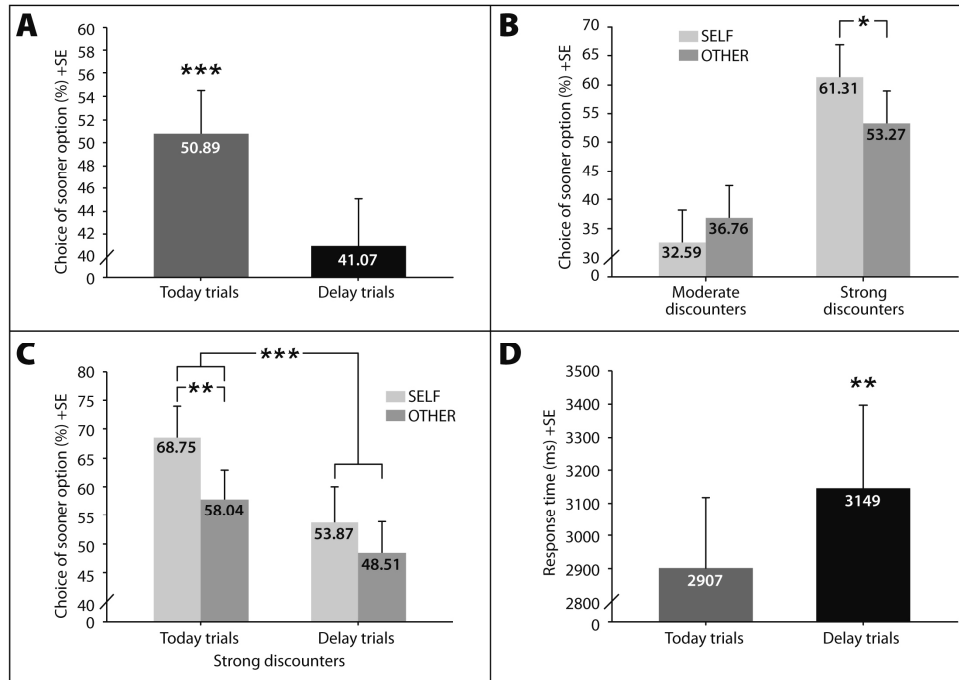


Figure 6.2: (A) Choice of sooner option significantly differs for today and delay trials ($F(1,27)=33.62$, $p<.001$). (B) Strong discounters significantly more often chose the sooner reward for SELF than for OTHER ($t(13)=-2.34$, $p=.036$). (C) Strong discounters chose the sooner reward in SELF significantly more often than in OTHER only in today trials. ($t(13)=3.18$, $p=.007$). (D) Response time is significantly shorter in today trials ($F(1,27)=9.12$, $p=.005$). (* $p<.05$, ** $p<.01$, *** $p<.001$; error bars represent standard errors (SE))

Taken together, we observed an immediacy effect in both, SELF and OTHER and could hence find no differences between choices made for SELF and OTHER. But in accordance with our hypotheses, we observed an influence of impulsivity on decision making for SELF and OTHER: Highly impulsive participants chose the immediate reward less often for the other person than for themselves.

6.3.2 Imaging results

Single subject contrast images generated for each participant were entered into a second-level analysis on the basis of Bayesian statistics (Neumann & Lohmann, 2003). For visualization, a threshold of 99 % was applied to the probability maps.

The hemodynamic response elicited by all trials that include an immediate option (today trials) in contrast to all trials without an immediate option (delay trials) was investigated for choices made in SELF and OTHER.

6.3.2.1 Today trials > delay trials in SELF and OTHER

In SELF, we found higher hemodynamic activity for choices including an immediate reward bilaterally within the pregenual anterior cingulate cortex and ventral striatum, in the right anterior medial prefrontal cortex (aMPFC, BA 32), and in the left anterior and posterior precuneus (see Figure 6.3A and Supplementary Table S4).

In OTHER, no such immediacy effect was observed in any of these areas (see Figure 6.3B and Supplementary Table S4).

6.3.2.2 Interaction effect of temporal distance and receiver

To analyze the interaction of differences between today and delay trials with the differences between SELF and OTHER, we calculated an interaction contrast of *temporal distance* (today trials vs. delay trials) and *receiver* (SELF vs. OTHER). The contrast revealed activation differences in the vicinity of the above reported pACC activation and aMPFC activation bilaterally, and in the left ventral striatum (see Figure 6.3C and Supplementary Table S4).

To further test whether today trials for SELF are indeed special and show higher activations than in any other condition, the above reported activated areas were subjected to a further post hoc analysis. Figure 6.3D shows the mean parameter estimates (i.e., parameters from the GLM) for the different conditions, indicating that the most elevated activation occurred during choices for SELF in today trials.

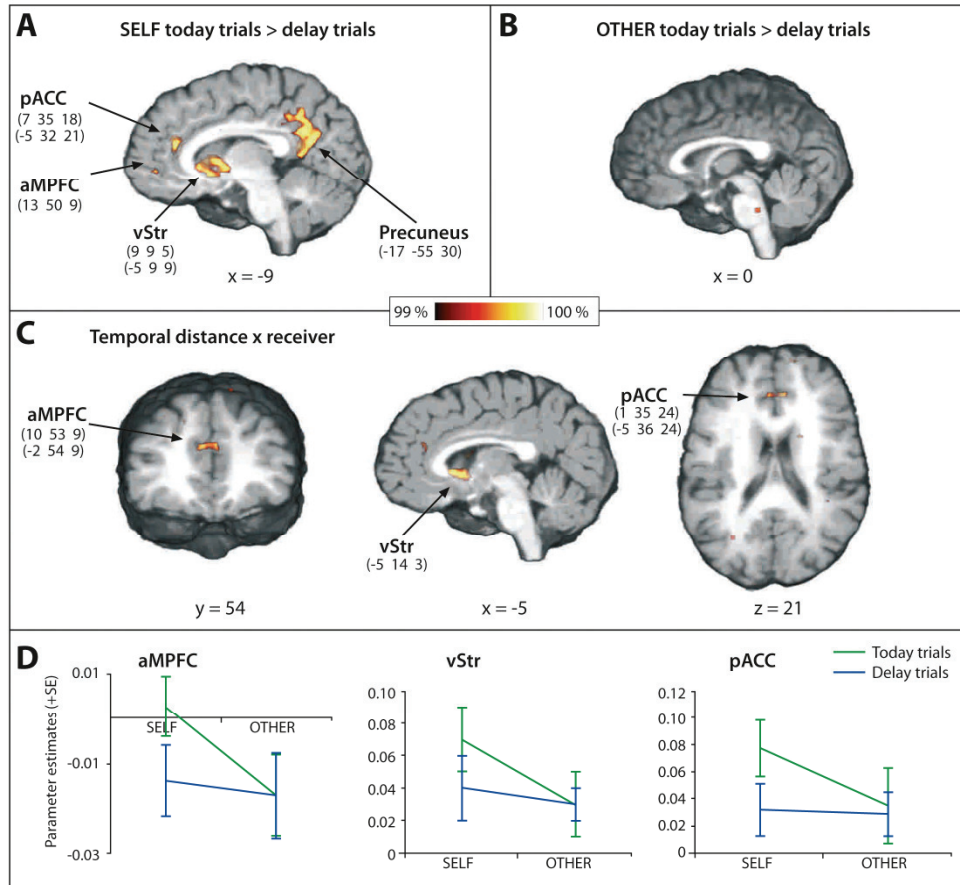


Figure 6.3: (A) Brain regions that were activated by choices containing an immediate option compared to choices with only delayed options in SELF. (B) There were no such activation differences between today and delay trials in OTHER. (C) An interaction contrast of temporal distance (today vs. delay trials) and receiver (SELF vs. OTHER) showed activation differences within the anterior medial prefrontal cortex (aMPFC), ventral striatum (vStr) and pregenual anterior cingulate cortex (pACC). (For visualization, a threshold of 99% was applied to the probability maps.) (D) Parameter estimates indicate that these activation differences were mainly due to elevated activation in today trials in SELF, whereas in all other conditions activation in these brain areas was similarly low.

6.3.2.3 Effects of “discounter type” on today trials > delay trials in SELF and OTHER

To identify hemodynamic activation differences depending on how patiently or impatiently participants were choosing in SELF, we contrasted today trials with delay trials, this time for participants with high and low discount values separately.

For participants who strongly discounted future rewards, we found higher hemodynamic activation for today trials compared to delay trials in SELF in the pACC and aMPFC bilaterally, in the left ventral striatum, and in the anterior and posterior precuneus bilaterally. In contrast, for more patient participants, who discounted future rewards only moderately, elevated activity within the network was not observed (see Supplementary Table S4).

In OTHER, highly discounting participants showed no elevated activation in the areas that were activated in SELF, except for an activation in the right MPFC. Likewise, for moderately discounting participants, no significant activation differences were observed (see Supplementary Table S4).

6.3.2.4 Effects of “discounter type” on the interaction of temporal distance and receiver

An interaction contrast of *temporal distance* and *receiver* for participants who strongly discounted future rewards yielded the following activation areas: pACC and aMPFC bilaterally, left ventral striatum, and anterior precuneus bilaterally. This effect occurred when choices for SELF were made in today trials (see Figure 6.4A and Supplementary Table S4).

In contrast, the interaction contrast of *temporal distance* and *receiver* for moderately discounting participants yielded no such neural activation differences (see Figure 6.4B and Supplementary Table S4).

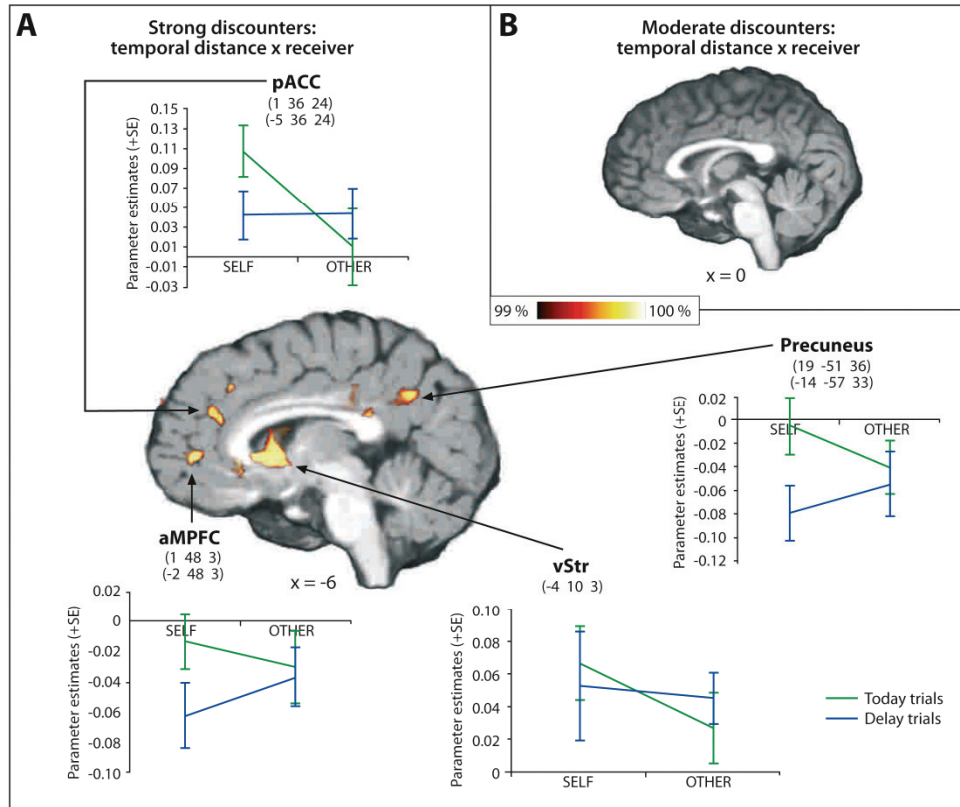


Figure 6.4: *Parameter estimates and brain regions with activation differences in the interaction contrast (temporal distance x receiver) (A) for strong and (B) moderate discounters. (For visualization, a threshold of 99% was applied to the probability maps.) Abbreviations: pACC: pregenual anterior cingulate cortex, aMPFC: anterior medial prefrontal cortex, vStr: ventral striatum.*

Together, according to our hypotheses we observed activation within a medial-prefrontal-medial-parietal network including the ventral striatum for the effects of immediacy when choices were made for oneself, but not when choices were made for another person. These activation differences were larger in strongly discounting participants, suggesting a correspondence of the observed activation and intertemporal choice behavior.

Contrary to our hypotheses, inconsistent choices were not only made in SELF, but also when participants chose for another person. This reveals a match of behavioral and hemodynamic

responses in SELF, but not in OTHER, and will be discussed in the general discussion (section 8).

7 Experiment 2

7.1 Introduction

In this study the interplay between hot and cool system processes was examined when participants did not make intertemporal decisions themselves, but only observed intertemporal decisions that were made by another person. This intertemporal choices' outcome was either for the observer herself – thus affecting the observer's payoff – or for yet another, different and unknown person. We were particularly interested in whether observing intertemporal choices activates the same brain areas that were activated when making intertemporal choices oneself. An affirmative answer to this question would indicate that the interplay of different cognitive systems in intertemporal choice would be a robust phenomenon that is insensitive to who is actually taking decisions. Furthermore, it was investigated whether the different activations that have been found between situations when participants make intertemporal choices for themselves and situations when the beneficiary is another person, do also prevail when observing intertemporal choices being made for oneself or another person. An affirmative answer to this question would imply that brain activity differentiates with respect to who is the beneficiary of intertemporal choice.

Recalling the open questions: “Does immediacy play a special role also when observing intertemporal choices?”, and “Do brain correlates of observing intertemporal choices being made differ between choices observed being made for oneself or for another person?” posed in section 4.1, we phrase the following hypotheses and expectations: We hypothesize that participants deliberately evaluate the possibility of immediate gratification in today trials (see also Merlo & Schotter, 2003). Hence, we expect quantity processing, interference control, and memory retrieval processes to play a role. Target regions are the lateral prefrontal and lateral parietal cortices, since these areas have previously been found to be engaged in the above mentioned processes (Coull, et al., 1998; Derrfuss, et al., 2004; Henson, et al., 1999; Ishai, et al., 2002). Hence, so-called cool system processes should play an important role here, when immediate gratification is possible. Further, at least when choices observed being made for another person, activation in the pACC and ventral striatum should not be enhanced when facing an immediate reward, as the observer is not “in charge”, the time of receiving a reward cannot be predicted for sure, and the reward is not received by the participant herself (Knutson, et al., 2001). An important question is, whether the same would be true for choices

observed being made for oneself. If so, with respect to the observer's brain activity when observing choices made for herself versus for another person, we would expect no significant difference. Empirical findings suggesting this being the case investigated correspondences between striatal activation and saliency (Tricomi, et al., 2004; Zink, Pagnoni, Martin-Skurski, Chappelow, & Berns, 2004). Both studies found higher activation when reward reception was salient, i.e., determined by a button press and not received passively by only observing a symbol indicating reward delivery.

In the present study, participants observed another person's (hereafter called the "decision maker") intertemporal decisions while their hemodynamic activity was measured. Participants inside the scanner viewed choice pairs consisting of a smaller, but sooner reward, and a larger, but later reward. After a few seconds they were shown the decision maker's choice for one of the two reward options. In one condition the recipient of the decision maker's choice was the observer herself ("SELF"), in another condition the recipient was yet another person ("OTHER"). While in SELF the possible rewards accrued to the observer, there was no option for the observer to influence the decision maker's choice (and hence the outcome).

