On the role of executive subcomponents, goal mechanisms, and methods of measurement in decision making under risk conditions

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Johannes Schiebener
aus
Duisburg

1. Gutachter: Prof. Dr. Matthias Brand

2. Gutachter: A.o. Univ. Prof. Dr. Margarete Delazer

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Study 2:

Schiebener, J., Wegmann, E., Pawlikowski, M., & Brand, M. (under review). Effects of goals on decisions under risk conditions: Goals can help to make better choices, but unrealistic high goals increase risk-taking. *Journal of Cognitive Psychology*.

Study 3:

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Table of contents

1. General Abstract

In several scientific disciplines human decision-making behavior has gained rapidly growing interest in the last decades. Neuropsychological research made remarkable effort to investigate the cognitive and emotional processes involved during decision making in different types of decision situations, for example under ambiguity and under risk conditions. In decisions under risk conditions, explicit information about the rules for gains and losses is available to the decision maker (Brand, Labudda, & Markowitsch, 2006; Yates & Stone, 1992). In the wide research field on this type of decisions, there are still theoretical and methodological gaps. Three outstanding gaps are addressed in this thesis. First, a neuropsychological model that theoretically describes the processes involved in these decisions was proposed by Brand and colleagues (2006) but still waits to be specified. Particularly, the model suggests executive functions as the main director of decision-making behavior, but it is not described in detail which subcomponents of the central executive system contribute in which way to decision making. Second, the model does not incorporate one of the main moderators of human behavior and cognitive performance: explicit outcome goals. Third, a methodological gap in decision-making research is to be found in the measurement of decision-making competences. For the measurement several laboratory gambling tasks are used. The variety of existing tasks as well the tasks' architectures severely restrict the theoretical and practical conclusions that can be drawn from the results they provide. The main problems of the tasks are that they differ with regard to several attributes, are often inflexible for experimental manipulation, and that their ecological validities are restricted due to their gambling orientation. The first two studies of this thesis aimed to fill the gaps in the theoretical model. Study 1 investigated the role of different executive subcomponents in decision-making performance. It was found that particularly strategy managing functions, such as planning and monitoring, predicted performance, while situation processing functions, such as attention/inhibition and coding of information, supported the strategy managing operations. Study 2 investigated the effects of explicit goals on performance in a decision situation that provides increased strategic control. Realistic and attainable goals were found to have a positive effect, improving decision-making performance. In contrast, if the goals were unrealistic and too high, performance decreased. Study 3 evaluated an innovative methodological framework for measuring decision-making performance. The new framework allows designing several decision-making problems within one real-world oriented and unitary story line. The attributes of three standard decision-making tasks were mapped to the new scenario and it was found that participants behaved similarly in the new scenario compared to the original tasks. This indicates that the new scenario measures decision-making performance accurately. The results of the three studies enhance the theoretical understanding of the neurocognitive processes involved in decision making under risk conditions and open new perspectives for the examination of decision-making competence. A specified theoretical model is suggested, which incorporates the executive sub-processes directing the decision-making process, as well as the role of explicit goal setting and other situational conditions. These adaptions are supposed to help to better explain variances in decision-making competence as they can be found in healthy persons as well as patients with neurological or psychiatric diseases.

2. General Introduction

Every day, humans have to make several decisions. Each decision can affect one or more aspects of the decision-maker's life, the lives of other individuals, the success of a company, or several other entities that may be affected by the consequences of the decision. For example, a business consultant may have an engagement in a business enterprise. The consultant is asked to attend managers' strategy-meetings and to provide professional advice. One day the consultant is behind the day's schedule, but needs to make sure to arrive with a minimum of delay at a meeting at the company's place of business. The company will only pay for the time the consultant is present. Therefore, depending on the amount of delay, the company will reduce the salary for the consultation. The consultant plans to go by car and has to decide between two routes to the company: One is very short and the consultant would arrive on time if the route is free of traffic jams. Unfortunately, on four of five working days there is a heavy traffic jam on this route and if this was the case today the consultant would arrive late and lose almost his whole salary. The alternative route is a long detour around the first route, and the consultant would certainly be late, resulting in a moderate loss of his salary. On this route it is also possible to get into a traffic jam. However, the traffic jam along this route is usually rather short and occurs only about three times a week. Thus, getting into a traffic jam would result in some increase of the delay and thereby a loss of three thirds of his salary. How will the consultant be able to make a decision that will probably lead to an advantageous outcome? This thesis investigates the cognitive abilities that are required to make an advantageous decision in this and comparable situations understood as decisions under risk conditions. This thesis also addresses possible situational influences on decision-making behavior. The focus is set on the neurocognitive functions involved in the decision and on the effect of explicit outcome goals as situational influence. Furthermore, it will be examined how the ability to make decisions advantageously can be measured in the laboratory.

Trying to understand human decision making is a topic that has gained rapidly growing interest in psychological science in the last two decades (i.e. from the 1990s to 2013). The psychological subfields of general psychology, neuropsychology, economic psychology, and neuroeconomics have made remarkable efforts towards a better understanding of the complex processes involved in decision making as well as the situational conditions influencing these processes and the resulting decisions (e.g., Bechara, 2011a; Brand et al., 2006; Ernst & Paulus, 2005; Kahneman, 2003; Loewenstein, Rick, & Cohen, 2008). Theoretically describing these processes and influences has not only relevance for decision-making researchers, but it is also important for practical reasons (e.g., Denburg et al., 2007). A precise description of the effects of situational influences and cognitive mechanisms on the quality of a decision could help humans to improve their decisions in several contexts of their lives (ranging from personal life to health problems or economic issues) (e.g., Bechara, Damasio, Damasio, & Anderson, 1994; Bettman, Luce, & Payne, 1998; Zamarian, Benke, Buchler, Wenter, & Delazer, 2010). Additionally, describing the basic neurocognitive mechanisms of decision making can uncover working points for therapy and training of patients with psychological disorders and neurological diseases that cause impairments in making advantageous decisions (e.g., Gleichgerrcht et al., 2010).

Often, like in the scenario of the consultant, decisions are made under conditions of risk. In this type of decision situation there is explicit information about the contingencies of the decision task available (Yates & Stone, 1992). The core information is the number of decision options, the possible consequences following them, and the probabilities of the occurrence of these potential consequences. One model of decision making under risk that has recently attracted attention was proposed by Brand, Labudda, and Markowitsch (2006). It describes particularly the neuropsychological mechanisms that are supposed to be involved in this type of decision situations. It is suggested that the decider can use the given information for the development of calculative long-term decision-making strategies (Brand et al., 2006). Thus, it is assumed that cognitive abilities determine the decision-making performance systematically. However, the model remains unspecific in particular details, namely concerning the neurocognitive processes underlying decision making as well as concerning the role of situational conditions potentially influencing decision-making performance. Therefore, the central aim of this thesis is to approach a specified version of the model of decision making under risk conditions.

Another topic of this thesis is the measurement of decision-making competences. In neuropsychological research decision making is assessed with several different laboratory tasks. These are used to measure decision making in healthy individuals and patients with neurological or psychiatric disorders. In these tasks, the participants play in casino-like gambling scenarios (e.g., Bechara et al., 1994; Rogers et al., 1999; Sinz, Zamarian, Benke, Wenning, & Delazer, 2008; Zamarian, Sinz, Bonatti, Gamboz, & Delazer, 2008) but so far it has been neglected to assess decision-making performances of healthy persons or patient samples using real-world oriented decision-making problems. Therefore, a further aim of this thesis is to test a new more real-world oriented measure of decision-making performance that could be applied in research and potentially in clinical practice. Moreover, it is supposed to be usable for experimental investigations that aim towards further theoretical progress.

This thesis consists of a theoretical background section (chapters 3 and 4), the reports of three studies (chapters 5, 6, and 7), and a general conclusion section (chapters 8 and 9). In the theoretical background section, the current state in the field of neuropsychological decision-making research, involving relevant theories and studies, is outlined on a general level. In the first part, the literature on emotional and cognitive processes in decision making is summarized. Thereafter, important theories on executive functions are outlined. These theories are the basis for the specifications in the decision-making model, which are mainly attained in this thesis. Subsequently, an overview over theory and research on goal setting and goal striving is provided in order to explain how and why goals may be involved in decision-making performance. In the last part of the theoretical background frequently used methods for the assessment of decision-making competences are compared. Additional to this general theoretical background, the report of each study also begins with a theoretical introduction (chapters 5.2, 6.2, and 7.2). In this, the specific core elements of the hypotheses for the particular study are explained. It has to be noted that the research reports are supposed to be readable as independent papers, that is without having read the theoretical background section. Therefore, and in order to make the specific hypotheses of each study comprehensible, some information which has already been explained in detail in the general theoretical background, is again pointed out in the introductions. Moreover, each research report also ends with a specific discussion of the results. After the description of the three studies, a general discussion on the new results of the three studies follows. In this section a revised version of the model of decision making under risk is proposed. Furthermore, conclusions for the assessment of decision-making abilities in future research and in clinical application are drawn.

3. Theoretical background

3.1. Decision making

Decision making is regarded as a complex process that can imply a number of cognitive and emotional mechanisms and can be influenced by the features of the decision task and by external conditions, in which the tasks are performed (Finucane & Lees, 2005). There are several theoretical approaches, which try to describe how decisions under different conditions are made and which abilities can determine how accurate (or how "good" or "advantageous") a person can make his/her decisions (e.g., Bechara, Damasio, Tranel, & Damasio, 1997; Brand et al., 2006; Ernst & Paulus, 2005; Finucane & Lees, 2005; Friedman & Savage, 1948; Kahneman & Tversky, 1979; Payne, Bettman, & Johnson, 1993). However, before explaining any theoretical view on how decisions are made, the different types of decision situations should be taken into consideration.

It is widely accepted that decision situations can be classified into decisions under certainty and decisions under uncertainty (Yates & Stone, 1992). In decisions under certainty the decider is informed about the consequences that will follow from the available decision options and there is certainty that these consequences will occur. In decisions under uncertainty, the potential consequences are not clear. One decision option can lead to different consequences. Based on how explicitly the decider is informed about the rules with which different consequences will occur, decisions under uncertainty are divided into two further subtypes. Decisions under ambiguous risk (following the convention from now on called "ambiguity") and decisions under objective risk (from now on called "risk") (Bechara et al., 1994; Brand et al., 2006; A. R. Damasio, 1994; Edwards, 1954; F. H. Knight, 1921). In decisions under ambiguity the decision maker is not explicitly informed about the rules for gains and losses. Thus, the decision maker can neither exactly predict which consequence will occur nor with which probability it will occur. Therefore, the decision maker has to rely on "hunches" and "guesses" toward the choice of an alternative, and has to learn from the feedback about positive and negative consequences associated with the alternatives in order to learn to decide for the more advantageous options (Bechara, 2011; Damasio, 1994). In the other subtype of uncertainty, decisions under risk conditions, the decision situation provides explicit information about the rules for gains and losses. This information involves the possible consequences of choices for the different alternatives and the probabilities with which the possible consequences will occur (Brand et al., 2006; L. G. Epstein & Wang, 1994).

Theory and research has mainly focused on decision making in the two subtypes of uncertainty. Making advantageous decisions under ambiguity or under risk requires the functioning of a number of cognitive and emotional processes. However, decision making in the two types relies to different amounts on these processes as has been suggested theoretically (see e.g., Bechara et al., 1997; Brand et al., 2006; Schiebener, Staschkiewicz, & Brand, in press) and demonstrated empirically (Brand, Recknor, Grabenhorst, & Bechara, 2007; Schiebener, Zamarian, Delazer, & Brand, 2011). In the following, three theoretical approaches on decision making will be introduced. The first one is Finucane's Person Task Fit framework of decision making competence (Finucane & Lees, 2005; Finucane, Mertz, Slovic, & Schmidt, 2005) that provides a holistic view on the possible components of decision-making competence. The second view is the somatic marker hypothesis together with a model of decision making under ambiguity, both aiming to explain how decisions under ambiguity are biased by emotional learning mechanisms (Bechara & Damasio, 2005; Bechara et al., 1997; A. R. Damasio, 1994). The third concept is Brand's model of decision making under risk conditions (Brand et al., 2006), which will be the central topic in this thesis because it focusses on the neurocognitive processes that are involved in decision making under risk.

3.1.1. The Person Task Fit framework

Finucane's Person Task Fit framework (PTF; Finucane & Lees, 2005; Finucane et al., 2005) aims at describing the elements that can build up the competence to make advantageous decisions in different situations and describes the possible external and internal (i.e., inherent in the person) influences on this competence. Finucane suggests that a person's competence to make favorable decisions consist of five elements that are explained in the following. The first element is the ability to structure the decision problem by recognizing and then categorizing the available decision options according to the subjective evaluation of possible consequences and the probabilities for these consequences (Frisch & Clemen, 1994). The second element is the comprehension of the available information about the decision situation. Before information can be used accurately in any cognitive process, it is necessary that it is understood correctly. For example, information about the probability of a consequence can only be used competently by a person who understands what the meaning of a probability is (Radvansky, 1999; Zamarian, Benke, et al., 2010). The third element is information integration. This is the ability to combine the relevant information and make rational use of it. The most important task of information-integration processes is the selection of a decision-making strategy, which is advantageous in the specific situation. Humans are normally equipped with a number of strategies from which they can chose adaptively depending on the attributes of the decision situation (Payne, Bettman, & Johnson, 1988). For example, in very complex situations of high relevance, it is often advantageous to apply a compensatory strategy. In this strategy, high cognitive effort is invested to compare all options including all their attributes with the aim to come to the best possible decision (Frisch & Clemen, 1994). In routine decisions it is often advantageous to save cognitive effort and use a non-compensatory strategy, for example by deciding on one simple criterion (e.g., for the alternative that is best in the most important attribute), instead of comparing all alternatives and attributes (S. Epstein, 2003; Payne et al., 1988, 1993). As fourth element of decision-making competence insight has been introduced. This is supposed to be the most complex element of decision-making competence. It is understood as the ability to recognize the relevance of information and its usefulness for the personal decision problem. This implies that an appropriate value is assigned to the information, that the own competence to make the decision is accurately estimated, that information is correctly connected to possible consequences, and that the personal impact of these consequences is adequately judged emotionally and cognitively (Appelbaum & Grisso, 2001; Dymek, Atchison, Harrell, & Marson, 2000; Harvey & Fischer, 1997; Sieck & Arkes, 2005). For example, to maintain a good financial status it is necessary to adequately appreciate the value of any earning that one puts at risk. Additionally, the probabilities of losing or receiving any earnings need to be connected to the broader consequences (which it can have for the general financial situation). Finally, it needs to be recognized when to leave the decision to an expert (e.g., one’s financial consultant). Beyond the four core elements of decision-making competence Finucane added a preliminary fifth element as a suggestion to the model: affective fluency. This accounts for the idea that emotional values and responses may also be involved in competent decision making (see also the next chapter about emotions in decision making, i.e. chapter 3.1.2).

The five elements of decision-making competence - decision structuring, comprehension, integration, insight, and affective fluency - are supposed to be affected by three factors. One is inherent in the person, the other two are allocated in the environment (Finucane & Lees, 2005; Finucane et al., 2005). Inherent influences on the ability to make highly competent decisions are decision-maker characteristics. Among these several abilities are mentioned, such as intelligence, memory, literacy, affective skills, or experience. The first category of environmental influences is called task characteristics. These are for example the decision situation’s complexity, the amount to which it is well or ill structured, or the extent of affective engagement it elicits in the individual. The second environmental factor involves context characteristics, such as socio-cultural values, time pressure, and decision support. A visualization of the PTF can be found in Figure 1.

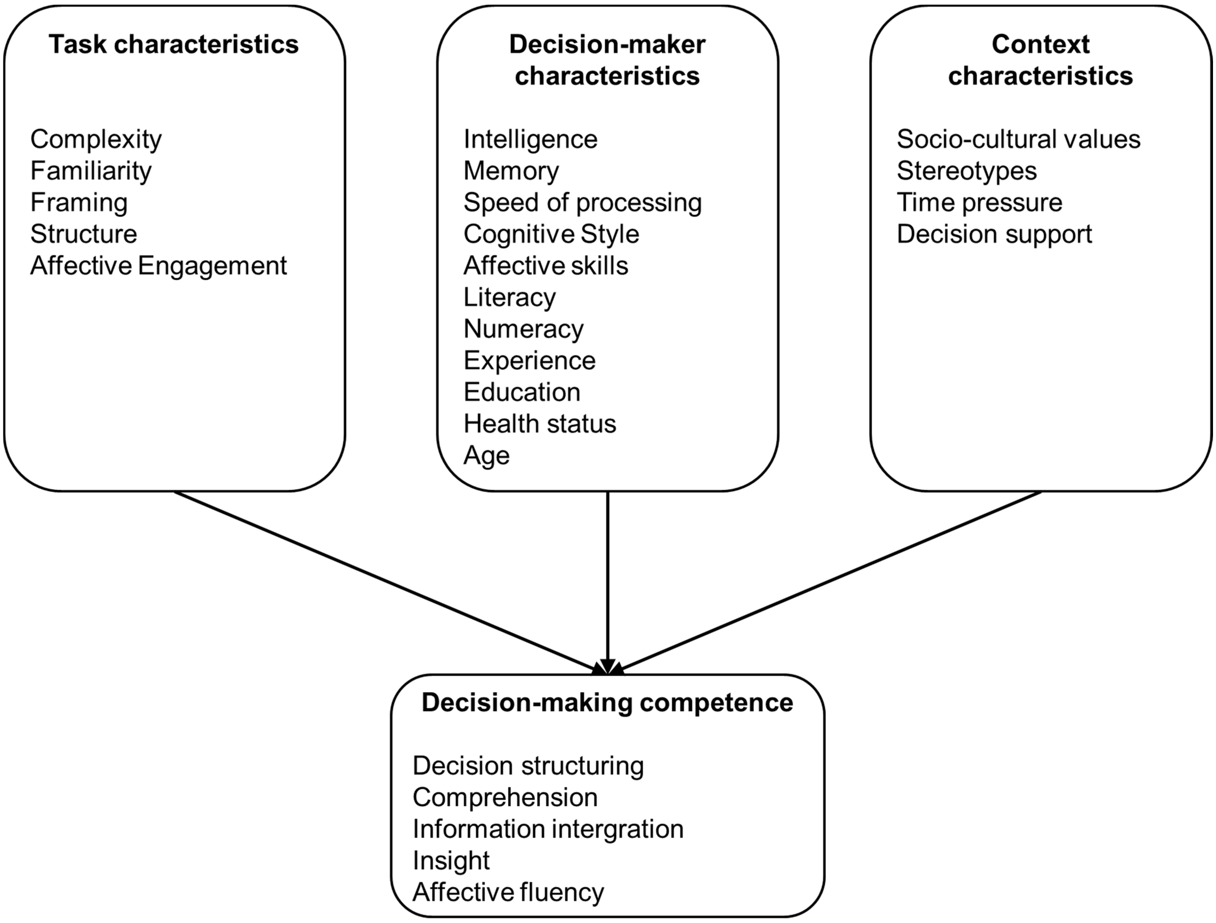

Figure 1. The PTF (Finucane & Lees, 2005; Finucane et al., 2005) involving three factors that are supposed to be the predictors of decision-making competence.

Finucane and colleagues (2005) suggest that "competent decision making occurs when an individual's cognitive abilities and other characteristics adequately match the demands of the decision task or context." (p.8). In other words, the fit between the characteristics of the decision situation and the characteristics of the decision maker determines the decision-making competence.

As can be seen, the framework provides a comparably broad view on the factors that may be important for making good decisions. Despite the broad focus, it also implies ideas regarding some specific and relatively basic cognitive and emotional functions that could be crucial for making good decisions. As outlined by Finucane and colleagues (2005) the PTF takes into consideration that there may be two basic systems of processing that can lead to decisions: an emotional ("intuitive") System 1 and a cognitive ("deliberative") System 2. These two systems have originally been suggested in several dual-process theories (J. S. B. T. Evans, 2003, 2008; Kahneman, 2003). The emotional System 1 works fast, parallel, automatically, and effortlessly, while its functioning is based on emotional signals. The cognitive System 2 works slowly, serially, controlled, and arduously, and is emotionally neutral. The emotional and the cognitive system may be differentially involved in the decision. There may be decisions, which are made quickly without cognitive effort, merely based on a gut feeling or intuition (System 1). In contrast, there may also be decisions, which are made after intense cognitive processes, such as comparisons of pros and cons or doing mathematical calculations (System 2). In line with the dual process theories some basic cognitive functions as well as emotional functions are mentioned as predictors of decision-making competence in the PTF. As basic cognitive domains memory, speed of processing, literacy, and numeracy are listed. Connected to emotional processing, affective skills, and additionally affective fluency are suggested.

In summary, the PTF has a relatively general focus on the several possible predictors of decision-making competence. Thereby, it can be regarded as an important advance in the theory on decision making. So far, studies and theoretical views in the field of general psychology have rather tried to describe decision making behavior as a product of relatively narrowly defined situational circumstances (e.g., as a product of the way probability information are "framed"; Tversky & Kahneman, 1981). Theoretical and empirical work in the field of neuropsychology rather have concentrated on individual differences in decision making in order to understand the abilities, processes and mechanisms potentially predicting decision-making behavior (Bechara & Damasio, 2005; Bechara et al., 1997; Brand et al., 2006) (see also 3.1.2, 3.1.3). The PTF tries to take theories and findings about the role of situational conditions as well as a person's individual characteristics into account in order to provide a general view on the external and internal factors, which affect decision-making competence. Furthermore, the PTF not only regards internal and external factors separately but regards them as interacting forces. In the empirical literature, particularly the potential interactions between situational variations and individual differences in person characteristics have only seldom been addressed so far, as has recently been pointed out by Appelt and colleagues (Appelt, Milch, Handgraaf, & Weber, 2011).

While the general or "global" focus of the PTF is one of its strengths this generality may be regarded as imprecise in some parts. For example, on the level of the person characteristics no model of neurocognitive processing is explicitly taken into account. Thus, the framework makes no assumption regarding the neurocognitive predictors of decision-making competence. Moreover, there is no evaluation of the importance of the mentioned individual abilities and whether there are cognitive or emotional functions, which are more systematically involved in decision making than other functions. Some functions may be more systematically involved because they are responsible for directing several cognitive and behavioral sub-processes leading to competent choice behavior. For example, the roles of working memory or executive functions are not defined in the model.

On the level of external characteristics (i.e., task characteristics and context characteristics) it is comprehensible that not all factors that may possibly affect decision-making competence are mentioned in the PTF. However, when aiming at describing the factors that should be crucial in real-life decision making, some further factors may be mentioned. Examples of such important factors are acute or chronic stress or the presence of explicit performance goals. The reason that these factors have been neglected in the formulation of the PTF may be that the evidence on the topic has been partly ambiguous (such as in the case of stress effects on decision making; for a recent overview see Starcke & Brand, 2012) or very rare (such as in the case of explicit goals Locke & Latham, 2002). Concerning the effects of stress on decision making, there has been remarkable scientific progress in the last years, but for understanding the role of explicit performance goals for decision making methodologically sound studies are still rare (see also chapter 3.3 and the Introduction of Study 2, chapter 6.2).

Overall, the PTF can be regarded as an important advance in the theory on decision making. In order to become a useful and structured framework it would need to take into account more systematically the internal emotional and cognitive mechanisms predicting decision-making performance as well as the role of several external factors which very frequently accompany real-life decision making.

This thesis concentrates on internal mechanisms in decision making as well as influences by external factors. The following part summarizes the current neuropsychological view on the emotional bases of advantageous decision making. The focus lies on decisions under ambiguity, in which emotional mechanisms have been suggested to be deeply involved in advantageous decision making (e.g., Bechara et al., 1997; Naqvi, Shiv, & Bechara, 2006).

3.1.2. Somatic markers: Emotions and decisions under ambiguity

When thinking about how to make advantageous decisions, for some it appears logical to assume that applying objective and fully rational reasoning is the best opportunity. Early theories suggested that humans calculate utilities of the given alternatives. In this calculation numerically coded evaluations of all possible outcomes were thought to be multiplied with the probability of their occurrence and the alternative with the highest resulting utility-value would be chosen (Arrow, 1971; M. Friedman & Savage, 1948; Keeney & Raiffa, 1993). Nevertheless, there are theoretical approaches and several studies, which have highlighted the role of automatic, emotional mechanisms for decision making, especially in decisions under ambiguity.

Recognizing the role of emotions for decision making was a result of a series of investigations of patients with relatively selective damages to specific brain areas. One of the most famous patients was Phineas Gage (Harlow, 1848, 1993). In the 19th century, he worked for a railway company in the United States of America. His acquaintances and friends respected him for his pleasantness, his reliability, and his sense of responsibility. One day at work a fatal accident happened. At a blasting operation an iron bar that was accelerated by the pressure of the explosion hit Gage. The bar pierced through his head. Surprisingly, Gage not only survived this accident. Although the bar had severely damaged parts of Gage’s brain, he recovered in hospital. He was still fully capable of speaking, thinking logically, and creating memories. However, his fellow men noticed severe changes in his personality. He lost his reliability, had difficulties in regulating his behaviors and moods, and was unable to follow advice if this was not in accordance with his currently perceived needs. For Gage’s fellow men and doctors it was difficult to understand how it was possible that a man who seemed to have fully intact cognitive functioning, could nevertheless develop suchlike dramatic changes in making decisions for his own behavior and for how to deal with other people. Later, it was recognized what the reason for Gage’s change had been. The iron bar had damaged one particular region in his brain, the ventromedial prefrontal cortex (Bechara, 2011b; H. Damasio, Grabowski, Frank, Galaburda, & Damasio, 1994; Harlow, 1848, 1993). This damage caused his pathology that was later called the frontal lobe syndrome (see e.g., Bechara, 2011a, 2011b; Milner & Petrides, 1984; Milner, 1963). This was also observed in several other patients and was further investigated in the 20th century (e.g., in the famous patient known as E.V.R.; Eslinger & Damasio, 1985). It was recognized that the syndrome was caused by damages to the ventromedial prefrontal cortex and the orbitofrontal cortex and that it was closely related to problems the patients had with anticipating the consequences of their actions and also to problems in recognizing and describing their emotions (e.g., Eslinger & Damasio, 1985; Stuss, Gow, & Hetherington, 1992).

A theoretical approach that was developed as an explanation for the problems of patients with the frontal lobe syndrome is the "somatic marker hypothesis" (Bechara & Damasio, 2005; A. R. Damasio, Tranel, & Damasio, 1991; A. R. Damasio, 1994). The hypothesis suggests that in decisions in ambiguous situations the decider can automatically learn to prefer the advantageous alternatives, by integrating his/her bodily emotional reaction to the expected feedback after the choice. In decisions under ambiguity the choices are made without explicit knowledge about the options attributes. Therefore, the decision has to be made randomly at the beginning of the task. After each choice there may be feedback about the consequences. This feedback, which is often rewarding or punishing, elicits an emotional reaction of the body (e.g., changes in heart rate, visceral modifications, or small muscle contractions). This reaction is then implicitly linked to the chosen alternative: A somatic marker is created. When the decision maker thinks about choosing this alternative again, the brain and body automatically react with a repetition of the experienced emotion. This can bias the decision to another alternative, if the feedback was punishing or it can bias the decision towards repeating the choice if the feedback was rewarding. There are two ways of anticipation: The so called body-loop and the as-if-body-loop. On the body loop the emotional anticipation is actually implemented in the body periphery. This bodily reaction can then be processed in the associated brain regions. In contrast, within the as-if-body-loop, the brain merely simulates the processing of the emotional reaction within the brain regions, without really enacting the reaction in the body periphery (Bechara & Damasio, 2005; A. R. Damasio, 1994).

In this process of emotional learning and reward anticipation, specific brain functions are supposed to be involved (e.g., Bechara & Damasio, 2005). The amygdala quickly triggers the bodily reaction, which is passed to the body by the brain stem nuclei. The sensory cortex processes the information about reward and punishment, particularly the elicited bodily reaction. The most important role in the creation of a somatic marker plays the ventromedial prefrontal cortex. In this region the somatic marker is set on the chosen alternative by linking the emotional reaction that has been triggered by the consequence of the decision to the chosen alternative. In this process also the dorsolateral region of the prefrontal cortex is supposed to be involved, being responsible for storing representations of behaviors. Additionally, the sensory system including the insular cortex, the striatum, and the ventral tegmental area are important for processing the bodily emotional anticipations of consequences. These are the so called hunches and guesses that can bias the next decisions. (For further details on the somatic marker hypotheses and neural processes supposed to be involved, please refer to Bechara & Damasio, 2005; Bechara, Damasio, Damasio, & Lee, 1999; Carter & Pasqualini, 2004; Gupta, Koscik, Bechara, & Tranel, 2010; Schiebener, Staschkiewicz, et al., in press; Shiv, Loewenstein, & Bechara, 2005; Verdejo-García, Pérez-García, & Bechara, 2006).

In order to investigate the role of emotions in decision making the Iowa Gambling Task (IGT) has been developed (Bechara, 2007; Bechara et al., 1994; Bechara, Tranel, & Damasio, 2000) and has become one of the most popular decision-making tasks for assessing decisions under ambiguity. In the IGT participants are not informed about the rules for gains and losses, including their amounts and their probability of occurrence. Participants have to choose 100 times between four decks of cards, and after each decision they receive feedback about their fictitious monetary gain. Sometimes additional to the gain they lose money. Gains and losses seem to occur arbitrarily, making it almost impossible for the decision maker to identify the exact probabilities for the occurrence. However, there are two advantageous decks. These offer frequent low gains and frequent slightly lower losses. Thus, continually choosing the advantageous decks leads to a positive final money capital. The other two decks are disadvantageous: They offer high gains, but sometimes very high losses. These losses are much higher than the accumulated gains. Therefore, choosing the disadvantageous decks frequently leads to a negative final money capital.

Several studies have been conducted using the IGT. These have often found support to the somatic marker hypothesis. Frequently, patients were examined, who had relatively restricted brain damages in those areas that were supposed to take a specific role in processing emotions as well as in the creation of somatic markers. There were patients with damage to the ventromedial prefrontal cortex or the amygdala, who sometimes showed intact cognitive functions, but failed to make advantageous decisions in the IGT (Bechara et al., 1994, 1997; Bechara, Tranel, Damasio, & Damasio, 1996; Brand, Grabenhorst, Starcke, Vandekerckhove, & Markowitsch, 2007). Moreover, in studies including patients and healthy participants impaired decision making has been found to be accompanied by reduced physiological reactions to feedback, as shown by skin conductance response measuring (Bechara et al., 1997; Carter & Pasqualini, 2004; Crone, Somsen, van Beek, & van der Molen, 2004; Suzuki, Hirota, Takasawa, & Shigemasu, 2003). Moreover, the IGT has been administered to several patients with psychiatric disorders, such as depression or borderline syndrome, who often showed abnormal decision-making performance because of their pathological emotional instability (Haaland, Landrø, Kano, Ito, & Fukudo, 2007; Must et al., 2006; Smoski et al., 2008). In order to provide an overview of research on emotional processes in the IGT, exemplary studies are listed in Table 1. These studies have investigated the role of emotional processing for decision making in the IGT in patients with brain damages, neurological diseases, and psychiatric disorders. Please note that the table has no claim of being complete. The studies listed are selected because they are exemplary for the field of research and/or the type of patient group. A similar overview can be found in Dunn, Dalgleish, & Lawrence, (2006).

Table 1. Summary of exemplary studies investigating the role of emotions in patients with brain damages, neurological diseases, and psychiatric disorders.