7.2 Method

7.2.1 Participants

Thirty right-handed, healthy volunteers (15 females) were recruited to participate in the study (mean age 25.1 years; SD: 2.9; range 20 - 31). All participants gave informed consent before participating. The experimental standards were approved by the local ethics committee of the University of Leipzig. Data were handled anonymously.

7.2.2 Behavioral task and stimuli

Before the experiment, participants were instructed that the experimental session consisted of two parts, and that the instructions for the - at this point not yet explained - second part would be presented on the display in the fMRI-scanner after the first part was completed.

Participants observed intertemporal choices that were made by another, unknown person, i.e., by the so-called decision maker. In part one of the experiment, half of our participants were

exposed to SELF in which the decision maker made choices for the observing participant. The other half of participants faced OTHER in part one of the experiment, meaning that they observed choices that were made for yet another, unknown person, i.e., neither for the observer nor for the decision maker. In this condition, before the first choice was presented, 15 photographs of human faces were shown to the participants for a couple of seconds (Jäger, Seiler, & Mecklinger, 2005). Participants were told that the choices they would observe being made were for one of these (randomly selected) persons. Attractiveness of the presented faces was rated as average beforehand by a different sample, in order to ensure that confounds due to attractiveness were excluded. These photographs were presented to make sure participants knew the other person the choices were made for was not identical with the person making the choices, but another, unknown person. In part two of the experiment, conditions were reversed. Hence, those participants starting with SELF then faced OTHER, and vice versa.

In each part of the experiment, each participant observed forty choices between a smaller, but sooner, and a larger, but later reward. In order to keep the participant's attention and to control for attention differences between SELF and OTHER, we randomly inserted a total of ten catch trials in the series of choices in each part of the experiment (with the restriction that there would never be two or more catch trials in a row). In the catch trials participants were asked to make an intertemporal choice themselves. In the ten catch trials (that are listed in Supplementary Tables 5 and 6) participants were allowed ten seconds to respond, and after they had indicated their choice by pressing one of two buttons spatially corresponding to the two stimulus locations, the yellow triangles immediately changed their colors to confirm the response. After the following presentation of the fixation cross on the black screen, the next experimental trial followed.

All intertemporal choices were presented on a screen with the smaller, sooner reward always presented on the left side (Figure 7.1). The duration of the presentation of a choice option matched the average response time participants of Experiment 1 needed to make their choices. These response times varied between 2.6 and 3.4 seconds.

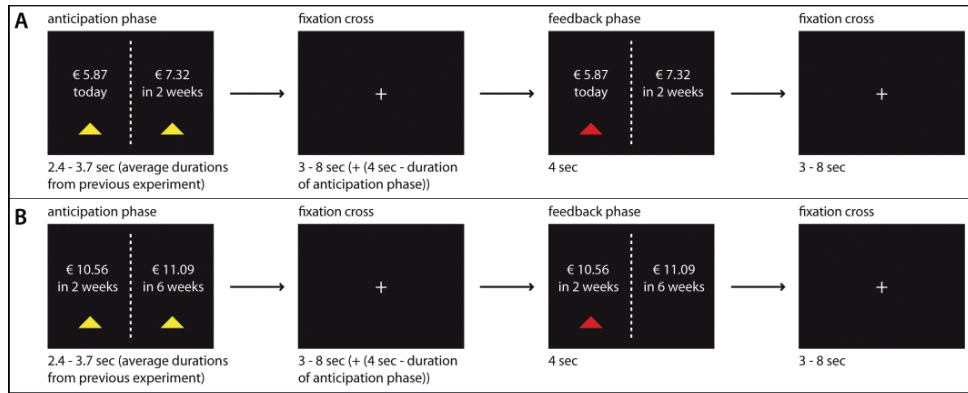


Figure 7.1: Design adapted from McClure et al. (2004), see Figure 1.3. Example of a presented choice in (A) a today trial and in (B) a delay trial are shown.

After the presentation of the choice options, a fixation cross in the centre of the black screen was presented, jittered from 3 to 9 seconds. Then the previously shown choice options were presented again, but now the chosen option was highlighted by displaying a red triangle beneath it (feedback phase). After 4 seconds, the screen went black again, with a fixation cross in its centre. As before, the duration of the presentation of the cross was jittered. Then the next choice was presented. The feedback phase was modelled in the GLM. But for reasons of keeping participants' impression of influence they had on a choice low, it was not determined during the experiment whether participants were satisfied with the choices made. Hence, information from this phase cannot be clearly interpreted, and was not considered furthermore.

Like in Experiment 1, two reward sets of 40 reward pairs each were used. Reward sizes, delay times, and matching methods of sizes and delays, were the same as in Experiment 1, and will not be explained in detail here (see section 6.2.2 for design details).

All observers faced identical actual choices in a particular experimental trial. These choices were averages of choices that had been made by participants of Experiment 1 that included identical choice options. For an overview of all rewards and delays to payment and the actual choice communicated to observers see Supplementary Tables 5 and 6.

Overall, each part of the experiment took about 15 minutes. At the end of the experiment one experimental trial of each part was selected randomly and paid out at the corresponding time. The reward chosen in the SELF-condition was delivered in cash to the observer on the date indicated in the chosen option. Immediate rewards were paid directly after the experiment, delayed rewards were delivered to the observer's home, or any other, more convenient place determined by the observer. In addition to the earnings from the SELF-condition, every participant was paid an additional amount of € 8 for taking part in the experiment. Note that catch trials were not paid because we wanted to avoid participants having an influence on their monetary outcome since we were interested in observation.

After the experiment was completed, a questionnaire was filled in by all participants, stating how satisfied they were with the choices made.

7.2.3 Imaging

Imaging was performed on a 3 Tesla scanner (Siemens TRIO, Erlangen, Germany). 26 axial slices (4mm thickness, 20% spacing, field of view (FOV) 19.2cm, data matrix of 64x64 voxels, and in-plane resolution of 3mm x 3mm) parallel to the bi-commissural plane (AC-PC) covering the whole brain were acquired using a single-shot echo-planar imaging (EPI) sequence (TR 2s, echo time (TE) 30ms, flip angle 90°). Two functional runs with 465 time points each were run with each time point sampling over the 26 slices. Prior to functional runs, 26 anatomical T1-weighted modified driven equilibrium Fourier transform (MDEFT; Norris, 2000; Ugurbil, et al., 1993) images (data matrix 256x256, TR 1.3s, TE 10ms) were acquired as well as 26 T1-weighted EPI images with the same spatial orientation as the functional data. The latter were used to co-register the functional scans with previously acquired high-resolution full-brain 3D brain scans.

7.2.4 Data analyses

The MRI data were processed as described in the Method section of Experiment 1 (section 6.2.4)

The design matrix of the present study included the following conditions: today trials (T), delay trials (D), feedback in today trials (FBT), feedback in delay trials (FBD), baseline

periods before and after T and D (NULL) and catch trials including response feedback (C). The duration of T and D varied from 2.6 to 3.4 seconds. The duration of FBT/FBD was always 4 seconds, while the duration of NULL varied from 3.6 to 9.4 seconds (providing even jittering). The duration of C is the sum of a self-paced decision (maximum: 10 seconds) and a feedback being presented for 2 seconds. Conditions were modeled separately for SELF and OTHER, and then concatenated.

An event-related design was used. The design matrix was generated with a synthetic hemodynamic response function (Friston et al., 1998; Josephs, Turner, & Friston, 1997). The model equation including the observation data, the design matrix, and the error term, was convolved with a Gaussian kernel of dispersion of 4 seconds FWHM to deal with the temporal autocorrelation (Worsley & Friston, 1995).

Contrast image generation and regions of interest analyses were carried out as described in the Method section of Experiment 1 (section 6.2.4). For details on the processes see also section 2.3.3, in which a general description of fMRI data analyses is given.

7.3 Results

To investigate whether there were different levels of attention when observing choices made for oneself compared to observing choices made for another person, we used a paired-sample t-test to test for differences between mean response times in catch trials intermixed in SELF and OTHER. We did not find a significant difference, which suggests equally sustained vigilance in both conditions ($t(29)=-0.932$, $p=.359$).

7.3.1 Today trials > delay trials in SELF and OTHER and interaction effects

To test for the specific brain correlates of choice options containing an immediate reward (today trials), we contrasted the hemodynamic response elicited by these trials with trials containing delayed options only (delay trials). We calculated separate contrasts for the two receiver types (SELF and OTHER), as well as an interaction contrast of temporal distance (today vs. delay trials) and receiver type (SELF vs. OTHER).

The main contrast of today and delay trials in SELF yielded higher activation for today trials within the ventral posterior cingulate cortex, posterior superior parietal lobule (pSPL) including intraparietal sulcus, and inferior frontal junction, (Figure 7.2A, cp. Supplementary Table 7). The contrast for OTHER similarly yielded higher activations for today trials in the vPCC, pSPL/IPS, and IFJ (Figure 7.2B, cp. Supplementary Table 7).

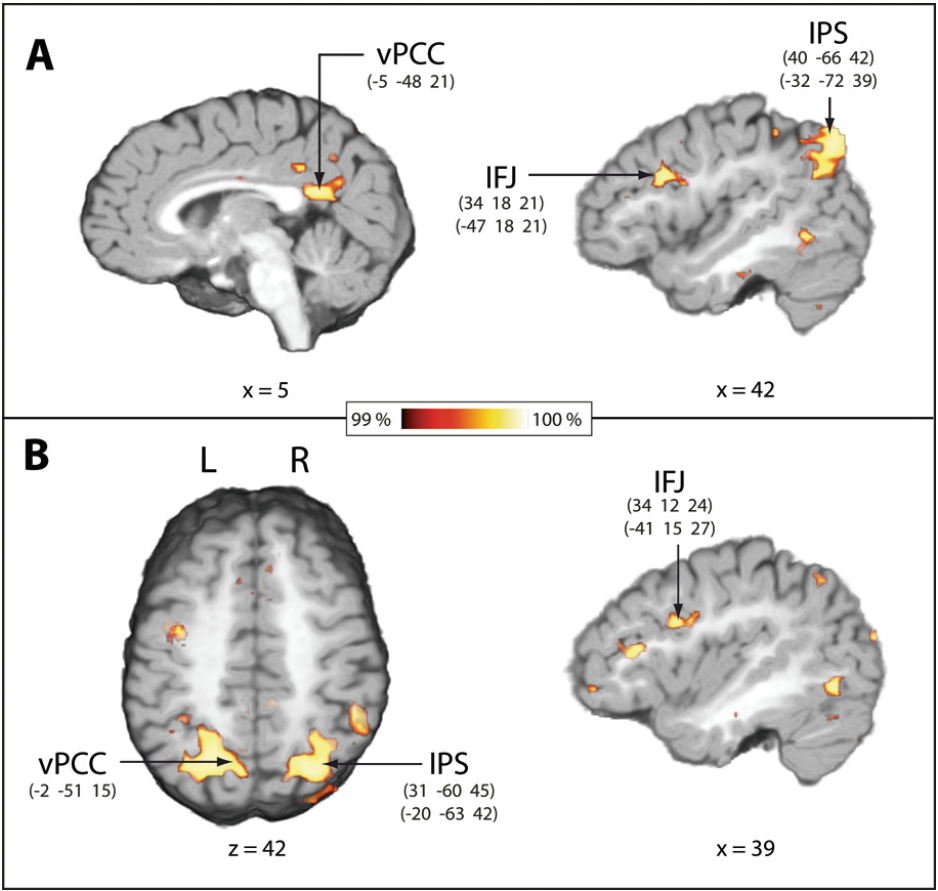


Figure 7.2: Contrasts of today and delay trials yielded similar activation differences in (A) SELF and (B) OTHER. Abbreviations: vPCC: ventral posterior cingulate cortex, IFJ: inferior frontal junction, IPS: intraparietal sulcus.

An interaction contrast of receiver type and temporal distance did not yield differences in any regions of interest we investigated in the main contrasts. Hence, in line with our expectations we could not identify any differences in activation for today and delay trials between SELF and OTHER.

7.3.2 Comparison with results of experiment 1

To investigate differences between active and passive decision making, we compared our results of participants only observing intertemporal choices with results from Experiment 1 in which participants had to make the choices themselves. In Experiment 1, we used the same design, with two exceptions: 1) In the anticipation phase, participants had as much time as they needed to respond. 2) Right after the decision phase, the feedback phase followed, presenting (for 2 seconds) what the participant had chosen. Then a fixation cross was presented for 12 seconds, until the next decision phase started. Preprocessing and statistic processes were administered as described for the present study. A conjunction analysis of our main contrast of today with delay trials in this study's SELF-condition with the same contrast of our previous experiment (where participants in the SELF-condition made decisions for themselves rather than observed choices being made for them) yielded an overlap of activation within parietal structures. It further showed that only in Experiment 1 an activation difference between today and delay trials in the pACC and ventral striatum could be found, whereas in our present study an activation difference in the IPS and IFJ could be found (Figure 7.3, cp. Supplementary Table 7). As null results have to be interpreted with care, we used the regions of interest from experiment 1 (i.e., pACC and ventral striatum) to calculate parameter estimates of activation in these areas in our present study. We then administered a repeated measurement ANOVA to further test potential activation differences between today and delay trials in these areas. As expected, the main effect of temporal distance (i.e., today vs. delay trials) was not significant ($p = .258$). Paired-sampled t-tests for the two areas separately also yielded p-values larger than .100 (ventral striatum: $p = .908$; pACC: $p = .103$).

A conjunction analysis of our interaction contrast with the same contrast of our previous experiment yielded no overlapping activation in our ROIs, but showed that activation differences between today and delay trials in SELF, but not in OTHER, were only observed when choices were actively made. As for the main contrast for SELF, activation differences within the pACC and ventral striatum could only be found in experiment 1.

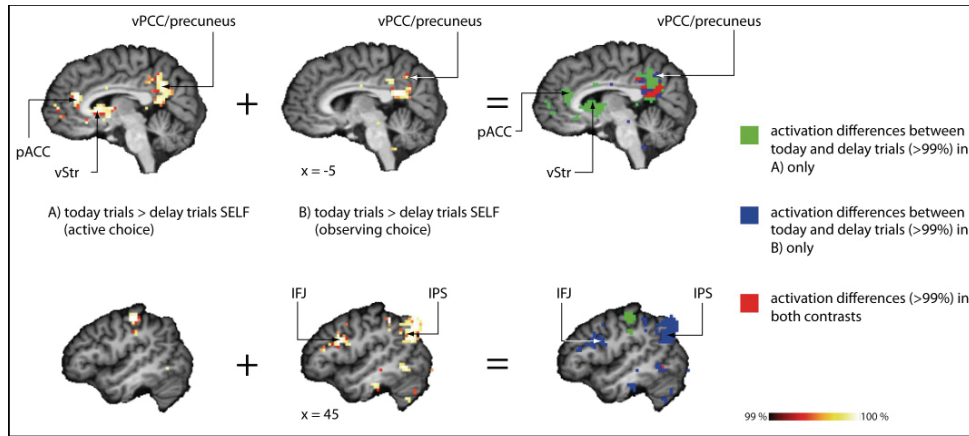


Figure 7.3: A conjunction analysis of the contrast comparing today and delay trials in *SELF* from experiment 1 and the present study yielded a partial overlap in the precuneus/vPCC only. Abbreviations: vPCC: ventral posterior cingulate cortex, IFJ: inferior frontal junction, IPS: intraparietal sulcus, pACC: pregenual anterior cingulate cortex, vStr: ventral striatum.

Taken together, our results support the hypotheses of stronger activation in lateral prefrontal and parietal areas for today compared to delay trials when participants only observe intertemporal choices. Furthermore, activation differences in the pACC and ventral striatum were neither found in *SELF* nor in *OTHER*, indicating no differential involvement of these areas in today and delay trials when choices were observed.

8 General Discussion

8.1 Making intertemporal choices for self and other (experiment 1)

8.1.1 Intertemporal choice for SELF

When intertemporal choices were made by oneself, the immediacy effect for SELF revealed activation in a medial-prefrontal-medial-parietal network including the ventral striatum. We thereby replicated the results by McClure and colleagues (2004). Specifically, the ventral striatum, pregenual anterior cingulate cortex, and anterior medial prefrontal cortex were found to be especially activated for choices in today trials made for oneself compared to all choices made for another person and compared to choices made in delay trials for oneself. These findings suggest that choices for SELF differentially activate an affective brain network, which is implicated in choices associated with the possibility of immediate gratification of one's *own* needs.

With respect to the involvement of the ventral striatum in emotion-driven processes such as opting for immediate rewards, note that the ventral striatum has been found to have strong reciprocal connections to neurons in the midbrain dopamine system (Breiter, et al., 2001; Schultz, et al., 1997). The midbrain dopamine system is thought to play a role in reward-dependent learning (Schultz, et al., 1997). Furthermore, findings of imaging studies suggest that the ventral striatum is also activated by reward anticipation (Knutson, et al., 2001) and that this activation is higher for more immediate rewards compared to more delayed ones (Hariri, et al., 2006; McClure, et al., 2004).

Like the ventral striatum, the ACC receives rich dopaminergic innervations, which indicates that it may be involved in reward-related processes (Gaspar, et al., 1989; Schultz, 1998). The elevated activity associated with the interaction of SELF and today trials was located in the pregenual ACC, which is an area in the ventral part of the ACC, anterior to the genu of the corpus callosum. This part of the ACC has been found to be engaged in decisions involving

gambles containing large gains (Rogers, et al., 2004) and has also been associated with happy emotions (Vogt, 2005).

We also observe heightened aMPFC activation for today trials in the SELF condition. The MPFC is active in self-related judgments (Craig, et al., 1999; Kelley, et al., 2002; Ochsner, et al., 2004), thought, and attention (Gusnard & Raichle, 2001). It has also been found to be involved in the processing of externally and internally cued emotions (Gusnard & Raichle, 2001; R. Lane, Reiman, Ahern, Schwartz, & Davidson, 1997; R. Lane, et al., 1998). It has been suggested therefore that the MPFC might be engaged in identifying and evaluating positive emotions (Drevets & Raichle, 1998). In the present study, this region showed more activation when participants chose a reward for themselves instead of for another person. The MPFC's higher engagement also in today trials shows that participants were more self-focused when there was an immediate option, and possibly more engaged with their own happy emotions towards immediate rewards, perhaps evaluating how good exactly such immediate gratification would feel.

All the above described areas were found to be involved in intertemporal choice when immediate gratification was possible (Hariri, et al., 2006; Kable & Glimcher, 2007; McClure, et al., 2007; McClure, et al., 2004). This suggests a location of hot system processes in these areas, with higher activation speaking for a higher probability that the immediate option will be chosen (Hariri, et al., 2006; Kable & Glimcher, 2007; McClure, et al., 2007; McClure, et al., 2004).

8.1.2 Intertemporal choice for OTHER

In accordance with our hypotheses concerning the effects of immediacy in OTHER, we did not observe any activation differences between today and delay trials when participants chose for another, unknown person. Likewise, there were no neural activation differences when comparing delay trials between choices made for oneself and choices made for another person. Together, these results suggest that the processes underlying choices made in today trials for OTHER are different from those in today trials in SELF. Particularly, we assume that choices in today trials may not be based on the same emotions and reward expectations that were engaged by today trials in SELF.

8.1.3 Strong and moderate discounters

Participants who strongly discounted future rewards chose the immediate option more often in SELF than in OTHER. This finding supports the hypothesis from Beisswanger et al. (2003), who assumed that behavioral differences in decision making for self and other are greater when the emotional involvement of the participants is higher. Hence, while strong discounters seemed to act more impatiently when choosing immediate rewards for themselves, they acted more patiently when choosing for another person.

Although strongly discounting participants chose more patiently for the other person than for themselves, they still chose dynamically inconsistently for the other person, as did moderately discounting participants. One possible explanation for this finding might be that the other person was not abstract enough, but defined as another participant of an experiment, and hence might have been considered similar to oneself. This finding indicates that the imaging and behavioral results for OTHER are not in accordance with one another. This can partially be explained by classical economic explanations, especially reliability effects. Specifically, immediate payments may be perceived to be more reliable since the participant does not face the risk that the experimenter will fail to deliver the delayed reward, and thus choose inconsistently out of reasons other than a desire for immediate gratification. Ruling out such effects, McClure et al. (2007) used primary rewards (water and juice) which were delivered to the participants in the scanner during the experiment, either immediately after they chose the immediate option or after a delay of a couple of minutes if participants chose a delayed option. Here, participants had to rely on the experimenter to deliver the chosen reward while they were still in the scanner, and hence, reliability effects were kept minimal. Interestingly, participants still inconsistently chose the sooner option more often when it was available immediately, suggesting that reliability effects were not causing this inconsistent behavior. In accordance, many behavioral studies on intertemporal choice have shown that participants choose inconsistently even when choosing between hypothetical instead of real monetary rewards (e.g. Green, et al., 1994; Madden, Begotka, Raiff, & Kastern, 2003), implying that even when receiving no real reward at all, people behave inconsistently. For our study, this implies that reliability effects are unlikely to be responsible for inconsistent behavior.

One alternative explanation is related to the manner in which decisions are taken in the two different conditions. The activation within the aMPFC and precuneus, which was found to be responsible for mostly self-related episodic memory retrieval and evaluation (Addis, et al.,

2004; Zysset, et al., 2002), suggests that in SELF there was a new evaluation based on the question what was preferred *right now* before *every choice*, while in OTHER participants might have employed another more general strategy that did not rely on a repeated evaluation of what the other person might have preferred. This conjecture could not be evaluated with the present paradigm, but it seems plausible and in keeping with our behavioral and neural findings, implying a need for additional research.

Taken together, our results imply that the processes underlying intertemporal choices that involve immediate rewards for oneself are different from processes underlying the processing of immediate rewards for other persons. Activations in emotion- and reward-related brain areas suggest that affective or hot system processes take place primarily when immediate gratification for oneself is possible. Making decisions for another person reduces these brain activations and let highly impulsive persons choose more patiently than when making decisions for themselves.

8.2 Observing intertemporal choices for self and other (experiment 2) in comparison to making choices for self and other (experiment 1)

In experiment 2, participants were observing intertemporal choices being made for themselves or for another, unknown person. Primarily, we were interested in neural activation differences between choices including an immediate reward (today trials) and choices exclusively including delayed rewards (delay trials). Our analyses show that observing choices being made in today trials triggers activation in brain areas associated with deliberative processing, suggesting that *observing* choices is accompanied by other cognitive processes than *actively making* choices (Tricomi, et al., 2004; Zink, et al., 2004).

8.2.1 Activation accompanying immediate rewards

In line with our assumptions, for both receiver types (SELF and OTHER), we found activation differences between today and delay trials in the ventral posterior cingulate cortex, inferior frontal junction, and posterior superior parietal lobule including the intraparietal sulcus when choices were observed being made. While the IPS was commonly shown to be engaged in quantity processing (Dehaene, et al., 2004; Dehaene, et al., 1996), the IFJ was

found to be involved in interference control, working memory (Derrfuss, et al., 2004), and, like the vPCC, in memory retrieval processes (Henson, et al., 1999; Ishai, et al., 2002; Takahashi, et al., 2008).

This supports our hypothesis that today trials, and thus the option of obtaining an immediate reward, were of special importance to participants on a deliberative level in a situation where the size and timing of the reward could not be influenced. Participants might have been more interested in the outcome of a choice when an immediate reward was obtainable than in trials in which both rewards were delayed.

When observing the choice options, participants probably tried to calculate and thus evaluate the likelihood that the sooner reward would be chosen, based on their memory of choices that had been made by the decision maker in previous trials. Furthermore, it is possible that they determined their own preferences, either irrespectively of the decision maker, or in comparison to what they thought the decision maker would choose. According to participants' statements in a post-experimental questionnaire, and according to the brain activation pattern, the last assumption is more likely. In the questionnaire, most participants had stated that they were mostly satisfied with the choices the decision maker had made. This requires that they themselves had preferences they could compare to the choices of the decision maker.

The activation in the IPS is in line with this interpretation, as in human imaging, lesion, and animal studies, this area was found to be largely involved in quantity processing (Dehaene, et al., 2004; Dehaene, et al., 1996; Roland & Friberg, 1985). The IPS also appeared to be engaged in memory retrieval processes (Takahashi, et al., 2008). This is also in line with the findings of McClure et al. (2004) who found the IPS to be more active during difficult choices (i.e., choices with an intermediate ratio of later to earlier reward) compared to easy choices (i.e., choices with a small or large ratio). Moreover, this activation was higher when the delayed reward was chosen in today trials, suggesting a stronger involvement of cool system processes when the urge of immediate gratification has to be overcome. Thus it is likely that participants in the present study (i.e., experiment 2) put more effort into predicting and/or choosing a reward when there was an immediate option available.

The IFJ, which we also found to be more activated in today than in delay trials, is an area located at the junction of the inferior frontal sulcus and inferior precentral sulcus. In human

fMRI studies, the IFJ was found to be consistently involved in cognitive control processes when task-switching, color-naming, and n-back tasks had to be carried out (Derrfuss, et al., 2004). The IFJ most likely supports the processes mentioned above by coordinating and controlling calculation processes while rewards and delays were presented, maintaining ongoing working memory processes, updating representations of the task (Derrfuss, et al., 2004; Konishi, et al., 1999).

The involvement of memory retrieval processes in our task is further supported by an elevated activation in the ventral part of the PCC, as this area was previously found consistently engaged in episodic memory retrieval (Maguire & Mummery, 1999; Wagner, et al., 2005). We suggest episodic memory retrieval to have played a role, since participants probably tried to keep in mind which options had been chosen in former trials and whether this choice strategy was consistent and/or in line with their own preferences.

8.2.2 Activation accompanying immediate rewards when observing choices vs. when actively choosing in SELF

In contrast to experiment 2, experiment 1 (section 8.1) yielded the (pACC) and ventral striatum most highly activated when an immediate reward could be actively chosen for oneself.

In experiment 2, we did not observe activation differences between today and delay trials within the ventral striatum or pACC. This implies that activation differences in these areas depend on whether participants can control the outcome by choosing actively or not (Tricomi, et al., 2004; Zink, et al., 2004). Being in charge hence seems to lead to stronger connections between activation and reward outcome (cp. experiment 1, section 6), suggesting this activation to correspond to saliency rather than reward per se. On the contrary, not being in charge seems to lead to more deliberative processing of intertemporal choices (Merlo & Schotter, 2003).

8.2.3 No activation differences when observing choices in SELF and OTHER

In experiment 2, there were no activation differences between SELF and OTHER in any of our regions of interest defined from experiment 1. In particular, no activation differences were found between today and delay trials in the ventral striatum and pACC.

We observed the above mentioned differences between today and delay trials in the IPS, IFJ and vPCC for both conditions, SELF and OTHER, suggesting that activation in these regions is not contingent on the person the choice was made for. As mentioned above, the IPS as well as IFJ are structures found to be involved in number processing and memory processes (Dehaene, et al., 1996; Derrfuss, et al., 2004; Roland & Friberg, 1985). These processes are carried out deliberately and with cognitive effort (Evans, 2008). Thus, these activations seem to reflect a general speciality of immediacy that does not rely on automatic and emotion-driven processes when an immediate reward can be obtained for oneself, but on deliberative processes carried out whenever there is an immediate reward observed, independently of the person who might obtain it.

8.3 Conclusion

Summarizing, there is no difference in brain activation between SELF and OTHER when participants can only observe intertemporal choices. This finding broadens those of experiment 1, in which participants were making decisions instead of observing them. Results further suggest that not being responsible for making and executing choices eliminates hot system brain activation in today trials. Rather, in the latter trials, regions involved in deliberative processing were activated through observation, indicating that immediacy indeed plays a special role here, but on an abstract, deliberative level when facing monetary rewards.

The main findings of the two studies presented above showed that intertemporal choice for self and other is represented differently in the brain, as an immediacy effect occurs only when choices are made for oneself, but not when choices are made for another person. This effect depends on the impulsivity of participants, and is stronger for impulsive participants. Importantly, an immediacy effect depending on the person the choice is made for, and on the decision maker's impulsivity, only occurs in the decision maker's brain. The effect was not observable in the brain of participants only observing choices being made, neither when

choices were made for themselves, nor when they were made for another person. Activation in areas of a neural network usually called reward circuitry hence seem to crucially depend on the “power of decision”. The role immediacy plays when observing choices but not making them is different. Activation in brain areas usually found to be involved in quantity processing, interference control, and memory processes were higher in choices including immediate rewards than in choices including exclusively delayed rewards. This indicates that the possibility of immediate gratification was more interesting to participants than receiving delayed rewards, even when not in charge of choosing the immediate reward themselves.

The following chapter will deal with limitations of and open questions brought up by our experiments. Alternative explanations of our findings and how to test them will be discussed.

9 Limitations and future perspectives

9.1 Why was there a mismatch of behavioral and imaging data in experiment 1?

In experiment 1, choices including immediate rewards were accompanied by higher activation in the pACC, ventral striatum, aMPFC, and precuneus than choices exclusively involving delayed rewards, when these choices were actively made for oneself. There were no such activation differences when choices were made for another person. A reasonable explanation would be that choices for another person are made irrespectively of the presence of immediate rewards, while choices made for oneself are more impulsive when there is an immediate option. Yet, the behavioral results show that this is not the case: Participants acted as impulsively and inconsistently when choosing for another person as they did when choosing for themselves. Possible explanations for this difference between the behavioral and imaging results could be reliability effects (irrespectively of emotional involvement) or strategical differences (see discussion of these effects in section 6.4.3).

A way to investigate reliability effects could be to align payments so that the experimenter's reliability plays no role, in a way similar to McClure et al. (2007), who delivered primary rewards (water and juice) while participants were still in the scanner. As described briefly in section 6.4.3, participants in this study had to rely on the experimenter to deliver the chosen reward irrespectively of immediacy and delay, and hence reliability effects were kept minimal. The fact that participants still chose inconsistently the sooner option more often when it was available immediately, indicates that reliability effects did not likely cause this inconsistent behavior. In accordance, many behavioral studies on intertemporal choice have shown that participants choose inconsistently also when choosing between hypothetical monetary rewards (e.g. Green, et al., 1994; Madden, et al., 2003), indicating that not an actual immediate payment alone elicits inconsistency, but that the mere thought about money plays a role. Hence, reliability does not seem responsible for an immediacy effect in our study, but nevertheless should be investigated in more detail in future studies in order to be ruled out completely.