Patient group	Deficit/impair-ment in the IGT?	Role of emotion/other interpretations	Author
Brain damage/lesions			
frontal lobe regions	yes	theoretically argued role of emotions/somatic markers	Bechara et al., 1994
frontal lobe regions	yes	reduced SCRs in anticipation of emotional rewards and punishments	Bechara et al., 1996
ventromedial prefrontal cortex	yes	reduced anticipatory SCRs, impaired decision making despite explicit knowledge about disadvantageous decks	Bechara et al., 1997
right vs. left ventromedial prefrontal cortex	right: yes left: no/marginally	right: processes emotional reaction to punishment left: processes emotional reaction to reward	Tranel, Bechara, & Denburg, 2002
orbitofrontal vs. dorsolateral vs. dorsomedial vs. large frontal cortex lesions	orbitofrontal: no dorsolateral: yes dorsomedial: yes large frontal: yes	impairments observed together with working memory and executive function deficits, orbitofrontal: intact decision making despite executive deficits	Manes et al., 2002
ventromedial prefrontal cortex vs. dorsolateral prefrontal cortex	ventromedial: yes dorsolateral: yes	ventromedial: problems with reversal reinforcement learning dorsolateral: independent of reversal learning	Fellows & Farah, 2005

amygdala	yes	impairments related to reduced anticipatory SCRs, inability to create bodily emotional reactions to reward and punishment	Bechara et al., 1999; Brand, Grabenhorst, et al., 2007
Neurological diseases			
multiple sclerosis	yes	impairments related to reduced anticipatory SCRs, but not to executive dysfunctions	Kleeberg et al., 2004; Nagy et al., 2006
Parkinson's disease	mixed results	impairments, probably dependent on medication, impulsivity, and state of dementia	Delazer et al., 2009; Euteneuer et al., 2009; Poletti et al., 2012; Poletti, Cavedini, & Bonuccelli, 2011; and several more. See overview in Gleichgerrcht, Ibánez, Roca, Torralva, & Manes, 2010
Alzheimer's disease	yes	impairments are suggested to result from emotional learning and working memory deficits as result of broad prefrontal cortex dysfunctions	Sinz et al., 2008
Huntington's disease	yes	decreased SCRs, decreased memory functions	Busemeyer & Stout, 2002; Campbell, Stout, & Finn, 2004
epilepsy	yes	independent of abnormalities in major emotion processing structures, problems with feedback learning	Bonatti et al., 2009; Delazer et al., 2011; Labudda et al., 2009
Psychiatric disorders			
depression	contradictory results	impaired: changes in emotional, especially reward processing unimpaired: risk avoidance, reduced interest in high gains of disadvantageous alternatives	Must et al., 2006; Smoski et al., 2008
borderline personality disorder	yes	emotional instability, deficits unrelated to cognitive abilities	Haaland et al., 2007
attention deficit hyperactivity disorder	adults: no adolescents: yes	impairments related to impulsivity/hyperactivity symptoms	Ernst et al., 2003; Toplak, Jain, & Tannock, 2005
schizophrenia	yes	deficits in reversal learning, and consciousness about own emotion	C. E. Y. Evans, Bowman, & Turnbull, 2005; Ritter, Meador-Woodruff, & Dalack, 2004; Shurman, Horan, & Nuechterlein, 2005

psychopathy	yes	impairments related to anxiety	Schmitt, Brinkley, & Newman, 1999; van Honk et al., 2002
Miscellaneous diseases/disorders			
substance addiction (heroin, alcohol, marijuana)	yes	slow learning, reduced anticipatory SCRs, unrelated to executive function deficits, insensitivity to long-term consequences, impairments related to brain shrinkage in ventromedial prefrontal cortex, dorsal anterior cingulate cortex and right hippocampal formation	Bechara, 2005; Clark & Robbins, 2002; Le Berre et al., 2012; Verdejo-García & Pérez-García, 2007; Whitlow et al., 2004
pathological gambling	yes	increasing preference for disadvantageous decks, seeking risk/high reward, deficits in feedback processing	Cavedini, Riboldi, Keller, D´Annucci, & Bellodi, 2002; Goudriaan, Oosterlaan, Beurs, & van den Brink, 2005
HIV with substance dependence	yes	inverse relation with sensation seeking and risky sexual practices, deficits unrelated with procedural learning abilities	Gonzalez, Wardle, Jacobus, Vassileva, & Martin-Thormeyer, 2010; Martin et al., 2004
chronic pain	yes	performance correlated with pain experience parallel to IGT administration	Apkarian et al., 2004
Narcolepsy-cataplexy	yes	seeking for high rewards, because of reduced emotional valence experience, impairments unrelated to executive functions	Bayard et al., 2011; Delazer, Högl, et al., 2011

These patient studies often underlined the role of emotion for decision making in the IGT. Nevertheless, an often discussed question is whether decision-making performance and the learning effects in the task are due to the creation of explicit knowledge about the hidden contingencies rather than to the emotional anticipation of consequences. The results of two studies remarkably underlined the importance of intact emotion processing for advantageous decision making in the IGT. In the first study, it has been found that patients with prefrontal cortex damages made disadvantageous decisions although they had already created conscious and correct knowledge about which IGT-decks were advantageous and which were disadvantageous (Bechara et al., 1997). Furthermore, brain-healthy participants were also observed with the IGT and they have begun to decide advantageously, even before explicit knowledge had been developed (Bechara et al., 1997). The second study demonstrated that even if the cognitive system (especially executive functioning) was interfered in processing the situation's information, intuitive hunches and guesses helped to make advantageous decisions (Turnbull, Evans, Bunce, Carzolio, & O'connor, 2005). Thus, one might be inclined to conclude that advantageous decision making in the IGT does not require cognitive processing.

Nevertheless, the independence from explicit cognition in IGT decision making has been questioned by critics of the task and the somatic marker hypothesis. As can be judged from the results in some patient populations with cognitive deficits (e.g., Alzheimer's disease and epilepsy patients) impairments in the IGT do not seem to be distinctly connected to impairments in emotional processing but also to executive functions or working memory. There are also studies, which investigated whether the role of emotional processing may have been overestimated and the role of cognition underestimated (for overviews refer to Buelow & Suhr, 2009; Dunn, Dalgleish, & Lawrence, 2006). Maia and McCelland (2004) found that participants report explicit knowledge in the IGT earlier, when they were asked for it very explicitly. In this study no evidence was reported for the assumption that emotional guidance by somatic markers precedes the development of explicit knowledge.

The connected question for the impact of basic cognitive functions on making good decisions under ambiguity was addressed in a model of decision making under ambiguity and in a number of studies. The model of decision making under ambiguity (Bechara et al., 1997) supposes that somatic markers can bias the decision essentially, but they should furthermore support cognitive reasoning strategies, also involved in the decision-making process. Reasoning strategies are suggested to process on the information about the decision situation (such as the number of available options) and the information about the experiences with the decision situation (such as previous gains and losses that have followed from choosing the different alternatives). The model of decision making under ambiguity is depicted in Figure 2.

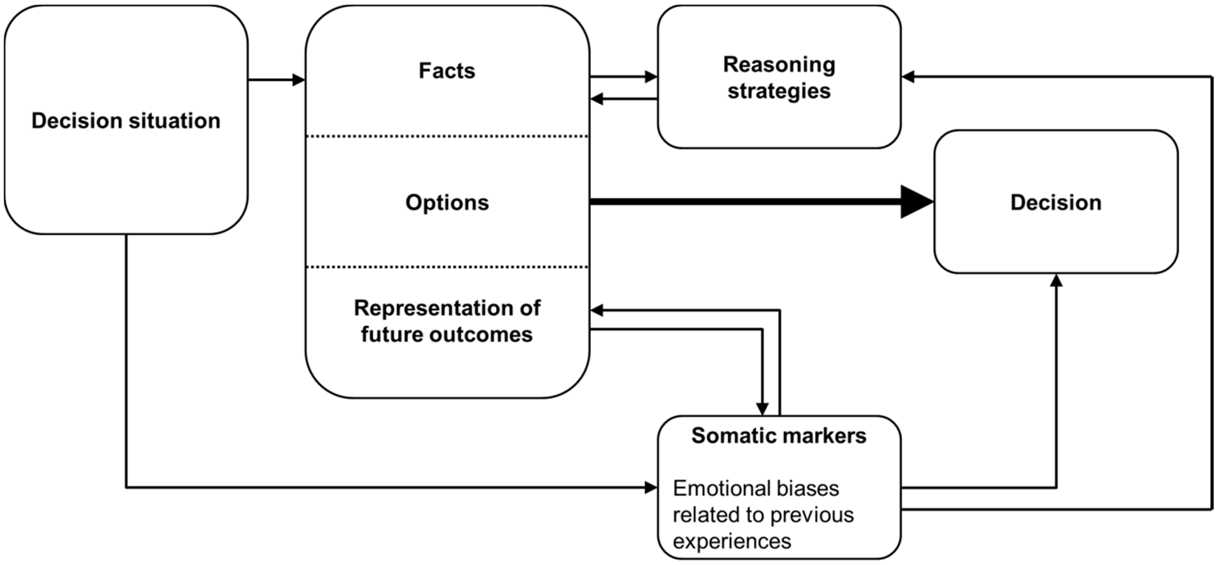

Figure 2. The model of decision making under ambiguity modified from Bechara et al. (1997).

It assumes that feedback about consequences is processed emotionally and that somatic markers guide subsequent decisions directly or by supporting reasoning strategies.

The model assumes that in decisions under ambiguity factual information about the decision situation is included in the development of reasoning strategies. Somatic markers and emotional processing are described to be elicited by feedback about outcomes and to directly bias the decisions or at least to support the reasoning strategies.

Therefore, neurocognitive functions could also be involved in decision under ambiguity beside a person's emotion. Especially working memory could be required because in this memory system representations about the situation and experiences might be kept available for active integration in cognitive processes. In the IGT, this can be the memory about which cards had been chosen and what the consequences were. Bechara, Damasio, Tranel, and Anderson (1998) investigated patients with lesions in brain areas closely involved in working memory functions (regions in the dorsolateral prefrontal cortex) and/or related to decision-making under ambiguity (regions in the ventromedial prefrontal cortex). It has been reported that decision making in the IGT was impaired especially in those patients, who had lesions in both areas. However, the results have also shown that decision-making performance was almost normal in patients who had lesions only in working memory regions but not in decision-making regions. The authors interpreted this finding as an indicator for an asymmetric relationship between decision-making under ambiguity and working memory. Working memory can be intact together with intact or impaired decision making, but intact decision making requires intact working memory functions (see also Bechara & Martin, 2004). However, there are several studies that suggested decision making in the IGT to be independent of working memory or executive functions. In the following Table (Table 2), exemplary studies that examined the role of general cognitive abilities, working memory, and executive functions in the IGT are summarized (for a similar overview please refer also to Toplak, Sorge, Benoit, West, & Stanovich, 2010).

Table 2. Exemplary studies, which investigated the role of neurocognitive functions for decision making under ambiguity in the IGT.

Patient group/brain-healthy individuals	Relationship between cognitive functions/explicit knowledge and IGT performance	Author
Studies on the topic "explicit knowledge about contingencies"		
healthy, prefrontal cortex damage	part of the participants showed explicit knowledge about good and bad decks, but advantageous decision making began earlier, or was unless not developed	Bechara et al., 1997
healthy	advantageous decision making comes with explicit knowledge	Maia & McClelland, 2004
Cognitive domain: General/Intelligence		
epilepsy	positive correlation with LPS reasoning scale	Labudda et al., 2009
substance abuse	no significant correlation with intelligence, working memory or different executive function measures	Barry & Petry, 2008; Bechara et al., 2001
schizophrenia with/ without cannabis use	positive correlation with Wechsler Adult Intelligence Scale (WAIS-III) / no significant correlation with Full Scale Intelligence Quotient (FSIQ)	Mata et al., 2008; Nakamura et al., 2008
borderline personality disorder	negative correlation with WAIS-III	Haaland et al., 2007
psychopathy	no significant correlation with WAIS-III / positive correlation with National Adult Reading Test (NART) IQ	Lösel & Schmucker, 2004; Mahmut, Homewood, & Stevenson, 2008
healthy	no significant correlation with NART IQ / positive correlation with Peabody Picture Vocabulary Test-III	Fein, McGillivray, & Finn, 2007; Patrick, Blair, & Maggs, 2008
Cognitive domain: Working memory		
healthy, lesions in ventromedial, dorsolateral/high mesial damages	dissociation between working memory and decision-making functions	Bechara et al., 1998
Alzheimer's disease	no significant correlation with digit span tasks	Sinz et al., 2008
epilepsy	positive correlation with digit span backwards	Labudda et al., 2009

schizophrenia	no significant correlations with delayed match to sample task	Shurman et al., 2005
attention deficits hyperactivity disorder	no significant correlations with digit span forwards or spatial span	Toplak et al., 2005
healthy	no significant correlation with digit span / in young adults: significant positive correlation with paced auditory addition test	Denburg, Tranel, & Bechara, 2005; Fein et al., 2007
Cognitive domain: Executive functions		
Parkinson's disease	correlation with color word interference test, no significant correlation with Wisconsin Card Sorting Test	Mimura, Oeda, & Kawamura, 2006
Alzheimer's disease	no significant correlation with Odd-Man-Out, shifting behavior in IGT correlated with inhibition subtest of FAB	Delazer, Sinz, Zamarian, & Benke, 2007; Sinz et al., 2008
epilepsy	correlation with color word interference test, no significant correlation with Modified Card Sorting Test	Labudda et al., 2009
schizophrenia	no significant correlations with Wisconsin Card Sorting Test, no correlations with Trail Making Test B	Fond et al., 2012; Nakamura et al., 2008; Ritter et al., 2004; Shurman et al., 2005
attention deficits hyperactivity disorder	no significant correlation with stop signal task or Go/No-Go task	Geurts, Van der Oord, & Crone, 2006
healthy	ascending learning curve in the IGT despite parallel executive load, correlations with Wisconsin Card Sorting Test in later trials of the IGT, seldom with overall performance, no correlations with color word interference test, but with stop task	Brand, Recknor, Grabenhorst, & Bechara, 2007; Denburg et al., 2005; Shuster & Toplak, 2009; Turnbull et al., 2005

As Table 2 shows, some studies reported connections between cognitive domains and IGT performance, while other studies found no relations. One explanation for these heterogeneous results may be that performance in different phases of the IGT relies to different amounts on cognitive functions. When the participants begin to understand the contingencies of the IGT, they can increase the application of reasoning strategies (Bechara et al., 1997; Maia & McClelland, 2004). This seems to be the reason for the finding that in healthy individuals decision-making performance is correlated with executive functioning and decision-making performance under risk in the later trials of the IGT (trials 41-100), while there is no such correlation in the first trials (1-40) (Brand, Recknor, et al., 2007; Y.-T. Kim, Sohn, & Jeong, 2011). Given the knowledge the participants have constructed in the later trials, the situation loses its ambiguity: The decision maker processes the initially ambiguous decision situation in a way that is comparable to the processing of a situation providing explicit risk conditions (Brand, Recknor, et al., 2007).

In summary, a high number of studies focused on the topic of decision making under ambiguity. Thus, the comprehension of the emotional and cognitive processes in this type of decision situation is relatively profound. Despite the existing critics of the somatic marker hypotheses (Buelow & Suhr, 2009; Dunn et al., 2006; Maia & McClelland, 2004) there is considerable evidence for one of its main suggestions: that physical emotional arousal and the activation of emotion-associated brain structures are involved in advantageous decision making. In several studies it has been observed that emotional processing was a correlate of decision making under ambiguity and that it can predict performance in this type of decision situation. Therefore, one can bear in mind that emotional processing plays a crucial role in decision making under ambiguity. Conscious cognitive processes and individual differences in cognitive abilities also seem to have a role, but its impact was observed to occur less systematically. The role of cognitive processing may depend on the amount of explicit knowledge that has been constructed by the decision maker.

As a methodological remark, it should be regarded that the scientifically gained knowledge about decision-making processes in ambiguous situations is largely based on studies using the IGT. On the one hand, it may be considered as favorable that commonly one standard measure is used across almost all studies. On the other hand, there is little empirical data on the question whether the findings with the IGT can be replicated in other decision-making tasks. For example, it is unclear whether behavior in the IGT, would change with a variation of the situation's attributes (e.g., if the decisions were not made in a gambling scenario, if the number of available choice options were increased or decreased, or if the level of ambiguity was varied). In general, it may be useful, if a task which allows varying such attributes systematically was available. This may also help to understand which situational attributes determine the amount of emotional and cognitive processing that is involved in advantageous decision making.

It has already been reported that cognitive functions were more systematically involved in decision situations that provide explicit information on the rules for gains and losses, namely in decisions under explicit risk conditions. In such a situation the development and application of calculative decision-making strategies is possible. The neurocognitive processes of strategic decision-making under risk conditions has been described in a model by Brand and colleagues (2006), which is explained in the following chapter.

3.1.3. Brand's model: Executive functions and decisions under risk

The main focus of this thesis are the neurocognitive processes involved in decision making under risk conditions, as they are suggested in the model by Brand and colleagues (2006). While there had already been several studies and a theoretical frame addressing the mechanisms in decision under ambiguity (as outlined in the previous chapter, 3.1.2), only little was understood about the neurocognitive and emotional mechanisms involved in decisions under risk conditions[1] (Brand et al., 2006). Then, studies showed that patients with cognitive deficits (e.g., with Korsakoff's syndrome and Parkinson's disease) were impaired in making this type of decisions advantageously and that this impairment was closely related to their reduced executive functions (Brand, Fujiwara, et al., 2005; Brand, Labudda, et al., 2004). Also, the case of a patient hinted toward a crucial involvement of these functions (Brand, Kalbe, et al., 2004). The patient was a woman, who had suffered from a colloid cyst of the foramen of monro. The cyst was removed in a surgery, which left no structural damages behind. However, changes in her brain metabolism occurred in the dorsolateral prefrontal cortex bilaterally, the cingulate gyrus, and the left fusiform gyrus. She had normal abilities in several cognitive domains, but reported to have problems with making decisions in everyday life. Neurocognitive tests revealed that she was selectively impaired in executive functions and these impairments were accompanied by disadvantageous decision making under risk conditions, as measured by a new laboratory task. Based on these findings in patients the model of decision making under risk was developed by Brand and colleagues (Brand et al., 2006). The model assumes an important role of executive functions for choosing advantageously under risk conditions. In contrast to decisions under ambiguity, making

[1] Please note that lines of research and theory in the general psychological area had already begun to describe how humans make decisions under risk conditions. This involved the investigation of so called compensatory and non-compensatory decision-making strategies, heuristics, influences of framing, anchors, or decision aids. This line of research is still advancing and expanding (classical and current examples of literature are: Bröder & Schiffer, 2003; Epley & Gilovich, 2001; Gigerenzer & Goldstein, 1996; Gigerenzer & Todd, 1999; Glöckner & Pachur, 2012; Kahneman & Tversky, 1979; Pachur & Olsson, 2012; Payne et al., 1993; Tversky & Kahneman, 1981; Yates, Veinott, & Patalano, 2003). However, the neuropsychological mechanisms of decision-making under risk, as well as the possible impairments in patients with neurological diseases or psychiatric disorders were only marginally understood.

advantageous decisions under risk should be clearly associated with cognitive functions, given that these decisions can be made on the basis of calculative strategies.

In the model, the process of decision making begins with the features of the decision situation. The most important features are the number of decision options and the information that is provided on the potential outcomes (e.g., possible monetary gains and losses) and the probabilities for these outcomes. These are either provided explicitly in a certain type of probability presentation (e.g., in percentages) or are calculable considering the rules of the decision-making task. These features are perceived by the decision maker and the acquired information “enters” the executive system by being represented in working memory. These working memory contents can be complemented by long-term memory contents associated with the given or comparable decision situations, general knowledge about probabilities, or previous experiences with consequences. Furthermore, general reasoning and problem solving strategies are said to be recalled from long-term memory. This recall and handling of information is supposed to be controlled by executive functions, such as categorization and cognitive flexibility. The authors point out the substantial contribution of executive functions to the decision-making process. Executive functions are thought to be responsible for combining the information in working memory and for controlling the reasoning processes that are required for the development of a decision-making strategy. The application of the strategy is also suggested to be controlled by executive components. After a decision is made there may be rewarding or punishing feedback about the consequences. The feedback is assumed to trigger an emotional reaction that causes the creation of somatic markers. Beside the emotional reaction, feedback can also be used on the cognitive level, for the adaption of information in long-term memory contents. The information about decision outcomes can be used for improving the understanding of the decision situation’s rules, for checking the success of the current decision strategy, and for revising the strategy (Brand et al., 2006).

Brand and colleagues (2006) suggested that decisions under risk conditions can therefore be made on the basis of two “routes” of processing: a cognitive and an emotional route. It should be possible to make advantageous decisions based on cognitive reasoning processes only. Moreover, advantageous decision making under risk can be learned emotionally, guided by somatic markers. However, both routes can interact, when somatic markers support the development of a reasoned strategy. The integration of both, cognitive and emotional processes, is suggested as the best way to making decisions under risk advantageously (Brand, Grabenhorst, et al., 2007; Brand, Laier, Pawlikowski, &

Markowitsch, 2009; Brand, Pawlikowski, et al., 2009; Brand, 2008). The model is depicted in Figure 3.

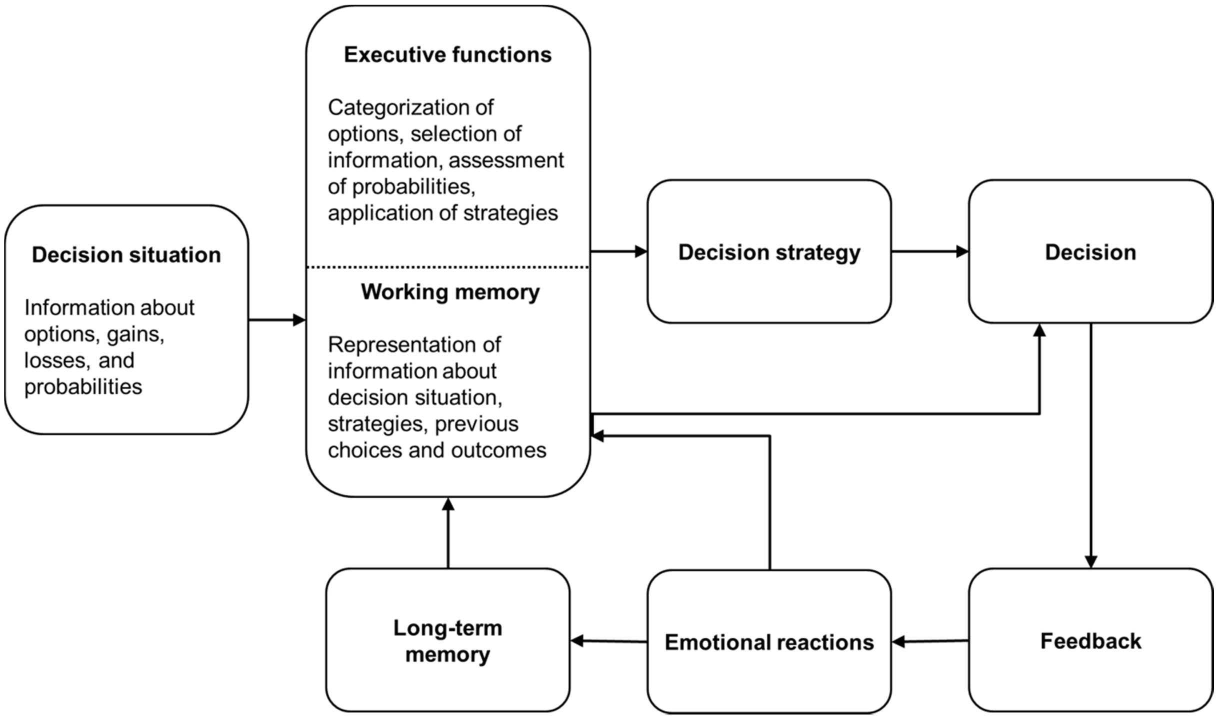

Figure 3. The figure shows the processes, which are supposed to be involved in decision making under risk conditions (Brand et al., 2006).

Executive functions are assumed to be crucial in the handling of information about the situation and integrating information from long-term memory, as well as in the development and control of reasoned decision-making strategies. Additionally, emotional reactions to and anticipations of feedback can bias the decision-making behavior.

Based on this theoretical model it is possible to make assumptions about the brain regions that are probably involved in decisions under risk. Especially the dorsolateral prefrontal cortex and the anterior cingulate cortex may be involved because of their association with executive functioning, such as categorization and cognitive flexibility (Burgess, 2000; Leber, Turk-Browne, & Chun, 2008; Lie, Specht, Marshall, & Fink, 2006; Loose, Kaufmann, Tucha, Auer, & Lange, 2006). Furthermore, emotion processing areas, such as the amygdala (LeDoux, 2007; Phelps & LeDoux, 2005; Salzman & Fusi, 2010) should be important for eliciting bodily reactions to and anticipations of feedback.

There are brain damage and brain activation studies, which found support for the involvement of the dorsolateral prefrontal cortex, the anterior cingulate cortex, and the amygdala (Brand, Grabenhorst, et al., 2007; Brand, Kalbe, et al., 2004; Labudda et al., 2008; R. D. Rogers, Owen, et al., 1999). Additionally, it was found that the inferior parietal lobe was involved in decision making with explicit information about probabilities and monetary consequences (Labudda et al., 2008). The authors suggested that this region was activated because it took part in handling numbers and in computations made prior to the decision (the role of the inferior parietal lobe for suchlike processes has been reported in several studies, e.g., Dehaene, Molko, Cohen, & Wilson, 2004; Pesenti, Thioux, Seron, & De Volder, 2000; Sandrini, Rossini, & Miniussi, 2004).

One measure of decision making under risk, which has been used frequently in recent studies, is the Game of Dice Task (GDT; Brand et al., 2005). In this task the participants try to increase a fictitious starting capital of €1,000. In each of 18 trials they have to guess which number will be thrown next by a single virtual die. They can bet on one single number (bet amount €1,000), or on combinations of two (€500), three (€200), or four numbers (€100). After the bet, the die is thrown. If the number that occurs on the die equals the number the participant has bet on, or is one of the numbers within the chosen combination the participant will win the amount of money. If one of the other numbers is thrown the participant will lose and the amount of money will be subtracted from the total capital. These rules are explicitly explained to the participant, before the task starts. What is not made explicit, but can be calculated, is that there are two high risk alternatives (betting on one and two numbers, with winning probabilities below 34%), and two low risk alternatives (betting on three and four numbers, with winning probabilities of 50% or higher). A positive final capital will most probably be possible when making very frequent decisions for the low risk alternatives, and no or very seldom decisions for high ris alternatives.

Two other tasks that have been used frequently in recent neuropsychological decision-making research are the Cambridge Gambling Task (CGT; Rogers et al., 1999) and the Probability-Associated Gambling (PAG) task (Sinz et al., 2008; Zamarian et al., 2008). In the CGT there are ten blue and red boxes presented in ratios that vary from trial to trial. The participants have to guess under which color the game's token is hidden. The probability of winning depends on the ratio of blue and red boxes. After the decision for blue or red has been made the participants have to decide how much fictitious money they want to bet on their guess. Therefore, a bet amount is presented and increases every five seconds. The participants can bet the current amount or wait for the next, higher amount.

In the PAG task, the subjects are confronted with the choice between a fixed sum (a gain or loss of €20) and a lottery gamble for which the winning probability is presented by displaying the content of the lottery urn. This contains 24 red or blue cubes in ratios that vary from trial to trial. When the participant decides to gamble, a cube is drawn from the urn. An amount of €100 is won if a red cube is pulled out and €100 is lost if a blue cube is pulled out. For more details on the tasks pease refer to chapter 3.4 and to Study 3.

Using the GDT, the CGT, and the PAG task several studies have been conducted with patient groups and healthy participants. Some of the studies have been conducted before the formulation of Brand's model (Brand et al., 2006) and have contributed to the model's assumptions. A substantial number of studies has also been conducted after the development of the model and have tested the models assumptions on the role of executive functions, working memory, or feedback processing. Also, other factors have been tested as predictors of decision-making performance, for example logical thinking abilities (e.g., Brand, Laier, et al., 2009; Schiebener et al., 2011), personality facets (Bayard, Raffard, & Gely-Nargeot, 2011; Brand & Altstötter-Gleich, 2008; D. Y. Kim & Lee, 2011), and external influences on decision-making (e.g., Bagneux, Bollon, & Dantzer, 2012; Schiebener, Wegmann, Pawlikowski, & Brand, 2012). In the following table (Table 3) an overview of neuropsychological studies with the three tasks is provided in order to summarize empirical evidence on the role of specific neurocognitive domains (e.g., executive functions and working memory) as well as the role of other factors with which decision-making performance was found to be associated. Based on this overview and on the assumptions in Brand's model (Brand et al., 2006), the gaps in research which will be addressed with the studies in this thesis will be pointed out.

Table 3. Studies investigating decision-making performances under risk conditions in patient groups and healthy individuals.

For the table studies were selected which investigated the involvement of neurocognitive functions, other domains (e.g., general intelligence or personality facets) and situational manipulations on decision making performance in the GDT, the PAG task, or the CGT.

Topic	Deficit in decisions under risk (task)	Decision-making performance was associated with… Neuro-cognitive function	Other domains	Situational manipulation	Authors
Patients with brain damages					
single case, patient with dorsolateral prefrontal cortex dysfunctions	yes (GDT)	selective deficits in executive functions	-	-	Brand, Kalbe, et al., 2004
ventral vs. orbitofrontal prefrontal cortex damage	ventral: yes (CGT) orbitofrontal: yes (CGT)	-	Ventral damage: increased betting, Orbitofrontal damage: decreased betting, but not accurately adjusted to probabilities	-	Rogers, Everitt, et al., 1999
insular vs. ventromedial prefrontal cortex lesions	both yes (CGT)	-	ventromedial: increased betting regardless of probabilities insular: impaired adjustment to probabilities	-	Clark et al., 2008
differential prefrontal cortex lesions	depending on lesion region (CGT)	deficits in working memory spatial span in the large-lesion patients	orbitofrontal: longer deliberation, large lesions: increased risk taking	-	Manes et al., 2002
aneurism in anterior communicating artery	yes (CGT)	-	damage to orbitofrontal prefrontal cortex or disconnection of ventromedial circuits	-	Mavaddat, Kirkpatrick, Rogers, & Sahakian, 2000

traumatic brain injury	no (CGT), yes (GDT)	-	impulsive betting, CGT performance inversely correlated with abnormalities, e.g. in thalamus, striatum, dorsolateral prefrontal cortex	-	Newcombe et al., 2011; Rzezak, Antunes, Tufik, & Mello, 2012
Patients with neurological diseases					
Parkinson's disease	yes (GDT) / only Parkinson's disease dementia (PAG task) / only medicated participants (CGT)	deficits in executive functions	-	-	Brand, Labudda, et al., 2004; Cools, Barker, Sahakian, & Robbins, 2003; Delazer et al., 2009; Euteneuer et al., 2009; Labudda et al., 2010
Huntington's disease	no (CGT)	deficits in visuo-spatial planning	-	-	Watkins & Rogers, 2000
Alzheimer's disease	yes (GDT, PAG task)	deficits in learning, executive functions	-	-	Delazer, Sinz, Zamarian, & Benke, 2007; Sinz et al., 2008
fronto temporal dementia	yes (CGT)	unassociated with executive functions and working memory	increased deliberation times before bets, risk taking	methylphenidate administration "normalized" risk taking	Rahman et al., 2006; Rahman, Sahakian, Hodges, Rogers, & Robbins, 1999
Korsakoff's syndrome	yes (GDT)	deficits in executive functions, memory functions	intelligence	feedback removal had no effect on performances of patients but of healthy subjects	Brand et al., 2005; Brand, Pawlikowski, et al., 2009
multiple sclerosis	yes (CGT)	attention	compared to controls reduced disappointment after loss, no differences in SCRs	-	Simioni et al., 2012

Urbach-Wiethe-Disease	part of the sample yes (GDT)	impairment particularly in patients with deficits in executive functions	reduced feedback SCRs	-	Brand, Grabenhorst, et al., 2007
mild cognitive impairment	yes (PAG-Revised)	-	integration of information from different sources, flexibility in adapting decision strategy	-	Zamarian, Weiss, & Delazer, 2011
epilepsy	no (GDT)	lower decision-making performance associated with executive functions	reduced decision-making performance associated with earlier onset of disease	-	Labudda et al., 2009
Patients with psychological/psychiatric disorders					
attention deficit hyperactivity disorder (adults and adolescents)	adults: no (GDT), yes (CGT) adolescents: only when GDT was administered second time	adults: higher medial orbitofrontal cortex activation in high-incentive reward processing task adolescents: parent-report of executive functions	adults: feedback processing (GDT), impulsive betting and problems with strategy adaption to probabilities (CGT)	repeated measurement with GDT, methylphenidate administration made CGT behavior saver	DeVito et al., 2008; Drechsler, Rizzo, & Steinhausen, 2008; Wilbertz et al., 2012
schizophrenia	mixed results	if impaired: associations with disease-caused deficits in executive functions	no association with clinical variables	-	Fond et al., 2012; Lee et al., 2007
borderline personality disorder	yes (CGT)	planning	impulsivity, disinhibition	-	Bazanis et al., 2002
obsessive compulsive disorder	no (GDT)	executive functions	SCR's comparable to healthy comparison participants	-	Starcke, Tuschen-Caffier, Markowitsch, & Brand, 2010; Starcke et al., 2009

compulsive hoarding	yes (CGT)	executive functions, planning, categorization	self-reported cognitive processing difficulties	-	Grisham, Norberg, Williams, Certoma, & Kadib, 2010
opiate dependence	yes (GDT) mixed (CGT)	executive functions, logical thinking	deficits in feedback processing, success in maintaining abstinence	-	Brand, Rothbauer, Driessen, Markowitsch, & Roth-Bauer, 2008; Passetti, Clark, Mehta, Joyce, & King, 2008
cocaine dependence	(CGT)	-	intelligence, IGT performance, delay discounting preferences	-	Monterosso, Ehrman, Napier, O'Brien, & Childress, 2001
abstinent drug abusers	yes (CGT)	-	changes in emotional regulation, lower SCR increase while making decisions	-	Fishbein et al., 2005
pathological/ problem gamblers	yes (GDT)	deficits in executive functions	deficits in feedback processing, stress hormone release associated with more advantageous decision making	-	Brand, Kalbe, et al., 2005; Labudda, Wolf, Markowitsch, & Brand, 2007
bulimia nervosa	yes (GDT)	deficits in executive functions	no association with other neuropsycho-logical variables, or personality measures	-	Brand, Franke-Sievert, Jacoby, Markowitsch, & Tuschen-Caffier, 2007
binge eating disorder	yes (GDT)	-	deficits feedback processing	-	Svaldi, Brand, & Tuschen-Caffier, 2010
restless legs syndrome	no (GDT)	-	-	-	Bayard, Yu, Langenier, Carlander, & Dauvilliers, 2010

narcolepsy	no (GDT)	-	-	-	Bayard et al., 2011
excessive online gamers	yes (GDT)	-	severity of psychiatric symptoms	-	Pawlikowski & Brand, 2011
young adults with suicidality	yes (CGT)	-	CGT performance significantly predicted suicidality	-	Chamberlain, Odlaug, Schreiber, & Grant, 2013
Healthy participants: studies investigating effects of task characteristics					
feedback	yes (GDT)	logical thinking, executive functions	calculative strategy development	feedback removal reduced GDT performance	Brand, Laier, et al., 2009; Brand, 2008
Healthy participants: studies investigating effects of person characteristics					
perfectionism	(GDT)	-	concern over mistakes, personal standards, but not other personality variables	-	Brand & Altstötter-Gleich, 2008
impulsivity	(GDT)	-	sensation seeking, urgency	-	Bayard, Raffard, & Gely-Nargeot, 2011
behavioral inhibition (BIS)/ behavioral approach system (BAS)	(GDT)	-	interaction between BIS and BAS predict risk taking after winning and losing experience	-	D. Y. Kim & Lee, 2011
risk taking tendencies	(GDT)	-	interaction between risk taking tendency and self-control predicts decision making	-	Dislich, Zinkernagel, Ortner, & Schmitt, 2010
Trait self-control and ego depletion	(GDT)	-	higher trait-self control associated with higher ego depletion and more risk taking	-	Imhoff, Schmidt, & Gerstenberg, 2013

testosterone level	(GDT)	-	-	testosterone administration had no effect on decision making	Goudriaan et al., 2010
young age (adolescents)	(GDT)	-	planned and unplanned risk taking in real life	-	Maslowsky, Keating, Monk, & Schulenberg, 2010
older age	yes (GDT)/ no (PAG)	individual level of executive functions and logical thinking	-	-	Brand & Schiebener, 2012; Zamarian et al., 2008
calculative strategies	(GDT)	executive functions, logical thinking	calculative processing of probability problems	-	Brand, Heinze, Labudda, & Markowitsch, 2008; Brand, Laier, et al., 2009
probability processing abilities	(GDT, PAG)	executive functions, logical thinking	advantageous handling of simple probability-based decision problems	-	Schiebener et al., 2011
Healthy participants: studies investigating effects of context characteristics					
stress	yes (GDT)	-	increased cortisol level	feedback removal reduced GDT performance descriptively	Starcke, Wolf, Markowitsch, & Brand, 2008
parallel working memory load	yes (GDT)	executive functions, working memory	-	parallel solving of 2-back working memory task reduced GDT performance	Starcke, Pawlikowski, Wolf, Altstötter-Gleich, & Brand, 2011
anchor effects, explicit goal setting	anchors: yes (GDT) goals: no (GDT)	executive functions	-	misleading comparison values (high final capitals of other players) reduced GDT performance	Schiebener, Wegmann, Pawlikowski, & Brand, 2012

decision support	no (GDT)	executive functions, working memory performance	-	advice for the advantageous alternatives improved GDT performance in subjects with low working-memory- and executive functions	Schiebener, Wegmann, Pawlikowski, & Brand, under review
emotion induction	no (GDT)	-	uncertainty related emotions	fear induction caused more advantageous (save) decision making compared to anger or happiness induction	Bagneux, Bollon, & Dantzer, 2012
methyl-phenidate administration	(modified CGT)	-	-	methyl-phenidate administration caused no changes in decision-making behavior or attentional performance	Shalev, Gross-Tsur, & Pollak, 2013
Healthy participants: studies investigating effects of physiological activation					
PET activation measuring	(CGT)	-	activation in medial, lateral, posterior prefrontal cortex	CGT compared to control condition	Rogers, Owen, et al., 1999
automatic activation	(GDT)	-	automatic activation unrelated to GDT behavior	-	Drucaroff et al., 2011

Notes. If no group comparison was performed the second column indicates only which task was used. For other overviews see also Brand et al., 2006; Clark & Manes, 2004; Gleichgerrcht et al., 2010.