Further experiments will become necessary to test for the appliance of different strategies when choosing for self and other, and the extent to which these differences might drive the observed mismatch between the behavioral and imaging data when choices for another person are made. As discussed above (in section 6.4.3), while for oneself every single choice was probably evaluated individually (with hot system processes playing a role), for another person a more general strategy might have been applied, including different sub-strategies depending on the involvement of immediate rewards, based on the participant's own preferences.

According to Parfit's (1984) theory, another reason for the observed mismatch could be that the other person might not be important enough to elicit the same brain activation differences as choices for oneself do. Hence, an interesting future study would be to boost up rewards for the other person to an amount which makes them as important to the participants as rewards chosen for themselves. The amounts needed could easily be determined by asking participants which amount another person must receive so that the participant is indifferent between getting a smaller amount X herself or letting the other person have the bigger amount Y. Afterwards, intertemporal choices for the other person between the enhanced amounts should be investigated in the fMRI-scanner. If activation differences between choices including an immediate reward and choices including only delayed rewards should appear as they did in SELF, then hot system processes would play a role when choosing for another person, too. This would be in line with Parfit's (1984) theory still, and would also suggest that two systems (hot and cool) exist, but that the hot system comes into play not only when immediate rewards are chosen for oneself, but also when they are high enough and received by another person. This would also be in line with the results of Kable & Glimcher (2007), who found higher activation in regions typically associated with hot system processes for higher and temporal closer rewards. Hence, it could possibly rule out immediacy as being a unique effect, but not dual-processing models per se. Features as reward size and temporal proximity might be mentally integrated to elicit hot system processes depending on their amount.

9.2 How to elicit different behavior for self and other?

The difference between self and other not being reflected in the behavioral data might also be due to the abstractness of rewards used. Humans might not react sensitively enough to monetary (i.e., secondary) rewards and hence might not be emotionally engaged enough to choose differently for themselves than for other persons. As Beisswanger et al. (2003) showed

in their study (and as we at least partly showed in our study separating the sample into high and moderate discounters), participants' emotional involvement plays a crucial role: The participant has to be emotionally involved in a situation herself in order to decide more patient (and in the long run more sensible) for another person. Hence, topics humans are usually highly emotionally involved in (like social relationships or life-time decisions) should be investigated in more detail. A problematic feature of such topics is that choices are often hard to categorize as better or worse than other choices. An example taken from Beisswanger and colleagues (2003, p. 134) asks the following question: "You have a crush on someone and are considering buying her a Valentine's Day gift. She doesn't know you very well, and you're worried about overwhelming her with the gift. You decide to....A. Not buy her a gift, or B. Buy her a gift." Such hypothetical choices were given to participants, who made them for themselves and for other persons, with the result that participants chose the more risk-taking option more often for the other person than for themselves. This result indicates that such questions elicit different choices for self and other, probably because of their impact on the participant's own feelings and (in this example) worries about social rejection when choosing for oneself. Nevertheless, the problem with such a choice is, that it cannot be clearly determined which would be the economically better (i.e., more rational) option to choose, i.e., to buy or not to buy the gift.

Intertemporal choice thus seems a good method to test this issue, as consistent and inconsistent behavior can easily be determined and hence defined as "rational" or "irrational" according to the definition given in section 2.1 (e.g. Eisenführ & Weber, 2002; Hastie & Dawes, 2001). In experiment 1 (section 6), participants made intertemporal choices for self and other, resulting in only strong discounters showing a difference in their behavior between choices made for themselves and choices made for another person. Here, a higher impulsivity when choosing for oneself seemed to lead to a less impulsive behavior when choosing for another person. This suggests that their higher emotional involvement when making choices for themselves (impulsivity; McClure, et al., 2006; McClure, et al., 2004) does not transfer to choices made for another person. This supports our hypotheses only partly, since although more patient, participants' behavior was still inconsistent when choosing for the other person. This finding suggests an influence of the aforementioned factors such as reliability effects, strategy, and lowered interest in the satisfaction of other persons. Still, when highly emotionally involved in a task oneself, it might be better to delegate a decision which can be made with more patience to yield a higher outcome by another person. However, given the

methodological constraints which required intertemporal choices to be rather artificial, a generalization of these findings to other areas can only be made with caution.

9.3 The role of empathy on intertemporal choice behavior for self and other

When it comes to money, a “usual” other participant might be in need of, but usually not depending on € 10 more now compared to in two weeks. When it comes to food or water on the other hand, the situation the participant is in is much more variable. Hence, it is much more necessary for the decision maker to empathize with the participant the decision is made for, i.e., with that participant’s momentary needs.

Empathy in general can be described as the capacity to “put oneself into another’s shoes”. Often, empathy is distinguished from the concept of “Theory of Mind” (TOM, as explained in section 1.1.1.3): While TOM adverts to understanding that another person has thoughts and feelings of her own, (emotional) empathy usually describes the capacity of feeling like another person (Singer, et al., 2004; Singer, et al., 2006). Another nomenclature used by some authors, distinguishes emotional from cognitive empathy (e.g. Dziobek, et al., 2008), whereas cognitive empathy is comparable to TOM.

An interesting future research question would be to investigate if empathy in such a scenario is more cognitive (TOM) or emotional. Will decision makers really “feel” with the other and choose appropriately (i.e., show the same brain activation as participants who experience a situation themselves), or will they cognitively think what the other might want (i.e., show different brain activation when another person is affected)? Studies by Singer et al. (2004; 2006) concerning emotional and cognitive empathy, found activation in the same brain areas (in the anterior insula and rostral anterior cingulate cortex) when pain was received by the participant herself or perceived to be delivered to another person. This indicates a neural simulation of pain when it is not received by oneself. Other studies found similar effects in other domains, such as sensation versus perception of touch (somatosensory cortex), and self-experienced disgust versus perceived disgust (anterior insula), (Jabbi, Swart, & Keysers, 2007; Keysers, et al., 2004; Wicker, et al., 2003). This suggests emotional empathy being applied in different domains when observing other persons experiencing what is not experienced this very moment by oneself.

In experiment 1 reported in section 3, no such empathetic activation was observed when choices were made for another person. A way to test to which extent empathy plays a role in intertemporal choice behavior for self and other, might be to use primary (e.g. juice) instead of secondary (e.g. monetary) rewards, as needs for these might be varied and communicated more convincingly. Here, a participant in the same situation (e.g., thirsty) as the person she is choosing for, might show similar brain activation and behavior when choosing for herself and when choosing for the other person. More interestingly, a participant who is in a different situation (e.g., not thirsty) than the other person (who is thirsty), might be more robust against an immediacy effect when choosing for the other person, than a participant who is in the same situation as the other person (i.e., thirsty) when choosing for the other person. This would suggest, that participants are not completely able to emotionally empathize with others when in a different situation, and support our hypothesis that it can be advantageous to delegate a decision to a person less involved. Hence, future research on this topic is necessary to further investigate the importance of decision delegation, which takes place in many areas of our lives.

9.4 Does concreteness of the other person matter?

Singer et al. (2006) could show that emotional empathy was experienced when a likable person was receiving pain. Hence, when decisions are made for a concrete other person, whose feelings and preferences are known or can be assumed, it would be not surprising if brain activation would not differ from when decisions are made for oneself. It has been shown before that behavior between choices for oneself and another person does not differ when another person is concrete (Hsee & Weber, 1997), which suggests that concrete others might be considered similar to oneself (i.e., as having similar preferences). In both cases, when feelings and preferences of others are assumed or inferred from own preferences, brain activation might be enhanced accordingly.

In experiment 1 (section 6), participants chose for a rather abstract other, which could be a reason for differences in brain activation to choices made for oneself. It might be harder to fully empathize with an abstract person than with a person sitting next to oneself (Hsee & Weber, 1997). To fully investigate this question, it would be necessary to vary the concreteness of the other person from completely abstract (“another human being”), over

rather abstract as in experiment 1 (“another student/participant”), to concrete (“the person sitting next to you/your friend”). In experiment 2 (section 7), the other person was also abstract as in experiment 1 (“another participant”), but additionally, pictures of potential “other persons” were presented to the participant. This made the other probably less abstract than in experiment 1, but was necessary to make sure participants understood that the “other person” the choices were made for was not identical with the person outside the scanner making the choices. Nevertheless, it cannot be excluded that the higher concreteness of the other person in experiment 2 led to similar activation when choices were observed being made for self and other. Hence, also in this paradigm, it would be very interesting to vary the concreteness of the other person in order to investigate brain activation for more or less concrete persons.

Our hypothesis would be, that varying the concreteness in experiment 1 should lead to higher activations in hot system brain areas, and less behavioral differences between today and delay trials, the more concrete the other person is. We believe this to be the case as emotional empathy was found to play a role in brain activation when a close other was involved (Singer, et al., 2004; Singer, et al., 2006). Further, behavioral studies on decision making found fewer differences between choices made for self and other when the other was more concrete (Hsee & Weber, 1997). In experiment 2, we would expect no differences corresponding to the concreteness of the other person, as here brain structures usually associated with memory, control, and quantity processing (i.e., cool system structures) are involved. These processes are not specifically self-related and hence can be expected to take place irrespectively of the receiver of a reward.

9.5 Are immediate rewards special?

Dual processing theories as well as the quasi-hyperbolic discounting model assume two systems to be responsible in intertemporal choice. McClure et al. (2004) could support the hypothesis that these systems are represented in the brain. In experiment 1 presented in this thesis, we could replicate their findings, supporting two system theories of an interplay of affective and deliberative working systems (Metcalf & Mischel, 1999; Mischel, et al., 2003), with immediate rewards being valued differently from delayed rewards.

The observed higher activation for immediate compared to delayed rewards in certain brain areas show that more immediate rewards are “special”, even though it is not possible to say if this is a “real” immediacy effect (i.e., if activation can exclusively be observed for immediate rewards), or whether activation declines gradually (i.e., becomes smaller, but can still be observed to be higher for rewards available tomorrow than for rewards available in two weeks). This question cannot be answered with the present studies. Nonetheless, irrespective of gradual or dichotomous differences in evaluating immediate and delayed rewards, the present studies have shown that (more) immediate rewards are processed differently from (more) delayed rewards, and hence support dual processing theories to a certain degree. This effect is present in both domains, when choosing and when observing choices. The involvement of different brain areas in these domains suggests that immediacy plays a special role, but also that this role is domain specific. While activation in the pregenual anterior cingulate cortex and ventral striatum suggest high affective (hot system) involvement in the task when immediate rewards are available, activation in the inferior frontal junction and intraparietal sulcus indicates deliberative and evaluative (cool system) processing of the choice options when choices are not made by oneself but observed being made.

Results of the behavioral study by Merlo and Schotter (2003) suggest that learning by observing (afterwards) leads to less emotion-driven decisions than learning by doing. (For a more detailed description of this study see section 3.2.1.) Our data support these results, and further also suggest that the inconsistency observed in intertemporal choice is not merely because of affective impulsiveness (“I want it now!”) but could partly also be due to deliberately evaluating immediate options more intensely than delayed options. Future research should investigate if participants who have observed choices being made for them, would afterwards choose in the same way participants do who made choices themselves before. The observed brain activation would suggest that it should not matter if the observed choices were made for the participant herself or for another, concrete person (as in the study by Merlo & Schotter, 2003).

9.6 Conclusion

Taken together, the present studies support dual processing theories as they could show that immediacy is “special”, or at least “more special”, than receiving delayed rewards. This speciality depends on different factors, i.e., whether a choice is actively made or observed

being made. When observing a choice, only cool system processes seem to operate. The person the choices are made or observed for also play a role: choices made for oneself are accompanied by different brain activation than choices made for another person, while activation during choices observed made for oneself or another person does not differ, and hence may rely on a more general mechanism.

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Supplementary Tables

Table S1: *Set 1 (presented to each participant in random order – for half of the participants this set was used in part 1, for the other half in part 2), (experiment 1)*

sooner reward r1	later reward r1'	payment time of r1	payment time of r1'	monetary difference (r1'-r1) in %
8.29	9.12	today	in 4 weeks	10
10.90	12.54	today	in 4 weeks	15
11.43	12.00	today	in 4 weeks	5
13.83	17.29	today	in 4 weeks	25
24.63	33.25	today	in 4 weeks	35
26.47	39.71	today	in 4 weeks	50
32.20	32.52	today	in 4 weeks	1
34.46	35.49	today	in 4 weeks	3
6.59	9.89	today	in 2 weeks	50
8.93	9.02	today	in 2 weeks	1
10.10	10.40	today	in 2 weeks	3
14.03	14.73	today	in 2 weeks	5
16.03	17.63	today	in 2 weeks	10
22.63	28.29	today	in 2 weeks	25
24.37	32.90	today	in 2 weeks	35
28.38	32.64	today	in 2 weeks	15
12.25	16.54	in 4 weeks	in 6 weeks	35
34.06	51.09	in 4 weeks	in 6 weeks	50
6.75	8.44	in 4 weeks	in 6 weeks	25
11.30	11.87	in 4 weeks	in 6 weeks	5
11.57	11.92	in 4 weeks	in 6 weeks	3
14.72	14.87	in 4 weeks	in 6 weeks	1
23.60	25.96	in 4 weeks	in 6 weeks	10
27.49	31.61	in 4 weeks	in 6 weeks	15
10.13	15.20	in 2 weeks	in 6 weeks	50
22.45	24.70	in 2 weeks	in 6 weeks	10
27.06	33.83	in 2 weeks	in 6 weeks	25

29.04	29.91	in 2 weeks	in 6 weeks	3
30.40	31.92	in 2 weeks	in 6 weeks	5
31.10	31.41	in 2 weeks	in 6 weeks	1
33.15	44.75	in 2 weeks	in 6 weeks	35
33.71	38.77	in 2 weeks	in 6 weeks	15
5.15	5.20	in 2 weeks	in 4 weeks	1
10.67	13.34	in 2 weeks	in 4 weeks	25
10.68	11.21	in 2 weeks	in 4 weeks	5
11.07	12.73	in 2 weeks	in 4 weeks	15
13.72	15.09	in 2 weeks	in 4 weeks	10
22.67	34.01	in 2 weeks	in 4 weeks	50
26.38	27.17	in 2 weeks	in 4 weeks	3
30.21	40.78	in 2 weeks	in 4 weeks	35

Table S2: Set 2 (presented to each participant in random order – for half of the participants this set was used in part 1, for the other half in part 2), (experiment 1)

sooner reward r2	later reward r2'	payment time of r2	payment time of r2'	monetary difference (r2'-r2) in %
6.14	6.75	today	in 4 weeks	10
8.14	8.22	today	in 4 weeks	1
12.28	16.58	today	in 4 weeks	35
12.78	13.42	today	in 4 weeks	5
17.82	22.28	today	in 4 weeks	25
25.26	26.02	today	in 4 weeks	3
25.45	38.18	today	in 4 weeks	50
26.50	30.48	today	in 4 weeks	15
10.16	11.18	today	in 2 weeks	10
12.41	13.03	today	in 2 weeks	5
12.67	15.84	today	in 2 weeks	25
12.69	17.13	today	in 2 weeks	35
14.19	14.62	today	in 2 weeks	3
26.92	40.38	today	in 2 weeks	50
28.37	32.63	today	in 2 weeks	15
30.62	30.93	today	in 2 weeks	1
5.95	8.03	in 2 weeks	in 4 weeks	35
27.36	30.10	in 2 weeks	in 4 weeks	10
28.57	28.86	in 2 weeks	in 4 weeks	1
28.97	36.21	in 2 weeks	in 4 weeks	25
29.05	30.50	in 2 weeks	in 4 weeks	5
31.99	32.95	in 2 weeks	in 4 weeks	3
33.18	49.77	in 2 weeks	in 4 weeks	50
34.09	39.20	in 2 weeks	in 4 weeks	15
6.32	9.48	in 2 weeks	in 6 weeks	50
7.49	7.86	in 2 weeks	in 6 weeks	5
8.42	10.53	in 2 weeks	in 6 weeks	25
10.07	10.17	in 2 weeks	in 6 weeks	1
14.64	16.84	in 2 weeks	in 6 weeks	15

26.26	27.05	in 2 weeks	in 6 weeks	3
33.41	36.75	in 2 weeks	in 6 weeks	10
33.45	45.16	in 2 weeks	in 6 weeks	35
17.06	25.59	in 4 weeks	in 6 weeks	50
33.57	45.32	in 4 weeks	in 6 weeks	35
8.73	8.82	in 4 weeks	in 6 weeks	1
13.70	15.76	in 4 weeks	in 6 weeks	15
14.17	15.59	in 4 weeks	in 6 weeks	10
25.66	26.94	in 4 weeks	in 6 weeks	5
31.13	38.91	in 4 weeks	in 6 weeks	25
34.18	35.21	in 4 weeks	in 6 weeks	3

Table S3: *Estimated β values (experiment 1)*

ID	B
1 [#]	.
2	0.74
3	0.90
4	1.15
5	0.87
6	0.83
7	0.91
8	0.91
9	0.89
10	0.86
11	0.75
12	0.73
13	1.35
14	0.80
15	0.99
16	0.62
17	0.66
18	0.90
19	0.87
20	0.93
21	0.88
22	0.84
23	0.51
24	0.83
25	1.40
26	0.85
27	0.83
28	0.71

[#] This participant always chose the later, and larger, reward. Thus estimation was not possible. The participant was included in the group of moderate discounters.

Table S4: Overview of neural activations (Talairach coordinates) in contrasts visualized in Figure 6.3 and 6.4 (experiment 1)

<i>Today trials > delay trials SELF</i>	x	y	z	max
Pregenual anterior cingulate cortex	7	35	18	99.99
Pregenual anterior cingulate cortex	-5	32	21	99.99
anterior medial prefrontal cortex	13	50	9	99.96
Precuneus	-17	-55	30	99.99
ventral striatum/caudate head	9	9	5	99.66
ventral striatum/caudate head	-5	9	5	99.63
anterior cingulate cortex	-14	44	3	99.96
Paracentral lobe	4	-19	48	99.91
inferior frontal junction	-44	8	30	100
superior frontal gyrus	19	26	30	99.97
middle frontal gyrus	-47	35	15	99.98
Postcentral gyrus	43	-22	51	99.99
Thalamus	4	-4	6	100
middle temporal gyrus	-35	-64	24	99.91
posterior superior temporal sulcus	-50	-49	18	100
inferior occipital gyrus	-35	-70	-6	99.74
inferior occipital lobe	40	-58	-3	99.93
<i>Today trials > delay trials OTHER</i>	x	y	z	max
inferior precuneus/posterior cingulate cortex	13	-55	18	99.9
inferior precuneus/parietal-occipital sulcus	-17	-61	21	99.98
retrosplenial cortex	-11	-49	9	99.81
posterior insula	37	-16	18	99.89
superior temporal gyrus	-44	-49	18	100
middle temporal gyrus	-53	-10	-9	99.99
superior occipital gyrus	-35	-85	24	99.97
middle occipital gyrus	34	-79	21	99.99
Brainstem	-5	-31	-27	99.72

<hr/>				
<i>(today trials SELF + delay trials OTHER) ></i>				
<i>(delay trials SELF + today trials OTHER)</i>	x	y	z	max
Pregenua anterior cingulate cortex	1	35	24	99.78
Pregenua anterior cingulate cortex	-5	36	24	99.73
anterior medial prefrontal cortex	10	53	9	99.83
anterior medial prefrontal cortex	-2	54	9	99.44
ventral striatum/head of caudate	-5	14	3	99.98
dorsal posterior cingulate cortex	4	-25	36	99.8
inferior frontal sulcus/frontomarginal gyrus	-32	47	3	99.99
inferior frontal gyrus	-44	23	0	99.86
middle frontal gyrus	-14	14	45	99.99
precentral gyrus	-50	14	27	99.91
Postcentral gyrus	22	-40	51	99.99
Postcentral sulcus	31	-37	36	99.97
callosomarginal sulcus	19	26	30	99.91
inferiorparietal gyrus	-53	-22	27	99.98
superior parietal lobe/intraparietal sulcus	-29	-55	45	99.86
fusiform gyrus	-38	-49	-3	99.87
inferior temporal gyrus	-50	-31	-9	99.98
<hr/>				
<i>strong discounters: (today trials SELF + delay trials</i>				
<i>OTHER) > (delay trials SELF + today trials OTHER)</i>	x	y	z	max
Pregenua anterior cingulate cortex	1	36	24	99.63
Pregenua anterior cingulate cortex	-5	36	24	99.94
anterior medial prefrontal cortex	1	48	3	99.86
anterior medial prefrontal cortex	-2	48	3	99.98
ventral striatum/caudate head	-4	10	3	99.84
Precuneus	-14	-57	33	99.98
Precuneus	19	-51	36	99.86
caudate body	8	10	10	99.79
subgenual anterior cingulate cortex	1	18	-9	99.11
dorsal posterior cingulate cortex	4	-24	33	99.98
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ventrolateral premotor cortex	-35	9	45	100
inferior frontal gyrus	-41	27	3	99.91
inferior frontal gyrus	-41	45	3	99.94
dorsal posterior cingulate cortex	4	-24	33	99.98
callosomarginal sulcus	19	27	30	99.9
Postcentral gyrus	49	-21	42	99.86
superior parietal lobe	34	-66	48	99.85
inferior parietal lobe/postcentral sulcus	-53	-24	30	99.97
inferior parietal lobe	-53	-45	45	99.98

moderate discounters: (today trials SELF + delay trials

OTHER) > (delay trials SELF + today trials OTHER)

	x	y	z	max
anterior midcingulate cortex	10	29	36	99.89
precentral gyrus	-38	-10	51	99.87
Postcentral sulcus	-29	-40	51	99.81
lateral anterior prefrontal cortex	-32	50	15	99.98

Table S5. *Set 1 (presented to each participant in random order – for half of the participants this set was used in part 1, for the other half in part 2). Rewards were presented for 2584 to 3389 ms (RT), until a choice was indicated (1=the sooner reward was chosen, 2=the later reward was chosen). (experiment 2)*

Experimental trials (not in order of presentation):

sooner reward r1	later reward r1'	payment time of r1	payment time of r1'	monetary difference (r1'-r1) in %	RT	Choice
8.93	9.02	today	in 2 weeks	1	2584	1
32.2	32.52	today	in 4 weeks	1	2584	2
10.1	10.4	today	in 2 weeks	3	2699	2
34.46	35.49	today	in 4 weeks	3	2699	1
14.03	14.73	today	in 2 weeks	5	2754	2
11.43	12	today	in 4 weeks	5	2754	1
16.03	17.63	today	in 2 weeks	10	2894	1
8.29	9.12	today	in 4 weeks	10	2894	2
28.38	32.64	today	in 2 weeks	15	3319	1
10.9	12.54	today	in 4 weeks	15	3319	2
22.63	28.29	today	in 2 weeks	25	3348	2
13.83	17.29	today	in 4 weeks	25	3348	1
24.37	32.9	today	in 2 weeks	35	2986	1
24.63	33.25	today	in 4 weeks	35	2986	2
6.59	9.89	today	in 2 weeks	50	2670	2
26.47	39.71	today	in 4 weeks	50	2670	1
5.15	5.2	in 2 weeks	in 4 weeks	1	3011	1
31.1	31.41	in 2 weeks	in 6 weeks	1	3011	1
14.72	14.87	in 4 weeks	in 6 weeks	1	3011	2
26.38	27.17	in 2 weeks	in 4 weeks	3	3179	1
29.04	29.91	in 2 weeks	in 6 weeks	3	3179	2
11.57	11.92	in 4 weeks	in 6 weeks	3	3179	1
10.68	11.21	in 2 weeks	in 4 weeks	5	3056	2
30.4	31.92	in 2 weeks	in 6 weeks	5	3056	1
11.3	11.87	in 4 weeks	in 6 weeks	5	3056	1
13.72	15.09	in 2 weeks	in 4 weeks	10	3222	1

22.45	24.7	in 2 weeks	in 6 weeks	10	3222	2
23.6	25.96	in 4 weeks	in 6 weeks	10	3222	2
11.07	12.73	in 2 weeks	in 4 weeks	15	3380	2
33.71	38.77	in 2 weeks	in 6 weeks	15	3380	1
27.49	31.61	in 4 weeks	in 6 weeks	15	3380	2
10.67	13.34	in 2 weeks	in 4 weeks	25	3389	2
27.06	33.83	in 2 weeks	in 6 weeks	25	3389	2
6.75	8.44	in 4 weeks	in 6 weeks	25	3389	1
30.21	40.78	in 2 weeks	in 4 weeks	35	3054	1
33.15	44.75	in 2 weeks	in 6 weeks	35	3054	2
12.25	16.54	in 4 weeks	in 6 weeks	35	3054	2
22.67	34.01	in 2 weeks	in 4 weeks	50	2899	2
10.13	15.2	in 2 weeks	in 6 weeks	50	2899	1
34.06	51.09	in 4 weeks	in 6 weeks	50	2899	2

Intermixed catch trials:

sooner reward r1	later reward r1'	payment time of r1	payment time of r1'
0.00	2.00	today	in 2 weeks
1.00	4.00	in 1 week	in 4 weeks
1.00	6.00	in 1 week	in 6 weeks
1.00	5.00	in 1 week	in 5 weeks
2.00	4.00	in 2 weeks	in 4 weeks
2.00	5.00	in 2 weeks	in 5 weeks
2.00	6.00	in 2 weeks	in 6 weeks
3.00	5.00	in 3 weeks	in 5 weeks
3.00	6.00	in 3 weeks	in 6 weeks
4.00	6.00	in 4 weeks	in 6 weeks

Table S6. *Set 2 (presented to each participant in random order – for half of the participants this set was used in part 1, for the other half in part 2). Rewards were presented for 2584 to 3389 ms (RT), until a choice was indicated (1=the sooner reward was chosen, 2=the later reward was chosen). (experiment 2)*

Experimental trials (not in order of presentation):

sooner reward r2	later reward r2'	payment time of r2	payment time of r2'	monetary difference (r2'-r2) in %	RT	Choice
30.62	30.93	today	in 2 weeks	1	2584	1
8.14	8.22	today	in 4 weeks	1	2584	2
14.19	14.62	today	in 2 weeks	3	2699	2
25.26	26.02	today	in 4 weeks	3	2699	1
12.41	13.03	today	in 2 weeks	5	2754	2
12.78	13.42	today	in 4 weeks	5	2754	1
10.16	11.18	today	in 2 weeks	10	2894	1
6.14	6.75	today	in 4 weeks	10	2894	2
28.37	32.63	today	in 2 weeks	15	3319	1
26.5	30.48	today	in 4 weeks	15	3319	2
12.67	15.84	today	in 2 weeks	25	3348	2
17.82	22.28	today	in 4 weeks	25	3348	1
12.69	17.13	today	in 2 weeks	35	2986	1
12.28	16.58	today	in 4 weeks	35	2986	2
26.92	40.38	today	in 2 weeks	50	2670	2
25.45	38.18	today	in 4 weeks	50	2670	1
28.57	28.86	in 2 weeks	in 4 weeks	1	3011	1
10.07	10.17	in 2 weeks	in 6 weeks	1	3011	1
8.73	8.82	in 4 weeks	in 6 weeks	1	3011	2
31.99	32.95	in 2 weeks	in 4 weeks	3	3179	1
26.26	27.05	in 2 weeks	in 6 weeks	3	3179	2
34.18	35.21	in 4 weeks	in 6 weeks	3	3179	1
29.05	30.5	in 2 weeks	in 4 weeks	5	3056	2
7.49	7.86	in 2 weeks	in 6 weeks	5	3056	1
25.66	26.94	in 4 weeks	in 6 weeks	5	3056	1
27.36	30.1	in 2 weeks	in 4 weeks	10	3222	1

33.41	36.75	in 2 weeks	in 6 weeks	10	3222	2
14.17	15.59	in 4 weeks	in 6 weeks	10	3222	2
34.09	39.2	in 2 weeks	in 4 weeks	15	3380	2
14.64	16.84	in 2 weeks	in 6 weeks	15	3380	1
13.7	15.76	in 4 weeks	in 6 weeks	15	3380	2
28.97	36.21	in 2 weeks	in 4 weeks	25	3389	2
8.42	10.53	in 2 weeks	in 6 weeks	25	3389	2
31.13	38.91	in 4 weeks	in 6 weeks	25	3389	1
5.95	8.03	in 2 weeks	in 4 weeks	35	3054	1
33.45	45.16	in 2 weeks	in 6 weeks	35	3054	2
33.57	45.32	in 4 weeks	in 6 weeks	35	3054	2
33.18	49.77	in 2 weeks	in 4 weeks	50	2899	2
6.32	9.48	in 2 weeks	in 6 weeks	50	2899	1
17.06	25.59	in 4 weeks	in 6 weeks	50	2899	2

Intermixed catch trials:

Sooner reward r2	later reward r2'	payment time of r2	payment time of r2'
0.00	2.00	today	in 2 weeks
1.00	4.00	In 1 week	in 4 weeks
1.00	5.00	In 1 week	in 5 weeks
1.00	6.00	In 1 week	in 6 weeks
2.00	4.00	In 2 weeks	in 4 weeks
2.00	5.00	In 2 weeks	in 5 weeks
2.00	6.00	In 2 weeks	in 6 weeks
3.00	5.00	In 3 weeks	in 5 weeks
3.00	6.00	In 3 weeks	in 6 weeks
4.00	6.00	In 4 weeks	in 6 weeks

Table S7. Reported are Talairach coordinates of activation peaks in the main contrasts of today and delay trials in *SELF* and *OTHER* (visualized in Figure 7.2), and the interaction contrast (temporal distance \times receiver). Only activation blobs that contain a minimum of 10 voxels are reported. (experiment 2)