As can be seen in the overview in Table 3, neuropsychological research on decision making under risk has become a very broad field, in which several predictors of decision-making performance have been investigated. Different decision-making tasks were used, yielding relations between decision making and different neurocognitive functions, as well as other domains. Additionally, some studies investigated the influence of experimental manipulations. The table shows that some parts of the theoretical model have already been supported by empirical evidence. The evidence supports the model's idea that decisions under risk are mainly guided by deliberate, cognitive processes, requiring abilities like logical thinking (Brand, Laier, et al., 2009; Schiebener et al., 2011) and calculative strategy development (Brand, Heinze, et al., 2008). Additionally, the positive impact of feedback on the development of an advantageous decision-making strategy could be demonstrated (Brand, 2008). Studies on the role of emotional processing indicated that bodily reactions seem to guide decisions to some extend only, playing a rather minor role, while cognitive processes seem to be more crucial (Brand, Grabenhorst, et al., 2007; Drucaroff et al., 2011).

Regarding the dual process view on decision making the evidence supports the idea that the processes preceding decisions under risk conditions rather tap into the cognitive System 2 than into the intuitive System 1 (Brand, Laier, et al., 2009; J. S. B. T. Evans, 2003; Kahneman, 2003). This interpretation has also been supported by the study by Starcke and colleagues (2011). The study showed that decision-making performance in the GDT substantially decreases when a task demanding executive System 2 processes has to be solved in parallel. This indicated that the GDT cannot be solved in normal quality if System 2 is hindered from processing on the decision task. In contrast in the IGT, which is thought to be associated with intuitive System 1 processing, it was found that decision-making performance was almost unaffected by a secondary System 2 task (Turnbull et al., 2005). In combination, these two studies with the GDT and the IGT indicate that decision making under risk substantially taps into System 2 processing, while decision making in the IGT more strongly taps into System 1 processing.

When regarding the overview of studies with the GDT, it is particularly remarkable that, as suggested in the model, executive functions or brain regions associated with executive processing have frequently been found to be closely related to decision-making performance. Executive functions are not only associated with decision-making performance on the level of bivariate correlations. They were also found to moderate effects of task variations (e.g., missing feedback), person characteristics (e.g., age), and external influences (e.g., misleading anchors) (Brand, Laier, et al., 2009; Brand & Schiebener, 2013; Schiebener et al., 2012). However, there are still substantial gaps in the current understanding of how executive functions build up the decision-making process. Several studies treated executive functions to some extent as a black box, although the executive system is thought to be a set of different subcomponents of cognitive and behavioral control functions instead of a unitary function. Studies on the role of different executive subcomponents are rare. In a study by Del Missier, Mäntylä, and Bruine de Bruin (2010), different subcomponents were regarded in their role for performance in two decision-making associated tasks. In the first task, called applying decision rules, the participants had to solve a decision-making problem by following a predetermined decision-making strategy. In the second task, called consistency in risk perception, they had to estimate how probable specific events should occur in different spans of time (one year vs. five years). To detect the relationships between performances in these two tasks and executive functions, not only a simple bivariate correlation approach was used, but a structure equation model was tested. Therefore, a theory guided test battery was assembled. Three subcomponents of executive functions were measured with two tasks each and analyzed on the level of latent variables. Latent variables represent the variance that is shared among the included tasks. The latent dimensions were shifting, updating and inhibition. The results showed that performances in the two tasks were related to different amounts to the subcomponents of executive functions. Applying decision rules was particularly related inhibition. The authors suggested that this relationship was due to the fact that the task required to selectively focus attention on the information that were relevant for applying the decision rule. Consistency in risk perception was related to shifting, probably because the task required shifting between judgment contexts. However, the study did not clearly address the question for the role of executive subcomponents in decision-making behavior under explicit risk conditions. The main reason is that the two "decision-making tasks" did not provide clearly risky conditions (with explicit rules for gains and losses and their probabilities) and, more importantly, they did not demand the participants to make decisions. The tasks rather asked the participants to perform operations, which may be *involved* in decision making that is to follow a decision-making algorithm (in the applying decision rules task) or to estimate probabilities (in the consistency in risk perception task). Nevertheless, the study should be regarded as a valuable contribution to the literature because it demonstrated that different executive functions contribute to different amounts to two competences probably involved in decision making.

Thus, it can be concluded from the literature overview that the results of the studies so far did not systematically point out the role of different executive subcomponents for decision making under risk. The model by Brand and colleagues (2006) has also remained unspecific in this part. The model does not describe which executive sub-functions should contribute to the different steps of the process (e.g., to capturing the features of the situation or to managing a current strategy; see Introduction of Study 1 for further details).

Another point, which is so far not addressed in the model and only sparsely in the neuropsychological literature, is the influence of variations in the situation, especially when these may adapt the cognitive processes that can determine decision-making performance. In the PTF it was suggested that situational conditions and person characteristics affect decision-making competence in interaction (Finucane & Lees, 2005). There have already been studies, which have shown that indeed the interaction between aspects of the situation and basic cognitive functions can predict decision-making performance. For example, it has been reported that misleading information about the decision situation can lead to increased risk taking, particularly in persons with relatively low executive functioning (Schiebener et al., 2012). A comparable effect, but in inversed manner, has been found for the interaction between supporting information about the decision situation and working memory functions as well as executive functions. Supporting information improved the decision-making performance of persons with lower functioning in these domains, while it had no effect on persons with better functioning, who decided advantageously anyway, even without the support (Schiebener, Wegmann, et al., under review).

Beside these external influences, there are also other situational conditions, of which the possible effects on decision-making performance are still unclear. One situational influence that is widely known to affect human performances, higher level cognitive processing and control of behavior, is the presence of explicit goals (Duncan, Emslie, Williams, Johnson, & Freer, 1996; Latham & Locke, 1991; Locke & Latham, 2006; Locke, 1996; Pervin, 1989). However, the role of explicit goals on making decisions strategically has only rarely been investigated (see Table 3, chapter 3.3, and Introduction of Study 2). Regarding the particular role of different executive functions and regarding the role of explicit goal setting, research is required to allow specifying the model in these two points.

An additional issue that is indirectly related to the theoretical assumptions in the model of decision making under risk (Brand et al., 2006) and is still a gap in research is the measurement of decision-making performances under risk conditions in healthy individuals as well as patients with neurological diseases, brain lesions, or psychological disorders. The model implicitly assumes that decision-making behavior is relatively stable in different situations with equal core features. These are the information about the rules for gains and losses, including the number of alternatives and the probabilities for gains and losses as well as their heights. This assumption is also underlying in research practice and clinical practice, in which, particularly under risk conditions, casino-like gambling paradigms are commonly used to measure decision-making performance (such as the GDT, CGT, and the PAG task; Brand et al., 2005; Rogers et al., 1999; Sinz et al., 2008; Weller, Levin, Shiv, & Bechara, 2007; Zamarian et al., 2008). It is thought that these gambling paradigms are models of real-world decision situations. Like real situations they provide different options, with more or less favorable outcomes which can occur with certain probabilities that are more or less explicitly known by the decision maker (Bechara et al., 1996; Brand et al., 2006; Denburg et al., 2007). However, it is unclear whether the gambling situation and the casino cues in these paradigms produce artifacts in the measurement of general decision-making performance. This may particularly be the case in patients with pathological gambling because they may react strongly to the tasks' addiction related gambling cues (e.g., Crockford, Goodyear, Edwards, Quickfall, & El-Guebaly, 2005; van Holst, van Holstein, van den Brink, Veltman, & Goudriaan, 2012). Furthermore, the paradigms are often inflexible and can rarely be modified for experimental manipulations (for further details on possible problems with the existing measurement methods see chapter 3.4 and the Introduction of Study 3). A flexible decision-making paradigm would be desirable for the measurement of decision-making performance and for testing whether decision-making behavior remains stable when the core features of one decision situation (e.g., a gambling task) are transferred to a real-world oriented scenario (e.g., deciding between car routes with different probabilities for traffic jams and different punishments in case of delay).

In summary, the model by Brand and colleagues (2006) should be specified concerning the role of different executive functions, and the role of explicit goal setting in decision making under risk. Furthermore, a flexible and real-world oriented decision-making paradigm should be developed for the measurement of decision-making abilities in research and clinical contexts. In the following the theory on executive functions and goal setting is summarized. Thereafter, different measures of decision decision-making performances are described in more detail and similarities and differences between them are discussed.

3.2. Executive functions

Executive functions can be defined as systems of cognitive control, which direct cognition and behavior that is planned, goal oriented, flexible, and effective (Alvarez & Emory, 2006; Baddeley & Hitch, 1974; Lezak, 1995). Nevertheless, it is still a topic of debate how executive functions should be defined exactly (Eslinger, Lyon, & Krasnegor, 1996; Stuss & Alexander, 2000). Here, it will briefly be explained how executive functions are understood in the literature in general and with respect to their association with working memory (chapter 3.2.1) and will then explain which subcomponents they are thought to be comprised of (chapter 3.2.2).

On a relatively general level, Norman and Shallice (1980) suggested two systems of behavioral control (Norman & Shallice, 1980; Shallice & Burgess, 1993). The first one, the contention scheduling system, should be responsible for controlling automatized routine behaviors. This system controls the behavior in situations, in which a person has knowledge (or "schemata" or "action plans") available about the actions to be implemented (e.g., when walking through the super market, in which one knows in which order the products of one's weakly usage are displayed). An automatized schedule is activated without mental effort, which implements the required behaviors (e.g., turning left at the third shelf and taking the cornflakes in the second row). The second system, the supervisory attentional system, is supposed to take control in new, or at least non-routinized actions (e.g., when visiting a new supermarket for making the weekly errand). Attention needs to be directed to relevant information (e.g., for walking through the corridors systematically and performing visual search for the breakfast products), interference by irrelevant information and inadequate behavior needs to be inhibited and new plans and decisions have to be made. Therefore, the supervisory attentional system requires high mental effort. Other authors described in more detail how these control processes may be implemented in human cognition. Baddeley and Hitch (1974) suggested that suchlike cognitive and behavioral control is a function of working memory. This approach is described in the following section.

3.2.1. Working memory and executive control

Working memory is supposed to be responsible for maintaining information temporarily and is considered an active memory system that processes and manipulates information cognitively. Thereby, it is an important link between perception, long-term memory, and controlled action. It can maintain representations of perceived information and representations of long-term memory-contents. It manipulates and integrates this information for example to design action-plans and to direct their conduction (Baddeley & Della Sala, 1996; Baddeley & Hitch, 1974; Miyake & Shah, 1999). There are several models of the architecture of working memory (for an overview see Miyake & Shah, 1999). The most acknowledged model is the multicomponent model, first suggested by Baddeley and Hitch (1974). This model assumes that working memory is not only responsible for short-term maintenance of information. Additionally, the so called central executive of working memory should control attention and information-manipulation (Baddeley, 2003, 2010).

The multicomponent model (Baddeley, 2003) suggests a central executive and a buffering system. The central executive directs the manipulation of information that is represented in the buffering system. The three parts of the buffering system are thought to hold limited amounts of representations of information for limited durations. The information is thought to be selected from the perceptual system (e.g., spatial and phonological information) and from long-term memory (represented by the bottom box in Figure 4). In the model, executive functions are understood as a set of tools, which process on the contents of working memory, such as selecting information and integrating them in the development and application of goal oriented action plans (see also Smith & Jonides, 1999). The multicomponent model is depicted in Figure 4.

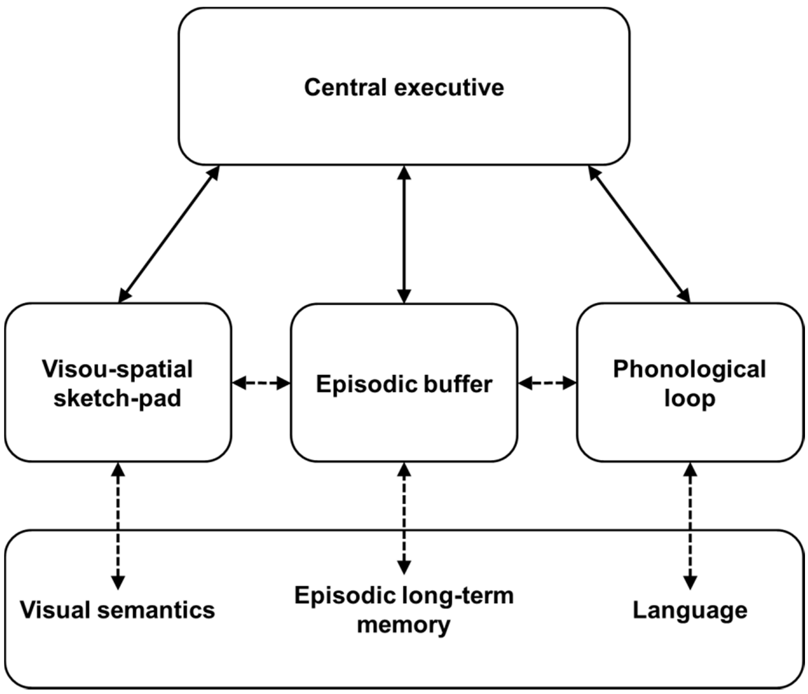

Figure 4. The multicomponent model of working memory adapted from (Baddeley, 2003, 2010).

In several studies the role of different brain structures for the suggested main components (central executive and buffering system) of the model have been investigated. The results indicated that there seem to be different brain regions and networks involved in the components. Thus, the results generally support the structure in the multicomponent model. The buffering components of working memory have found to be related to brain areas that are also associated with encoding of information (Jonides, Lacey, & Nee, 2005). These are areas in the posterior parietal cortex, which are supposed to house the content buffers (Cohen et al., 1997; Gathercole, 1994). An important role of widely distributed regions in the prefrontal cortex have been suggested by several studies' results (Cabeza, Dolcos, Graham, & Nyberg, 2002; D'Esposito et al., 1995; Müller & Knight, 2006; Müller, Machado, & Knight, 2002; Rypma & D'Esposito, 1999; Rypma, Prabhakaran, Desmond, Glover, & Gabrieli, 1999). Especially, the dorsolateral prefrontal cortex has been found to be relevant in the active maintenance and rehearsal of memory-contents. Interestingly the region yields higher activations when more content has to be rehearsed (Callicott et al., 1999). Thus, there may indeed be a partitioning of the buffering component (posterior parietal regions) and the executive maintenance and manipulation component (prefrontal cortex regions) of working memory, as suggested by Baddeley and Hitch (1974).

Further studies' results have moreover suggested that beside these main brain regions, additional regions seem to support specific working memory components. Some of them are involved in the buffering- and others in the executive processing component. For example, higher baseline levels of dopamine in the striatum predicted higher working memory capacity (R Cools, Gibbs, Miyakawa, Jagust, & D'Esposito, 2008). Additionally, the basal ganglia have been found to be associated with working memory capacity and - in interaction with the prefrontal cortex - with filtering of incoming information (McNab & Klingberg, 2008; Voytek & Knight, 2010). It was reported that the hippocampus takes a part in creating links ("bindings") between different information (Henke, Weber, Kneifel, Wieser, & Buck, 1999; Mitchell, Johnson, Raye, & D'Esposito, 2000) and in the process of buffering information (O. Jensen & Lisman, 2005). The cerebellum is associated with verbal memory operations (Smith, Jonides, & Koeppe, 1996; Smith & Jonides, 1997). Moreover, also emotional processing in the limbic system seems to be relevant for working memory functioning. However, the underlying mechanism is not understood sufficiently yet. Amygdala activation might be associated with good working memory functions even if the stimuli are not emotional (Schaefer & Gray, 2007) but paradoxically, amygdala damage can result in increased working memory capacity (Morgan, Terburg, Thornton, Stein, & Van Honk, 2012). It is unclear whether amygdala activation normally interferes with performance in working memory tasks without emotional stimuli and whether this interference is decreased when the amygdala is damaged (Kapur, 1996).

As can be judged from this short overview, the model by Baddeley (2003) has strongly been supported by empirical evidence. Therefore, the core assumption regarding a working memory buffering system and a central executive system is also applied in this thesis. However, the main topic of the work at hand is the role of sub-functions of the central executive for decision making. Thus the possible subcomponents of the central executive are discussed in the following chapter. (Subcomponents of buffering or "storage" functions of working memory are examined and discussed in other works, e.g. Oberauer, Süß, Wilhelm, & Wittman, 2003; Süß, Oberauer, & Wittmann, 2002.)

3.2.2. Subcomponents of executive functions

In the multicomponent model Baddeley (2003) considers the central executive as one system but suggests that it may be comprised of different subcomponents. As basic components that are required by any attention-control process he mentions focusing, dividing, and shifting of attention (Baddeley & Logie, 1999; Baddeley, 2003). Indeed, patients with brain damages that caused the so called dysexecutive syndrome (i.e., patients with severe problems in controlling goal oriented behavior and cognition) did not show the same patterns of impairments in different executive tasks. Rather, different brain areas seemed to make contributions to the performance in different tasks (Burgess, Alderman, Evans, Emslie, & Wilson, 1998; Burgess, Veitch, de Lacy Costello, & Shallice, 2000; Stuss & Alexander, 2000). Thus, it seems probable that there is a separation of different subcomponents.

In the literature several arrangements into different sub-functions can be found (a well-structured overview was provided by Jurado & Rosselli, 2007). Examples of arrangements are in one theory volition, planning, purposive action, and effective performance (Lezak, Howieson, Loring, Hannay, & Fischer, 2004) or in another theory planning, initiation, preservation, and alteration of goal-directed behavior (Hobson & Leeds, 2002). In the following, two particular approaches toward a fractionation of executive functions will be presented more detailed. These approaches are currently well accepted in the literature and are based on behavioral and brain-imaging data. One was provided by Miyake and colleagues (2000) and the other one by Smith and Jonides (1999).

Miyake and colleagues (2000) suggested three basic functions of the executive system and investigated their separation in a behavioral experiment with healthy participants. The three functions were shifting, updating, and inhibition. Shifting is the ability to shift (or "switch") between several tasks, cognitive operations, or mental representations. Updating is the function that monitors and refreshes the contents of working memory. This implies detecting information that is no longer required, as well as encoding new information and actively updating working memory with it. Inhibition means the ability to control dominant and automatic behavior and, if necessary, to be able to prevent oneself from executing an automatic but inaccurate action. In their study Miyake and colleagues (2000) investigated a large sample of healthy individuals with a battery of nine executive functioning tests. Always three were supposed to tap into one of the three functions, respectively. Using confirmatory factor analysis and structure equation modeling, the authors modeled the three functions as latent variables. The full model with all three domains was then compared to models in which the tests for all three functions were subsumed in one latent variable or in which the possible combinations of two functions were subsumed. It has been found that the full model, suggesting three latent variables, was better represented in the data than the other models. This result supported the suggestion of separable executive subcomponents and the expectation that shifting, updating, and inhibition are separable basic functions of the executive system. Later, the literature has also reported data, which was in line with this finding (Fisk & Sharp, 2004; N. P. Friedman et al., 2008; Miyake & Friedman, 2012; Verdejo-García & Pérez-García, 2007). Additionally, a fourth component of behavioral control was found to be separable from these functions. Verdejo-García & Pérez-García (2007) examined 81 substance dependent participants and 37 brain-healthy controls with a large test-battery for executive functions and with the IGT. In a factor analysis four "executive" components were found: Once more updating, shifting, inhibition, and - as fourth component - decision making under ambiguity in the IGT. This result supports the view that there may be three basic executive functions and it points out that decision making under ambiguous conditions remains separable from them. Nevertheless, it is unclear whether decision making under ambiguity can be seen as a fourth component of the central executive of working memory, given that decisions in the IGT can be biased emotionally and rely only to some extent on higher cognition (see chapter 3.1.2). Furthermore, it has to be noted that the heuristic eigenvalue > 1 criterion was applied in the factor analysis. This criterion has been criticized in the methodological literature (e.g., Conway & Huffcutt, 2003; Fabrigar, Wegener, MacCallum, & Strahan, 1999; Ford, MacCallum, & Tait, 1986).

In summary, there is evidence for the idea of three components to be involved in the general concept of executive functions. However, as pointed out by Miyake and colleagues themselves, the three components should be the most basic functions of the central executive, but do not encompass all functions. The authors suggested that "the relationship between these relatively basic executive functions and more complex concepts like 'planning' needs to be examined" (p.90, Miyake et al., 2000). It may be possible that there are also hierarchically higher positioned functions, which control or „recruit" the basic functions for the purpose of implementing goal-directed behavior. A division into five functions, instead of three, was suggested by Smith and Jonides (1999). They reviewed brain-imaging studies with different executive-functioning tasks. From these studies the authors inferred that there may be five components of the central executive, which have been found to be associated with distinct regions in the prefrontal cortex. These functions are defined as follows:

Attention/inhibition: This is the ability to direct attention toward relevant information and inhibit irrelevant information as well as automatic or dominant responses or reactions that do not fit the demands of the task.

Task management: This function is responsible for reacting to different tasks and arranging serial processing on them by shifting between them flexibly.

Planning: This is the ability to plan the processing on several subtasks, which need to be solved to attain a certain goal.

Monitoring: This is the ability to supervise the processing on sequential tasks, by updating and checking working memory contents and determine the next steps to take.

Coding: This function is responsible for coding information into working memory buffers in order to maintain representations of the information and its time and place of appearance.

Theoretically, one can assume that these five functions may be organized in a hierarchical structure, with basic "lower level" functions and "higher level" functions that direct the lower level functions. Smith and Jonides (1999) suggested that attention/inhibition and task management could be called the most basic functions of the central executive. However, when thinking about the definition of the five subcomponents another hierarchical arrangement may also be conceivable. Lower level functions may be attention/inhibition and coding. They are required in almost any situation, in which information is cognitively processed. As can also be inferred from the multicomponent model (Baddeley, 2003) as well as from best reasoning, it is inevitable to focus attention on information and code it into working memory before a cognitive operation is able to make active use of the information. The main reason for defining the two functions as lower level is that they need to be directed, by the higher level functions. One may assume that the directing, clearly higher level functions are planning and monitoring. For example, planning requires focusing attention on the task's information, to encode them, and to code one's plan for solving the task into working memory. Monitoring requires to direct attention towards information that is required to supervise the state of the task for which the next steps need to be determined. Task management seems to be a function in between the two levels of hierarchy. On the one hand it is very basic (as suggested by Smith and Jonides, 1999), because when working on any task it is required that one is able to switch between the sub-operations that are required to solve the task. Additionally, task management is controlled by the higher level functions. For example, in a planning-process switches between the tasks can be predetermined. On the other hand task management seems to be on a higher level than attention/inhibition and coding, because one function of task management is to direct these attention and coding processes. For example, task management is responsible for shifting the attention between information about the task. However, although, assuming a hierarchical organization of the subcomponents appears reasonable, it still needs to be tested empirically. Thus, a possible hierarchical arrangement is investigated in Study 1.

In empirical research on executive functions, a large number of different tests have been used to measure the diverse components of executive abilities in healthy individuals and patients. With many of these tests it is tried to tap specific subcomponents, but the involvement of other components cannot be excluded in most of the tests. Jurado and Rosselli (2007) provided an overview about some often used tests and test batteries. Table 4 presents a similar selection of typical tests and indicates which domain they were originally supposed to measure. Additionally, and crucially for the conceptualization of Study 1, it is suggested which domain they probably tap in the arrangement of five components proposed by Smith and Jonides (1999).

Table 4. Common tests of executive subcomponents ordered by Smith and Jonides' components they probably tap (attention/inhibition, coding, task management, planning, monitoring).

Test (+ short description)	**Originally supposed to measure**	**Smith and Jonides' components the test probably taps**	**Author**
Color Word Interference Test (name printing-colors of color-words, instead of reading out the words)	inhibition/inference control, processing speed	attention/inhibition (requires focusing attention on color and to inhibit the impulse of reading out the word)	Bäumler, 1985; Stroop, 1935
Go/No-Go (react to target category stimuli and inhibit reaction to non-target stimuli)	attention, categorization, inhibition, reaction speed	attention/inhibition (requires maintaining attention on emerging stimuli and inhibiting response to non-targets)	Mesulam, 1985
Stop Signal Task (categorize stimuli categories by key stroke and inhibit response when acoustic signal occurs)	inhibition	attention/inhibition (requires maintaining attention on emerging stimuli and inhibiting response after acoustic signal)	Logan, 1994; Miyake et al., 2000
TMT A (connect numbers on paper in ascending order)	psychomotoric processing speed	attention(/inhibition) (requires attention for visual search)	Reitan, 1958
TMT B (connect numbers alternating with letters on paper in ascending order)	psychomotoric processing speed, divided attention, shifting	attention/inhibition, task management (requires attention for visual search, inhibiting impulse of continuing connecting in the actual category, shifting between categories)	Reitan, 1958
Digit Symbol Substitution Test (code digits into symbols as indicated in a coding-key-table)	coding, psychomotoric processing speed, perceptual speed,	coding (requires quick coding of the information in the key table into working memory)	Royer, 1971; Wechsler, 1981
F-A-S (name as many different words as possible starting with a particular letter)	verbal fluency, long-term memory access	unclear, may tap attention/inhibition for maintaining focus on the task, or monitoring to keep track of already named words	Benton & Hamsher, 1989
Five Point Test (draw one or more straight lines between five point always resulting in unique patterns)	figural fluency, fluid and divergent thinking	unclear, may tap attention/inhibition for maintaining focus on the task, or monitoring to keep track of already used patterns	Regard, Strauss, & Knapp, 1982

Semantic, categorical fluency tasks (name as many words as possible alternating between two categories, e.g., sports and fruits)	verbal fluency, long-term memory access, shifting, cognitive flexibility	task management (requires efficiently shifting between the categories and the strategies of memory search and word selection)	Aschenbrenner, Tucha, & Lange, 2000
Go/No-Go with flexibility demand (like Go/No-Go, but target in one block are non-targets in the next and there are partly overlapping stimuli-attributes, e.g. blue bird in one, red bird in other category)	attention/inhibition, shifting	attention/inhibition, task management (requires the same as Go/No-Go, but additionally flexible switching between the target categories)	Verdejo-García & Pérez-García, 2007
Wisconsin/Modified Card Sorting Test (sort cards with symbols according to unknown sorting rule (type, number or color of symbols) to target cards	categorization, rule detection, cognitive flexibility, shifting	depending on used variable. Non-perseverative errors: planning trial and error sorting and monitoring its outcomes is required to quickly and systematically finding out the new sorting rule. Perseverative errors: task management and cognitive flexibility is required to shift smoothly to a new rule	Berg, 1948; Nelson, 1976
Tower of London (sorting different colored rings on three bars to a target position)	planning, inhibition	depending on used variable. Number of moves: logical planning is required to reach target position in as few moves as possible. Number of rule violations: inhibition is required to abide to the rules instead of intuitively sorting the rings the “easier” way.	Shallice, 1982
Tower of Hanoi (sorting rings of different sizes on three bars to a target position)	planning, inhibition	planning and inhibition, alike Tower of London, but regarded as more complex/difficult.	Simon, 1975
Brixton Spatial Awareness Test (observing changing position of different colors circles and predicting the next position)	rule detection	monitoring is required to keep upright information about previous circle positions, in order to detect the rule and to abide to it consequently.	Burgess, 1997

Note. Attention/inhibition and coding are only mentioned as measured constructs, if the test is suggested to measure particularly these domains. Principally, these functions could be mentioned in all tasks, because following the hypothesis of a hierarchical arrangement, it should be necessary in each of the task to maintain attention, inhibit false responses, and code information into working memory. However, some tasks are designed in the way that the main variance is supposed to be produced by individual differences in higher level functions. Thus the lower level functions that may be involved in solving the tasks are not mentioned additionally.

There is a considerable number of studies with these and comparable tests of executive components. Many studies have also investigated the neurological bases of the different components. Jurado and Rosselli (2007) provided an overview about the results of neuroimaging studies that examined brain activations in a planning task (the Tower of London), attentional control tasks (e.g., the Color Word Interference Test), cognitive flexibility tasks (e.g., the Wisconsin Card Sorting Test), and different verbal fluency tasks. In almost all of the studies, investigating the different domains, prefrontal cortex activation has been associated with performing the tasks. Particularly, the dorsolateral prefrontal cortex bilaterally seems to be involved in planning (Goethals et al., 2004; Morris, Ahmed, Syed, & Toone, 1993) and attentional control (Collette et al., 2001; Kaufmann et al., 2005). In cognitive flexibility, the superior medial frontal lobe seems to be activated additionally (Stuss & Knight, 2002). In fluency tasks, the left dorsolateral prefrontal cortex was frequently found to be activated (Jahanshahi, Dirnberger, Fuller, & Frith, 2000; Phelps, Hyder, Blamire, & Shulman, 1997). Additionally, involvements of subcortical areas, such as the striatum or the anterior cingulate cortex, and the thalamus were found (Periáñez et al., 2004; Phelps et al., 1997), underlining the connections between frontal, posterior, and subcortical areas (Collette & Van der Linden, 2002; Elliott, 2003). Some authors concluded that the prefrontal regions direct behavior but in order to work accurately they rely on the functionality of other regions providing informational input (Alvarez & Emory, 2006; Anderson, Northam, Hendy, & Wrenall, 2001).

In summary, behavioral and neurological investigations yielded convincing evidence for the assumption that executive functions are not a unitary system but are fractionated into interacting subcomponents. A systematic investigation of the role of the different subcomponents for decision making under risk conditions has not been undertaken so far. This topic is addressed in Study 1 of this thesis.

3.3. Goal setting

This chapter addresses the theory about and the research on goals and goal setting with respect to its role for human behavior. It has often been demonstrated that goals can affect human performance in working on different types of tasks. This has been regarded as an important topic because in the industrial society it was of high interest to discover ways to optimize human work performances (Locke & Latham, 2002). Nevertheless, it has so far only very rarely been investigated how goals affect performances in decision making. In life decisions are frequently made with conscious knowledge about the own goals for the consequences. Often suchlike decisions are made under risk conditions. For example, before driving to a business meeting one might have to choose between longer and shorter routes with different probabilities for traffic jams, and this decision might be made with the goal to save as much of one's time as possible. In private life decisions are also made with clear goals. For example when choosing between money investment models one may aim to gather a specific amount of money until a clearly defined point in time, in order to be able to pay the deposit for a real estate. In Study 2, the effects of explicit outcome goals for the performance in the GDT will be investigated. In the following a brief overview about the literature on the relationships between goal setting and performance will be presented.

Early theories about motivation suggested that there are inner drives which determine human behavior. It has been assumed that these motives, such as the need for achievement, operate unconsciously (McClelland, Atkinson, Clark, & Lowell, 1953). Later, the view emerged and has gradually been established that humans have conscious purposes and goals, which influence their behavior (Ryan, 1970). In this research, goals have been defined as „the object or aim of an action, for example, to attain a specific standard of proficiency, usually within a specified time limit" (Locke & Latham, 2002, p. 1). Several studies have been conducted that investigated how conscious goals affect behavior and performance and what the mechanisms behind the goal-performance relationship might be (for summaries see e.g., Locke & Latham, 2002, 2006). The central finding is that goals improve performances in numerous different tasks (Locke & Latham, 1990) such as solving anagrams (Shah & Kruglanski, 2002), learning the contents of a university course (Latham & Brown, 2006), or in sport activities (Locke & Latham, 1985). However, the magnitude of improvement was found to depend on core attributes of the goal, specific mechanisms within the person, and moderating variables, such as attributes of the situation. Based on these findings, a theoretical model of goal setting was formulated by Locke and Latham (2002). The model is depicted in Figure 5.