<i>Today trials > delay trials SELF</i>	x	y	z	max
Superior parietal lobule/posterior intraparietal sulcus	-32	-72	39	100.00
Superior parietal lobule/posterior intraparietal sulcus	40	-66	42	100.00
Inferior frontal junction	-47	12	21	99.99
Inferior frontal junction	34	18	21	99.99
Precuneus	-8	-57	42	99.82
Precuneus	4	-66	36	99.95
Ventral posterior cingulate cortex	-5	-48	21	99.99
Ventral posterior cingulate cortex	-5	-42	36	99.81
Posterior midcingulate cortex	-2	-12	30	99.65
Middle frontal gyrus	-47	51	-3	99.61
Middle frontal gyrus	-41	3	57	100.00
Middle frontal gyrus	40	6	42	99.95
Inferior frontal gyrus	-53	24	15	100.00
Superior frontal gyrus	1	51	-15	99.93
Superior frontal gyrus	16	27	-15	99.86
Superior frontal sulcus	22	12	42	100.00
Inferior parietal lobule	43	-39	45	99.98
Middle occipital gyrus	-32	-66	3	99.87
Middle occipital gyrus	28	-81	27	99.87
Middle temporal gyrus	-32	-66	21	99.90
Middle temporal gyrus	-50	-42	6	99.94
Inferior temporal gyrus	55	-54	-12	100.00
Posterior superior temporal sulcus	-38	-54	15	100.00
Anterior superior temporal sulcus	-47	-9	-15	99.98

Cerebellum	-17	-36	-21	99.81
Cerebellum	4	-48	-33	99.88
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<i>Today trials > delay trials OTHER</i>	x	y	z	max
Superior parietal lobule/posterior intraparietal sulcus	-20	-63	42	100.00
Superior parietal lobule/posterior intraparietal sulcus	31	-60	45	100.00
Inferior frontal junction	-41	15	27	99.99
Inferior frontal junction	34	12	24	99.99
Precuneus	-8	-72	39	99.97
Precuneus	16	-66	42	99.97
Ventral posterior cingulate cortex/ retrosplenial cortex	-2	-51	15	99.96
Anterior dorsolateral prefrontal cortex	-41	33	13	99.99
Anterior dorsolateral prefrontal cortex	34	35	15	99.99
Superior frontal gyrus	-20	48	-15	99.89
Superior frontal gyrus	10	33	39	99.95
Inferior frontal gyrus	-41	30	6	100.00
Inferior frontal gyrus	34	30	9	100.00
Inferior frontal sulcus	34	12	24	100.00
Middle frontal gyrus	37	48	-6	99.97
Middle occipital gyrus	-29	-78	9	99.99
Middle occipital gyrus	52	-60	-3	100.00
Middle occipital gyrus	52	-60	-3	100.00
Clastrum	31	18	0	99.99
Fusiform gyrus	-38	-63	-6	100.00
Fusiform gyrus	28	-90	-12	99.96
Middle temporal gyrus	-62	-30	-21	100.00
Cerebellum	40	-63	-18	99.99
Cerebellum	4	-72	-18	99.98
Cerebellum	10	-72	-27	99.94
Cerebellum	43	-57	-30	99.96

Cerebellum	40	-75	-30	99.76
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<i>Interaction contrast (temporal distance x receiver)</i>	x	y	z	max
Superior posterior insula cortex	-32	-12	18	99.94
Brain stem	-2	-45	-36	99.83
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List of Figures

Figure 2.1: <i>Exponential and hyperbolic discount functions. From Kalenscher & Pennartz (2008).</i>	8
Figure 2.2: <i>Quasi-hyperbolic discount function in relation to an exponential and a hyperbolic discount function. From Angeletos et al. (2003).</i>	10
Figure 2.3: <i>Stimulus presentation in study by McClure et al. (2004). Adapted from McClure et al. (2004).</i>	17
Figure 2.4: <i>Activated brain regions when participants made intertemporal choices containing an immediate reward compared to choices containing exclusively delayed rewards. From McClure et al. (2004).</i>	18
Figure 2.5: <i>Activated brain regions when participants made intertemporal choice compared to seeing a black screen. From McClure et al. (2004).</i>	24
Figure 6.1: <i>Design of Experiment 1. (Adapted from McClure et al. (2004), see Figure 2.3) ..</i>	52
Figure 6.2: <i>Behavioral results of Experiment 1.</i>	57
Figure 6.3: <i>Activated brain regions and parameter estimates when participants made intertemporal choices containing an immediate reward compared to choices containing exclusively delayed rewards for SELF and OTHER.</i>	59
Figure 6.4: <i>Activated brain regions and parameter estimates when strongly (and moderately) discounting participants made intertemporal choices containing an immediate reward compared to choices containing exclusively delayed rewards for SELF and OTHER.</i>	61
Figure 7.1: <i>Design of Experiment 2. (Adapted from McClure et al. (2004), see Figure 2.3) ..</i>	66
Figure 7.2: <i>Activated brain regions and parameter estimates when participants made intertemporal choices containing an immediate reward compared to choices containing exclusively delayed rewards for SELF and OTHER.</i>	69
Figure 7.3: <i>A conjunction analysis of the contrast comparing today and delay trials in SELF from Experiment 1 and 2.</i>	71

List of Tables

Table 2.1: <i>Characteristics of the two systems put forward in dual-processing theories. From Metcalfe & Mischel (1999)</i>	11
Table S1: <i>Set 1 (stimulus material, experiment 1)</i>	105
Table S2: <i>Set 2 (stimulus material, experiment 1)</i>	107
Table S3: <i>Estimated β values (experiment 1)</i>	109
Table S4: <i>Overview of neural activations in experiment 1</i>	110
Table S5: <i>Set 1 (stimulus material, experiment 2)</i>	113
Table S6: <i>Set 2 (stimulus material, experiment 2)</i>	115
Table S7: <i>Overview of neural activations in experiment 2</i>	117

Abbreviations

ACC	Anterior Cingulate Cortex
aMCC	anterior Medial Cingulate Cortex
ANOVA	Analysis of Variance
BA	Brodmann Area
BOLD	Blood-Oxygenation-Dependent
D	Delay trial
DLPFC	Dorsolateral Prefrontal Cortex
dPCC	dorsal Posterior Cingulate Cortex
DUT	Discounted Utility Theory
EPI	Echo-Planar-Imaging
FB	Feedback trial
fMRI	function Magnetic Resonance Imaging
FWHM	Full Width at Half Maximum
GLM	General Linear Model
IFJ	Inferior Frontal Junction
IPS	Intraparietal Sulcus
LIPSIA	Leipzig Image Processing and Statistical Inference Algorithms
LOFC	Lateral Orbitofrontal Cortex
LPFC	Lateral Prefrontal Cortex
MCC	Medial Cingulate Cortex
MDEFT	Modified Driven Equilibrium Fourier Transform
MOFC	Medial Orbitofrontal Cortex
MPFC	Medial Prefrontal Cortex
MRI	Magnetic Resonance Imaging
NULL	presentation of baseline period (black screen with fixation cross)
OFC	Orbitofrontal Cortex
pACC	pregenual Anterior Cingulate Cortex
PCC	Posterior Cingulate Cortex
PD	Parkinson Disease
PET	Positron Emission Tomography
PFC	Prefrontal Cortex
pMCC	posterior Medial Cingulate Cortex
SPM	Statistical Parametric Map

T	Today trial
VLPFC	Ventrolateral Prefrontal Cortex
vPCC	ventral Posterior Cingulate Cortex
vStr	ventral Striatum

Bibliographic details of the dissertation

Albrecht, Konstanze

Brain correlates of cognitive processes underlying intertemporal choice for self and other

Universität Leipzig, Dissertation

145 pages, 214 bibliographical references, 12 figures, 8 tables

Abstract

Offered the choice between two monetary rewards, most people would prefer \$10 today over \$12 in a week, while only few would prefer \$10 in a year over \$12 in a year and a week. Many behavioral studies so far found that humans behave dynamically inconsistent and irrationally when making such monetary decisions called intertemporal choices. Psychological theories assume that special cognitive processes take place only when immediate gratification is possible, leading to such preference reversals. Self-theories suggest that these processes are special in decision making for oneself. Choices made for another person should not elicit the same processes and thus are assumed to be made in a more consistent manner regardless of immediacy. If this assumption holds true, it would have a high impact on explaining mechanisms important in decision delegation processes.

In our first experiment, we investigated brain activation and choice behavior when intertemporal choices were made for oneself and for another, unknown person. We found that when an immediate reward was included in the choice set, intertemporal choices made for oneself were accompanied by activation in highly emotion- and reward-related areas, such as the pregenual anterior cingulate cortex, and the ventral striatum. However, none of these areas showed elevated activation when making such choices for another person. While this is in accordance with our hypothesis concerning the brain correlates of intertemporal choices for self and other, we did not find any behavioral differences in the choices the participants made for themselves and others: In both cases subjects inconsistently chose the smaller, but sooner, reward more often if it was available immediately.

To investigate these discrepancies between choice and neural activation in detail, we splitted our sample into two groups, depending on subjects' individual discount values. Within the group of subjects who discounted future rewards more strongly, we could find the same differences in brain activation patterns between self and other as before. In accordance with

these brain activation differences, we also found behavioral differences between decisions for self and other in this group of strongly discounting subjects: They more often chose the larger, later reward for the other person than for themselves. This shows that at least subjects who discounted future rewards very strongly for themselves chose less impulsively for others.

In our second study we investigated another variable influencing brain activation during such intertemporal choices: passivity. Can humans keep a “cool head” while watching what is decided for them without having any possibility to intervene?

We used the same paradigm, this time letting our participants only observe choices being made for them or for another person. We found greater activity in the inferior frontal junction, intraparietal sulcus, and precuneus when participants observed choices yielding immediate compared to delayed rewards, for both self and other. A conjunction analysis with experiment 1 yielded that contrary to experiment 1, neither when making choices for oneself nor when making choices for another person, activation differences in the pregenual anterior cingulate cortex (pACC) and ventral striatum were found, indicating no differential involvement of these areas in today and delay trials when choices were observed. We concluded that immediate rewards were also special here, but relying on a more general mechanism, because their reception could not be actively influenced.

Zusammenfassung

Einleitung

Traditioneller Theorie der Ökonomie zufolge verhalten sich Menschen rational, eigennützig, zeitlich konsistent und nutzenmaximierend (Samuelson, 1937). Empirische psychologische und ökonomische Forschung hat diverse Verletzungen dieses Modells des „Homo oeconomicus“ aufdecken können (Ainslie, 1975; Frederick, Loewenstein, & O'Donoghue, 2002). Ein wichtiges Ergebnis dieser Forschung ist, dass Menschen sich nicht zeitlich konsistent verhalten. In bestimmten Entscheidungssituationen, auch intertemporale Entscheidungen genannt, weisen sie Präferenzumkehrungen auf. Bietet man Menschen z.B. die (intertemporale) Entscheidung zwischen € 10 jetzt und € 12 in einer Woche an, diskontieren viele die zukünftige Belohnung und entscheiden sich für die sofortige Option. Bietet man ihnen hingegen die gleichen Entscheidungsoptionen um ein Jahr in die Zukunft verschoben an, also € 10 in einem Jahr und € 12 in einem Jahr und einer Woche, wählen viele Menschen die sich zuvor für die frühere Option entschieden haben die spätere Belohnung. Ein solches Entscheidungsverhalten ist eine starke Verletzung des Discounted Utility (DU) Modells, welches von einer exponentiellen Diskontierung zukünftiger Belohnungen ausgeht und keine Präferenzumkehrungen modelliert (Samuelson, 1937).

Neuere Diskontierungsmodelle berücksichtigen Präferenzumkehrungen indem sie einen hyperbolischen (Ainslie & Haslam, 1992; Frederick, et al., 2002) oder quasihyperbolischen (Laibson, 1997) Diskontierungsverlauf annehmen. Diese Modelle werden beide durch empirische Daten unterstützt, aber sie machen unterschiedliche Annahmen über die zu Grunde liegenden kognitiven Prozesse intertemporaler Entscheidungen: Hyperbolische Diskontierung benutzt nur einen Parameter und geht davon aus, dass alle Informationen und Vorstellungen in einen Prozess integriert sind. Das quasihyperbolische Modell hingegen postuliert, basierend auf psychologischen Zweiprozesstheorien, zwei Parameter. Zweiprozesstheorien gehen davon aus, dass intertemporale Entscheidungen auf zwei Prozessen (oder Systemen) beruhen: Schnelle, automatische, emotionale und intuitive Prozesse, die impulsiv sofortige Genugtuung wollen („hot“ System-Prozesse, modelliert durch den β -Parameter), die langsamen, deliberativen und reflektiven Prozessen („cool“ System-Prozesse, modelliert durch den δ -Parameter) gegenüberstehen (McClure, Laibson, Loewenstein, & Cohen, 2004; Metcalfe & Mischel, 1999). Zweiprozessmodelle

nehmen an, dass die zeitliche Nähe einer Belohnung wichtig ist. Sie gehen davon aus, dass „hot“ System-Prozesse eine größere Rolle spielen, wenn eine sofortige Belohnung möglich ist (McClure, et al., 2004; Metcalfe & Mischel, 1999). Dementsprechend wird ein Angebot von € 10 dem Angebot von € 12 vorgezogen, wenn es sofort erhältlich ist, aber nicht, wenn es erst zu einem Zeitpunkt in der Zukunft erhältlich ist. Diese Annahmen spiegeln sich auch in psychologischen und philosophischen Selbsttheorien wider, die von multiplen Selbstern ausgehen, wobei ein zukünftiges Selbst nicht wie das gegenwärtige Selbst behandelt wird, sondern eher wie eine andere Person wahrgenommen wird (James, 1890; Parfit, 1984). Seine „Selbste“ unterschiedlich zu behandeln kann zu Präferenzumkehrungen führen, da Menschen annehmen können, dass ein zukünftiges Selbst andere Präferenzen als ein gegenwärtiges Selbst hat (Kivetz & Tyler, 2007). Es wurde gezeigt, dass Entscheidungen für ein zukünftiges Selbst idealistisch sind. Teilnehmer einer Studie wählten Universitätskurse, die ihnen eine respektvolle Behandlung und ernsthafte Auseinandersetzung mit ihren Standpunkten versprachen. Entscheidungen für ein gegenwärtiges Selbst hingegen scheinen pragmatisch zu sein. Wenn Teilnehmer der Studie zwischen verschiedenen Kursen mit sofortigem Beginn wählten, entschieden sie sich häufiger für Kurse, die gute Noten und weniger Arbeit versprachen (Kivetz & Tyler, 2007). Dementsprechend scheinen Menschen sofortige Belohnungen zu bevorzugen, da dies pragmatisch ist. Aber sie würden in Zukunft gern geduldiger und selbstdisziplinierter sein und haben daher andere Präferenzen, wenn keine sofortige Belohnung erhältlich ist.

McClure und Kollegen (2004) benutzten funktionelle Magnetresonanztomographie (fMRT) um die Annahme zweier Systeme (oder Prozesses, oder Selbstes) zu untersuchen. Ihre Arbeit konnte zeigen, dass die hämodynamische Aktivität im ventralen Striatum (vStr), prägenualen anterioren cingulären Cortex (pACC) und Precuneus größer war wenn sofortige Belohnungen gewählt werden konnten (wie z.B. € 10 jetzt vs. € 12 in einer Woche) als wenn ausschließlich zukünftige Belohnungen zur Verfügung waren (wie z.B. € 10 in einem Jahr vs. € 12 in einem Jahr und einer Woche). Die Autoren bezeichnen diese Areale, die schon oft im Zusammenhang mit der Verarbeitung von Emotionen und Belohnungen berichtet wurden, als „hot“ System-Areale oder β -Areale. Sie gehen davon aus dass durch eine höhere Beteiligung dieser Areale in der Verarbeitung sofortiger Belohnungen impulsivere Entscheidungen getroffen werden (d.h., dass die frühere der späteren Belohnung vorgezogen wird).

In dieser Arbeit benutzen wir fMRT um zu untersuchen, ob intertemporale Entscheidungen für andere Personen auf anderen Verarbeitungsprozessen beruhen als Entscheidungen für sich selbst. Wir wollten damit folgende Fragen beantworten: 1) Sind unterschiedliche Gehirnareale beteiligt, wenn Menschen intertemporale Entscheidungen für sich selbst oder andere Personen treffen? 2) Treffen Menschen Entscheidungen für andere Menschen auf einer deliberativeren Basis, verhalten sich konsistent mit ökonomischer Theorie und entscheiden also rationaler wenn sie selbst nicht von ihren Entscheidungen betroffen sind? Diese Fragen sind besonders in Zusammenhang mit Entscheidungsdelegation interessant. In Politik, medizinischer Behandlung und bei Gerichtsprozessen ist nicht nur Expertise gefragt, sondern auch ein objektiver Blickwinkel der zu rationaleren Entscheidungen führt. Patienten oder Klienten sind selbst oft nicht in der Lage, Entscheidungen in gleicher Weise zu treffen, da sie persönlich und emotional involviert sind (Moran, Macrae, Heatherton, Wyland, & Kelley, 2006).

Weiterhin waren wir an den kognitiven Prozessen in Teilnehmern interessiert, die zusehen wie Entscheidungen für sie oder andere Personen getroffen werden. Können sie einen „kühlen Kopf“ behalten während sie Entscheidungen beobachten müssen, deren Ausgang sie nicht beeinflussen können? D.h., 1) Sind unterschiedliche Gehirnareale beteiligt wenn Entscheidungen mit sofortiger Belohnung beobachtet werden im Vergleich zum Beobachten von Entscheidungen mit ausschließlich zukünftigen Belohnungsoptionen? 2) Unterscheiden sich Aktivierungen in Abhängigkeit davon, ob das Treffen von Entscheidungen für sich selbst oder für eine andere Person beobachtet wird?

Experiment 1

In diesem ersten Experiment trafen Teilnehmer eine Serie intertemporaler Entscheidungen zwischen entweder einem sofortigen, kleineren und einem späteren, größeren Geldbetrag (von hier an „today trials“ genannt), oder zwischen einem früheren (aber nicht sofortigen), kleineren und einem späteren, größeren Geldbetrag (von hier an „delay trials“ genannt). Sie trafen 40 der 80 Entscheidungen für sich selbst, und 40 Entscheidungen für eine andere, unbekannte Person.

Wir nahmen an, dass intertemporale Entscheidungen keine Präferenzumkehrungen zeigen würden, wenn diese Entscheidungen für eine andere Person getroffen werden. Diese

Annahme trafen wir auf Grund der oben erwähnten Selbsttheorien und empirischen Ergebnissen, die davon ausgehen dass Menschen andere (gegenwärtige und zukünftige) Personen ähnlich behandeln wie zukünftige Selbste (James, 1890; Parfit, 1984). Entsprechend erwarteten wir im Gehirn die Beteiligung unterschiedlicher Areale in Abhängigkeit vom Empfänger der Belohnung: der Teilnehmer selbst („self“) oder eine andere Person („other“). Wir sagten Aktivierungsunterschiede zwischen „today trials“ und „delay trials“ in den Arealen die von McClure et al. (2004) identifiziert wurden nur dann voraus, wenn Entscheidungen für sich selbst getroffen wurden. Wir erwarteten diesen Unterschied nicht, wenn Entscheidungen für andere Personen getroffen wurden. Dies wäre im Einklang mit Zweiprozessmodellen und Selbsttheorien, die von gegenwärtigen und zukünftigen Selbsten ausgehen.

Da behaviorale Studien zeigten, dass Unterschiede in Entscheidungen für sich selbst und andere Personen von der emotionalen Involviertheit der Teilnehmer abhingen, erwarteten wir außerdem, dass emotionale Involviertheit, also Impulsivität, eine Rolle spielen würde (Beisswanger, Stone, Hupp, & Allgaier, 2003; McClure, Botvinick, Yeung, Greene, & Cohen, 2006). Wir gingen davon aus, dass höhere Impulsivität zu größeren behavioralen und Aktivierungsunterschieden in „today trials“ zwischen „self“ und „other“ führt.

Im Einklang mit unseren Hypothesen beobachteten wir einen Einfluss der Impulsivität auf das Entscheidungsverhalten für „self“ und „other“: Hoch impulsive Teilnehmer (definiert durch den Wert des β -Parameters) wählten die sofortige Belohnung für den anderen weniger oft als für sich selbst. Betrachtet man allerdings das gesamte Wahlverhalten, zeigten Teilnehmer im Widerspruch zu unseren Hypothesen Präferenzumkehrungen für beide, sich selbst und die andere Person. Das bedeutet, dass Teilnehmer (unabhängig vom Empfänger) die frühere Belohnung häufiger wählten, wenn diese sofort und nicht erst später erhältlich war.

Entsprechend unserer Erwartungen beobachteten wir Aktivierungen in einem medial-präfrontalen-medial-parietalen Netzwerk, welches das ventrale Striatum enthält, wenn eine sofortige Belohnung für sich selbst möglich war, aber nicht, wenn eine solche für eine andere Person angeboten wurde. Diese Aktivierungsunterschiede waren größer bei stark diskontierenden (impulsiveren) Teilnehmern und lassen daher einen Zusammenhang der beobachteten Aktivierung und des intertemporalen Entscheidungsverhaltens vermuten.

Experiment 2

In diesem zweiten Experiment beobachteten Teilnehmer das Treffen von intertemporalen Entscheidungen für sie und für andere Personen. Das Paradigma gleichte dem von Experiment 1, nur das jetzt kein Tastendruck zur Anzeige der eigenen Entscheidung nötig war. Die Teilnehmer sahen stattdessen, welche der beiden dargebotenen Optionen gewählt wurde. Ihnen wurde mitgeteilt, dass diese Entscheidungen von einem anderen Studienteilnehmer außerhalb des MRT getroffen wurden. Die Teilnehmer im Tomographen beobachteten 80 Entscheidungen, wobei 40 davon für sie, und 40 für eine andere, unbekannte Person getroffen wurden.

Wir nahmen an, dass auch hier die Möglichkeit einer sofortigen Belohnung eine wichtige Rolle spielt. Ein behaviorales Experiment zeigte, dass das Beobachten von Entscheidungen zum Lernen einer erfolgreicherer Gewinnstrategie führt als das Treffen von Entscheidungen (Merlo & Schotter, 2003). Wir erwarteten entsprechend, dass das Beobachten von Entscheidungen mit der Möglichkeit einer sofortigen Belohnung nicht notwendigerweise mit Aktivierungen in emotions- und belohnungsrelatierten Hirnarealen einhergeht. Stattdessen erwarteten wir Aktivierungen in lateralen präfrontalen und parietalen Arealen, die zuvor im Zusammenhang mit Kalkulations- und Gedächtnisprozessen berichtet wurden (Dehaene, Molko, Cohen, & Wilson, 2004; Derrfuss, Brass, & von Cramon, 2004; Henson, Rugg, Shallice, Josephs, & Dolan, 1999; Ishai, Haxby, & Ungerleider, 2002). Weiterhin wurde die Frage untersucht, ob es Aktivierungsunterschiede in Abhängigkeit des Empfängers der Belohnung („self“ oder „other“) im zeitlichen Zusammenhang mit der Auszahlung („today trials“ oder „delay trials“) gibt.

Unsere Ergebnisse stützen unsere Hypothesen, die höhere Aktivität in lateralen präfrontalen und parietalen Arealen für „today trials“ im Vergleich zu „delay trials“ beim Beobachten von Entscheidungen vorhergesagt haben. Wir konnten erhöhte Aktivität im inferioren Kreuzungsareal und im intraparietalen Sulcus beobachten, wenn eine sofortige Belohnung („today trials“) eine Option war, unabhängig davon, wer diese Belohnung erhalten sollte. Dies spricht dafür, dass die Versuchsteilnehmer stärker am Ausgang der Entscheidungen interessiert sind, wenn diese eine sofortige Belohnungsoption enthalten. Außerdem zeigte eine Konjunktionsanalyse mit Experiment 1, dass im Gegensatz zu Experiment 1, hier keine Aktivierungsunterschiede im pACC oder vStr gefunden werden konnten. Dies weist darauf

hin, dass die Beteiligung dieser Areale in „today trials“ und „delay trials“ sich nicht unterscheidet wenn Entscheidungen nur beobachtet und nicht selbst getroffen werden (Elliott, Newman, Longe, & Deakin, 2004; Tricomi, Delgado, & Fiez, 2004; Zink, Pagnoni, Chappelow, Martin-Skurski, & Berns, 2006).

Schlussfolgerung

Die beiden Studien konnten zeigen, dass die Möglichkeit einer sofortigen Belohnung sich von der Möglichkeit einer zukünftigen Belohnung unterscheidet.

Aktivierungen in emotions- und belohnungsrelatierten Arealen wie dem vStr und pACC waren stärker wenn sofortige Belohnungen für den Teilnehmer selbst wählbar waren, aber nicht wenn diese für die andere Person gewählt werden konnten. Dies weist darauf hin, dass unterschiedliche, möglicherweise weniger affektive Prozesse beteiligt sind, wenn Entscheidungen für eine andere Person getroffen werden. Dies kann eine wichtige Rolle bei Entscheidungsdelegationen in Verhandlungen spielen.

Außerdem konnten wir zeigen, dass die Möglichkeit einer sofortigen Belohnung auch wichtig ist, wenn Entscheidungen beobachtet werden. Aktivierungen in lateralen präfrontalen und parietalen Hirnarealen sprechen dafür, dass hier allerdings eher „cool“ System-Prozesse beteiligt sind. Die Einflussmöglichkeit, die ein Mensch auf Entscheidungen hat, scheint also eine wichtige Rolle für die Beteiligung von „hot“ System-Prozessen zu spielen. Das Nicht-Verantwortlichsein für eine Entscheidung scheint hingegen zu weniger emotionaler Involviertheit zu führen.

Zusammenfassend weisen diese Befunde darauf hin, dass Entscheidungen für sich selbst von anderen Aktivierungen als Entscheidungen für andere Personen begleitet werden. Das dies nicht der Fall ist, wenn das Treffen von Entscheidungen für sich selbst oder eine andere Person nur beobachtet wird, deutet darauf hin, dass hier ein allgemeinerer, deliberativer Mechanismus beteiligt ist.

Summary

Introduction

According to traditional economic theory, people behave rationally, selfish, consistently over time, and utility maximizing (Samuelson, 1937). Manifold violations from this model (also known as “homo economicus”) have been found in empirical psychological and economic research (Ainslie, 1975; Frederick, et al., 2002). Most importantly for this thesis, it has been found that people do not behave consistently over time. Instead, people show preference reversals in specific decision situations that are termed intertemporal choice. For instance, given the (intertemporal) choice between € 10 now and € 12 in a week, many people would discount the future reward and decide to take the immediate reward. Offered the same choice shifted in time by a year, i.e., between € 10 in one year and € 12 in a year and a week, several of those who chose the sooner option before would now choose to wait for the larger payoff. This choice behavior is a strong violation of the discounted utility (DU) model, which assumes exponential discounting of future rewards, and models no such preference reversals (Samuelson, 1937).

More recent discount models take into account preference reversals by assuming hyperbolic (Ainslie & Haslam, 1992; Frederick, et al., 2002) or quasi-hyperbolic (Laibson, 1997) discounting. Both these models fit empirical data well, but make different assumptions concerning the underlying processes: Hyperbolic discounting uses only one parameter, assuming an integration of all information and desires into one process. The quasi-hyperbolic discount model on the contrary posits two parameters based on psychological dual-processing theory. This theory assumes that two kinds of processes (or systems) are engaged in temporal discounting: Fast, automatic, emotional, and intuitive processes impulsively going for immediate gratification (hot system processes, modelled by the β parameter), which are opposed by slow, deliberative, and reflective processes (cool system processes, modelled by the δ parameter), (McClure, et al., 2004; Metcalfe & Mischel, 1999). It is suggested that due to the temporal proximity of the reward, hot system processes play a bigger role when an immediate reward is available than when both rewards are delayed (McClure, et al., 2004; Metcalfe & Mischel, 1999). Hence, € 10 are preferred to € 12 when available immediately, but not when available after a delay period. This is also in line with assumptions of

psychological and philosophical self theories, suggesting multiple selves with a future self being treated as if it were another person rather than being the same as the present self (James, 1890; Parfit, 1984). Treating one's "selves" differently can lead to preference reversals, since people might assume a future self to have other preferences than a present self (Kivetz & Tyler, 2007). Choices for a future self have been shown to be idealistic (i.e., participants chose to attend a future college course offering respectful treatment of the students and serious consideration of the students' points of view). On the contrary, choices for a present self are more pragmatic (i.e., participants chose to attend an immediately starting college course offering good grades and a low work load), (Kivetz & Tyler, 2007). Accordingly, human beings seem to go for immediate rewards because it is pragmatic, but want themselves to be more patient and self-controlled in the future, and thus their preferences may change when no immediate reward is available.

McClure and colleagues (2004) investigated the assumption of two systems (or processes, or selves) using functional magnetic resonance imaging (fMRI). Their work showed that hemodynamic activation in the ventral striatum (vStr), pregenual anterior cingulate cortex (pACC), and precuneus was larger in choices involving immediate rewards (e.g. €10 now vs. €12 in a week) compared to choices involving exclusively delayed rewards (e.g. €10 in a year vs. €12 in a year and a week). The authors labelled these areas, which have often been reported to be involved in reward and emotion processing, as "hot system or β areas". They claim that due to a higher involvement of these areas when immediate rewards are involved, choices made are more impulsive (i.e., the sooner reward is chosen over the later reward more often).

In this thesis, we used functional magnetic resonance imaging (fMRI) to investigate whether intertemporal choice for another person relies on different processes than intertemporal choice for oneself. We wanted to answer the following questions: 1) Are different brain areas involved when people make intertemporal choices including immediate rewards for themselves and for another person? 2) Do human beings make choices for other persons on a more deliberative basis, behave more consistently with economic theory, and hence decide more rationally when they themselves are not affected by their decisions? This is of importance in different fields of decision delegation, such as politics, medical treatments, and legal cases. Not only is expertise asked in these fields, but also an objective view leading to a

more rational decision. Patients or clients themselves might often not be able to decide in this manner, because of their personal and emotional involvement (Moran, et al., 2006).

We were further interested in brain activation of participants observing choices being made for them by other persons. Can they keep a “cool head” while watching what is decided for them without having any possibility to intervene? i.e., 1) Are different brain areas engaged when choices involving immediate rewards are observed compared to choices exclusively involving delayed rewards? 2) Does brain activation differ when choices are observed being made for oneself and for another person?

Experiment 1

In this first experiment, participants made a series of intertemporal choices, each either between an immediate, smaller reward and a later, larger reward (from here on called “today trials”), or between a sooner, (but not immediate) smaller and a later, larger reward (from here on called “delay trials”). They made 40 of the 80 choices for themselves, and 40 choices for another, unknown person.