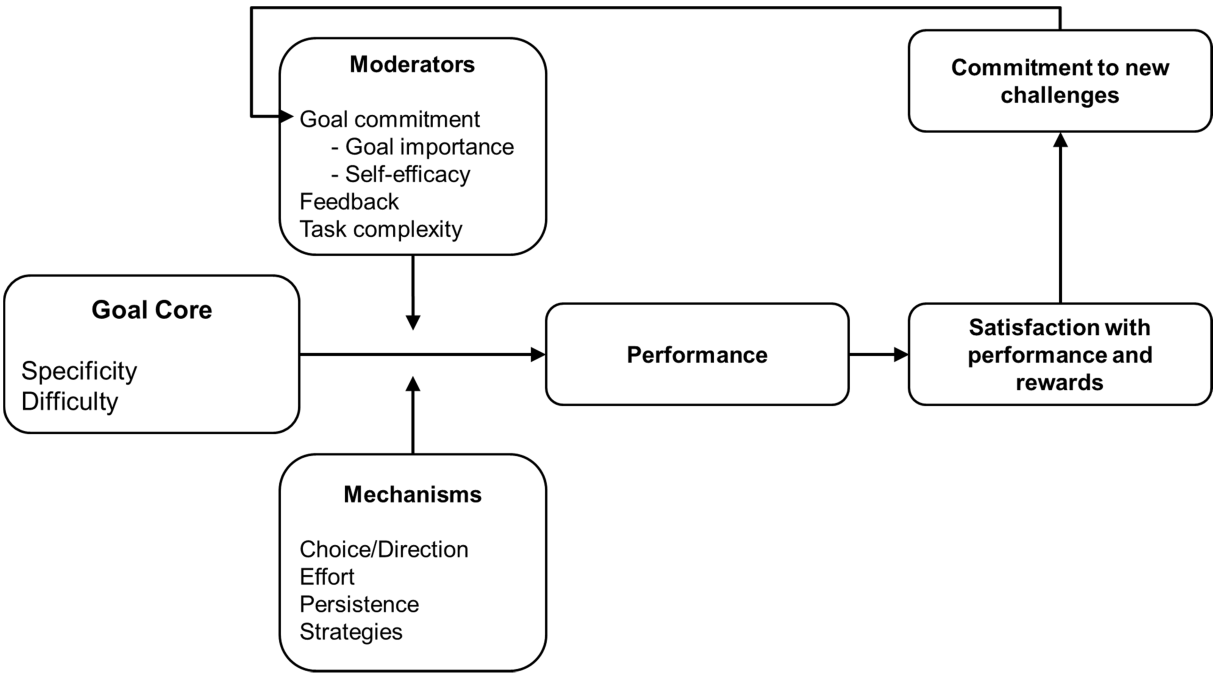

Figure 5. The model of goal setting with core attributes of the goal as direct influences on task performance, as well as variables moderating the goal-performance relationship (Locke & Latham, 2002).

The authors argue that the core attributes, which fundamentally determine the goal-effect are the goal's difficulty and its specificity. It has been found that the highest levels of effort and the best performances were attained when the goals were very high. Performance only decreased when reaching the goals was objectively impossible or when the limits of the person's abilities was reached (e.g., Locke, 1982). Additionally, it has been observed that goals not only need to be difficult but also specific. Humans perform better when they have a clearly defined goal, instead of an ambiguous goal, such as to do ones best (Hall, Weinberg, & Jackson, 1987; Locke & Latham, 1990). As described in the review by Locke and Latham (2002), the experimentally induced effects of difficulty and specificity often had large effect sizes. However, in a few investigations it has been found that there are some cognitive tasks, such as maze-tracing tasks, in which performance was better with ambiguous goals (Sweller & Levine, 1982). Furthermore, persons with ambiguous goals were found to use more systematic problem-solving strategies than persons with explicit goals (Vollmeyer, 1996).

In the model, the effect of a goal's core attribute on performance is suggested to be implemented by goal mechanisms and influenced by moderators. The first goal mechanism is the direction of attention toward goal relevant information. This involves the choice of goal relevant activities: directing attention toward feedback about performance on goal relevant subtasks or choosing learning material that will help to approach the learning goal (Locke & Bryan, 1969; Rothkopf & Billington, 1979). The second mechanism is the insertion of effort. Goals can increase the amount of cognitive or physical energy an individual invests in a task (e.g., Bandura & Cervone, 1983). Besides increased momentary effort, a third mechanism, persistence, is triggered by goals. Individuals take effort for longer times when they have hard goals (LaPorte & Nath, 1976). As fourth mechanism, goals activate cognitive strategies. It is suggested that when being faced with a performance goal humans automatically begin to retrieve strategies from long-term memory or to develop new strategies for the given task by using available skills or knowledge (Latham & Baldes, 1975; Wood & Locke, 1990).

Additionally to the mechanisms triggered by goals Locke and Latham (2002) suggested that three moderators affect the relationships between goal core, goal mechanisms, and task performance. The main moderator is the personal commitment to the goal. Commitment comprises the experienced self-efficacy and the subjective evaluation of the goal's importance. Individuals show stronger goal induced performance improvements if they experience mastery over the means that are required to reach the goal and if they evaluate the goal as important, for example after participating in its formulation (Erez, Earley, & Hulin, 1985). The overall commitment is also suggested to be affected by previous experiences with the tasks, involving a person's satisfaction with the own performance, and with the rewards that have followed performing on the task (Locke & Latham, 2002). These experiences are thought to determine the willingness to commit to new challenges and affect the commitment to the actual goal. The second moderator is feedback about the progress towards the goal. Persons need to be informed about their progress in order to determine whether goal mechanisms (e.g., effort or persistence) need to be increased in order to perform according to what the goal requires (Matsui, Okada, & Inoshita, 1983). The third moderator is the tasks complexity. This is a moderator because it influences the individual's success of developing and applying a good strategy for the task. People differ in their ability to develop problem solving strategies. When the problem is simple the effect of goal setting on performance is large because in most individuals the goal triggers the development of an accurate goal-oriented strategy. When the problem is more complex the effect of goal setting becomes smaller because only some of the people manage to develop a good strategy (Wood, Mento, & Locke, 1987).

This model of goal setting assumes that several cognitive operations are responsible for realizing the effects of goals on performances. Among them are the direction of attention, processing of feedback, monitoring of success, or the development of strategies (Locke & Latham, 2002). These operations, which are suggested to be particularly induced by goals that are specific and difficult, are also thought to be directed by the central executive system (Baddeley, 2003; Miyake et al., 2000; Smith & Jonides, 1999). Thus, executive functions are defined as functions responsible for realizing goal oriented behavior and cognition (see 3.2 and Lezak et al., 2004) and the same cognitive operations are also suggested to be involved in advantageous decision making under risk conditions (Brand et al., 2006). However, there are only a few studies, which have addressed the role of goals for decision making. These studies allowed only limited conclusions because the methods had shortcomings and the findings partly contradicted each other. In some studies, it has been found that goals can cause more advantageous decision making under ambiguity and under risk, but only under the influence of specific situational manipulations (Hassin, Bargh, & Zimerman, 2009; Schiebener et al., 2012). Other studies reported increased risk taking, especially when the actual state of outcome was below the goal (D. Knight, Durham, & Locke, 2001; Lopes & Oden, 1999; Payne, Laughhunn, & Crum, 1980, 1981) (for more details please refer to the Introduction of Study 2). Given this scarcity of data, Locke and Latham (2002) called for studies on the relationship between goals and decision making. Furthermore, in case that the effects of goals on decision-making performance are comparable to the effects of goals on cognitive tasks, goal setting should be included as a variable in the specified model of decision making under risk conditions, which is aspired in this thesis. Thus, the role of goals for decision making under risk is investigated in Study 2.

3.4. Assessment of decision-making competence

When aiming at investigating decision-making behavior it has to be regarded that decision-making competences can be assessed with a number of different tasks. This chapter is about a selection of the tasks that have previously been used in neuropsychological studies and in clinical diagnostic. It has to be noted that these tasks have not been developed to describe decision-making behavior or decision-making strategies in general. Most of the tasks have originally been developed in order to reveal decision-making impairments in patient population and to reveal the reasons for these impairments, such as reduction in neurocognitive functioning or emotional processing (Bechara et al., 1994; Brand et al., 2006; Sinz et al., 2008; Zamarian et al., 2008). Furthermore, the tasks have been applied to investigate the mechanisms involved in decision making in healthy individuals (e.g., Bayard, Raffard, et al., 2011; Brand, Laier, et al., 2009; see also the overview in chapter 3.1.3 and Table 3).

In the following four of these tasks will be compared. The IGT, the CGT, and the GDT because these have been mentioned as the most important decision-making tasks in neuropsychological research (Gleichgerrcht et al., 2010). As a fourth task the PAG task is included in the comparison because this has frequently been applied in recent studies (e.g., Schiebener et al., 2011; Zamarian et al., 2008, 2011). The aim of this chapter is not to describe the tasks in detail, but to point to similarities and differences between them (descriptions of the tasks can be found in 3.1.3 and in the Methods section of Study 3). The comparison will take place along three criteria: The tasks' levels of ambiguity, situational stability, and complexity. The level of ambiguity is chosen as a criterion because one core attribute of a task is to what extent it measures decision making under ambiguity or under risk and this can determine the amount of different cognitive and emotional processes involved in processing on the task (Brand et al., 2006; Schiebener et al., 2011). Situational stability has been chosen because the introduced models of decision making suggest long-term strategies to be involved in decision making. The stability of the situation should crucially determine the possibility to develop a long-term strategy (Brand, Fujiwara, et al., 2005; Brand et al., 2006). Complexity is a criterion because it may be important for the amount of cognitive demands that are required to process the decision-making situation accurately (e.g., to understand the rule for gains and losses) (Finucane & Lees, 2005).

Level of ambiguity. The IGT is the only tasks of the selected three tasks, which has been designed as measure of decision making under ambiguity. It is the most ambiguous task, because no explicit information about the possible outcomes and their probabilities is provided to the decision maker. Furthermore, the number of trials is not mentioned and the final capital is displayed only graphically, not as exact amounts (Bechara et al., 1994; Bechara, 2007). In the GDT, CGT, and the PAG task the participants are explicitly informed about the rules for gains and losses and their probabilities. However, some ambiguity is involved because in all cases the exact numerical probabilities can only be calculated instead of being explicitly given in numerical format. In the GDT, they can be calculated by dividing the number of sides the die has by the number of numbers the participant bets on. In the CGT the ratio of blue and red boxes determines the winning probability. In the PAG task the ratio of blue and red cubes determines the winning probability in the lottery gamble. The CGT and the PAG involve some further ambiguity because the tasks do not inform about the number of trials to be played. Additionally, in the CGT the participant does not know the amount of the next bet. After having decided for one or the other color, a bet amount is displayed for five seconds and then it is raised automatically by the computer. The participant has to press a button in order to bet the currently displayed amount or can wait for the next, unknown, higher amount. In the PAG task some ambiguity is caused by the probability presentation format. It is improbable that the participants manage to count the 24 red or blue cubes in order calculate the probability. Thus the decision can presumably only be made on the basis of an estimation of the ratio. By contrast, in the GDT, there is no further ambiguity than the already mentioned probability presentation format. All other information is explicitly provided (e.g., the number of trials to play or the exact capital).

Situational stability. In all four decision-making paradigms the task of the participant as well as the number of options to choose from remains stable. However, in the CGT and the PAG task the rules for gains and losses change from trial to trial. In both tasks the ratio of blue and red boxes or cubes changes. Additionally, the possible amounts change. In the CGT the ascending bet amounts are different from trial to trial and in the PAG task the fixum can be a gain or a loss. Furthermore, there is a ten seconds time limit for the decision in the PAG task. After the ten seconds, the fixum is automatically chosen and the next lottery is presented. In the CGT there is a five second time limit for choosing a bet amount. Thereafter, a higher amount is presented. In the IGT the amount of the outcomes differ from trial to trial. In the GDT the situation remains stable in all trials. The options are the same in all trials, as well as the probabilities for gains and losses and their possible heights.

Complexity. The complexity of the task is defined by the number of available options and the simplicity of the presentation of information about probabilities, gains, and losses. The CGT and the PAG task seem to have the lowest degree of complexity. In both tasks it has to be decided between two options, betting on blue or red in the CGT, and gambling or taking the fixum in the PAG task. In the CGT the betting phase that follows after the decision for red or blue causes additional complexity compared to the PAG task. However, in the PAG task the probability presentation is more complex because there are 24 blue or red items, while there are only ten items in the CGT. In contrast to the CGT and the PAG task, the IGT is more complex with regard to the number of available options (four), but there is no information explicitly provided about probabilities or possible gains. However, one may argue that this makes the task very complex, because in order to understand the task's rules the participants would need to infer them from the varying amounts of gains and losses indicated in the feedback. Regarding the number of available options, the GDT is the most complex task because there are 14 alternatives. However, there are only four different amounts of money that can be won or lost. These are associated with the four risk classes (betting on one, two, three, or four numbers together) in which the options could be categorized (please note that this categorization requires cognitive operations of complexity-reduction, which may not be fully intact in all individuals). Nevertheless, the GDT has previously been regarded as a comparably complex task because of the possibility to apply long-term strategies: The participants have to decide how to gamble, instead of only whether to gamble or not, such as in the PAG task (Brand & Markowitsch, 2010).

Because of the differences regarding these three criteria, advantageous decision making in the tasks is supposed to rely to different amounts on several cognitive domains (e.g., Schiebener et al., 2011). Higher levels of ambiguity might increase the demand on emotional/intuitive processing, because there is not enough information available for solving the tasks based on cognitive processing. In this case making advantageous decisions requires to learn from the feedback and to anticipate rewards and punishments intuitively by processing emotional signals in the body periphery (Bechara & Damasio, 2005; A. R. Damasio, 1994). Nevertheless, when the decision maker better understands the rules for gains and losses the contribution of executive functions should increase, as has been demonstrated in studies with the IGT (Brand, Recknor, et al., 2007; Y.-T. Kim et al., 2011). Furthermore, the dependence on feedback varies with the amount of ambiguity: When the information about the rules is complete and explicit, principally no feedback needs to be required for finding out which alternatives are advantageous. If the situation is ambiguous the profit from and the dependency on feedback should increase (see also the arguments in Brand, Laier, et al., 2009; Brand, 2008).

The level of situational stability has been suggested to further determine the impacts of different executive functions on decision-making performance (Brand, Fujiwara, et al., 2005; Brand & Markowitsch, 2010). In situations that vary from trial to trial, such as in the CGT and the PAG task, cognitive flexibility may be required (Zamarian et al., 2011). Additionally, in the PAG task, best performance is achieved if switches are made between choosing the fixum and the lottery: In high winning probability conditions it is advantageous to switch from the very save, conservative fixum to gambling in the lottery. In other words, deciding conservatively is not always the best option in the task. Thus, it is suggested that the PAG task measures decision-making performance sparsely influenced by the general tendency to avoid risks (Sinz et al., 2008). In the CGT and the PAG tasks the time for making decisions is limited and therefore advantageous decision making may also require a certain amount of attention and a minimum speed of processing. In the more stable tasks, the GDT and the IGT, the development of long-term strategies is possible. Particularly, in the GDT a reasoned long-term strategy can be planned from the very beginning. Furthermore, the success of this strategy can be monitored over the course of the task by using the feedback of previous trials. Additionally, it is possible to revise the strategy if necessary. Thus, reasoning abilities and higher level executive functions have been found to be involved in decision making in the GDT (see e.g., Brand, Laier, et al., 2009; Euteneuer et al., 2009, and chapter 3.1.3).

The complexity of the task may affect the cognitive effort that is required to find out which alternatives are advantageous. For example, if there are more options, more information about their attributes need to receive attention and to be coded into working memory representations. Comparing these options with regard to their favorability (e.g., in terms of expected values) should then also be more taxing with regard to cognitive effort. The load on memory may additionally be increased when the feedback varies from trial to trial, like in the IGT.

These differences between the tasks and the associated varying demands on cognitive and emotional processes were suggested as explanations for differential decision-making impairments of patient populations in one task, but not in the other. For example, this has been reported for patients with Parkinson’s disease who were sometimes found to be impaired in the IGT (e.g., Delazer et al., 2009; Ibarretxe Bilbao et al., 2009). However, sometimes they were not impaired in the IGT, but in the GDT (Euteneuer et al., 2009). Another study found that they were impaired in the CGT (Roshan Cools et al., 2003), while a further result suggested that they were impaired in the PAG task, but only when they had symptoms of dementia (Delazer et al., 2009). These results seem to be in inconsistent. One reasons for the inconsistent findings might be that impairments in decision making are due to the medication the patients received (Roshan Cools et al., 2003). However, it remains unclear how the existing differences between the tasks affected the differential results. Therefore, the results' interpretability is constrained. The differences between the tasks may be regarded as a methodological problem. A further problem of the tasks is caused by a similarity. All of them take place in gambling scenarios and have only little in common with real-world decision-making situations. This may decrease the ecological validity of measurement. It would be desirable for theoretical research and for clinical diagnostics to have a common decision-making scenario, which consist only of a minimum of gambling cues, and in which the level of ambiguity, the level of stability, and the level of complexity could be varied systematically. The first step into this direction is taken in Study 3 of this thesis. In this study, a new framework for the assessment of decision-making competences is evaluated. This framework allows the implementation of several decision-making problems within one common story line in which experimental manipulations can be flexibly realized.

4. Conclusion from theoretical background

After this literature review it becomes obvious that decision-making research is a broad field, in which a lot of knowledge has already been gained about the emotional and cognitive factors that determine the competence to choose advantageously in different situations. Nevertheless, there are still remarkable gaps in the theoretical approaches, especially regarding decisions under risk conditions. Furthermore, in research practice and clinical application decision-making abilities are still inconsistently measured. In this thesis theoretical as well as practical progress is aspired. First, the theoretical model of decision making under risk conditions is supposed to be specified. Therefore, research is necessary, particularly regarding the contributions of different executive subcomponents to the decision making-process. Additionally, the effects of goal setting on decision making should be investigated. Second, this thesis aims at evaluating a unitary method for the measurement of decision-making abilities. This is supposed to be useful in research and in clinical diagnostic.

These theoretical and methodological progresses are not only important for understanding how advantageous decisions under risk are made and how they may be improved in everyday lives of healthy individual. The findings might also support the development of domain-specific techniques for therapy and training programs for patients, who suffer from problems with making advantageous decisions.

5. Study 1: Contributions of different executive functions to decision making under risk conditions - Test of a structural equation model.

5.1. Abstract

The complex process of decision making under risk is supposed to recruit executive functions. Several studies showed that advantageous decision making is often accompanied by good executive functioning. How single components of the executive function system contribute differentially to the decision-making process has not been clarified so far. We investigated direct and indirect influences of different executive functions on performance in a laboratory decision-making task, the Game of Dice Task (GDT). Based on Brand's model of decisions under risk (2006) and the definition of executive functions by Smith and Jonides (1999) we modeled three latent variables, representing the executive domains supposed to be involved in decision making. The domains were situation processing (consisting of coding and attention/inhibition tasks), flexibility (including task management tasks), and strategy management (measured by planning and monitoring tasks). The results of a structural equation model indicated that particularly the latent dimension strategy management influenced decision making under risk directly, while situation processing and flexibility had no direct but an indirect effect: Mediation analysis suggests that situation processing affects decision making mediated by strategy management. As supposed in the model of decision making under risk, especially higher level control processes including planning and monitoring seem to affect decision-making performance. Lower level functions such as coding, and attention/inhibition are elementary components that are required for the functioning of the higher level processes.

5.2. Introduction

5.2.1. Overview

Executive functions are considered as a set of different functions of cognitive control. They control goal oriented behaviors in several environmental contexts (see e.g. Lezak et al., 2004). It is supposed that these functions are fundamentally involved in decision making, especially under risk conditions. In these situations, strategies can be planned and applied, given that the decision situation provides explicit information about the rules for the occurrence of positive or negative outcomes (Brand et al., 2006). In several previous studies correlations between advantageous decision making under risk and performances in executive tasks have been reported (e.g., Brand et al., 2009; Euteneuer et al., 2009), but it has not been demonstrated yet, to what extent different sub-functions of the executive system contribute to the processes in decisions under risk. In the work at hand, we use a structural equation model (SEM) approach to investigate the role of different executive functions and their interactions for decision-making performance under risk conditions.

In the following, the previous theoretical considerations and empirical findings that lead to the question of the current work will shortly be reviewed, with a focus on relationships between measures of decision making and measures of executive functions. The assumptions summarized in Brand's model of decision making under risk (Brand et al., 2006) and in Smith and Jonides' model of executive functions (Smith & Jonides, 1999) will be used to derive the hypothesized SEM that aims at decomposing the role of different executive functions in decisions under risk.

5.2.2. Decision making and executive functions

In real life and in laboratory research decisions are often made under ambiguity or risk (see Yates & Stone, 1992 and chapter 3.1). Under conditions of ambiguity the decider does not know the rules and probabilities for the occurrence of potential positive and negative consequences. Therefore, the decision needs to be rather based on emotional reactions learned from the feedback of previous trials. These emotional reactions, often perceived as hunches and guesses, can bias toward choosing from advantageous alternatives, and can prevent individuals from choosing disadvantageous alternatives (Bechara et al., 1997). Previous studies with the IGT provided evidence for the assumption that bodily emotional reactions (so called somatic markers) can bias the decision maker toward the advantageous alternatives (Bechara et al., 1994, 1999; Blakemore & Robbins, 2012; Dunn et al., 2006). To what extent cognitive functions also predict behavior in the IGT is still discussed. While some works suggest that good IGT performance does not require conscious cognition (Bechara et al., 1997; Bechara, Damasio, Tranel, & Damasio, 2005; Toplak et al., 2010) others report that cognitive processes, like executive functions and conscious knowledge about the cards contingencies are also fundamentally involved in decision making in the IGT (Gansler, Jerram, Vannorsdall, & Schretlen, 2011; Maia & McClelland, 2004). Regarding decisions under ambiguity in the IGT, there has already been an SEM study investigating the role of individual differences in cognitive abilities for decision-making performance (Gansler et al., 2011). In this study three latent dimensions of cognitive functioning were defined: attention, general neuropsychological ability, and executive functions. The dimensions were used as predictors of IGT performance in the initial 40 trials and the last 60 trials of the task. It was found that particularly in the latter trials if the IGT basic attention functions as well as higher executive control functions predict IGT performance. This result also supported the idea that particularly, in the later trials the participants seem to arrive at an understanding about the attributes of the decks. This may also explain why the behavior in the later trials of the IGT is correlated with decision-making behavior under objective or "explicit" risk conditions (Brand, Recknor, et al., 2007; Y.-T. Kim et al., 2011). (For detailed information on the topic of decision making under ambiguity please refer to chapter 3.1.2.)

In decisions under clearly objective risk conditions, the rules for gains and losses are explicitly available to the decider. The probabilities linked to the given alternatives are either provided explicitly or are at least calculable. When additionally these rules remain stable over duration of the decision task, the decider can develop and apply cognitive strategies from the beginning (Brand, Heinze, et al., 2008). The processes probably involved in decision making under risk have been described on the theoretical level in a model by Brand and colleagues (2006; described in detail in chapter 3.1.3 and depicted in Figure 3). The beginning of the decision-making process is marked by the decision situation providing information about probabilities and possible outcomes such as gains or losses. Working memory is thought to hold representations of these features and to recall experiences with the given or other decision situations and knowledge about certain situational aspects. Executive functions are supposed to process on the working memory contents with the task to categorize options, to select information, and to develop decision strategies, as well as to apply them systematically. These operations are supposed to lead to the decision. After the decision, there may be feedback about the outcome. This can be handled on two routes: A cognitive and an emotional route. On the cognitive route executive functions are required to use feedback for conscious monitoring of the decision strategy's success and for the revision of the current strategy. On the emotional route the feedback causes an emotional reaction making it possible to automatically develop hunches and guesses (somatic markers) toward the options that are less risky than others. As can be seen, the role of executive functions is assumed at different stages of the model, but it is not specified in detail *which* executive functions are required within the different cognitive processes and how they collaborate with each other.

When considering the literature, it is apparent that there is so far no unitary definition of executive functions (see chapter 3.2). Nevertheless, the different existing definitions principally agree that executive functions are control systems allowing humans to regulate behavior that is planned, goal oriented, flexible, and effective (Anderson, Anderson, & Jacobs, 2008; Jurado & Rosselli, 2007; Lezak et al., 2004; Shallice & Burgess, 1996). For this purpose executive functions participate in a working-memory system, in which they have the task to manipulate the information held in short term storage (Baddeley & Hitch, 1974; Baddeley, 1998; Smith & Jonides, 1999). Furthermore, models propose different arrangements of sub-domains of executive functions. A relatively detailed taxonomy of five sub-domains was suggested by Smith and Jonides (1999). The five domains have been found to be differently allocated in areas of the prefrontal cortex. The domains and their tasks are: attention and inhibition (directing attention to relevant cues and inhibiting irrelevant information and reactions), task management (organizing sequential operations on complex tasks by scheduling subtasks and switching attention between them), planning (sequentially planning subtasks to advance toward a goal), monitoring (determining the next step in a sequential task by checking and updating working memory contents), and coding (coding representations in working memory, and linking them to time and place of occurrence). (For more details on subcomponents of executive functions please refer to the theoretical background section 3.2.2.)

Smith and Jonides (1999) pointed out that there should be different levels of executive functions. They defined attention/inhibition and task management as “the most elementary” (p. 1596; Smith & Jonides, 1999) functions and by that probably meant that these two functions have to perform basic processes that are necessary to perform other higher level functions, such as planning and monitoring. For example, planning different tasks requires to focus attention on them and to switch between them. In other literature on executive functions different levels have also been assumed. For example, a subdivision into three functions has often been used. These three are inhibition, updating and shifting (N. P. Friedman et al., 2006, 2008; Jurado & Rosselli, 2007; Miyake et al., 2000; Miyake & Friedman, 2012; Salthouse, Atkinson, & Berish, 2003). Miyake and colleagues (2000) pointed out that this division is not exhaustive, but covers only the most basic functions of the executive system, and it omits higher level functions, like planning and monitoring.

The role of executive functions for decision making under risk has frequently been investigated using the Game of Dice Task (GDT; Brand et al., 2005). The task provides explicit rules for gains and losses and their probabilities, and these rules remain stable over the task’s duration (for a detailed description of the GDT see 3.1.3 or the methods section

5.3.3). The GDT has recently been mentioned as one of the most important measures of decision making (Gleichgerrcht et al., 2010) and has been used in various studies with different patient populations, for example patients with schizophrenia (Fond et al., 2012), binge eating disorder (Svaldi et al., 2010), narcolepsy (Bayard, Abril, et al., 2011), or restless legs syndrome (Bayard et al., 2010). Especially, decision-making performance of patients with specific neurological disorders, resulting in executive dysfunctions, was compared to performance of healthy control participants. Examples are patients with prefrontal cortex damage (Brand, Kalbe, et al., 2004), Korsakoff's syndrome (Brand, Fujiwara, et al., 2005; Brand, Pawlikowski, et al., 2009), Parkinson's disease (Brand, Labudda, et al., 2004; Euteneuer et al., 2009; Rossi et al., 2010), or Alzheimer's disease (Delazer et al., 2007). In various studies also other decision tasks than the GDT were used to investigate the roles of executive function deficits for decision making under risk (e.g., Rogers et al., 1999; Manes et al., 2002; Sinz et al., 2008).

The results from such behavioral studies lead to the relatively clear conclusion that executive functions are important in making decisions under risk conditions. Together with impairments in executive functions the patients showed, compared to healthy controls, more preference for the highly risky options in the GDT. Additionally, correlations between performances in executive functioning tests and decision-making performance were observed and had moderate or sometimes high effect sizes (Brand, Pawlikowski, et al., 2009; Drechsler et al., 2008; Euteneuer et al., 2009; Fond et al., 2012; Mäntylä, Still, Gullberg, & Del Missier, 2012). In healthy participants the role of executive functions in risky choice situations has also been investigated, in order to understand the mechanisms contributing to normal healthy decision-making behavior. In line with the findings in patient samples relationships between executive domain tests and decision tasks were found (Brand, Laier, et al., 2009; Brand & Markowitsch, 2010; Del Missier, Mäntylä, & Bruine de Bruin, 2012; Schiebener et al., 2011). Furthermore, participants with very good executive abilities seem to be less negatively influenced by distracting information about the decision situation (Schiebener et al., 2012). Additionally, it has been demonstrated that not only executive functions, but also working memory functions, which are closely related to the executive system, are required for making good decisions under risk (Starcke et al., 2011).

In healthy individuals variances in decision making were explained by executive functions in the low to moderate effect size range (variance explanations about 5-30%). This indicates that of course other person variables (such as impulsivity; Bayard et al., 2011) and situational influences (such as task complexity or acute stress; Brand & Markowitsch, 2010; Finucane & Lees, 2005; Starcke & Brand, 2012) should affect choice behavior. The evidences from behavioral studies addressing the role of executive functions where also supported by brain functioning studies examining brain activations while decisions under risk were made (Labudda et al., 2008; R. D. Rogers, Owen, et al., 1999). These showed activations in regions involved in higher level executive processes, especially responsible for working memory functions, behavioral flexibility, and conflict management (e.g. dorsolateral and orbitofrontal prefrontal cortex, as well as anterior cingulate cortex).

As can be judged from this short literature review, there has already been a high number of studies that have made valuable contributions to our understanding of the relations between decision making and executive domains (see also chapter 3.1.3 and Table 3). However, detailed conclusions concerning the composition of the executive mechanisms underlying decision making under objective risk conditions remain unattained. One of the reasons is that neuropsychological background testing was often not designed for theory driven analysis but rather for simple comparisons of some basic neurocognitive functions (e.g., Brand et al., 2005; Zamarian et al., 2010). If broader executive assessment had been applied, this was not used for advanced statistical evaluation (e.g., Drechsler et al., 2008). Another reason is that, especially in patient studies, sample sizes are often too small for complex path- or structural equation modeling. Furthermore, samples in decision-making research are often artificial because of over proportional representation of students and young participants (Chu & Spires, 2000; Cokely & Kelley, 2009; Lejarraga & Gonzalez, 2011; Samuels & Whitecotton, 2011; Schiebener et al., 2012, to mention only some). Investigating samples with such narrow ranges in age and educational status may on the one hand help to reduce variance that is not controlled for. On the other hand the "real" variance in cognitive functions that are age sensitive (Boone, 1999; Charlton et al., 2008; Grady, Springer, Hongwanishkul, McIntosh, & Winocur, 2006; Salthouse et al., 2003; Salthouse & Miles, 2002; R. West, 2000) may only poorly be represented in such samples.

Because of the mentioned methodological limitations, in most cases only zero-order correlations or sometimes multiple regressions have been reported between decision-making performances under risk and standard measures of different executive sub-functions. Most of these analyses yielded low to moderate effect sizes. In the following, we shortly sum up some of the found simple relationships between measures of different executive functions and of decision making, to see whether conclusions about the differential involvement of executive sub-functions can be made. Correlations between decision tasks and the Wisconsin Card Sorting Test (WCST; Berg, 1948; Heaton et al., 1993; Nyhus & Barceló, 2009) or its modified version (MCST; Nelson, 1976) have been reported in several studies (e.g., Brand et al., 2006; Brand et al., 2009; Schiebener et al., 2012, 2011). The test is referred to as an executive task supposed to measure higher level functions, like planning, monitoring, rule learning, problem solving, or categorization (see also Miyake et al., 2000). With performances in n-back paradigms (A. R. A. Conway et al., 2005) also moderate correlations have been found previously (Starcke et al., 2011). This task is often used as test of working memory functions, but requires not only working memory capacity but also executive processes, especially monitoring (A. R. A. Conway et al., 2005). Furthermore, decision making significantly correlated with time needed in the Trail Making Test (TMT; Reitan, 1958) in version A and B (Schiebener et al., 2011; Zamarian et al., 2008) or only in version B but not A (Brand, Laier, et al., 2009). Version A is supposed to measure psychomotoric processing speed while version B is regarded to tap into inhibition as well as shifting abilities and into divided attention. Correlations between decision making and simple attention/inhibition tasks, like the Color Word Interference Test (CWIT; Bäumler, 1985; Stroop, 1935) were reported around zero and not significant (Brand, Fujiwara, et al., 2005). Unfortunately, only few studies applied theory guided test batteries of executive functions together with decision-making tasks. Drechsler and colleagues (2008) reported correlations between GDT performances and the scores of the Behavior Rating Inventory of Executive Function (BRIEF; Gioia et al., 2000), in which parents of adolescents were asked to rate executive abilities of their children in different sub-domains (e.g., inhibition, shifting, working memory, planning, and monitoring; please note the problems concerning the validity of questionnaire measures of executive functioning; Toplak et al., 2012). In the small samples of 24 healthy participants the correlations descriptively seem to be stronger when regarding executive abilities of rather higher levels (shifting, monitoring, organization), but weaker in basic functions (initiation, inhibition, working memory) (In the study, the GDT was played two times. Here, we refer only to the correlations from the first time the task was administered). In contrast, in the patient group of 23 patients with attention-deficit/hyperactivity disorder (ADHD), the correlations were descriptively higher with the scores of the basic functions, inhibition, and initiation. This indicates that problems with these abilities explain a part of the decision making problems in ADHD.

This analysis of previously reported zero-order correlations in healthy individuals seem to indicate that correlations have frequently been found between decision making under risk and higher level executive functions, but less steadily with very basic functions. But still, as mentioned above, a systematic approach with a clear prior conceptualization of executive functions is missing. This gap is supposed to be filled with the current study.

5.2.3. The current study – a latent dimension model to test the role of different executive functions in decisions under risk

In this work we apply the division into five executive functions, as suggested by Smith and Jonides (1999): attention/inhibition, task management, planning, monitoring, and coding. We decided to apply this taxonomy because it includes very basic components as well as higher level functions which potentially direct the basic components. Based on this structure, we model the executive components within different parts of the decision-making process as it has been proposed in Brand’s model (Brand et al., 2006). As outlined above, the model suggests that executive functions should participate in different cognitive procedures, accounting for advantageous decision making.

The most basic procedure is the perception of the relevant information offered by the situation as well as the implementation of this representation in working memory. We call this function *situation processing*. As the second function, Brand’s model (Brand et al., 2006) supposes that decision options need to be categorized by their features and accordingly they should be evaluated cognitively. The main features of the options are their possible gains and losses and their probabilities. For categorization and cognitive evaluation it is required to resolve the cognitive conflict between possible gains and their related probabilities. The conflict is that favorably high gains are related to unfavorably low winning probabilities, while low gains are related to high winning probabilities. Resolving this conflict appropriately should require the ability to be flexible by sharing attention and by shifting between the two categories (gain heights vs. probabilities). Therefore, we call this function *flexibility*. As the third function, Brand’s model suggest that a decision strategy is developed, its application planned, and its success monitored. This possibly leads to an adaption of the strategy. This function is called *strategy management*.