We hypothesized that intertemporal choice would show no preference reversals when choices were made for another person. This prediction was made on the basis of the aforementioned self theories and empirical findings on intertemporal choice, that assume human beings to treat other (present and future) persons and future selves similarly (James, 1890; Parfit, 1984). Accordingly, we further expected brain correlates of intertemporal choice to differ when choices were made for self and other. We predicted activation differences between choices involving immediate rewards (today trials) and choices involving exclusively delayed rewards (delay trials) in the areas found by McClure and colleagues (2004) only, when choices were made for oneself. We did not expect these differences when choices were made for another person. This would be in line with dual processing theories and self theories stating multiple selves and distinguishing present selves and future selves.

Since behavioral differences in decision making for self and other depending on the emotional involvement of the participants in the task were found, we further expected that emotional involvement, expressed by impulsivity, would play a role (Beisswanger, et al., 2003; McClure, et al., 2006). We hypothesized that higher impulsivity leads to higher behavioral and activation differences in today trials between self and other.

In accordance with our hypotheses, we observed an influence of impulsivity on decision making for self and other: Highly impulsive participants (defined by the value of the β parameter) chose the immediate reward less often for the other person than for themselves. Concerning overall choice behavior, contrary to our hypothesis, participants showed preference reversals for both themselves and other persons when making intertemporal choices. That is, participants chose the sooner over the later option more often if it was available immediately than if it was delayed (irrespective of the receiver). As expected, we observed activation within a medial-prefrontal-medial-parietal brain network including the ventral striatum for the effects of immediacy when choices were made for oneself, but not when choices were made for another person. These activation differences were larger in strongly discounting participants, suggesting a correspondence of the observed activation and intertemporal choice behavior.

Experiment 2

In this second experiment, participants observed intertemporal choices being made for themselves and for other persons. The paradigm equalled that of experiment 1, but here, instead of pressing a button to indicate their choice, participants only saw which of the two options was chosen. They were told that this choice was being made by another participant on a computer outside of the fMRI-scanner. Participants in the scanner observed 80 choices made (outside the scanner). 40 of these choices were made for themselves and 40 choices were made for yet another, unknown person (outside the scanner).

We hypothesized that immediacy (as displayed in today trials) plays a special role when observing choices being made by another person. A behavioral experiment showed that observing choices leads to learning a more successful winning strategy than making choices oneself (Merlo & Schotter, 2003). We accordingly expected the observation of choices involving immediate rewards not necessarily being accompanied by activation in emotion- and reward related brain areas, but rather by activation of lateral prefrontal and parietal areas reported to be involved in calculation and memory processes (Dehaene, et al., 2004; Derrfuss, et al., 2004; Henson, et al., 1999; Ishai, et al., 2002). Further, the question about activation differences between observing choices made for oneself and observing choices made for

another person was explored by varying the receiver (self and other) as well as the temporal distances of the rewards (today trials and delay trials).

Our results support the hypothesis of stronger activation in lateral prefrontal and parietal areas for today compared to delay trials when participants observed intertemporal choices. We found elevated activation in the inferior frontal junction and intraparietal sulcus when choices including immediate rewards were involved. This suggests that participants were more strongly interested in the outcome of a choice when it contained an immediate option. Furthermore, a conjunction analysis of the two experiments yielded that contrary to experiment 1, neither when observing choices for oneself nor when observing choices for another person, activation differences in the pACC and vStr were found. This indicates that the involvement of these areas in today and delay trials does not differ when choices are observed (Elliott, et al., 2004; Tricomi, et al., 2004; Zink, et al., 2006).

Conclusion

In summary, the present studies could show that immediacy (i.e., the possibility of receiving immediate rewards) differs compared to receiving delayed rewards.

Activation in emotion- and reward-related regions like the vStr and pACC was elevated more highly when immediate rewards were available for oneself compared to for another person. This suggests that different, probably less affective processes are engaged when choices are made for another person, underlining the importance of decision delegation in cases such as negotiation.

Further, the special role of immediacy also showed when choices were observed being made by another person. Activation in lateral prefrontal and lateral parietal areas was found when decision making was observed, hence only cool system processes seemed to operate. This suggests that the influence a person has on a decision plays a crucial role concerning the involvement of hot system processes. Not being in charge of making a decision assumingly leads to less emotional involvement.

Together these findings suggest that choices made for oneself are accompanied by different brain activation than choices made for another person, while activation during choices observed made for oneself or another person did not differ, and hence may rely on a more general, deliberative mechanism.

Curriculum Vitae

Name	Konstanze Albrecht
Date of birth	20.07.1980
Place of birth	Torgau
Since 2006	Doctoral candidate at the Max Planck Institute for Human Cognitive and Brain Sciences
1999-2005	Course of studies in Psychology at the University of Leipzig
1992-1999	Joe-Polowsky-Gymnasium, Torgau
1987-1992	Polytechnische Oberschule „Wladimir Komarow“, Weidenhain

Verzeichnis der eigenen Publikationen und Vorträge

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Selbstständigkeitserklärung

Hiermit erkläre ich, dass die vorliegende Arbeit ohne unzulässige Hilfe und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt wurde und dass die aus fremden Quellen direkt oder indirekt übernommenen Gedanken in der Arbeit als solche kenntlich gemacht worden sind.

Konstanze Albrecht

15.03.2009

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- 41 Peggy Bungert
*Zentralnervöse Verarbeitung akustischer Informationen
Signalidentifikation, Signallateralisation und zeitgebundene Informationsverarbeitung bei Patienten mit erworbenen Hirnschädigungen*
- 42 Daniel Senkowski
Neuronal correlates of selective attention: An investigation of electro-physiological brain responses in the EEG and MEG
- 43 Gert Wollny
Analysis of Changes in Temporal Series of Medical Images
- 44 Angelika Wolf
Sprachverstehen mit Cochlea-Implantat: EKP-Studien mit postlingual ertaubten erwachsenen CI-Trägern
- 45 Kirsten G. Volz
Brain correlates of uncertain decisions: Types and degrees of uncertainty
- 46 Hagen Huttner
Magnetresonanztomographische Untersuchungen über die anatomische Variabilität des Frontallappens des menschlichen Großhirns
- 47 Dirk Köster
Morphology and Spoken Word Comprehension: Electrophysiological Investigations of Internal Compound Structure
- 48 Claudia A. Hruska
Einflüsse kontextueller und prosodischer Informationen in der auditorischen Satzverarbeitung: Untersuchungen mit ereigniskorrelierten Hirnpotentialen
- 49 Hannes Ruge
Eine Analyse des raum-zeitlichen Musters neuronaler Aktivierung im Aufgabenwechselparadigma zur Untersuchung handlungssteuernder Prozesse
- 50 Ricarda I. Schubotz
Human premotor cortex: Beyond motor performance
- 51 Clemens von Zerssen
*Bewusstes Erinnern und falsches Wiedererkennen:
Eine funktionelle MRT Studie neuroanatomischer Gedächtniskorrelate*
- 52 Christiane Weber
*Rhythm is gonna get you.
Electrophysiological markers of rhythmic processing in infants with and without risk for Specific Language Impairment (SLI)*
- 53 Marc Schönwiesner
Functional Mapping of Basic Acoustic Parameters in the Human Central Auditory System
- 54 Katja Fiehler
Temporospatial characteristics of error correction

- 55 Britta Stolterfoht
Processing Word Order Variations and Ellipses: The Interplay of Syntax and Information Structure during Sentence Comprehension
- 56 Claudia Danielmeier
Neuronale Grundlagen der Interferenz zwischen Handlung und visueller Wahrnehmung
- 57 Margret Hund-Georgiadis
Die Organisation von Sprache und ihre Reorganisation bei ausgewählten, neurologischen Erkrankungen gemessen mit funktioneller Magnetresonanztomographie – Einflüsse von Händigkeit, Läsion, Performanz und Perfusion
- 58 Jutta L. Mueller
Mechanisms of auditory sentence comprehension in first and second language: An electrophysiological miniature grammar study
- 59 Franziska Biedermann
Auditorische Diskriminationsleistungen nach unilateralen Läsionen im Di- und Telenzephalon
- 60 Shirley-Ann Rüchemeyer
The Processing of Lexical Semantic and Syntactic Information in Spoken Sentences: Neuroimaging and Behavioral Studies of Native and Non-Native Speakers
- 61 Kerstin Leuckefeld
The Development of Argument Processing Mechanisms in German. An Electrophysiological Investigation with School-Aged Children and Adults
- 62 Axel Christian Kühn
Bestimmung der Lateralisierung von Sprachprozessen unter besondere Berücksichtigung des temporalen Cortex, gemessen mit fMRT
- 63 Ann Pannekamp
Prosodische Informationsverarbeitung bei normalsprachlichem und deviantem Satzmaterial: Untersuchungen mit ereigniskorrelierten Hirnpotentialen
- 64 Jan Derrfuß
Functional specialization in the lateral frontal cortex: The role of the inferior frontal junction in cognitive control
- 65 Andrea Mona Philipp
The cognitive representation of tasks Exploring the role of response modalities using the task-switching paradigm
- 66 Ulrike Toepel
Contrastive Topic and Focus Information in Discourse – Prosodic Realisation and Electrophysiological Brain Correlates
- 67 Karsten Müller
Die Anwendung von Spektral- und Waveletanalyse zur Untersuchung der Dynamik von BOLD-Zeitreihen verschiedener Hirnareale
- 68 Sonja A.Kotz
The role of the basal ganglia in auditory language processing: Evidence from ERP lesion studies and functional neuroimaging
- 69 Sonja Rossi
The role of proficiency in syntactic second language processing: Evidence from event-related brain potentials in German and Italian
- 70 Birte U. Forstmann
Behavioral and neural correlates of endogenous control processes in task switching
- 71 Silke Paulmann
Electrophysiological Evidence on the Processing of Emotional Prosody: Insights from Healthy and Patient Populations

- 72 Matthias L. Schroeter
Enlightening the Brain – Optical Imaging in Cognitive Neuroscience
- 73 Julia Reinholz
Interhemispheric interaction in object- and word-related visual areas
- 74 Evelyn C. Ferstl
The Functional Neuroanatomy of Text Comprehension
- 75 Miriam Gade
Aufgabeninhibition als Mechanismus der Konfliktreduktion zwischen Aufgabenrepräsentationen
- 76 Juliane Hofmann
Phonological, Morphological, and Semantic Aspects of Grammatical Gender Processing in German
- 77 Petra Augurzky
Attaching Relative Clauses in German – The Role of Implicit and Explicit Prosody in Sentence Processing
- 78 Uta Wolfensteller
Habituelle und arbiträre sensomotorische Verknüpfungen im lateralen prämotorischen Kortex des Menschen
- 79 Päivi Sivonen
Event-related brain activation in speech perception: From sensory to cognitive processes
- 80 Yun Nan
Music phrase structure perception: the neural basis, the effects of acculturation and musical training
- 81 Katrin Schulze
Neural Correlates of Working Memory for Verbal and Tonal Stimuli in Nonmusicians and Musicians With and Without Absolute Pitch
- 82 Korinna Eckstein
Interaktion von Syntax und Prosodie beim Sprachverstehen: Untersuchungen anhand ereigniskorrelierter Hirmpotentiale
- 83 Florian Th. Siebörger
Funktionelle Neuroanatomie des Textverstehens: Kohärenzbildung bei Witzen und anderen ungewöhnlichen Texten
- 84 Diana Böttger
Aktivität im Gamma-Frequenzbereich des EEG: Einfluss demographischer Faktoren und kognitiver Korrelate
- 85 Jörg Bahlmann
Neural correlates of the processing of linear and hierarchical artificial grammar rules: Electrophysiological and neuroimaging studies
- 86 Jan Zwickel
Specific Interference Effects Between Temporally Overlapping Action and Perception
- 87 Markus Ullsperger
Functional Neuroanatomy of Performance Monitoring: fMRI, ERP, and Patient Studies
- 88 Susanne Dietrich
Vom Brüllen zum Wort – MRT-Studien zur kognitiven Verarbeitung emotionaler Vokalisationen
- 89 Maren Schmidt-Kassow
What's Beat got to do with it? The Influence of Meter on Syntactic Processing: ERP Evidence from Healthy and Patient populations
- 90 Monika Lück
Die Verarbeitung morphologisch komplexer Wörter bei Kindern im Schulalter: Neuropsychologische Korrelate der Entwicklung

- 91 Diana P. Szameitat
Perzeption und akustische Eigenschaften von Emotionen in menschlichem Lachen
- 92 Beate Sabisch
Mechanisms of auditory sentence comprehension in children with specific language impairment and children with developmental dyslexia: A neurophysiological investigation
- 93 Regine Oberecker
Grammatikverarbeitung im Kindesalter: EKP-Studien zum auditorischen Satzverstehen
- 94 Şükrü Barış Demiral
Incremental Argument Interpretation in Turkish Sentence Comprehension
- 95 Henning Holle
The Comprehension of Co-Speech Iconic Gestures: Behavioral, Electrophysiological and Neuroimaging Studies
- 96 Marcel Braß
Das inferior frontale Kreuzungsareal und seine Rolle bei der kognitiven Kontrolle unseres Verhaltens
- 97 Anna S. Hasting
Syntax in a blink: Early and automatic processing of syntactic rules as revealed by event-related brain potentials
- 98 Sebastian Jentschke
Neural Correlates of Processing Syntax in Music and Language – Influences of Development, Musical Training and Language Impairment
- 99 Amelie Mahlstedt
*The Acquisition of Case marking Information as a Cue to Argument Interpretation in German
An Electrophysiological Investigation with Pre-school Children*
- 100 Nikolaus Steinbeis
Investigating the meaning of music using EEG and fMRI
- 101 Tilmann A. Klein
Learning from errors: Genetic evidence for a central role of dopamine in human performance monitoring
- 102 Franziska Maria Korb
Die funktionelle Spezialisierung des lateralen präfrontalen Cortex: Untersuchungen mittels funktioneller Magnetresonanztomographie
- 103 Sonja Fleischhauer
Neuronale Verarbeitung emotionaler Prosodie und Syntax: die Rolle des verbalen Arbeitsgedächtnisses
- 104 Friederike Sophie Haupt
The component mapping problem: An investigation of grammatical function reanalysis in differing experimental contexts using event-related brain potentials
- 105 Jens Brauer
Functional development and structural maturation in the brain's neural network underlying language comprehension
- 106 Philipp Kanske
Exploring executive attention in emotion: ERP and fMRI evidence
- 107 Julia Grieser Painter
Music, meaning, and a semantic space for musical sounds
- 108 Daniela Sammler
The Neuroanatomical Overlap of Syntax Processing in Music and Language - Evidence from Lesion and Intracranial ERP Studies

- 109 Norbert Zmyj
Selective Imitation in One-Year-Olds: How a Model's Characteristics Influence Imitation
- 110 Thomas Fritz
Emotion investigated with music of variable valence – neurophysiology and cultural influence
- 111 Stefanie Regel
The comprehension of figurative language: Electrophysiological evidence on the processing of irony
- 112 Miriam Beisert
Transformation Rules in Tool Use
- 113 Veronika Krieghoff
Neural correlates of Intentional Actions
- 114 Andreja Bubić
Violation of expectations in sequence processing
- 115 Claudia Männel
Prosodic processing during language acquisition: Electrophysiological studies on intonational phrase processing