Within the three processes – situation processing, flexibility, and strategy management – different executive functions, as defined by Smith and Jonides (1999), should be required. Situation processing should include coding and attention/inhibition. Information about the decision situation needs to be coded into working memory representations and attention is necessary to process the relevant features of the situation. Inhibition is important to suppress the processing of irrelevant information and to inhibit unplanned behaviors (Hobson & Leeds, 2002; Miyake et al., 2000; Smith & Jonides, 1999). Flexibility should require task management abilities, including shifting of attention, and switching effectively between relevant categories (gains/probabilities) (Miyake et al., 2000; Smith & Jonides, 1999; Verdejo-García & Pérez-García, 2007). Strategy management should include planning and monitoring functions. These are necessary to plan a strategy, perform actions according to the strategy as well as monitoring its success (Borkowsky & Burke, 1996; Smith & Jonides, 1999). Based on the specifications in Brand's model, it can be assumed that the very elementary situation processing is not directly involved in the final decision-making process, but is a precondition, required by the two higher level processes – flexibility and strategy management – which should directly affect decision-making behavior under risk conditions. For example, the higher level process strategy management includes monitoring of the success of a decision-making strategy. This monitoring function should "recruit" lower level situation processing, because this is necessary to make monitoring possible (Smith & Jonides, 1999). In detail, for monitoring it is necessary that attention is focused on the heights of occurring gains or losses and that this information is coded into working memory. Part A of Figure 1 depicts Brand's model of decision making and highlights the processes in which executive functions should pronouncedly be involved. Part B of Figure 6 shows the empirically testable model that projects these executive functions. The current study was designed in order to test whether this model will find empirical support and in order to describe the executive processes' differential influences on decision-making performance under risk conditions.

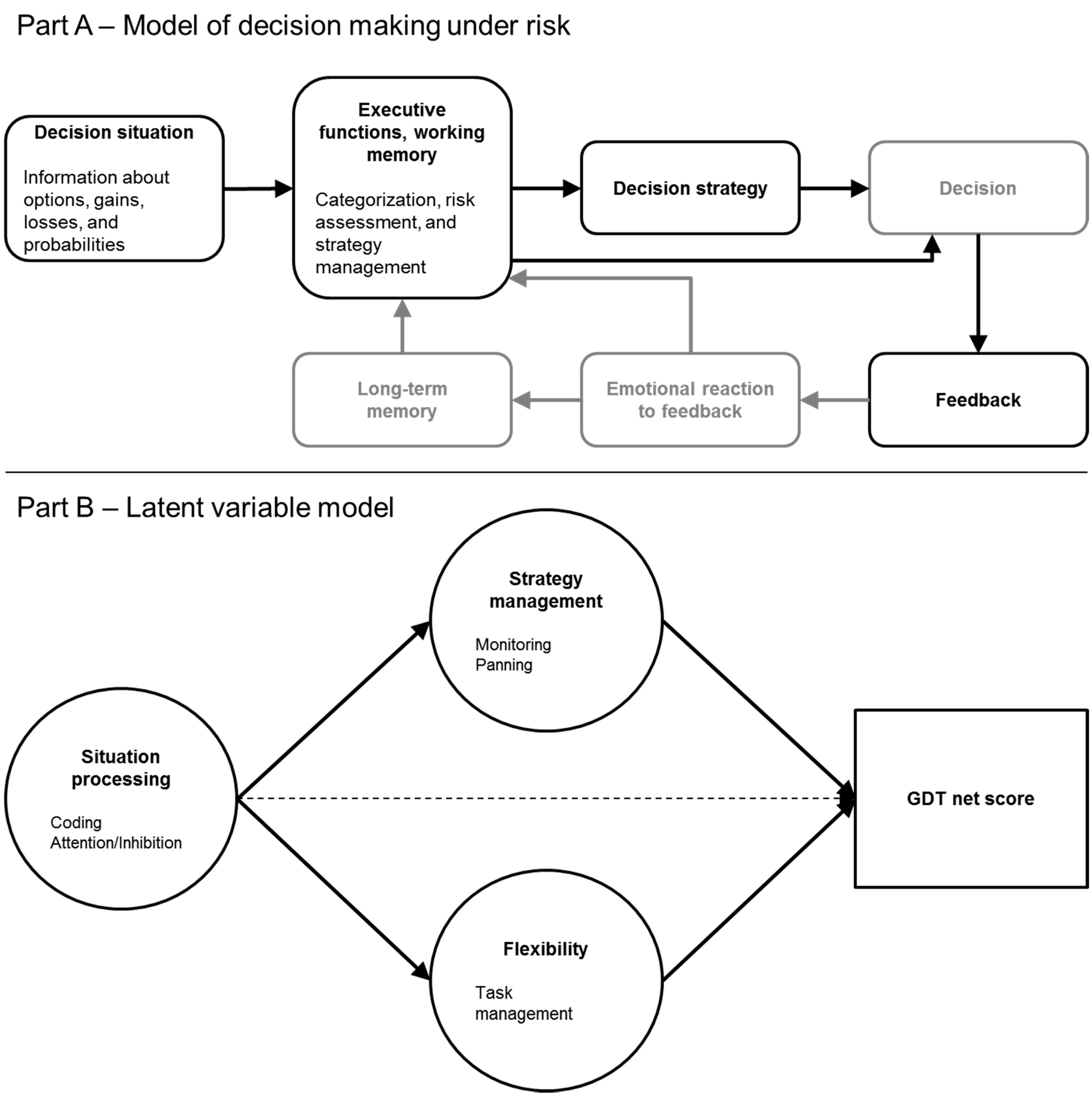

Figure 6. The model of decision making under risk conditions and the suggested latent variable model of executive functions.

Part A. The model of decision making under risk, as suggested by Brand et al. (2006). Executive functions should particularly participate in three sub-processes: (1) basal processing of the decision situation, (2) categorizing alternatives and their risks, (3) and developing and managing a decision strategy initially as well as by monitoring the feedback from a series of decision trials. In the figure, the processes in which executive functions should be pronouncedly relevant are colored in full black.

Part B. The latent variable model that is tested in the study at hand. It projects the assumptions in Brand's model, suggesting three processes, which mainly require executive functions. Basal executive functions, like coding situation features into working memory and holding attention on relevant features, are supposed to be the precondition for two more complex processes. These two are flexibility and strategy management. Flexibility, as representing task management functions, is assumed to participate in categorization and conflict management (e.g., the conflict of high possible gains being connected to high risk). The executive functions required for strategy management guide the development, the application, monitoring, and the revision of strategies, initially as well as in reaction to feedback.

To test the model, we gathered a large sample of participants with a respectable age range and heterogeneous in education and actual professional status. All participants completed the GDT and an extensive battery of executive tests, with at least two tests, representing each of the three latent executive domains (situation processing, flexibility, strategy management).

5.3. Method

5.3.1. Participants

In total, 270 brain-healthy participants (113 males, 157 females), aged 18-86 years (*M* = 34.44 years, *SD* = 16.35 years) were assessed. Of them, 96 (36 %) were students. All were recruited by local advertisement and tested at the department of General Psychology: Cognition, at the University of Duisburg-Essen. They were paid €20 for participation, students received credits for courses. None of the participants had a history of neurological or psychiatric diseases, as determined by screening interview and self-report questionnaire. The study was approved by a local ethics committee. Participants who were 50 years or older were screened for dementia with the DemTect (Kalbe et al., 2004), but none of them showed signs of dementia (DemTect scores were 13 or higher).

5.3.2. Instruments/Procedure

As a measure of decision making under risk, the GDT was used (Brand, Fujiwara, et al., 2005). After the GDT, a series of neuropsychological tests was administered to the participants. In the following we present the paradigms used to tap the three executive domains supposed to be involved in decision making: situation processing (coding, attention/inhibition), flexibility (task management), strategy management (monitoring, planning). More detailed descriptions of the tasks can be found in Lezak et al. (2004). Please note that the tasks are not suggested to tap exclusively the domain which we assigned them to. The multivariate CFA and SEM approaches used in this study, build latent variables from the manifest measures (i.e., the used tasks). The latent variables then represent the variance that is shared among the manifest variables assigned to one domain. Therefore, it is in preparation for CFA and SEM analyzes, not sufficient to regard, which domain the task was originally supposed to measure. Instead, when assigning manifest variables to latent dimensions, it has in the first place to be considered, which tasks strongly *share* what is aimed to be represented by the latent variable.

Additionally to the executive tests, the LPS subtest reasoning was applied to all participants in order to estimate general intelligence (Horn, 1983). Furthermore, subsamples but not all participants additionally completed the IGT, further tests of executive functions as well as questionnaires of which the data are not reported here. Overall the investigation lasted 1.5 to 2.5 hours (about two hours on average). All experimenters were experienced with neuropsychological investigations and were carefully trained in the correct administration of the tasks.

5.3.3. Decision making under risk – Game of Dice Task

The Game of Dice Task (GDT; Brand et al., 2005) measures decision making under risk conditions. In the computerized task participants have the goal to increase the fictitious capital of €1,000 in18 throws of one virtual die. Each time before the die is thrown, participants guess which number (1-6) will occur. Then the die is thrown and the participants win if they have guessed correctly and lose if they have guessed wrong. They can bet on one single number or a combination of two, three, or four numbers. Participants win if the chosen number or one of the numbers among the chosen combination is thrown. If one of the other numbers is thrown, they lose. For example, they can bet on one single number, such as the number “2”. Then the die is thrown. If the number “2” occurs on top of the die, €1,000 is won. If one of the other numbers occurs (the 1, 3, 4, 5, or 6), €1,000 is lost. When betting on two numbers, such as on the numbers “1” and “2”, the related gain/loss is €500. The die is thrown and €500 is won if the number “1” or “2” occurs and €500 is lost if one of the other numbers occurs (the 3, 4, 5, or 6). Analogously, the participants can also bet on three numbers or on four numbers. Each option is associated with explicit, stable gains and losses and probabilities: €1,000 gain/loss for the choice of a single number (winning probability 1:6), €500 gain/loss for two numbers (winning probability 2:6), €200 gain/loss for three numbers (winning probability 3:6), and €100 gain/loss for four numbers (winning probability 4:6). Participants are instructed about all rules for gains and losses as well as the number of trials. Accompanied by distinct sounds, the actual gains/losses are presented on the screen after each throw and the actual overall capital is as well as the number of remaining rounds are permanently actualized and visualized (for a detailed description of the GDT see Brand et al., 2005).

The alternatives can be grouped into “highly risky”, “disadvantageous” decisions (one or two numbers with a winning probability less than 34%) and “lowly risky”, “advantageous” decisions (three or four numbers with a winning probability of 50% and higher). In the lowly risky decisions it is most probable that choosing them should lead to a positive balance in the long run, because the winning probabilities are 50% or higher, promising at least to retain the starting capital of €1,000. Highly risky alternatives should result in a negative balance, because the winning probabilities are below 34%.

Main measures. As measure of GDT performance, a net score is calculated by subtracting the number of high risk choices from the number of low risk choices. A positive net score indicates advantageous choice behavior.

5.3.4. Executive domains

5.3.4.1. Situation processing (coding, attention/inhibition)

5.3.4.1.1. Digit Symbol Substitution Test

The Digit Symbol Substitution Test (Wechsler, 1981) is a paper-pencil task supposed to measure coding and processing speed. Participants are required to draw simple symbols below 63 one-digit numbers (1-9). The symbols, which are supposed to be drawn below the digit, are defined in a coding key table. The test time is 90 seconds.

Good performance in this task requires particularly fast and correct coding of new information into working memory. Participants who are fast in remembering the symbols for each digit can make more correct responses in the given time.

Main measure. Performance in the Digit Symbol Substitution Test is measured by the number of correct symbols drawn below the given numbers.

5.3.4.1.2. Trail Making Test part B (TMT B)

The TMT B (Reitan & Wolfson, 1995; Reitan, 1958) is a measure of processing speed with focus on inhibitory control (attention/inhibition). In this paper-pencil-task, participants are confronted with a sheet showing encircled numbers (1-13) and letters (A-L). They are instructed to connect numbers and letters alternating in numerical, respectively alphabetical order, starting with 1, proceeding to A, followed by 2, B, etc., and ending with 13.

Good performance in this task requires attention in order to maintain fast psychomotoric processing, as well as efficient inhibition of the automatic impulse to simply draw a line to the next number or letter in the order. Often, TMT B performance is measured with a residual score or a difference score in which the performance in the TMT A is subtracted out. Then the TMT B can be regarded as a measure of cognitive flexibility. We use only the TMT B raw score here in order to have a measure that represents the individual efficiency of attention and inhibition processes instead of cognitive flexibility.

Main measure. The measure of performance in the TMT B is the time needed to fulfill the task (shorter times indicate better performance).

5.3.4.1.3. Color Word Interference Test (CWIT) – Interference trial

The interference trial of the CWIT (Bäumler, 1985; Stroop, 1935) is a paper task assessing attention and inhibition with a focus on interference control. Participants are confronted with a list of 72 repeating color words on a piece of paper. The meaning of each word differs from its ink color. The possible words and possible ink colors are red, blue, green, and yellow. Participants are asked to name the ink color of each word in the printing order as quickly as possible. Therefore they have to inhibit the impulse to simply read the words.

Good performance in this task requires attention and efficient inhibition of the automatically interfering impulse to read out the word, instead doing what is required, that is to name the color. As with the TMT B, for the CWIT also the raw score is used instead of a residual or difference score because the test was employed as a measure of attention/inhibition instead of cognitive flexibility.

Main measure. The performance in the CWIT is measured by the time needed to name the 72 colors (shorter times indicate better performance).

5.3.4.2. Flexibility (task management)

5.3.4.2.1. Semantic shifting

A semantic shifting verbal fluency task from the Regensburger Wordfluency Test (Aschenbrenner et al., 2000) was used as measure of task management functions (flexibility, shared attention, shifting). In this test, participants are asked to name as many fruits and sports as possible, in alternating sequence (sport-fruit-sport-fruit etc.) using each sport/fruit only once. The time limit was two minutes.

Good performance in this task requires task management functions, particularly efficient shifting between the two categories and between used strategies (e.g., naming fruits in the order they are arranged in the supermarket).

Main measure. The main measure of this task is the number of correctly named words.

5.3.4.2.2. Go/No-Go

The Go/No-Go task (Verdejo-García & Pérez-García, 2007) is a reaction task that substantially requires cognitive flexibility and category control. In the computerized paradigm, one of four possible drawings is presented on the screen: a black mouse, a black duck, a blue bird, or a red bird. Participants are instructed to press a key as quickly as possible in case the presented picture belongs to the target category and to inhibit a reaction if the presented stimulus does not belong to the target category. The task consists of four blocks with 20 stimulus presentations. In the first and third block, the drawings of the mouse and the blue bird serve as target category, in the second and fourth block, the duck and the red bird are the targets. Each drawing is presented for maximally 1,000 ms, with an inter-stimulus interval of 900 ms. Feedback is given in form of two distinct sounds lasting 600 ms. The task is practiced in two tests trials with 10 stimuli presentations in each trial.

Good performance in this task requires not only attention for fast and correct reacting, but especially management of changing tasks and different categories. Four categories have to be managed in alternation and with partially overlapping attributes (reacting to the bird can be both, right and wrong, depending on the color). Furthermore, participants need to switch efficiently between the changing target stimuli, in order to prevent false reactions, for example to non-target stimuli, which have been target stimuli in previous trials. Therefore, performance in the Go/No-Go has previously been reported to be related to task management functions (e.g., to shifting; Verdejo-García & Pérez-García, 2007).

Main measure. Two variables are used to measure performance in the Go/No-Go. These are the average time needed for correct reactions (shorter times indicate better performance) and the number of correct responses (with a possible range from 0 to 80).

5.3.4.3. Strategy management (monitoring, planning)

5.3.4.3.1. Modified Card Sorting Test (MCST)

The MCST (Nelson, 1976) is a modified version of the Wisconsin Card Sorting Test (WCST; Berg, 1948) tapping into planning and monitoring, as well as rule learning, and categorization. In this computerized paradigm, participants are confronted with a deck of cards displaying a certain number (1-4) of shapes (square, circle, triangle, or star) in a certain color (blue, red, green, or yellow). They are asked to sort every card that appears on the screen to one of four target cards without knowing what sorting rule to apply. The cards can be sorted by the number of shapes, the shape itself or the color of the shapes. Visual and acoustic feedback is given so that participants can use it to find out the correct sorting rule. After six correctly sorted cards, participants are notified that the rule has changed and then they have to find out the new sorting rule.

The task requires the participants to monitor previously used sorting rules and the previously received feedback. Then they have to plan the next sorting trials according to this information. Therefore, the task is used as a measure of monitoring and planning. In the literature the MCST is also called a measure of cognitive flexibility, particularly when the number of completed categories or the number of perseverative errors are used as variables.

Main measure. In order to tap monitoring and planning instead of cognitive flexibility, the number of non-perseverative errors was used as main measure of MCST performance. A non-perseverative error is made when a card is incorrectly sorted but not according to the sorting rule of the previously completed category. Fewer non-perseverative errors indicate better performance in the MCST).

5.3.4.3.2. Balanced Switching Task (BST)

The BST is based on a voluntary task switching paradigm used by Arrington and Logan (2004). The newly developed BST was used to asses monitoring and planning functions. In this computerized task participants have to work on four tasks and have to switch between them voluntarily with the aim to proceed to equal amounts on each of the tasks. The BST contains two sets of stimuli (A: two-digit numbers from 01 to 99 and B: abstract geometric shapes with diagonal hedging). In each set, the participant can work on one of two tasks at a time. In set A, task 1 is to indicate whether the presented number is odd (press “d” on the keyboard) or even (press “f”). Task 2 is to indicate whether the number is below 50 (“j”) or above 50 (“k”). In set B, task 1 is to indicate whether the diagonal hedging within the shape is going to the upper left (“d”) or to the upper right (“f”). Task 2 is to indicate whether the shape is oriented vertically (more high than broad, “j”) or horizontally (more broad than high, “k”). By pushing on the space bar the participants can switch between the sets A and B. Within the sets, they can switch between the tasks 1 and 2, by simply switching between the response keys (“d”, “f”/“j”, “k”). Only one stimulus is presented at a time and the participants have to apply only one of the four tasks with each presented stimulus.

The participants are informed that they have three aims: to work on all tasks as equally often as possible, classify the stimuli as correct as possible, and work on as many stimuli as possible (by making fast reactions). They are also informed that switching between the sets with the space bar would be associated with a loss of time. This rule was used to increase the load on monitoring abilities. It can be assumed that the rule causes a motivation to stay for longer times with one task. These longer times increase the effort of monitoring, how long and often they have worked on the other tasks before and the effort of remembering to make further switches.

The participants are not informed about the duration of the task and the stimulus presentation times. The task is administered two times, each time for exactly four minutes. Each stimulus is presented until the participant responds, but maximally for 1,000 ms. The inter-stimulus interval was 500 ms, a switch between sets A and B costs 1,250 ms of the overall time. All subtasks and the overall task are practiced and the experimenters made sure that the task was fully understood before the main task started.

Good performance in the BST requires monitoring and planning of working progress in different tasks. The participants have to monitor that there are other tasks to work on. Also they have to monitor, how often and how much they have worked on the different tasks in previous trials. Furthermore, good performance in the task can be reached by planning and applying a strategy for systematic switching between the tasks.

Main measure. For each participant, the so called *deviation score* was computed. The formula for the score equals the formula for computing the standard deviation of a sample. For each participant the deviation score provides the deviation from the optimally equal performance. A deviation score of 0% indicates optimal performance, i.e. each task was performed equally often. A deviation score of 43% indicates worst possible performance showing that the participant has worked only on one task. In detail, it was computed which percentage of the overall number of presented stimuli was presented within each of the four tasks (e.g., number of presented stimuli in task 1 divided by the number of overall presented stimuli). In the formula below, this value is denoted by the variables taskA1, taskA2, taskB1, and taskB2. From this value the optimal value of equal performance (25% in each task) was subtracted and the result squared. This was done for each task. The results were summed and then divided by four. From this result the root was taken.

$$\textit{deviation score} = \sqrt{\{[(\text{taskA1} - 25)^2 + (\text{taskA2} - 25)^2 + (\text{taskB1} - 25)^2 + (\text{taskB2} - 25)^2]/4\}}$$

5.3.4.3.3. 3-back task

The 3-back task was originally designed as a test of working-memory updating, but taps into the executive domain of monitoring (A. R. A. Conway et al., 2005). In the computerized 3-back task, participants monitor the identity of digits from ‘‘0’’ to ‘‘9’’, which are presented randomly and participants have to indicate whether or not the actual number is equal to the one presented three numbers before. Numbers are displayed for 500 ms and the inter-stimulus interval is 2,750 ms. Visual feedback is given with a green check mark for a right response and a red cross for a false response. Numbers that equaled the one presented three numbers before were presented with a probability of 33% (Schoofs, Preuss, & Wolf, 2008). All participants completed five blocks with 24 presented numbers per block. The first block served as practice.

Good performance in the task requires efficient and fast monitoring of working memory contents, as well as fast and correct responding to stimuli.

Main measure. The 3-back performance is measured by the percentage of correct responses in the last four blocks.

5.3.5. Statistical analyses

Statistical standard procedures were carried out with IBM SPSS Statistics (version 20.0, 2011, SPSS inc. IBM, Chicago). Pearson correlations were calculated to test for zero-order relationships between two variables. The SEM analysis was computed with MPlus 6 (Muthén & Muthén, 2011). There were no missing data. Before testing the full model, the fits of the latent dimensions were also tested using confirmatory factor analysis (CFA) in MPlus. For both, SEM and CFA, maximum likelihood parameter estimation was applied.

For the evaluation of model fits we applied standard criteria (Hu & Bentler, 1999, 1995). The fit indices were: χ^2 test (significant values indicate that the data does not fit with the model), standardized root mean square residual (SRMR; values below .08 indicate good fit with the data), comparative fit indices (CFI/TLI; values above .90 indicate a good fit, values above .95 an excellent fit), and root mean square error of approximation (RMSEA; "test of close fit"; a value below .08 with a significance value below .05 indicates acceptable fit). For applying mediator analysis it was required, according to Baron and Kenny (1986), that all variables included in the mediation should correlate with each other.

5.4. Results

In the following, the results will be reported in five steps beginning with presenting the descriptive values of the sample's performance in the neuropsychological test battery, followed by the correlations between performance in the GDT and the executive test battery. Thereafter, a CFA with the three latent dimensions will be applied to verify the arrangement of manifest variables within the three latent dimensions. In the next step the results of the SEM of the full model will be reported, followed by the mediation analysis of the hypothesized mediation effects.

5.4.1. Neuropsychological performance

The description of the sample including estimated intelligence, performances in the executive tests and the GDT can be found in Table 5.

Table 5. Descriptive values of the sample's performances in the intelligence estimation test, the GDT and the executive functioning tests.

	Range	***M***	***SD***
IQ[a]	85 - 140	117.46	12.11
GDT net score [b]	-18 - 18	8.07	10.06
Digit symbol [c]	30 - 63	55.57	8.67
CWIT [d]	42 - 180	70.39	17.45
TMT B [d]	20 - 266	64.20	29.94
Semantic shifting [c]	12 - 40	25.08	4.56
Go/No-Go reaction time [d]	430.80 – 804.85	585.83	57.61
Go/No-Go correct reactions [c]	44 - 80	75.57	5.14
MCST [e]	0 - 31	7.27	5.63
BST [f]	.00 - .43	.09	.09
3-back [c]	.04 - .98	.65	.17

[a] estimated with subtest reasoning of the *Leistungsprüfsystem* [German intelligence test battery]
[b] net score (number of low risk decisions – number of high risk decisions)
[c] number/percentage of correct responses
[d] time needed (higher scores represent worse performance)
[e] number of non-perseverative errors (higher scores represent worse performance)
[f] Deviation score (percentage of deviation from optimally balanced performance on all four tasks)

The mean scores in the GDT and the other common neuropsychological tests were all in the normal range, as known from other investigations (e.g., Brand et al., 2009; Jensen & Rohwer, 1966; Lineweaver et al., 1999; Sheridan et al., 2006; Tombaugh, 2004; Verdejo-García & Pérez-García, 2007).

5.4.2. Correlational analyses

The correlations between the main measures of the applied tests are shown in Table 6.

Table 6. Correlations between GDT net score and tests of executive functions.

		1 GDT net score [b]	2	3	4	5	6	7	8	9
2	Digit symbol [c]	.22**								
3	TMT B [d]	-.22**	-.52**							
4	CWIT [d]	-.15*	-.58**	.43**						
5	Semantic shifting [c]	.05	.20**	-.21**	-.15*					
6	Go/No-Go reaction time [d]	-.05	-.25**	.21**	.24**	-.15*				
7	Go/No-Go correct reactions [c]	.19**	.23**	-.25**	-.17**	.16**	-.21**			
8	MCST [e]	-.21**	-.31**	.21**	.21**	-.16**	.12*	-.24**		
9	BST [f]	-.22**	-.35**	.34**	.32**	-.18**	.07	-.25**	.30**	
10	3-back [c]	.23**	.47**	-.40**	-.43**	.12*	-.22**	.21**	-.34**	-.44**

[b] net score (number of low risk decisions – number of high risk decisions)
[c] number/percentage of correct responses
[d] time needed (higher scores represent worse performance)
[e] number of non-perseverative errors (higher scores represent worse performance)
[f] deviation score (percentage of deviation from optimally balanced performance on all four tasks)
* $p \leq .05$
** $p \leq .01$

Most of the measures of executive functions are significantly correlated with the GDT net score with low to moderate effect sizes. Only the number of correct responses in the semantic shifting task and the reaction times in the Go/No-Go are not correlated with the GDT. Age was inversely correlated with the GDT net score (r = -.25, p < .001) and with performances in all measures of executive functions (rs from -.20 to -.54, ps < .001), except semantic shifting (r = -.01, p = .90).

5.4.3. Latent dimensions in CFA

In order to systematically test the proposed theoretical model, we first tested the factor model, which means that it is tested whether the latent dimensions are acceptably represented by the manifest variables. Therefore, CFA analysis was performed with the three latent dimensions. Overall, the CFA model yielded an excellent fit with the data. The χ^2 test of model fit indicated no significant difference between model and data, χ^2 = 24.43, df = 24, p = .437. The RMSEA was .01 with p < .001, the CFI was 1.00, the TLI was 1.00, and the SRMR was .03.

The first latent dimension “situation processing” was well represented by the scores in the Digit Symbol Substitution Test, the TMT B, and the CWIT as intended. The second latent construct “flexibility” was significantly represented by the semantic shifting task, Go/No-Go reaction times for correct responses, and the number of Go/No-Go correct responses. The third theoretically argued dimension "strategy management" was well represented by the scores in the MCST, the BST, and the 3-back. In all three latent constructs, the manifest variables significantly loaded on the latent factor. The factor loadings and standard errors can be found in Table 7.

Table 7. Coefficients of the manifest variables' loadings on the latent dimensions, tested with CFA in MPlus.

Latent dimension	**Manifest variables**	**β**	***SE***
Situation processing	Digit symbol	.81***	.04
	TMT B	-.65***	.04
	CWIT	-.70***	.04
Flexibility	Semantic shifting	.35***	.08
	Go/No-Go reaction time	-.44***	.08
	Go/No-Go correct reactions	.46***	.08
Strategy managment	MCST	.47***	.06
	BST	.60***	.05
	3-back	-.74***	.05

*** $p \leq .001$

The CFA indicates that the latent dimensions are acceptably represented by the manifest variables. Only in the dimension flexibility the factor loadings were weaker (from .34 to .47) but sufficient, given that they loaded significantly on the latent dimension and that the model fitted excellently with the data. The internal consistencies within the three dimensions were relatively low (Cronbach's α: situation processing: .75; flexibility: .34; strategy management: .64). This is not surprising given that low consistency has been described previously for measures executive functions (Denckla, 1996; Rabbitt, 1997). Low consistency probably occurs because the variance in the tasks measuring executive components is not exclusively produced by individual differences in the component they are supposed to measure. The tasks also demand other neurocognitive performances to different amounts (e.g., processing speed, numeracy, etc.). Potential problems of low internal consistency are encountered by the CFA because the latent variables represent the variance that is reliably shared within the manifest variables of a latent factor (Brown, 2006). Thus, in summary, the suggested model of executive sub-functions can be accepted.

5.4.4. Full SEM

The proposed complete theoretical model with GDT net score as dependent variable yielded an excellent fit with the data. The χ^2 test was not significant, $\chi^2 = 32.10$, $df = 31$, $p = .412$, suggesting that the data do not significantly differ from the model. The RMSEA was .01 with $p < .001$, the CFI was 1.00, the TLI was 1.00, and the SRMR was .03. The model with all factor loadings and β-weights is shown in Figure 7.

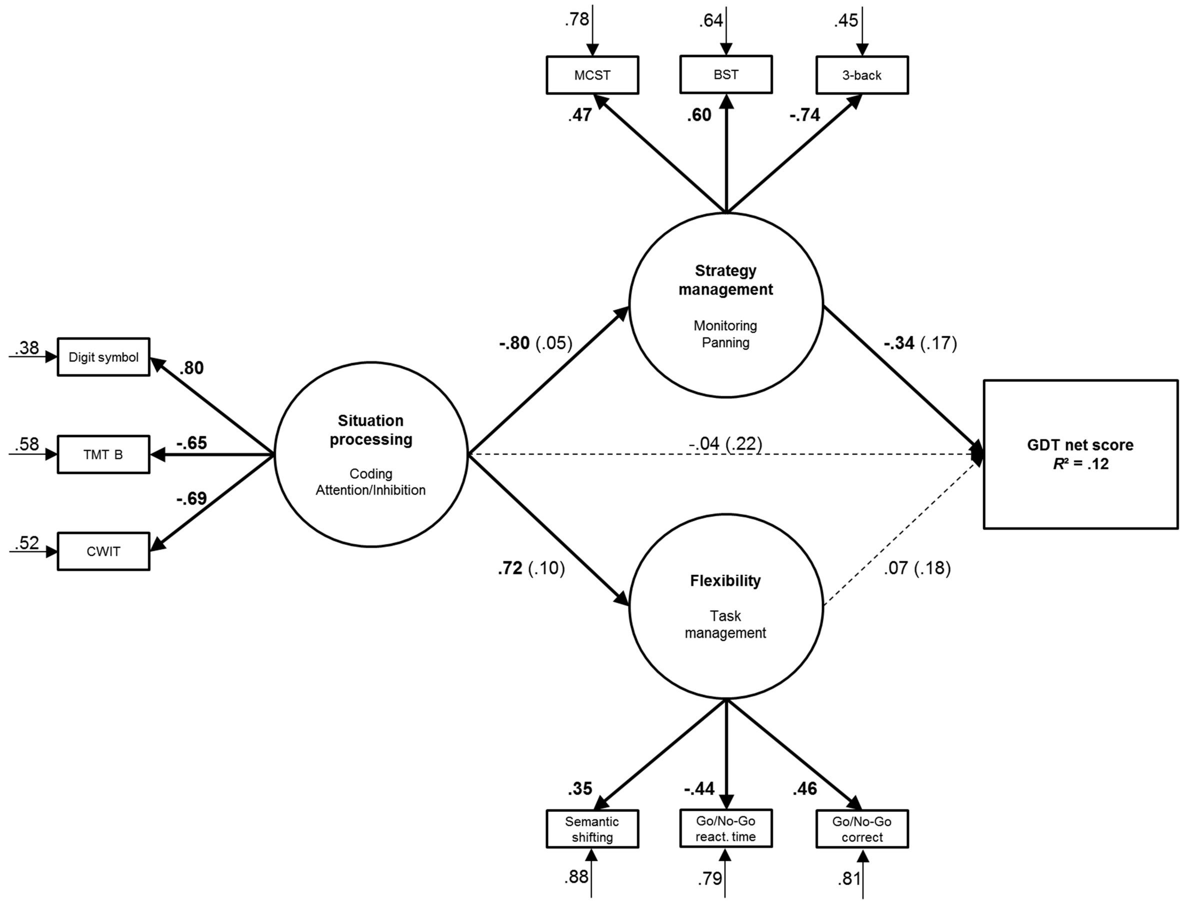

Figure 7. The full SEM with latent and manifest variables.

Bold faced numerals and arrows with full lines are significant at $p \leq .05$, arrows with dashed lines are not significant. The standard errors of the regression estimators can be found in the parentheses. As can be judged from the factor loadings, the latent dimension are acceptably represented by the manifest variables. In total, 12 % of the variance of the GDT net score is explained. Decision-making behavior is significantly predicted by strategy management, while situation processing and flexibility do not affect the performance in the decision-making task. Abbreviations: BST = Balanced Switching Task, CWIT = Color Word Interference Test, GDT = Game of Dice Task, MCST = Modified Card Sorting Test, TMT = Trail Making Test.

Overall, 12% of the variance in decision making in the GDT were significantly explained by the regression model ($R^2 = .12$, $p = .012$). Remarkably, the regression coefficient β from the three latent dimensions to GDT net score indicate that only strategy management significantly affected GDT performance (β = -.34, $p = .025$; note that the β-weight is negative because better performance in the tests is represented by lower test values, given that e.g., the number of errors are used). The two other latent variables, situation processing (β = -.04, $p = .425$) and flexibility (β = .07, $p = .362$), did not significantly contribute directly to the explanation of decision-making behavior in the GDT.

5.4.5. Mediator analyses

Mediator analyses were computed in order to analyze whether situation processing functions affect GDT decision making indirectly, mediated by the higher level functions, flexibility and strategy management. The indirect effect from situation processing over flexibility to GDT net score was not significant (β = .05, $p = .362$). In contrast, the mediator effect from situation processing over strategy management to GDT net score was significant and had a moderate regression-weight (β = .27, $p = .030$).

5.5. Discussion

The aim of this study was to decompose the role of different executive functions for decision making under risk conditions, measured with the GDT. We tested a theoretically argued model, projecting the processes of deciding under risk, as suggested by Brand and colleagues (2006), and based on the arrangement of executive functions as suggested by Smith and Jonides (1999). We defined three sub-processes of decision making, in which executive functions were supposed to participate: situation processing (including coding and attention/inhibition), flexibility (including task management), and strategy management (including monitoring and planning). The model assuming these processes to predict decision making fitted excellently with the data. The observed amount of variance explanation (i.e., 12%) in the decision-making task can be regarded as a respectable proportion. Thus, the SEM results supported the assumption that executive functions are fundamentally involved in decision making under risk. Moreover, it was found that not all executive sub-domains directly contribute to the prediction of decision-making behavior. Only those higher level functions that are probably required for the management of strategies, directly influence decision making in the GDT. However, basic situation processing functions have an indirect impact, because they are substantially involved in strategy-management functions.

The correlations between the GDT net score and tests of executive functions already indicated relationships, thereby supporting the general assumption of a relation between risky decision making and executive functions, as raised in Brand's model and shown in various previous studies (e.g., Brand et al., 2009; Drechsler et al., 2008; Euteneuer et al., 2009; Sinz et al., 2008 and many more cited in the Introduction, 5.2). However, even in this large sample the correlational analysis could again not help to answer the question, which executive domains contribute to decision making to what extent. Analogue with the results of previous studies, it was not possible to detect any informative pattern in the correlations. The correlations had comparable heights, independent of whether the tests measured basal attention/inhibition abilities or higher level functions, such as planning or monitoring.

Modeling the main functions as latent variables on the basis of the theory of decision making as well as the theory of executive functions helped to arrange the tests according to three underlying constructs. The CFA analyses indicated that the dimensions were sufficiently represented by the test scores (Note that the combinations of tests are in line with arrangements in previous studies using other executive tests and are also in line with theoretical approaches on executive functions; Borkowsky & Burke, 1996; Smith & Jonides, 1999; Miyake et al., 2000; Verdejo-García & Pérez-García, 2007).

The overall SEM, which tested the effects of these functions on GDT performance, confirmed the assumptions made in Brand's model of decision making under risk conditions: Especially higher level functions, including monitoring and planning abilities, yielded an effect on decision-making behavior. This dimension was called strategy management because it is assumed in Brand's model and reported in the literature that executive functions contribute to developing a calculative strategy and to applying it (Brand, Heinze, et al., 2008), to monitoring its success under consideration of the feedback as well as to revising it (Brand, Laier, et al., 2009; Brand, Pawlikowski, et al., 2009). For example, development and application of a strategy can imply a first assessment of probabilities (see also Schiebener et al., 2011) and consciously developing a plan for a certain number of following decisions (Brand, Heinze, et al., 2008). Speculatively speaking, such a first strategy may resemble "probability matching". In this strategy the participant would plan four choices for four-number options and two for other options, given that the winning probability in the four number combination is 4:6 (an irrational, but often applied strategy in simple probability problems; Fiorina, 1971; R. F. West and Stanovich, 2003). A subsequent application of this strategy as well as its revision would involve especially monitoring functions: A working memory representation of previous choice behavior (how often the four number combination and other combinations have been chosen) would need to be kept upright, together with the memory of feedback, which had followed from these choices. Successful monitoring can then result in an optimization of the initial strategy, e.g., when the participant recognizes that the two choices for other, more risky alternatives resulted in high losses. In this case the probability matching strategy might be dismissed and replaced by the rational maximization strategy. This would be choosing four numbers in every trial and accepting the occasionally occurring low losses. Participants with weak abilities in planning or monitoring could fail in one or more of these points' steps: In development and application of a first strategy, in monitoring of its success and/or in improving the strategy.

Therefore, the involvement of these higher level functions of the executive system is reasonable. Furthermore, it is in line with theoretical considerations that lower level functions, coding and attention/inhibition, as represented in the situation processing dimension, do not directly contribute to decision making under risk (Brand et al., 2006). However, the mediator analysis indicated that these functions are the precondition for strategy management functions and thereby indirectly influence decision making. This result is reasonable, because good strategy management beforehand requires to code information about the decision situation into working memory. This includes representations of the task's rules, the given decision options, their possible outcomes, and also the experience from previous trials. Furthermore, it is necessary to focus attention, namely on the actual overall money capital or the heights of gains and losses following a choice. Additionally, it is necessary to inhibit automatic impulses, such as emotionally initiated urges to depart from the current strategy, for example, by having an unplanned try with a risky alternative that lures with a possible quick high gain.

The question remains why flexibility – representing task management functions – did not significantly affect decision making in the GDT. We had expected that the ability to flexibly shift between categories would be involved in resolving the conflict between the heights of outcomes and the risks associated with these. This had been suggested by the observed brain activity in the anterior cingulate cortex in a very similar dice problem (Labudda et al., 2008). The behavioral data with executive functioning tests now suggest that the role of flexibility is less pronounced than had been hypothesized. However, there may remain two methodological reasons for the absence of an influence of flexibility. The first is that conflict resolving is undertaken by functions included in the dimension strategy management, implying tests in which beside the main processes of planning and monitoring, it is also necessary to be cognitively flexible. For example in the MCST, it is necessary to switch to a new sorting technique quickly or in the BST participants need to smoothly release themselves from one task and switch to another. However, the variables that were used to measure MCST and BST performance should explicitly not tap into the flexibility domain, like perseverative errors in the MCST or switching costs in the BST would have. The second reason may be that the dimension flexibility was not optimally represented by the tests used. Although the tasks included in this latent variable (semantic shifting, Go/No-Go) should tap into the flexibility domain (see e.g., Verdejo-García & Pérez-García, 2007), future studies should aim at investigating the role of flexibility for decision making by using flexibility tasks, which share more variance that can be ascribed to flexibility abilities.

The results of this study have implications for the theory on decision making under risk, as well as for clinical application. They support the assumptions in Brand's model and beyond that they enhance our understanding of the neurocognitive processes involved in decision making, not only by showing *that* executive functions are fundamentally involved in decision making under risk, but also *which* executive functions contribute to decision-making performance and *how* they collaborate in influencing decision-making performance. For application in clinical contexts, in therapy, and in cognitive training it can be deduced that higher level executive functions as well as lower level functions should be focused when aiming at improvements of decision-making abilities. Impairments in decision making can be grounded on reduced functions in coding, attention/inhibition, as well as planning and monitoring. Thereby, the results also support the findings of previous works, that problems with mastering complex requirements in life can result from defects in different executive domains (Burgess, 2000).

In the future, further neurocognitive processes involved in decision making under risk should be decomposed, not only with a focus on executive functions. Especially, it seems to be a logical step to examine the role of different working-memory functions (storage, processing, supervision; see e.g., Oberauer et al., 2003) and their interaction with executive functions in predicting decision making under risk. The main reason is that the strategy management domain, with the strongest impact on GDT performance, was composed of tests, probably strongly collaborating with working-memory functions. For example, performance in the BST should involve the working-memory function, which has been called supervision

(Oberauer et al., 2003). Also, the 3-back task should tap into typical storage and updating abilities (A. R. A. Conway et al., 2005; Oberauer et al., 2003).

Furthermore, it is still unclear how executive functions contribute to a particular strategy choice in risky situations. R. F. West and Stanovich (2003) reported that participants with better scores in a general cognitive ability measure more often decided for the rational maximization strategy instead of using irrational strategies. However, the literature on decision-making strategies and heuristics has previously neglected to pursue individual differences in specific cognitive abilities as explanations for variations in strategy choice (Appelt et al., 2011).

Additionally, to improving our understanding about the neuropsychological mechanisms involved in decision making, the results of this study also have implications for the current view on the structure of executive functions. The different executive sub-functions that were investigated empirically so far were concentrated on the basic functions inhibition, shifting, and updating (Miyake et al., 2000; Verdejo-García & Pérez-García, 2007). The more complex structure as it was suggested by Smith and Jonides (1999) also includes higher level functions - planning and monitoring - but was not yet investigated in larger samples. In the current study, three sub-functions were identified, which involve lower and higher level processes: situation processing, flexibility, and strategy management (which could also be called “monitoring”). Situation processing seems to include basic operations that are responsible for incorporating the features of a complex real-world situation into a working-memory representation. The other two functions - flexibility and strategy management - make use of the basic function, probably directing its application toward a higher goal. The idea of one basic component of executive functions and two additional, more specifically operating components is in line with recent work by Friedman, Miyake and colleagues (N. P. Friedman et al., 2008; Miyake & Friedman, 2012). Therein, the original model of three very basic functions was extended. It was pointed out theoretically and based on empirical data that there may be one common executive functioning component and two specific components. The common executive function represents shared functions that are involved in the two specific components. The two specific components, updating-specific and shifting-specific, were suggested to be unique additional functions. The authors reported that the common executive functions were closely associated with performance in tasks that have originally been used to measure inhibition in the three component model. The results of our study go hand in hand with this finding, since we also found attention/inhibition processes to be major components of the more specifically operating functions, strategy management and flexibility. Thus, the structure of executive functions that manifested in our large dataset with 270 participants is in line with the literature. Additionally, the structure may extend existing ideas by also regarding complex, higher level control functions. In order to further understand the organization of the executive system, this structure may be tested against other arrangements of executive functions that have previously been suggested in the literature (for a review see Jurado & Rosselli, 2007).

6. Study 2: Effects of goals on decisions under risk conditions: Goals can help to make better choices, but unrealistic high goals increase risk-taking

6.1. Abstract

Although decisions in real life are often made under the influence of goals, empirical studies on goals in decision-making performance are rare. Theoretically, explicit goals may improve decision-making performance by triggering higher cognitive effort in strategy development. In contrast, theories also suggest that unrealistic high goals may increase disadvantageous risk-taking. We tested the effects of explicit goals for the outcome in a modified version of a frequently used decision-making task, the Game of Dice Task. The modification allowed increased influence of cognitive strategies by providing control over the number of decision trials. On the one hand, subjects with an explicit goal made higher percentages of advantageous decisions from the task's beginning. On the other hand, subjects with exceptionally high goals took more disadvantageous risks. Goal setting probably improves analytical processing, which benefits the development of advantageous decision-making strategies, but only when the goal is realistic and not too high.

6.2. Introduction

In many domains of everyday life, reaching a desired goal depends upon making advantageous decisions. Nevertheless, there is only some research, which investigated how goals affect decision-making performance. Therefore, in a review addressing the effects of goals on human behavior, Locke and Latham (2002) stated that relationships between goals and risk handling would need further examination. In this manuscript, we address the effects of goals on decisions under risk conditions, measured by a frequently used gambling task, the Game of Dice Task (GDT; Brand et al., 2005).

Several empirical studies in different psychological disciplines dealt with the role of goal setting, striving, and monitoring for human performance (see chapter 3.3). So far, researchers assume that goals are fundamentally integrated in behaviors containing effort, persistence, and self-regulation, and that goals often cause better performances in different situations (Elliot & Fryer, 2008). Monitoring ones current behavior with respect to its goal-orientation is responsible for maintaining and improving performances over longer spans of time (for research, theories, and reviews on goal effects see e.g., Elliot & Fryer, 2008; Latham & Locke, 1991; Lewin, 1931, 1935; Locke & Latham, 1990; Pervin, 1989; Pervin & John, 1999).

These effects on performance depend on specific attributes of the goals. The core attributes are their specificity (that the goal is explicitly known to the person and is clearly measurable) and their difficulty (how challenging is it to reach the goal; see Locke & Latham, 2002). The main findings about these two attributes are that goals have stronger positive effects, the more specific and the more difficult they are (Locke and Latham, 2002). It is said that a specific and difficult goal can improve performance because it triggers so called goal mechanisms (Locke & Latham, 2002): The direction of attention toward the goal-relevant information and subtasks that are required to reach the goal, the increase of cognitive and bodily effort, the increase of persistence and the development and application of goal oriented cognitive and behavioral strategies.

But how may goals affect decision-making performance? One may assume that explicit and difficult goals improve decision-making performance, because the goals trigger increased attention on the relevant attributes of the decision situation, an increase of cognitive effort for evaluating the characteristics of the decision options, leading to an improved development of a decision-making strategy, and more persistence in adhering to the developed strategy. Such a positive relationship between goals and decision making would be in line with results from neuropsychological research. Goal monitoring and goal-oriented behavioral control are considered to tap into higher level executive functions, which are related to frontal lobe brain areas and are necessary for the strategic utilization of individuals' resources (Duncan et al., 1996; Levine et al., 2000; Manly, Hawkins, Evans, Woldt, & Robertson, 2002; Smith & Jonides, 1999). In this point, goal-directed behavior and decision making have a commonality: Frontal brain areas and executive processes are also known to be important for making advantageous decisions, especially under conditions of risk (e.g., Brand, Labudda, & Markowitsch, 2006; Brand, Laier, Pawlikowski, & Markowitsch, 2009; Del Missier, Mäntylä, & Bruine de Bruin, 2010, 2012; Drechsler, Rizzo, & Steinhausen, 2008; Euteneuer et al., 2009; Labudda et al., 2008; Wilbertz et al., 2012). Thus, it may be possible that handling goals is involved in the cognitive processes of advantageous decision making and that for this reason explicit goal setting could enhance decision-making performance.

In contrast, other theoretical approaches state that very high goals, or very high motivation may rather cause increased risk-taking, which is often disadvantageous in real life decisions and in laboratory decision-making tasks (Bechara, 2001; Brand et al., 2006). For example the Yerkes-Dodson law, predicts that performance should be best when the current motivation is medium but performance decreases when motivation becomes too high (Broadbent, 1965; Teigen, 1994; Yerkes & Dodson, 1908). Furthermore, Atkinson (1957) suggested that people who have strong need for achievement have an increased preference for immediate risks. Heath, Larrick, and Wu (1999) assumed that goals act as new reference points in the value function, which was proposed in the prospect theory (Kahneman & Tversky, 1979). Therefore, individuals are supposed to be satisfied with the outcome of their decisions, if it is above the goal and dissatisfied if the outcome is below it. Furthermore, they should seek riskier options, if they are below their goal or threatened not to reach it. In contrast, they should chose saver options, if they are already above the goal. Support for this relationship of goals and risky decision making has been found in studies in which subjects had to choose between different lottery gambles with varying probabilities for gains and losses (Lopes & Oden, 1999; Payne et al., 1980, 1981).

So far, only few studies have addressed the roles of goals for decision-making performance. In these studies it has been focused on decisions under ambiguity and decisions under risk (for the definitions of the two types of decision situations see chapter 3.1). In order to examine effects of unconscious goal pursuit in decisions under ambiguity (in the IGT), the task was once administered to subjects who were beforehand primed on performance motivation (Hassin et al., 2009). Hassin and colleagues (2009) found that the induced unconscious goal pursuit had a positive effect on the last 50 trials of the used task version with 250 trials (Hassin et al., 2009). Although this manuscript does not focus on the roles of goals for decisions under ambiguity, but for decision making under risk, this result is relevant here. The reason is that in the later trials of the IGT, the underlying rules (that the decks C and D are better than A and B) become aware to the subjects (Bechara et al., 1997). Therefore, relations have been found between decision-making behavior in the IGT and decisions under risk measured by the GDT. Especially in the late trials of the IGT, decision-making performance was found to be correlated with decision making in the GDT (Brand, Recknor, et al., 2007; Y.-T. Kim et al., 2011; Noël et al., 2007).

In another study it was examined how goals with varying difficulties affect risk-taking behavior in a multiplayer computer game (Knight, Durham, & Locke, 2001). In the computer game, called BOLO, the subjects steered virtual tanks. In teams, they tried to earn points by destroying as many enemy emplacements as possible and lose as little tanks as possible. The enemy emplacements would also try to destroy any tank that entered their firing range. The subjects had to decide whether to attack an emplacement or not. Attacking an enemy emplacement was especially risky when it stood close to other emplacements. In this case, making an attack was risky, because it was likely that the subjects' tank would unwillingly enter the firing range of the other emplacement. There were also emplacements, which stood close to trees. Behind the trees, tanks could shelter while attacking. According to these circumstances, the emplacements were categorized as low risk, moderate risk, or high risk emplacements. The subjects' risk-taking was measured by the number of attacks against emplacements in the three categories. The teams were assigned to differently high goals for the number of points they were supposed to earn. The teams' behaviors showed that higher goals caused more risky attacking behavior. Furthermore, higher goals lead to higher point scores in the game. The results therefore suggested that higher goals increase risk-taking. In the case of BOLO, however, this was also associated with better task performance (higher amount of points received).

These empirical results, with the IGT or BOLO, allow only limited conclusions about the effects of goals on decision-making performance. The main reason is that they partly have methodological constraints. In the IGT-study by Hassin and colleagues (2009), goals were not specific, but unconscious (a priming condition was used to induce unconscious goal pursuit). In the multiplayer game BOLO, as used by Knight et al. (2001), the decisions were made in groups and it is unclear whether this had an effect on risk-taking (increased risk-taking of groups was reported earlier, e.g. in Kogan & Wallach, 1967; Pruitt & Teger, 1969). Additionally, task performance in the computer game was probably influenced by the individuals' psychomotoric processing speeds, reactions times, and other variables, which may have also been affected by the goals.

Because of these constraints in the past studies, we aimed at investigating the effect of goals for strategic decision making in a controlled and approved environment. In our first goal-study, which has been conducted before the study we report in the manuscript at hand, we used the GDT, a frequently applied decision-making task in neuropsychological research (see chapters 3.1.3, 3.4 or e.g., Bayard, Raffard, & Gely-Nargeot, 2011; Brand et al., 2009; Euteneuer et al., 2009; Gleichgerrcht, Ibánez, Roca, Torralva, & Manes, 2010). In the study (Schiebener, Wegmann, Pawlikowski, & Brand, 2012), the subjects defined a goal before playing the GDT in the standard 18-trial version. The results revealed no immediate effect of goals on GDT performance. However, goals were related to choice behavior in two ways.

Firstly, goals together with executive functions interactively influenced the negative impact of an anchor effect on GDT performance. The anchor was triggered by social comparisons with extraordinary successful players. Therefore, a top ten list with very high gains was presented. This presentation caused very disadvantageous decision making, but the negative effect was influenced by goals: With goals there was a reduction of the anchor effect in subjects with high executive functions, but an increase of the anchor effect, in subjects with lower executive functions. Additionally, there was a moderate to high inverse correlation between the height of the self-set goals and the performance in the GDT. This indicated that higher goals may be related to more disadvantageous (i.e. very risky) choices. Therefore, it seems that explicit goals play a role in decisions under risk but this depends on situational circumstances and individual differences in executive functions.

However, the influences of goal mechanisms (effort, persistence, and strategy development; Locke & Latham, 2002) may have been limited, because the GDT has several restrictions. Restrictions are for examples the fixed number of decision trials, the predetermined options to choose from, or the amounts of money that can be bet.

Therefore, we used a modified GDT version in the current study. In this we deleted one of the restrictions: the limitation of decision trials. In this new version, the "GDT open end", the subject could freely decide when to end the game. This provides more strategic control and allows the subjects to plan their decision strategies with enhanced influence of goal mechanisms. In consideration of an explicit goal, subjects might make more cognitive and behavioral effort and be more persistent in enduring making many decisions for the lowly risky alternatives, although these only slowly lead toward an increase of the money capital. Furthermore, a subject could plan this behavior strategically. He/she could, for example, define the goal to reach a gain of €2,000 (so he would have to win additional €1,000 to the start capital). To achieve this target he/she may apply the following strategy: choose one number (gain/loss €1,000) maximally three times, if the goal is not attained thereafter, be persistent in choosing a four numbers option (expecting to win €100 in 4 of 6 trials and to lose €100 in 2 of 6 trials) until the intended capital is exactly reached.

The main question of the current study is whether goal setting in advance of the task's beginning has an effect on behavior in such a task version. We expect that goal setting improves the overall performance in this version of the GDT because the goal setting process triggers enhanced cognitive processing. Additionally, we want to examine, how goal oriented decision-making behavior develops over different phases of the task, in order to differentiate between an effect of the deliberate goal-setting process (which should influence decisions from the task's beginning) and the goal-monitoring process (which may cause better maintenance of decision-making performance over task duration).

In summary, the three aims of the current study are to determine (1) whether goals positively affect strategic decision making in a GDT version with open end, (2) how goal setting and goal monitoring differently contribute to possible effects of goals, and (3) whether very high goals and are related to disadvantageous decision making.

6.3. Method

6.3.1. Subjects

Seventy-seven subjects participated in the study. They were aged 18 to 65 years (mean age = 26.36, *SD* = 10.17 years), 39 were females, and mean school-education was 12.77 years, *SD* = 0.83). Testing took place at the Department of General Psychology – Cognition, University of Duisburg-Essen, Germany. None of the subjects had a history of neurological or psychiatric disease as determined by a screening interview. The study was approved by a local ethics committee.

6.3.2. Design

Subjects were randomly assigned to one of two conditions. In the experimental group (n = 37, females n = 19) the subjects had to define a goal before starting the GDT, in the control group (n = 40, females n = 20) the GDT was played without prior goal setting.

The groups did not differ in gender, χ^2 (1, N = 77) = 0.01, p = .906, age, $t(75) = -0.64$, p = .527, school-education $t(75) = 1.01$, p = .316 or intelligence as estimated by the logical reasoning subtest of the German intelligence test battery (Horn, 1983), $t(75) = 1.20$, p = .236.

6.3.3. Instruments

Game of Dice Task: version “open end”

The Game of Dice Task (GDT; Brand et al., 2005) is a computerized task, which measures decision making under risk conditions. In the GDT, the subject has the task to gain as much fictitious money as possible and to lose as little of it as possible, by betting on the throws of a single virtual die. The subject has a start capital of €1,000 by. Before each throw, the subject has to guess, which number (1-6) will occur next. He/she can bet on a single number or on a combination of numbers. The subject wins if the number thrown is identical with the number he/she has bet on, or is one of the numbers in the combination he/she has bet on. Otherwise the subject loses. Each option is associated with explicit and stable gains and losses as well as winning probabilities: €1,000 gain/loss for the choice of a single number (winning probability 1:6; expected value -€666.67), €500 gain/loss for two numbers (winning probability 2:6; expected value -€166.67), €200 gain/loss for three numbers (winning probability 3:6; expected value €0), and €100 gain/loss for four numbers (winning probability 4:6; expected value €33.33). For example, the subject can bet on a combination of two numbers (e.g., the “3” and the “4” together), which will result in a gain of €500 when the “3” or the “4” is thrown, but it will result in a loss of €500 when one of the four remaining numbers not chosen is thrown (e.g., “1”, “2”, “5” or “6”). Before beginning the task, rules are explicitly described in the test instruction, containing explicit information about the rules for gains and losses, and the amounts of money associated with each of the different possible options. Gains and losses are permanently visualized on the screen. After each throw, the gain or the loss is indicated on the screen accompanied by a distinct sound (the jingle of a cash machine for a gain; a dull tone for a loss). The current total capital and the number of the remaining trails are also displayed on the screen (for a detailed description of the GDT see Brand et al., 2005).

In the present study we used a modification of the GDT. It was modified regarding the number of decision trials. In contrast to the original GDT, in which 18 decisions have to be made, subjects were allowed to play as long as they wanted. They were explicitly instructed that they could end the game whenever they wanted by clicking on a designated button in the task’s interface. The subjects did not know that the task would automatically be terminated after a maximum of 60 trials. After the instructions, the subjects in the goal condition were asked to define a goal, which means the final account (in €) they wanted to achieve. Subjects in the control condition started directly after the instructions without setting a specific goal for their final capital.

GDT variables. We used eight variables to describe decision-making behavior in the GDT.

(1) Percentages of decisions for each of the four risk classes: These are the numbers of decisions for one single number, for two numbers, for three numbers, or for four numbers, each in relation to the overall number of trials a subject had played.

(2) Percentage of low risk decisions: We measure the percentage of low risk ("advantageous") decisions over the whole task. The alternatives in the GDT can be grouped into low risk, advantageous decisions (three or four numbers with a winning probability of 50% and higher) and high risk, disadvantageous decisions (one or two numbers with a winning probability below 34%). Choosing the low risk alternatives should lead to a positive balance in the long run. Even the three-number alternative, can be regarded as a good choice, although it has an expected value of zero. It is a good choice, because it promises to retain the start capital of €1,000. In contrast, the high risk alternatives result in a negative balance with high probabilities. This separation into low risk and high risk decisions has been applied in a lot of previous studies because it has proven to accurately measure decision-making abilities in healthy samples and patient populations (to mention only some examples: Bagneux, Bollon, & Dantzer, 2012; Bayard et al., 2011; Euteneuer et al., 2009; Wilbertz et al., 2012).

However, the analysis of low risk vs. high risk decisions is superficial, because it neglects differences between the two alternatives allocated within high risk and low risk, respectively. For example, by classifying the one- and the two number alternatives into one class (high risk), one ignores that the expected value of the one number alternative (expected value = -€666.67) is four times lower than the expected value of the two number alternative (expected value = -€166.67). Thus, we computed the following expected value score, indicating the average expected value per decision.

(3) Expected value per decision: The variable indicates the average expected value per decision (expected value per decision = summed expected values of all decisions/number of decision trials). The numbers of choices for each alternative is multiplied with the alternative's expected value and these products are summed afterwards. In other words, the decisions are weighted by the expected value. The resulting score was divided by the number

of trials played, in order to measure decision-making performance relative to the number of trials.

(4) Additionally, we analyzed the overall pattern of behavior (1), and the expected value per decision (3) in three blocks of task duration: the first 33%, the second 33% and the third 33% of the decisions, which were made. Note that the absolute number of trials was different for each subject, because the number of trials was not fixed in this modified GDT version.

(5) Final capital: This is the real final capital a subject has reached (final capital = start capital + gains - losses).

(6) Expected final capital: This is the theoretically expected outcome given the subjects' choices and the expected values of their choices (expected final capital = start capital + summed expected values as explained in (3)).

(7) Number of trials: This is the number of trials a subject has played before ending the GDT.

(8) Aspired goal: This is the subject's self-set goal for final capital.

As one main measure of performance, we choose variable number three, the expected value per decision, because it is a simple single measure of the overall advantageousness of decisions.

6.3.4. Statistical analyses

Statistical analyses were carried out using SPSS Statistics version 19. Kolmogorov-Smirnov-Test was used as test for normal distribution. Impact of goal setting on GDT performance was tested by t-tests. The pattern of choices between the different alternatives in the GDT, the development of decision-making behavior over the three blocks as well as the comparison between sub-groups with differently high goals was compared with repeated measures ANOVA. Relationships between two variables were analysed by Pearson correlations.

6.4. Results

First, we tested whether decision-making performance differed between subjects with and without goal setting. The overall patterns of decisions for the four alternatives (one number, two numbers, three numbers, and four numbers) was comparable in both groups. The patterns can be found in Figure 8.

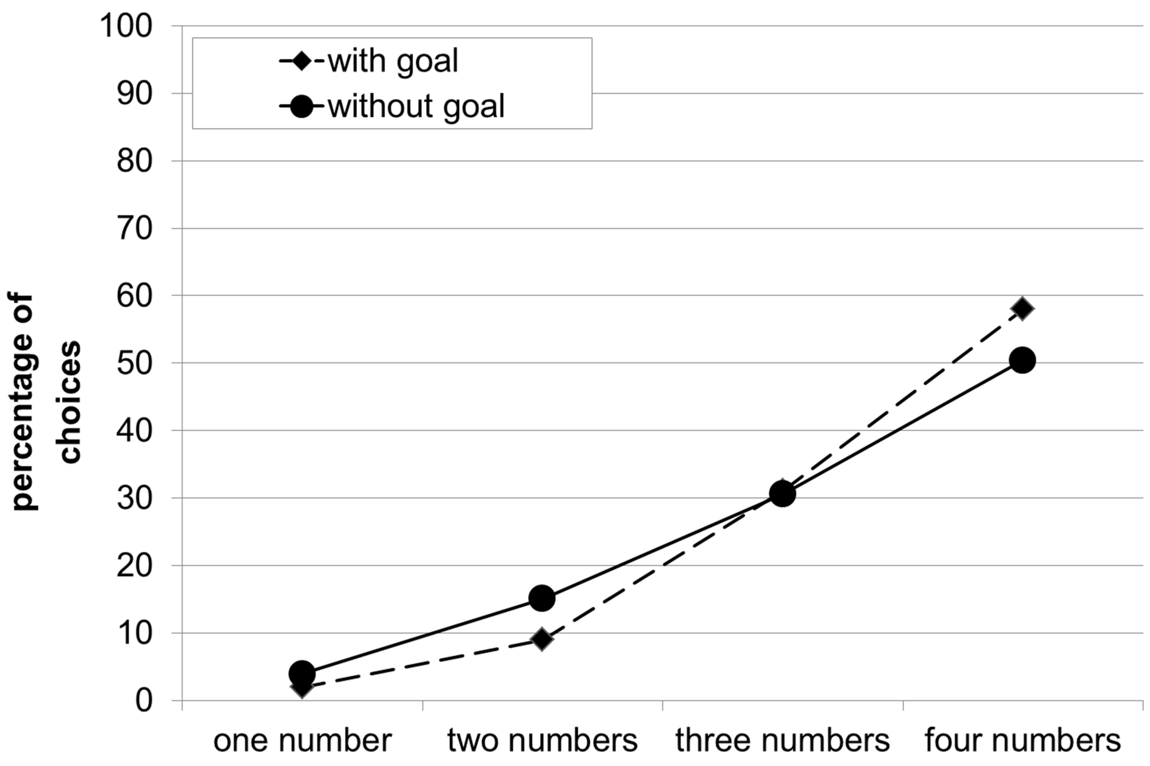

Figure 8. The patterns of choices in the GDT, expressed in the percentages of choices for one single number, two numbers, three numbers and four numbers.

On average, the subjects in both groups preferred alternatives with lower risks over alternatives with higher risks. The inner subject effect of alternative was significant, $F(1.34, 100.55) = 76.01$, $MSE = 8.84$, $p < .001$, $\eta_p^2 = .50$, but the interaction between alternative and goal was not, $F(1.34, 100.55) = 1.22$, $MSE = 0.14$, $p = .286$, $\eta_p^2 = .02$, indicating no significant effect of goals on the overall pattern of decision-making behavior. The means of the cumulative measures of GDT performance can be found in Table 8.

Table 8. Results of the GDT in the two conditions.

	with goal *M* (*SD*)	without goal *M* (*SD*)	*t*	*p*	*d*
Low risk decisions in %	89.06 (13.42)	80.99 (19.14)	2.15	.035	0.49
Expected value per decision (€)	-8.55 (42.28)	-34.59 (71.85)	1.96	.054	0.44
Expected final capital (€)	511.63 (1700.66)	-166.76 (2738.41)	1.32	.193	0.30
Final capital (€)	518.92 (2020.70)	-310.00 (3471.41)	1.29	.201	0.29
Number of trails	35.27 (17.50)	36.03 (17.83)	-0.19	.852	0.04
Aspired goal (€)	2162.16 (934.03) (Range 500-5000)	-			

These mean comparisons indicate that subjects who had defined a goal performed better in the GDT. In the performance variables, the positive effects had moderate sizes, with Cohen's *d*'s from 0.30 to 0.49. The two main performance variables, low risk decisions in % and expected value per decisions were significant at the level $p \leq .05$. The difference between the two final capital variables did not reach significance.

In the following it is analyzed whether the development of decision-making performance gives a hint on the question, whether the goal setting or the goal monitoring process is responsible for the positive effect of goals. Therefore, we analyzed whether goals influenced decision-making performance over the course of the task. We divided the number of trails for each subject in three equal blocks and calculated the expected values per decision in each of the three blocks. It was found that descriptively, in both groups, decision-making performance decreased over the course of the task (see Figure 9).

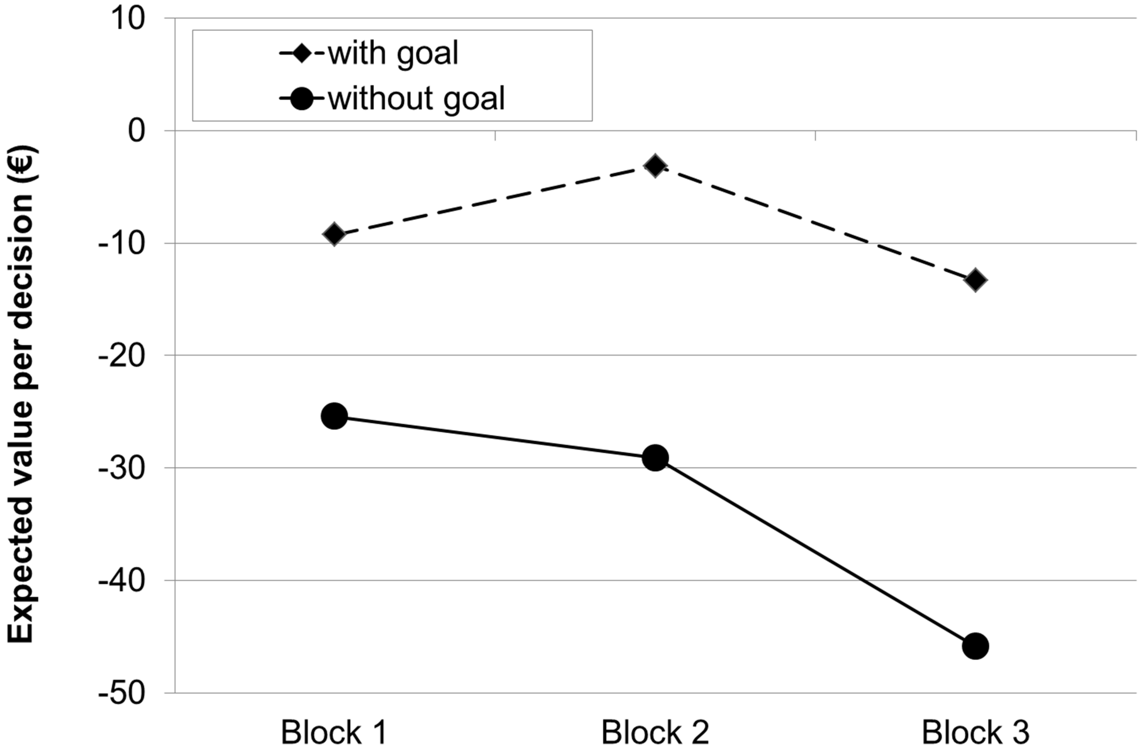

Figure 9. Comparison of the expected values per decision, in the first 33% (block 1), the second 33% (block 2) and the third 33% (block 3) of the GDT's duration.

It can be seen that GDT performance decreased in the later trials, but this decrease was found in both groups, with and without explicit goal setting.

With repeated measures ANOVA we compared the expected values per decision between the three blocks (block 1, 2, and 3) as within subject factor and the condition (with and without goal) as between subject factor. The results showed no significant effect of block, $F(1.86, 139.38) = 1.81$, $MSE = 4604.70$, $p = .170$, $\eta_p^2 = .02$, and no interaction between block and group, $F(1.86, 139.38) = 0.55$, $MSE = 1398.45$, $p = .565$ $\eta_p^2 = .01$. This result indicates that performance was in both groups relatively stable over the duration of the task, and this stability was not dependent on whether the subjects had explicitly defined a goal.

To test whether preferences between the four different alternatives in the GDT, differed between the three blocks of task duration, we calculated an analogue analysis with the overall pattern of choice between GDT's four classes of alternatives. The percentages of choices for the alternatives was used as within subject factor (four levels: one number, two numbers, three numbers, four numbers) and block as within subject factor (three levels: block 1, 2, and 3) and group as between subject factor (with/without goal). There was a significant main effect of alternative, $F(1.32, 99.02) = 75.85$, $MSE = 26.99$, $p < .001$, $\eta_p^2 = .50$ and a significant interaction between alternative and block, $F(3.44, 258.00) = 2.60$, $MSE = 2.60$, $p = .045$, $\eta_p^2 = .03$, indicating that the pattern of preference changed over the three blocks. However, this effect did not interact with explicit goal setting: The interaction between alternative and group, $F(1.32, 99.02) = 1.13$, $MSE = 0.40$, $p = .308$, $\eta_p^2 = .02$, and the three-way interaction between alternative, block and group, $F(3.44, 258.00) = 1.30$, $MSE = 0.70$, $p = .273$, $\eta_p^2 = .02$, were not significant and had small effect sizes. In summary, the analyses of decision-making behavior in the course of the task indicate that performance was relatively stable over task duration independent of whether a goal had been set or not.

In the following the aspired goals and their relations with GDT performance were analyzed, in order to test whether very high goals are associated with more risk-taking. The defined goal was reached or exceeded by 18 of the 37 subjects (48.6%). The heights of the self-set goals were positively correlated with the percentage of decisions for the risky alternative betting on two numbers ($r = .41$, $p = .013$) and inversely correlated with the percentage of low risk decisions ($r = -.36$, $p = .027$), the expected value per decision ($r = -.27$, $p = .111$), and the expected final capital ($r = -.29$, $p = .087$) but not with the real final capital ($r = -.05$, $p = .754$). The correlation between goal-height and the number of trials was positive ($r = .46$, $p = .004$). The correlations suggest that higher goals were related to more risky decision making and higher goals were associated with playing more trials in the task.

In an additional analysis we addressed the question, whether goals which are unrealistic, are particularly related to risky decision making. We used the data to find out which goal heights may be defined as unrealistic. In the 40 subjects who had not defined a goal, 28 (70.00%) had a fictitious money outcome below €2,000, 5 subjects (12.50%) reached exactly €2,000 and 7 (17.00%) reached more than €2,000. Thus, a goal above €2,000 was defined as unrealistic in this GDT version. According to this definition we separated the subjects in the goal condition into three goal-height subgroups: goal below €2,000 ($n = 10$; expected value per decision $M = €3.45$, $SD = €33.52$), goal exactly €2,000 ($n = 15$, expected value per decision $M = €4.28$, $SD = €33.71$) and goal above €2,000 ($n = 12$; expected value per decision $M = -€34.61$, $SD = €48.86$). The expected values per decision were then compared between these three groups. An ANOVA with goal-height group as between subject factor and expected value per decision as dependent variable showed a significant main effect of goal-height group, $F(2, 34) = 3.92$, $MSE = 6029.58$, $p = .029$, $\eta_p^2 = .19$. The single pair comparisons reveal that subjects with a goal above €2,000 made significantly more risky decisions than subjects with a goal of exactly €2,000, $p = .045$. This analysis demonstrates that especially subjects with an unrealistic goal above €2,000 made riskier decisions.

6.5. Discussion

We investigated the effect of goals on decisions under risk in a modified version of a gambling task, the GDT (Brand et al., 2005). In the task version used in this study, the subjects could autonomously control the number of choice trials. The main result is that subjects who had to set explicitly an individual goal before beginning with the task, made relatively more advantageous decisions than subjects who did not have to define an individual goal. Nevertheless, goals and decisions seem to have an ambivalent relationship. They cause better decisions on average, but goals that are very high are associated with more risk-taking behavior.

The average positive effect can be explained in line with the theory on the mechanisms involved in goal setting (e.g., Locke & Latham, 2002) and also in line with the literature on decision making (e.g., Brand, Heinze, Labudda, & Markowitsch, 2008). As will be explained in the following it is plausible that setting an explicit goal triggers cognitive goal mechanisms that can improve decision-making performance. In our first goal study with the GDT (Schiebener et al., 2012), goals had no direct influence on decision making, but only under certain situational and individual circumstances. Another study (Brand et al., 2008) showed that persons who deliberately develop their choice strategies make more advantageous decisions. A third study reported the accuracy of choices to be positively affected by the encouragement to endeavour in deliberation before making a decision (Thomas & Millar, 2012). Therefore, it is probable that prior goal definition can operate as trigger for analytical-executive processes, which are positively related to decision making in the GDT (Brand, Laier, et al., 2009; Euteneuer et al., 2009). The request to define a goal presumably triggers a more elaborate process of task comprehension and strategy development, because reflecting accurately about which final balance to aspire principally requires an analysis of the current decision situation (Brand et al., 2006). For example, the subjects need to process on the amounts of possible gains and losses and to determine the steps, which are necessary to reach certain gains in allowance of the underlying probabilities. However, the goal-setting effect could not be observed in our first goal study with the 18-trial standard version of the GDT. The results of the current study, suggest that the reason might indeed have been that the normal GDT is relatively restrained. Particularly, there are restraints with regard to the subject's possibilities to apply goal mechanisms (i.e., to increase cognitive effort for strategy development, and to be persistent in behaving advantageously). In contrast, when subjects have the opportunity to decide how many decisions to make, and therefore have increased control over whether they can attain their goal, defining a goal helps to make advantageous/low risk decisions.

Regarding the progress of choice behavior over the three phases of the GDT it was found that performances of the subjects in the goal group and of those in the control group significantly decreased in the later trials. However, this decrease was observed with and without explicit goal setting. These data suggest that not all of the three goal mechanisms – effort, persistence and strategy improvement (Locke & Latham, 2002) – affected decision-making behaviour. In particular, it may be possible that especially strategy development was improved by goal setting. Subjects with goals performed better from the first block on, probably because they had a more goal-oriented strategy from the very beginning. In contrast, subjects with and without explicit goals made comparable effort (the number of decision trials made was not different between the groups) and showed comparable persistence (in both groups performance slightly decreased over the three blocks). Therefore, it seems to be rather the goal setting than the goal monitoring process, which is responsible for improved decision making when having to define a goal.

Beyond the positive effect of goal setting on decision-making performance – which was revealed on the level of general mean comparisons – there seems to be also a negative relationship between the height of the goals and decisions. This result is in line with the findings of our previous study with the GDT (Schiebener et al., 2012) and also with reports of other authors who found higher goals related to riskier strategies (D. Knight et al., 2001). Therefore, it seems that goals are ambivalently related to decision-making under risk: They can cause more advantageous decision making, but can also be a threat, when they are too high and thus unrealistic. Nevertheless, it is still unclear, what the mechanisms behind the negative relationship between goal-height and decision-making performance may be. Possibly, decision makers with unrealistic self-set goals tend to choose the riskier alternatives, because these lure with high gains, which offer the chance to reach the high goal in few trials. Furthermore, it may be possible that in risky situations, the adequacy of a goal's difficulty can be important (J. W. Atkinson, 1958). In the GDT the adequacy of goal setting and decision-making performance should be affected by the magnitude of the initial comprehension of the decision situation's rules for gains and losses and the associated probabilities. Individuals with a rather weak initial comprehension of the task's rules may set themselves inadequate, very high goals, and later make less advantageous decisions in the task, both as a result of their inferior task-comprehension.

The results do not only improve our understanding of goals in strategic decision making, but also encourage future research and have implications for real-life issues. In future studies, the mechanism behind the relationship between goal height and risky decision making should be examined. These studies could, for example, experimentally manipulate goal heights and analyze whether their effects on decision making under risk, are moderated by cognitive, particularly executive, functions. Persons who often make decisions under risk in real life (e.g., in managerial positions) might profit from the current study's findings. Goal setting can be applied as an instrument, which helps to plan decisions more strategically. However, goals are only helpful when they are realistic and not too high. Our conclusion is, when a decision situation is principally controllable by an individual, realistic goals are helpful for making advantageous decisions. When the goals are too high, risk-taking behavior increases.

7. Study 3: Truck dispatcher task: A new methodological framework for applying standard neuropsychological decision-making tasks

7.1. Abstract

In neuropsychological decision-making research several different tasks are used to measure decision-making competences in patients and healthy study-participants. Unfortunately, the existing tasks are often inflexible for modification, use different scenarios, and include several gambling cues. Therefore, comparisons between participants' performances in different tasks are difficult. We developed the Truck Dispatcher Framework (TDF), in which different decision-making tasks can be designed within one unitary, flexible, and real-world oriented story line. To test the story line TDF-analogues of three standard decision-making tasks (Game of Dice Task, Probability-Associated Gambling task, Iowa Gambling Task) were developed. In three experiments with brain-healthy participants the behavior in standard decision-making tasks and the TDF-analogues of them were compared. Similar behaviors indicate that the TDF-tasks measure decision making appropriately. Thus, the TDF is recommended for experimental and clinical research because it allows examining decision-making competences in tasks with different demands but taking place within one unitary story line.

7.2. Introduction

In research and clinical application, a multitude of paradigms is used for the measurement of decision-making behavior and competence. Unfortunately, it can't be excluded that differences in the framing plots of the tasks weaken the comparability of their results. Furthermore, most of the tasks are inflexible regarding experimental modification, which means that they cannot be modified with respect to complexity etc. easily. An additional aspect, which may produce limitations concerning the generalization of the results to real-life decision-making abilities, is the gambling associated environment in the common decision-making tasks. The aim of the work at hand was to develop a new decision-making framework for research and for examination of decision-making competences in clinical context. Requirements for such a framework should be the following:

1. It should be adaptable for different research and diagnostic questions.

2. Those adaptions should be realizable within one story line.

3. The story line should provide reality oriented decision-making problems.

4. The story line should be poor in typical gambling-cues.

5. The story line should allow for the projection of main features of standard neuropsychological decision-making tasks.

The motivation for developing a framework with these attributes originates from considerations of weaknesses of the decision-making tasks as they are currently used in research. In the last decades, psychological science has shown increased interest in human decision-making processes. Research on decision making has been conducted with different orientations, including general psychological, economic and neuropsychological foci (see e.g., Bechara, 2011; Gleichgerrcht et al., 2010; Weber & Johnson, 2009). One growing field of decision-making research is allocated within the neuropsychological domain. The main aims here are decomposing the neuropsychological and biological bases of cognitive and emotional mechanisms in decision making, as well as characterizing difficulties with decision making in different patient populations (e.g., Brand, Labudda, & Markowitsch, 2006). For these aims a variety of decision-making tasks has been developed. These tasks try to simulate decision situations as they also exist in real life albeit reduced with regard to their complexity (see e.g., Bechara, Tranel, Damasio, & Damasio, 1996; Denburg et al., 2007). Decision situations in real life and in the laboratory have common features: A person has two or more options to choose from, these options have different possible outcomes that vary in favorability and in the probability of occurrence, and the availability of information about possible outcomes and their probabilities can also vary.

Most of the decision-making research is concerned with decisions under ambiguity and risk (see chapter 3.1 and Yates & Stone, 1992). For measuring decision-making behavior under ambiguity the most frequently used task in neuropsychological studies is the Iowa Gambling Task (IGT; Bechara, 2007; Bechara, Damasio, Damasio, & Anderson, 1994; Bechara, Tranel, & Damasio, 2000). For the measurement of decision making under risk different tasks have been applied. Only some examples are the Game of Dice Task (GDT; Brand, Fujiwara, et al., 2005), the Probability Associated Gambling task (PAG task; Sinz, Zamarian, Benke, Wenning, & Delazer, 2008; Zamarian, Sinz, Bonatti, Gamboz, & Delazer, 2008), the Cambridge Gambling Task (Rogers et al., 1999), the Cups Task (Levin & Hart, 2003), the Columbia Card Task (Figner, Mackinlay, Wilkening, & Weber, 2009), or the Balloon Analogue Risk Task (Lejuez et al., 2002).

This manuscript mainly concentrates on decision-making under risk conditions. The tasks mentioned have similarities and differences, which result in problems when aiming at comparing the tasks' results (see also chapter 3.4). The main commonalities are those, which justify their classification as decision tasks addressing decisions under risk: The outcomes have a numerical format (monetary fictitious gains and losses), and probabilities for gains and losses can be computed or relatively accurately estimated with the given information about the tasks' rules. Thus, the exact expected values of the available options can be calculated. Another feature shared by many of the tasks is that the interfaces and metaphors are constituted of cues as they normally occur in real-life gambling situations, for example in casinos. The GDT uses dices, the Columbia Card Task uses cards, and the PAG task uses lotteries. For many participants, be it patients or healthy individuals, these gambling situations are very different from the situations, in which they make decisions in real-life. Furthermore, there may be aversions against gambling in general because some participants generally deny playing for money in real life. Additionally, it is often comprehensibly argued that some of the tasks are measures of goal-oriented, strategic and analytic decision making, which should principally also occur in real life (Brand, Heinze, et al., 2008; D. Knight et al., 2001; Lopes & Oden, 1999; Schiebener et al., 2012). Nevertheless, best reasoning suggests that the provided gambling situations may only weakly operate on the participants' motives and may not be recognized by the subjects as being related to any "strategic" behavior but rather to simple luck. Principally, specific memories of experiences with the gambling cues, such as the memory of good or bad luck with a certain number on a die, could also affect the behavior of participants (Brand et al., 2006).

Furthermore, the gambling cues may affect the behavior of specific patient populations (Brand et al., 2006). For instance reduction in decision making performance has been found in pathological gamblers in decisions under risk in the GDT (Brand, Kalbe, et al., 2005), or the Coin Flipping task, and the Cups Task (Brevers et al., 2012) as well as in decisions under ambiguity in the IGT (Rossi et al., 2010). In these studies, tasks with gambling cues have been used intentionally to investigate the dysfunctional mechanisms contributing to the gambling problems as they occur in the patients' real lives. However, given that the tasks make use of the gambling cues, the generalizability of the results is limited, because the participants' pathological cue reactivity (e.g., craving reactions) might affect functions which are also involved in decision making (e.g., executive functions or working memory; Brand et al., 2006; Crockford, Goodyear, Edwards, Quickfall, & El-Guebaly, 2005; Field & Cox, 2008; van Holst, van Holstein, van den Brink, Veltman, & Goudriaan, 2012; Kushner et al., 2008). The state of the patients' decision-making abilities in situations without gambling cues therefore remains unclear. For investigations with patients as well as with healthy participants it would be desirable to have a decision-making scenario, which has a more application-orientated story line with a more comprehensible performance goal, as it might be known from real life (e.g., "earn as much valuable possessions as possible", or "make a good job", instead of "win as much money as possible by gambling").

Another problem with the existing tasks is the lack of comparability among them. For example, the tasks differ from each other with regard to the scenarios they provide (cards games, lotteries dice games and so on), number of alternatives, the heights of gains and losses, or the styles of probability presentations. This variance in task design offers problems for patient studies as well as for the investigation of theoretical assumptions with experimental studies. One main problem is the poor comparability of results from the different tasks. There are for example studies, which revealed differential impairments and correlates in decisions in task measuring decisions under ambiguity vs. other tasks, measuring decisions under risk. For example when patient populations were impaired in decision making under ambiguity, but not under risk it was interpreted that the patients have impairments in mechanisms contributing to advantageous decision making under ambiguity, while the mechanisms contributing to decisions under risk were regarded as being intact (Bayard et al., 2010; Brand, Grabenhorst, et al., 2007; Brevers et al., 2012; Euteneuer et al., 2009; Zamarian et al., 2008). Although these interpretations are principally comprehensible, the differences in the used tasks' scenarios, numbers of alternatives, or heights of gains and losses may have confounded the observed divergent or convergent impairments in different types of decision situations. It would be helpful for experimental research and in clinical application to be equipped with tasks that can be varied in one certain aspect (e.g., the amount of ambiguity), but to keep all other aspects stable (e.g., the general scenario, the number of alternatives, the heights of gains and losses, and the probabilities).

Unfortunately, the existing gambling tasks have only a low degree of flexibility in terms of potential modifications, for example when aiming at increasing the tasks' complexity. For example, the GDT works with a 6-sided die, which is naturally restricted to certain ranges of probabilities for the occurrence of possible dice events (from 1:6 to 6:6). Furthermore, typical feedback in most tasks is restricted to gain and loss events: In the GDT the rolled number either was correctly guessed, or it was not, which then leads to a gain or a loss; in the IGT there is a specific gain, and sometimes there is also a specific loss. The lists of examples for inflexibilities of tasks could be continued indefinitely. Thus, it would require awkward changes in the existing tasks architecture as well as the story line to add variations in feedback events (e.g., different reasons for positive or negative outcomes, which vary in emotional valence or intensity). These limitations in flexibility reduce the tasks' usefulness for experimental investigations in which systematic variations are required (e.g., researchers as well as clinical neuropsychologists may want to vary a task's complexity, its outcome probabilities, or its heights of gains and losses).

In summary, the main weaknesses of the existing neuropsychological gambling tasks are their abundance of gambling-cues, their limited comparability, because of the use of different scenarios, and their poor flexibility for application in experimental investigations. Therefore, we designed a new scenario – a framework – which aims to overcome the existing shortcomings. In the following we explain the new framework's story line, in which various decision-making situations under ambiguity and under risk can be realized.

7.2.1. The Truck Dispatcher Framework

The new computerized decision-making environment is called Truck Dispatcher Framework (TDF). Its story takes place in a fictitious country called "Cognitia". Here, the participant is starting a new job in a logistics enterprise, a company called "TruckTrans". He/she is the dispatcher, responsible for making decisions about the routes that the company's trucks take when transporting goods to business customers. The participant's aim is to lead TruckTrans to economic success by attaining the best financial outcomes from the given orders. For this, it is necessary to minimize the costs for any transport and to maximize the resulting revenue. Occurring costs for TruckTrans are for example caused by the working hours of the truck-drivers or by the fuel required for a tour. Consequently, costs are higher if the route strongly strains these resources (because the route is long and/or takes much time) and lower if it conserves resources (because the route is short and/or fast). Revenue is reached by delivering goods to TruckTrans' customers in time. However, delivering in time is always threatened because trucks might get stuck in traffic jams that cause a delay. In this case the customers charge contractual penalties, possibly making such a delivery a loss-making business. Thus, the participant has to decide for routes that lead to positive revenue. The routes which the participant has to choose from can be associated with different possible gains (in case of delivery in time), and costs (in case of traffic jam) and the probabilities for these outcomes.

The story line of the TDF is flexible and capable to adapt, add, or remove story details in order to realize various decision-making problems. Thus, in the context of this story line, various tasks can be implemented in the TDF, and their features can be manipulated. For example the number of decision options can be varied (number of possible routes to take), as well as the options' probabilities for traffic jams, or the options' attributes (different types of routes, such as city streets or highways), or the type of feedback (reasons for traffic jam, as well as different punishments and rewards, other than only monetary ones).

The aim of the current study was to validate this scenario. Therefore, we investigated whether it is possible to base different, frequently used neuropsychological decision-making tasks on the common story line of the TDF. We used two standard tasks measuring decisions under risk conditions. Additionally, we also tested one task measuring decision making under ambiguity. The question was whether the TDF tasks would allow for a valid measurement of the same underlying construct, which the original tasks measure. If they did, it can be concluded that the story line of the TDF does not produce problems in the measurement of decision making and thus the TDF can be recommended for the application in experimental research and for first testing in clinical contexts in the future.

For this study, the core features of the original tasks were implemented within the story line of the TDF. These core features are the rules for gains and losses, their probabilities, the number of decision options, and the number of trials (Brand et al., 2006). However, the story line in which these features were implemented was – obviously – different in the TDF. Furthermore, there were very small differences in the probability presentation formats, as well as the user interfaces. These differences may affect decision-making behavior in the TDF (even irrelevant surrounding information can affect decision making, see e.g., the literature on framing and anchoring Englich, Mussweiler, & Strack, 2006; Epley & Gilovich, 2006; Kühberger, 1998). If they do, these effects need to be described, in order to be able to evaluate performances in TDF tasks adequately in future studies and in clinical application.

In the current study, three TDF-tasks were tested on brain-healthy participants. The focus of this study lay on tasks measuring decisions under risk conditions. Therefore, the

Game of Dice Task (GDT; Brand, Fujiwara, et al., 2005) and the Probability-Associated Gambling (PAG) task (Delazer et al., 2007; Zamarian et al., 2008) were used. In an additional Experiment we also tested whether the Iowa Gambling Task (IGT; Bechara et al., 1996, 2000), the standard task assessing decisions under ambiguity, could also be implemented within the TDF.

Each participant played both the original task and the TDF version, either beginning with the original task or with the TDF task. It was tested whether the overall patterns of behavior were comparable across both tasks and whether performances in both tasks correlated with each other. If the main features of the original tasks have successfully been integrated in the TDF counterparts, the patterns of behavior should be comparable. Given the differences in the story line or probability presentation formats, small systematic differences in behavior may also occur, but must not affect the general pattern of behavior. Additionally, the measures in the original and the TDF task should be correlated.

In the following, the literature on the tested decision-making task is shortly summarized. Additionally, it is explained which behavior in the task can be defined as typical (i.e., normal for brain-healthy subjects). This is important to evaluate whether the pattern of the participants' behavior in the TDF counterpart can be regarded as comparable to the behavior in the original task, indicating that projecting the main features of the original task has been successful.

7.2.2. Game of Dice Task (GDT)

The GDT is a computerized task, assessing decision making under risk conditions (Brand et al., 2005). In each of 18 decision trials, the participants have to guess which number will be thrown next by a single virtual six-sided die. The GDT has been developed in order to examine the impact of executive functions on strategic decision making under risk conditions (see also chapter 3.1.3 and Brand, Fujiwara, et al., 2005). For this aim it was important that the decision situation has explicit rules for gains and losses as well as their probabilities and that these rules remain stable over the whole duration of the task. It was suggested that in this stable situation executive functions, like categorization, set-shifting or planning should be important for the development, application and revision of advantageous long term strategies (Brand, Heinze, et al., 2008).

So far, the GDT has been used in numerous studies with patient samples and healthy participants. For example, in patients with Parkinson's disease (Brand, Labudda, et al., 2004; Euteneuer et al., 2009), alcoholic Korsakoff's syndrome (Brand, Fujiwara, et al., 2005; Brand, Pawlikowski, et al., 2009), attention-deficit/hyperactivity disorder (Drechsler et al., 2008), Alzheimer's disease (Delazer et al., 2007), pathological gambling (Brand, Kalbe, et al., 2005), binge eating disorder (Svaldi et al., 2010), narcolepsy (Bayard, Abril, et al., 2011; Delazer, Högl, et al., 2011), restless legs syndrome (Bayard et al., 2010), and Urbach Wiethe disease (Brand, Grabenhorst, et al., 2007) it was shown that impairments in executive functions as well as in the emotional processing of feedback can result in reduced decision-making performance in the GDT. In a review about decision making in patients with neurodegenerative diseases, the GDT was mentioned as one of the most important tasks in clinical and neuropsychological decision-making research (Gleichgerrcht et al., 2010). In studies with healthy participants the role of executive functions, logical thinking, feedback processing, calculative strategy development, age-associated cognitive decline (e.g., Brand et al., 2008; Brand, Laier, Pawlikowski, & Markowitsch, 2009; Brand & Markowitsch, 2010; Brand & Schiebener, 2012; Schiebener, Zamarian, Delazer, & Brand, 2011) as well as perfectionism and impulsivity (Bayard, Raffard, et al., 2011; Brand & Altstötter-Gleich, 2008) for GDT performance has also been described.

It can be inferred from these studies that a normal decision-making pattern of healthy participants is reflected in a preference for the advantageous alternatives, resulting in a positive net score. When regarding the pattern of all choices between the four risk classes healthy participants more often choose the alternatives with higher winning probabilities and less often choose alternatives with lower winning probabilities. However, it was sometimes found that slightly more choices were made for the combination of three numbers than for the combination of four numbers (e.g., Brand et al., 2004). A TDF version of the GDT was tested in Experiment 1.

7.2.3. Probability-Associated Gambling (PAG) task

The PAG task is a computerized task also measuring decision making under risk conditions (see also chapter 3.1.3 and Sinz et al., 2008; Zamarian et al., 2008). In the task, participants are asked to decide between taking a fixum (a fixed gain or loss of €20) or gambling in a lottery for which the probabilities for winning and losing are displayed by the ratio of red and blue cubes in an urn.

The PAG task was developed to examine decision-making behavior under risk conditions in a situation, in which the amounts of gains and losses and their probabilities are explicit but change from trial to trial. Additionally, the task provides a situation with a conflict between taking a risk and deciding for the most conservative option. In other tasks, such as the GDT, the most conservative choice, with the lowest risk is at the same time the most advantageous choice (at least on the long run). In the PAG task it is sometimes more advantageous to take a risk (choosing the lottery gamble), instead of deciding conservative (take the fixum), because the expected value of the gamble is higher than the amount of the fixum. Thus, the task is supposed to measure decision-making performance without being undermined by the participant's general tendency to avoid risks.

The PAG task was used in a number of studies, mostly for the examination of patient populations. Patients with Alzheimer's disease (Sinz et al., 2008), Parkinson's disease dementia (Delazer et al., 2009), mild cognitive impairment (Zamarian, Weiss, et al., 2010), and after traumatic brain injury (Bonatti et al., 2008) showed a decreased performance in the original PAG task or modified versions of it. These effects were associated with reduced executive functions and problems with integrating information from different sources or with adapting decision strategies. Older aged individuals (Zamarian et al., 2008), patients with Parkinson's disease without dementia (Delazer et al., 2009) and patients with temporal lobe epilepsy (Bonatti et al., 2009) showed normal performance in the PAG task although they displayed problems with decision making under ambiguity (as measured by the IGT).

Overall, studies showed that a normal, healthy pattern of decision making in the PAG task constitutes choosing the lottery more often in the higher and less often in the lower winning-probability conditions. A TDF version of the PAG task was tested in Experiment 2.

7.2.4. Iowa Gambling Task (IGT)

In addition to the two main studies, we also aimed to evaluate the possibility to design a TDF version of the Iowa Gambling Task (IGT). This task is supposed to measure decision making under conditions of ambiguity. Participants have to choose cards from four decks. No information is provided about the probabilities for gains and losses or their possible heights. Immediately after each choice the computer indicates the amount of gained money. At unpredictable times, an amount of loss of money follows the win. From this feedback the participants can learn that the task has two advantageous decks leading to a positive capital in the long run. The other two decks are disadvantageous leading to a highly negative capital in the long run.

The IGT was originally developed to test the somatic marker hypothesis (see also chapter 3.1.2 and Bechara et al., 1994; Bechara & Damasio, 2005; A. R. Damasio, 1994), assuming that in healthy persons, advantageous decision making can be learned automatically, because it is guided by bodily emotional reactions to rewards and punishments. The task attempts to model real life decision making by providing a situation, in which outcomes of different options and the probabilities of these outcomes are ambiguous. Gains and losses from the different decks are not obvious and seem to occur unsystematically, thus preventing the participant to be able to detect the probabilities for different outcomes. Participants have to follow their intuitive hunches and guesses, probably created by the emotional reactions to the task's feedback (e.g., Bechara et al., 1997).

The IGT has been used in an uncounted number of studies with patients and healthy individuals. From the results of studies with patients who had lesions in the prefrontal cortex (Bechara et al., 1997, 1996; Bechara, 2004; Northoff et al., 2006) or to the amygdala (Bechara, Damasio, & Damasio, 2003; Gupta et al., 2010) and from studies with patients with psychiatric disorders (Haaland et al., 2007; Must et al., 2006; Smoski et al., 2008) it was concluded that particularly emotional reactions to feedback and the bodies anticipation of it are important for decision making in the IGT.

Other studies also investigated the roles of cognitive functioning for the behavior in the task both in healthy individuals and patients (Brand, Recknor, et al., 2007; Maia & McClelland, 2004, 2005; Toplak et al., 2010; Turnbull et al., 2005). In summary, it seems that although emotions are very important for decisions in the IGT, there is also an influence of conscious knowledge about the task's contingencies and cognitive abilities, which predicts decision-making performance, at least in the later trials when the rules for gains and losses have become aware to the participant (Brand, Recknor, et al., 2007; Y.-T. Kim et al., 2011). For reviews about cognitive and emotional correlates of decision making in the IGT refer also to Buelow and Suhr (2009) and Dunn, Dalgleish, and Lawrence (2006).

The decision-making pattern of normal, healthy participants typically shows an ascending learning curve over the tasks duration, with increasing preference for the two advantageous decks (e.g., Turnbull et al., 2005). Often, it has also been reported that the learning curve slightly descends in the last block of the task (e.g., Torralva et al., 2012;

Verdejo-García, Benbrook, Funderburk, David, & Bolla, 2007). A TDF version of the IGT was tested in Experiment 3.

7.3. Experiment 1 (GDT)

7.3.1. Method

7.3.1.1. Participants

A total of 120 brain-healthy participants (55 males) took part in Experiment 1. They were aged 18-75 years, *M* = 29.17 years, *SD* = 13.51 years. Participants were recruited by local advertisement and tested at the department of General Psychology: Cognition, at the University of Duisburg-Essen. None of them had participated in one of the other studies reported here, or in a comparable study in the department. They received no financial compensation, but students received credits for courses. None of them reported a history of neurological or psychiatric diseases, as determined by a self-report questionnaire. The study was approved by a local ethics committee.

7.3.1.2. Materials

7.3.1.2.1. Original task: GDT

As already described in the Introduction, the GDT is a computerized game with dice. In first part of the instruction, a screenshot of the game's surface is shown to the participants and the task is explained as follows:

"This is a game of dice. Your task is to win as much money and to lose as little money as you can. You start with a balance of €1,000. In a total of 18 rounds, one die is thrown and you are supposed to guess the correct number each time. The result of each throw is random. Before each new throw, you are to choose one single number or a combination of several numbers. If the result matches your guess, you win. Otherwise you lose."

The principle of the GDT is then additionally illustrated by using examples of possible bets, supported by screenshots, which illustrate exemplary gambling situations. For each possible risk category (betting on one, two, three, and four numbers) one example is explained in the following manner:

"*You can also bet on two numbers together, for example, the number 3 and 4. If the result is one of these two numbers you win €500. If the result is any of the other numbers, i.e., 1, 2, 5, or 6, you lose €500.*"

By means of these examples, the participants are informed that the available options are related to specific amounts of gain or loss (from €100 for bets on combinations of four numbers to €1,000 for bets on one single number). Additionally, a summary of the rules is presented before the task starts. The key features of the GDT are indicated in more detail in Table 9.

7.3.1.2.2. TDF version of the GDT: TDF-GDT

In the TDF-GDT participants have the goal to earn as much fictitious money as possible and to lose as little as possible. First the story (or the "scenario) is explained to the participants. They are informed that they are in the role of a dispatcher of the fictitious logistics company TruckTrans, which is based in the fictitious country Cognitia. As truck dispatchers, the participants have to decide which routes the trucks take to drive to the customers. The principle of the game is then explained as follows:

"*On six working days of a week it is allowed to drive with trucks on Cognitia's highways. Planning the tours for the trucks cost-effectively is a demanding task because there are several possibilities to let the trucks drive to the customer. There are not only routes over single highways but also over combinations of several highways. Depending on how many highways the truck uses, it takes different amounts of time to deliver the goods. If it uses more highways the delivery takes longer. Then the costs for TruckTrans are higher and the profit is lower. If the truck drives over few or even only one highway, it arrives earlier at its destination. Thus, the costs for TruckTrans are lower and the profit is higher.*

Please note: The quicker TruckTrans promises to deliver the goods, the higher is the gain, but the higher is also the contractual penalty, if the goods are note delivered in time.

However, on the tours to the customers a truck can get into a traffic jam. Then delivering the goods on time fails. This results in a contractual penalty for this tour and means financial loss for TruckTrans."

After the explanation of the story, the user interface is presented to the participants and their concrete task is explained to them, while the parts of the user interface, which are explained, are highlighted:

"*You make decisions for the routes on 18 days. Your starting capital is €1,000. On the left side you can see how often there were traffic jams on the particular routes. Note, that it is irrelevant whether there was a traffic jam on one route at the day before. There could be a traffic jam at the next day or it could be free. You can send the truck on single highways or on several highways. On the right side you see how much money you can win or lose with tours on the available routes. Depending on the number of highways on a route, the truck needs different amounts of time for delivering the goods. When the truck uses few highways it will reach its destination quicker. Therefore, the costs for TruckTrans are lower and the profit is higher. If the truck drives on several highways, it takes longer. Then the costs for TruckTrans are higher and the profit is lower. However, the truck can also get into a traffic jam. In this case it will not succeed in delivering the goods in time. This results is the indicated contractual penalty, which means loss for TruckTrans.*"

Like in the GDT, there are 14 options for the decision, and the options can be categorized into four risk classes (driving over one single highway, combinations of two, three, or four highways). The possible choices are also explained using examples, such as the following:

"You may for example let the truck drive over two highways, for example, H18 and H22. On this route there is a traffic jam on 4 of 6 days, and on 2 of 6 days the route is free. You cannot know whether the route is free today. The traffic situation of the previous day is also irrelevant. If the route is free, the truck arrives in time and you earn €500. If the truck gets into a traffic jam, it arrives too late and you lose €500."

The key features of the GDT have all been applied in the TDF-GDT, as presented in the direct comparison in Table 9. Find pictures of the GDT and the TDF-GDT in Figure 10.

Table 9. The key features of the GDT and the way they were implemented in the TDF-GDT.

Key feature	GDT	TDF-GDT
Scenario	dice game	logistics company
Probability coding	6-sided die	routes with probabilities for traffic jam on 6 days
Choice alternatives	number combinations	highway combinations
Number of alternatives	14 die combinations	14 routes
Risk classes (gain/loss)	4 different types of number combinations	4 different lengths of routes
1:6 (€1,000)	one single number	direct route over one highway
2:6 (€500)	combinations of two numbers	detour over two highways
3:6 (€200)	combinations of three numbers	detour over three highways
4:6 (€100)	combinations of four numbers	detour over four highways
Number of trials	18 die throws	18 truck tours
Visual feedback	green or red colored amount of gain or loss, total capital	green or red colored amount of profit or costs, total capital
Auditory feedback	gain: jingle of a cash machine, loss: dull tone	gain: quickly passing truck, loss: noise of traffic jam

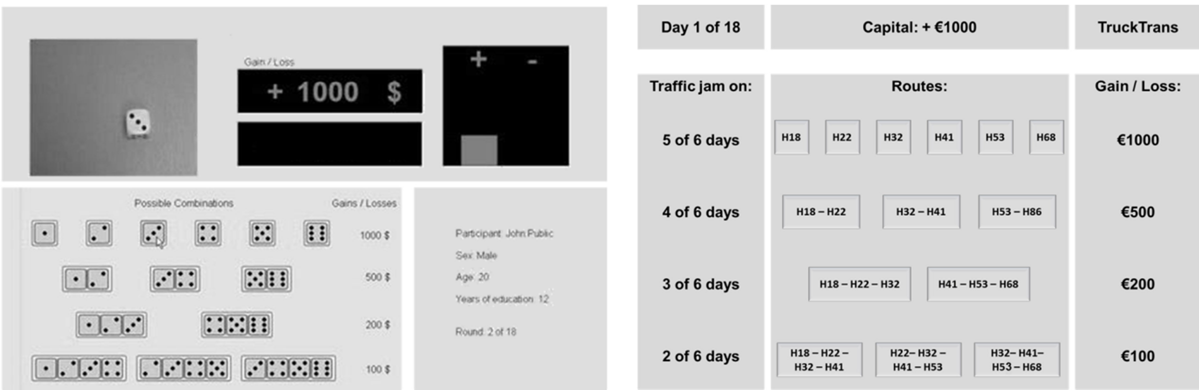

Figure 10. The left half the figure shows the user interface of the GDT. On the right half it shows the user interface of the TDF-GDT.

Both tasks have equal numbers of alternatives with equal gains and losses related to them. The starting capital is also equal in both tasks. A difference between the two tasks is that the probabilities are not explicitly provided in the GDT, but they are in the TDF-GDT.

Measures. Decision-making behavior in both tasks, the GDT and the TDF-GDT, is first analyzed in the overall pattern of choices, by counting the number of choices for the different alternatives, i.e., the number of choices for the four risk classes (one number/highway, two numbers/highways, three numbers/highways, or four numbers/highways). As cumulative measure of decision-making performance the net score is used. Based on the outcome probabilities, the given alternatives can be grouped into low risk (advantageous) and high risk (disadvantageous) options. Choices for alternatives with winning probabilities of 50% or higher are advantageous (GDT: bets on three or four numbers, TDF-GDT: tours over three or four highways). Choosing them consequently promises to end the task with at least as much money as with which it was started. The other choice alternatives are disadvantageous because the winning probabilities are below 34%. Choosing these alternatives will result in more losses than profits (GDT: bets on one or two numbers, TDF-GDT: routes over one or two highways). The net score is calculated by subtracting the number of disadvantageous choices from the number of advantageous choices.

7.3.1.3. Statistical analyses

For the statistical analyses SPSS version 20.0 was used. Comparisons of means were computed with t-tests or with repeated measures ANOVAs. For multiple mean comparisons Bonferroni's correction was used. Relationships between two variables were described with Pearson's product-moment-correlation coefficient.

7.3.2. Results

In the first step of our analysis, we tested the behaviors in the two tasks for sequence effects, in order to determine whether data of the whole group (those who performed the original GDT at first and those who performed the TDF-GDT at first) can be used for further comparisons between the tasks. A repeated measures ANOVA was computed using the number of decisions for the risk classes (one, two, three, and four numbers/highways) and task (GDT, TDF-GDT) as within subject factors and sequence (GDT first, TDF-GDT first) as between subject factor. We found no significant effect of sequence as the interaction between risk class and sequence was not statistically relevant, $F(2.12, 249.64) = 1.41$, $p = .245$, $\eta_p^2 = .01$. Therefore, the data were analyzed independent of the sequence of task administration.

In the next step we compared the behaviors in the two tasks. As can be seen in Figure 11, the pattern of behavior in both tasks was comparable to the pattern, which is known from previous GDT studies: On average participants preferred alternatives with lower risk over alternatives with higher risk. However, in the GDT preference steadily increased with decreasing risk, while in the TDF-GDT preference for the lowest risk alternatives (four highways) and the second lowest risk alternatives (three highways) were relatively similar.

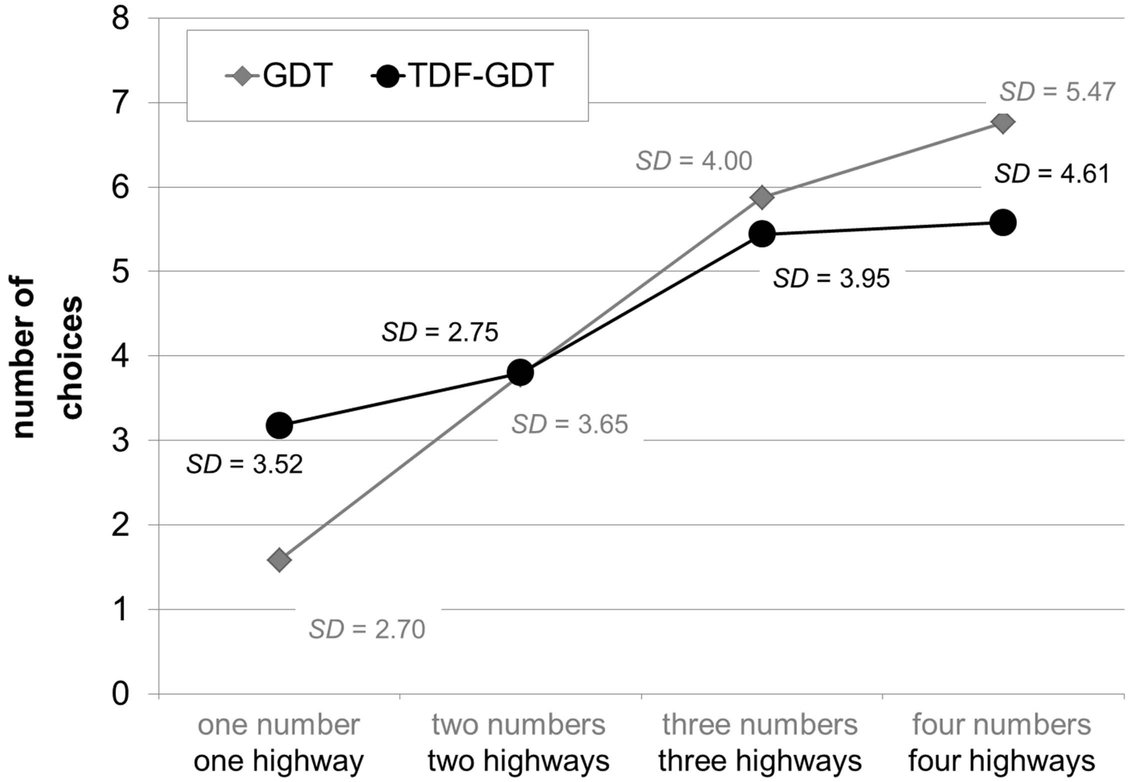

Figure 11. The figure shows the decision-making behavior in the GDT and the TDF-GDT.

It describes the mean number of decisions in the four different risk categories, that is one single number/one highway, combinations of two numbers/two highways, combinations of three numbers/three highways, and combinations of four numbers/four highways. As can be seen the overall pattern of behavior is comparable in both task: There is a preference for options with higher winning probabilities.

To compare the behavioral patterns, we computed a repeated measures ANOVA with the risk class and task (GDT, TDF-GDT) as within subject factors. There was a main effect of risk class, $F(2.13, 253.16) = 26.35$, $p < .001$, $\eta_p^2 = .18$, as well as an interaction between risk class and task, $F(2.55, 303.57) = 6.20$, $p = .001$, $\eta_p^2 = .05$. This result indicates that there were differences in the behavior in the two tasks. Single pair comparisons between the numbers of decisions for equivalent risk categories in the two tasks showed that in the TDF-GDT significantly more decisions for one highway were made than decisions for one single number in the GDT, $p < .001$. The differences between the other three risk categories were not significant, *p*s > .017 (please note that the Bonferroni corrected significance threshold was $p = .0125$). To test whether the participants showed the normal general pattern in both tasks - that is a preference for alternatives with lower risks - additional repeated measures ANOVA with only the variables of the GDT or the TDF-GDT were computed. In the GDT there was a significant effect of risk class, $F(2.11, 251.07) = 28.96$, $p < .001$, $\eta_p^2 = .20$. The single pair comparisons showed significant differences between the risk categories, *p*s $\leq .001$, except for the difference between the number of choices for combinations of three and four numbers, *p*s $< .99$.

For the TDF-GDT the pattern was also significant as indicated by the effect of risk class, $F(2.37, 282.06) = 9.11$, $p < .001$, $\eta_p^2 = .07$. The single pair comparisons showed significant differences between the means of decisions for highly risky alternatives (one and two highways) compared to lowly risky alternatives (three and four numbers), *p*s $< .05$. The comparisons between three and four highways as well as between one and two highways were not significant, *p*s $> .38$. This analysis indicates that the average preference for lower risks, as it is known from GDT-studies, was present in the TDF-GDT.

The net scores of the two tasks are depicted in Figure 12. The net score in the GDT was significantly higher, $t(119) = -3.33$, $p = .001$, $d = 0.32$.

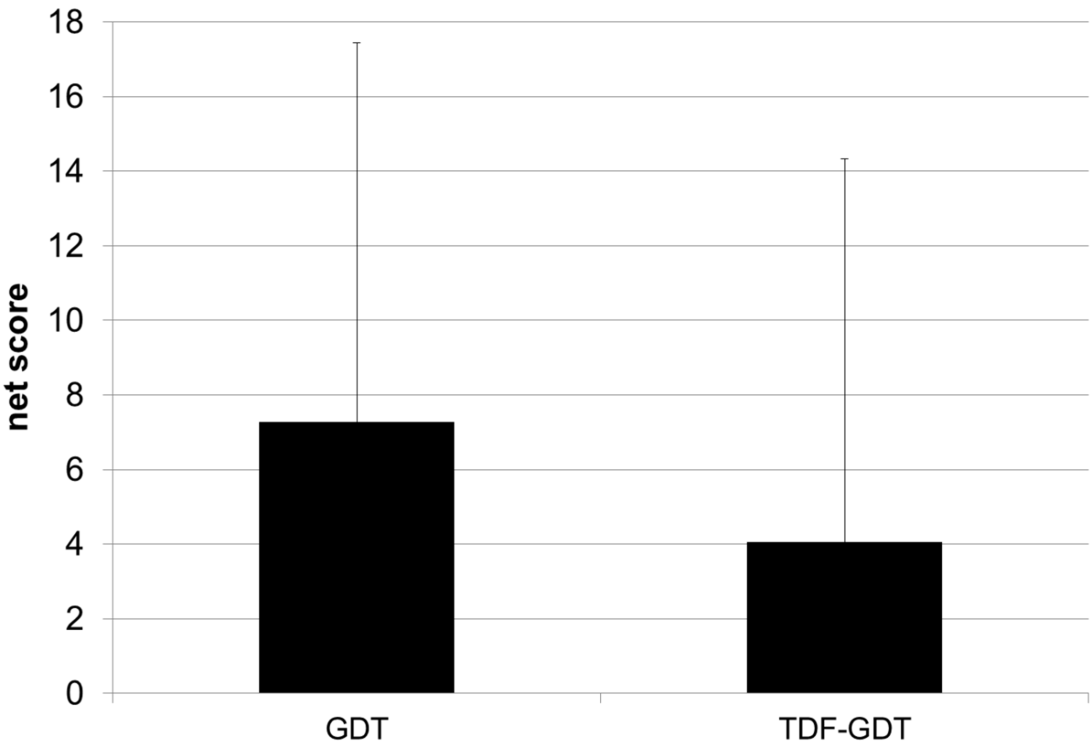

Figure 12. The mean net scores in the GDT and the TDF-GDT.

The mean net score in the TDF-GDT was smaller than the net score in the original GDT and the effect size of the differences was small. The error bars represent standard deviations.

The correlations between the variables of the two tasks can be found in Table 10. As can be seen, there were moderate correlations between the numbers of decisions for alternatives within the four risk classes and the net scores of the original GDT and the TDF-GDT.

Table 10. Correlations between the variables of the GDT and the TDF-GDT.

		highways				**net score**
		one	two	three	four	
GDT	one number	**.32****	.14	-.20*	-.15	-.29**
	two numbers	.32**	**.39****	-.06	-.42**	-.42**
	three numbers	-.15	.07	**.23***	-.12	.06
	four numbers	-.26**	-.38**	-.03	**.45****	.38**
	net score	-.40**	-.35**	.15	.38**	**.46****

* $p \leq .05$ (two-tailed)
** $p \leq .01$ (two-tailed)

7.3.3. Discussion

In summary, the results of Experiment 1 show that decision-making behavior in the TDF-GDT was comparable to the behavior in the GDT in this sample and also to the GDT behavior as it is known from previous studies (e.g., Brand, Laier, et al., 2009). In both tasks the participants preferred less risky options over riskier options, showed a positive overall performance (i.e., positive net scores) and the performance measures correlated moderately between the tasks. These results indicate that the core features of the GDT have successfully been integrated in the story line of the TDF-GDT. The slight differences between performance indicators in the two tasks (more risky decisions in the TDF-GDT) may be due to several reasons (e.g., the more complex cover story, or the other probability-presentation format in the TDF-GDT), which could be examined in upcoming studies. Given the conceptual correspondences of the two tasks, and the comparable behavioral patterns of the participants as well as the correlations shown, the slight differences in behavior do not affect the conclusion that the TDF-GDT seems to measure the same underlying construct as the GDT.

7.4. Experiment 2 (PAG task)

7.4.1. Method

7.4.1.1. Participants

In total 124 participants (53 males) took part in Experiment 2. Their age was 18-62 years, *M* = 28.98 years, *SD* = 10.74 years. The criteria for inclusion and exclusion were the same as in Experiment 1.

7.4.1.2. Materials

7.4.1.2.1. Original task: PAG task

In the PAG task (Sinz et al., 2008; Zamarian et al., 2008) participants have to decide between taking a fixed amount of gain or loss and gambling in a lottery. The principle of the task is explained in the instructions as follows:

"*The following task is a gambling task. Please imagine that you are the participant in a lottery and you have the aim to win as much money as possible. Your task: In each trial you have the choice between two options and you are supposed to decide for one of them:*

Option 1(left half of the screen): You take the fixum. Then, depending on the trial, either a small amount of money is subtracted from your capital (€20) or this amount (€20) is added to your capital. Please regard the plus or minus sign ahead of the number.

Option 2 (right half of the screen): You gamble for €100. Explanation: In the grey box there are different amounts of red and blue cubes. From these the computer draws one in each trial. If a red cube is drawn, you win €100, because the red cubes are the winning cubes. If a blue cube is drawn, you lose €100, because the blue cubes are the losing cubes.

In each trial you have ten seconds time for deciding for one of the two options."

If no decision is made, the fixum is chosen automatically. The participants are not explicitly told that they have to make 40 decisions, that there are always 24 cubes, and that the ratio of red and blue cubes changes pseudo-randomly between four different ratios that define the winning probability (3:21 or 12.5%, 9:15 or 37.5%, 15:9 or 62.5%, and 21:3 or 87.5%). They also do not know that every probability occurs five times with the positive and five times with the negative fixum.

Which choice is advantageous and which is disadvantageous depends on the ratio of red and blue boxes. If the winning probability is high (62.5% or 87.5%) it is advantageous to play the gamble and disadvantageous to take the fixum (irrespective of whether it is positive of negative). If the winning probability is low (12.5% or 37.5%) it is always advantageous to decide for the fixum and disadvantageous to gamble.

7.4.1.2.2. TDF version of the PAG task: TDF-PAG task

In the TDF-PAG task, the participants have to decide between a fixed sum of gain or loss and a chance event, analogue to the PAG task. They decide whether a truck uses the highway or the country road to drive to the customer. Like in the TDF-GDT, first the framing story is explained, including the information that TruckTrans is a logistics company, aiming to maximize profits by delivering the goods to the customers in time, that longer routes are associated with higher costs, and that contractual penalties will follow if a truck arrives at its destination with delay. The principle of the TDF-PAG is then described as follows:

"*It is discriminated between routes over the highway and routes over the country road. Normally, the country road is the slower option and causes higher costs and less profit for TruckTrans. In contrast, it is possible to drive faster on the highway and the truck arrives earlier at its destination. The costs are lower and the gain is higher. However, in Cognitia there can also be traffic jams. Therefore, before each choice for a route, the map of Cognitia is displayed. This shows the current traffic jam situation in the country. Then you have to consider whether you chose the country road and thereby accept longer driving time. It can however also not be guaranteed that the country road is always free, but you will be informed about this before you chose the route. Please note: The quicker TruckTrans promises to deliver the goods, the higher is the contractual penalty, if the goods do not arrive at the customer in time. So, chose the route, which appears to provide the quickest arrival and thereby the highest profit, given the current conditions."*

Then the tasks surface is explained to the participants, while always the relevant part of the surface is highlighted:

"*You decide for the routes on 40 days. Your starting capital is €1,000. On the left side, the map shows the actual traffic jam situation in Cognitia. The red trucks show that they are in a traffic jam. The blue trucks display a free highway. Note, that only the current traffic jam situation is relevant.*

On the right side, the situation on the country road is presented. The country road is either free or blocked. You are now asked to make your decision based on the current traffic jam situation and the situation on the country road: You can chose either the country road, with which you can win or lose €200, or the highway with which you can win or lose €1,000. Please tick your choice with the mouse. The choice will be symbolized with a black dot. For your decision you have ten seconds. If you do not decide within ten seconds, the country road is chosen automatically."

Then the options are explained using an example:

"You may for example choose the country road because of many traffic jams on the highway, although you know that the country road is blocked. You lose €200. You may also send the truck on the highway, despite many traffic jams. If you get into a traffic jam you lose €1,000. If the highway is free, you gain €1,000. If you decide to send the truck on the country road, because of many traffic jams and because you know that the country road is free, you win €200."

Like in the PAG task the participants are neither informed about the exact number of blue and red trucks on the map nor about their ratio (like in the PAG task, the number of red and blue items could be counted by the participant). The possible ratios of red and blue trucks are equivalent to those in the original PAG task and therefore winning probabilities are also the same. The key features of the PAG task have all also been realized in the TDF-PAG, as presented in the direct comparison in Table 11. Pictures of the PAG task and the TDF-PAG task can be found in Figure 13.

Table 11. The key features of the PAG task and the way they were implemented in the TDF-PAG.

Key feature	PAG task	TDF-PAG
Scenario	lottery	logistics company
Probability coding	ratio of red and blue cubes	ratio of trucks on free highways (blue) and on highways with traffic jams (red)
Choice alternatives	2: fixum, lottery gamble	2: country road, highway
Risk classes (gain/loss)	4 different ratios of red and blue cubes: 3:21, 9:15, 15:9, 21:3	4 different ratios of trucks on free highways and in traffic jams: 3:21, 9:15, 15:9, 21:3
Occurrence of the different probabilities	each probability occurs five times with the positive and five times with the negative fixum	each probability occurs five times with a free and five times a blocked country road
gains/losses	fixum: €20 lottery: €100	country road: €200 highway: €1,000
Number of trials	40 lotteries	40 truck tours
Visual feedback	visualization of pulled cube, amount of gain or loss, total capital	green or red colored amount of profit or costs, total capital
Auditory feedback	gain: applause, loss: dull tone	gain: quickly passing truck, loss: noise of traffic jam

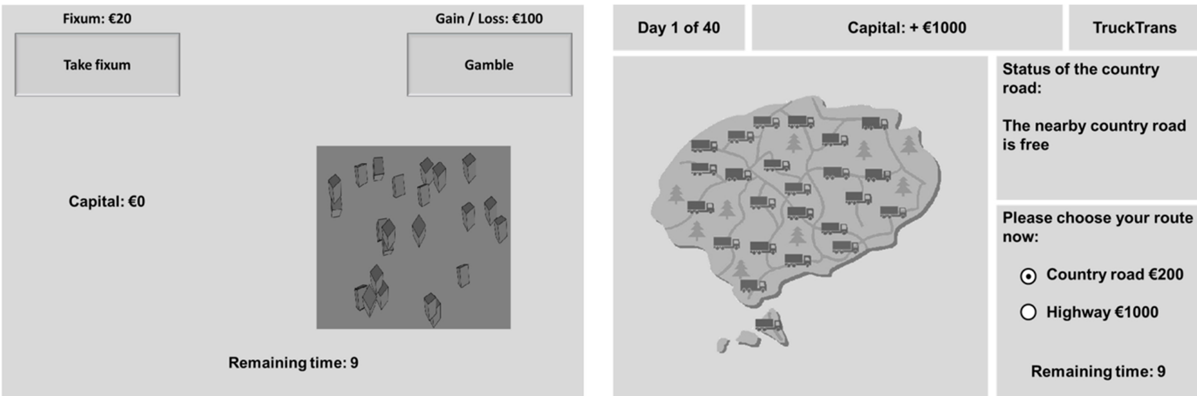

Figure 13. The left part of the figure shows the interface of the PAG task, the right side shows the TDF-PAG task.

In both tasks there are two options: choosing the save amount of gain or loss (fixum/country road) or choosing the option with uncertain outcome (lottery gamble/highway). In both tasks the probabilities for gains and losses in the uncertain option are visualized by the ratio of red and blue items (cubes/trucks). There are two differences between the two tasks: The number of remaining trials is explicitly provided in the TDF-PAG task but not in the PAG task. The monetary amounts in the TDF-PAG task are all ten times higher than the monetary amounts in the original PAG task.

Measures. Decision-making performance in the PAG task and the TDF-PAG task is measured by the frequency of decisions for gambles (PAG task: choosing the lottery; TDF-PAG task: choosing the highway) in the different ratios of blue and red items (cubes or truck symbols; 3:21: "low winning probability", 9:15: "moderately low winning probability", 15:9: "moderately high winning probability", 21:3: "high winning probability"). Higher numbers of decisions for gambles in the two high winning probabilities indicate better decision-making performance; higher numbers of gambles in the low winning probabilities indicate worse performance.

7.4.1.3. Statistical analyses

The methods for the statistical analyses were the same as in Experiment 1.

7.4.2. Results

First, the behavior in the two tasks, the original PAG task and the TDF-PAG task, were controlled for sequence effects. A repeated measures ANOVA was computed using the number of gambles in the four probability conditions (low, moderately low, moderately high, and high winning probabilities) as well as task (PAG task, TDF-PAG task) as within subject factors and sequence (PAG task first, TDF-PAG task first) as between subject factor. There was neither a significant interactions between sequence and task, $F(1, 122) < 0.01$, $p = .966$, $\eta_p^2 < .01$, nor between sequence and the number of gambles in the four probabilities, $F(1.78, 216.50) = 0.05$, $p = .936$, $\eta_p^2 < .01$. Therefore, the behavior in the two tasks was compared independent of sequence.

In both tasks, participants made more decisions for lottery/highway in higher winning probability conditions and less of these decisions in lower winning probability conditions (see Figure 14). The pattern is comparable in both tasks, but it seems that the participants systematically made more gambles in the TDF-PAG in all probability conditions.

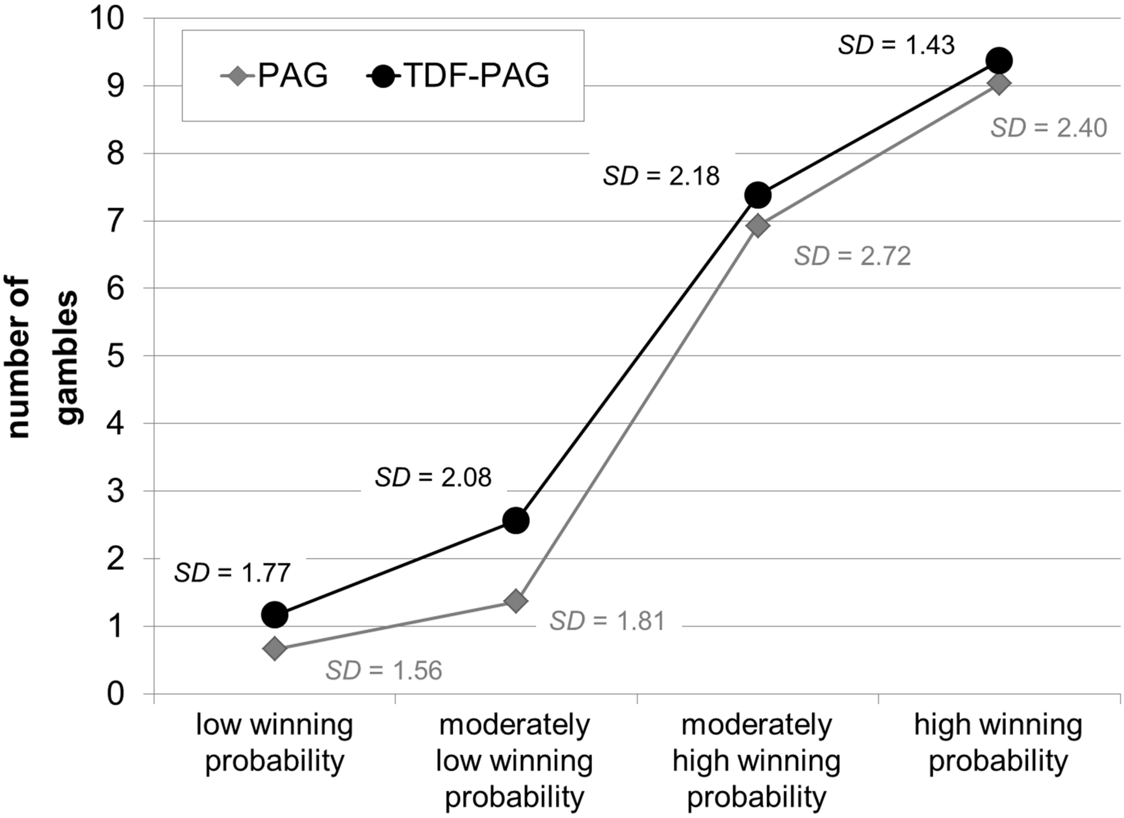

Figure 14. The figure shows the mean number of decisions for the "gambling" option (lottery/highway) in the PAG task and the TDF-PAG task.

In both tasks there is a comparable pattern, with more decisions for the gambling option when the winning probabilities of the gambles were higher. There is a higher preference for gambling in the TDF-PAG task, as can be judged from the higher position of the TDF-PAG task curve.

The repeated measures ANOVA supported this impression, showing a significant effect of task, $F(1, 123) = 20.05$, $p < .001$, $\eta_p^2 < .14$, and an interaction between task and the number of gambles in the four probabilities, $F(2.24, 275.27) = 3.83$, $p = .019$, $\eta_p^2 = .03$. Single pair comparisons of the means frequencies of decisions for gambling in the analogue probability conditions in the PAG task and the TDF-PAG task revealed that in the TDF-PAG significantly more decisions for gambles were made in the two low probability conditions, *p*s < .004. The differences in the two high probability conditions were not significant, *p*s > .111 (the Bonferroni corrected significance threshold was $p = .0125$). To test whether the normal PAG task pattern - more gambles in higher winning probability conditions - was present in both tasks repeated measures ANOVAs with only the variables of the PAG task or the TDF-PAG task were performed. In the PAG task the effect of the mean frequency of gambles in the four probability conditions was significant, $F(1.83, 225.41) = 559.25$, $p < .001$, $\eta_p^2 = .82$. All single pair comparisons between the probabilities were also significant, *p*s < .001. When regarding the TDF-PAG only there was also a significant effect of the mean frequency of gambles in the four probability conditions, $F(2.05, 252.07) = 547.25$, $p < .001$, $\eta_p^2 = .82$. The single pair comparisons were all significant, *p*s < .001. This result shows that the normal behavior, as it is known from previous PAG task studies, was also present in the TDF-PAG task.

In Table 12 the correlations between the variables of the two tasks are shown. As can be seen, the correlations between the analogue variables in the two tasks had low to moderate effect sizes.

Table 12. Correlations between the numbers of gambles in the four winning probability conditions of the PAG task and the TDF-PAG task.

		TDF-PAG Task			
		low winning probability	moderately low winning probability	moderately high winning probability	high winning probability
PAG task	low winning probability	**.35****	.22*	-.16	-.24**
	moderately low winning probability	.28**	**.27****	-.13	-.12
	moderately high winning probability	-.11	-.07	**.20***	.25**
	high winning probability	-.17	-.06	.18	**.34****

* $p \leq .05$ (two-tailed)
** $p \leq .01$ (two-tailed)

7.4.3. Discussion

The results of the Experiment with the PAG task and a TDF version of the PAG task show that decision-making behavior in the two tasks was comparable. As known from previous PAG task studies, participants made on average more choices for lottery gambles/highways when the related winning probabilities were higher (Schiebener et al., 2011; Zamarian et al., 2008). A difference was found in the frequency of gambling in the low winning probability lotteries. When the winning probabilities were low or moderately low the participants made more decisions for the highway in the TDF-PAG than decisions for the lottery in the PAG task. This slightly more risky behavior does however not affect the conclusion that the general pattern is comparable between the two tasks, given that the general gambling patterns were closely connected to the winning probability in the gamble, as indicated by the high observed effect sizes of the lotteries' winning probabilities (in both tasks the η_p^2 of the inner subject variable "probability" was .82). The correlations between the numbers of decisions for gambles in the four different probability conditions were in the low to moderate range. In summary the results indicate that the features of the PAG task have successfully been integrated in the TDF story line and that the TDF-PAG task measures the same underlying construct as the standard PAG task.

7.5. Experiment 3 (IGT)

7.5.1. Method

7.5.1.1. Participants

The sample was comprised of 40 brain-healthy participants (21 males). They were aged 19-54 years, *M* = 26.65, *SD* = 9.43 years and had a mean school-education of *M* = 12.26 years, *SD* = 1.94 years. The inclusion and exclusion criteria were the same as in Experiment 1 and 2.

7.5.1.2. Materials

7.5.1.2.1. Original task: IGT

The IGT is a computerized task, in which the participants' chose between four decks of cards. They are instructed as follows:

"*You will now play a game with cards. Your task is to choose one card from one of the four decks. Then you will win money. Sometimes additionally a loss follows after the gain. You are supposed to try to win as much money as possible and to lose as little of it as possible. There are good and bad decks, but you have to find out yourself which decks are good and which are bad.*

The participants do neither know the number of trials (which is 100) nor the gains and losses that will follow the choices from the decks. Immediately after each choice the computer indicates the amount of gain accompanied by a distinct positive sound. At unpredictable times, an amount of loss follows, together with a negative sound. There are two advantageous decks, C and D, providing low gains, and only low occasional losses. Choosing them consistently will in the long run lead to a positive money balance. The other two decks, A and

B, are the disadvantageous ones. They offer high gains, but occasionally very high losses. In the long run, choosing these decks very often, will lead to a high negative money balance.

7.5.1.2.2. TDF version of the IGT: TDF-IGT

In the TDF-IGT the participants' can chose between four routes to the customer. Like in the two other TDF versions first the general story of the game is explained. Then the specific principle of the TDF-IGT is described:

"*You task is to organize the tours of the trucks in the way that TruckTrans earns as much money as possible and loses as little of it as possible. Your starting capital will be €1,000. In Cognitia it is also possible that a truck gets into a traffic jam on its tour to the customer. This causes a contractual penalty, which is a financial loss that is accounted beside the payoff for the delivered goods. Whether there was a traffic jam on a route the day before is irrelevant for the situation at each new day. Independent from what happened the days before, the truck may get into a traffic jam or the route may be free. When planning a certain tour you can unfortunately not know whether there will be a traffic jam on the route you chose. However, in Cognitia there can be routes, on which traffic jams are more frequent, while there are other routes on which traffic jams occur less frequent. Therefore some routes are more advantageous than others.*"

Analogue to the IGT, the participants are not told that the two routes in the lower row are advantageous, resulting in low profits, and only low occasional contractual penalties. In the long run, choosing them consistently will lead to a positive money balance. The other two routes in the upper row are the disadvantageous, with higher short term profits but occasionally very high contractual penalties. In the long run, choosing these routes will lead to a high negative money balance. All the contingencies for gains and losses are exactly the same as in the IGT (Bechara et al., 2000). The key features of the IGT and how they are implemented in the TDF-IGT are shown in Table 13. A picture of the IGT and the TDF-IGT can be found in Figure 15.

Table 13. The key features of the IGT and the way they were implemented in the TDF-IGT.

Key feature	IGT	TDF-IGT
Scenario	card game	logistics company
Probability coding	no explicit probability information	no explicit probability information
Choice alternatives	4 cards	4 routes
gains/losses	as defined in Bechara et al., 2000	as defined in Bechara et al., 2000
Number of trials	100 card selections	100 tours
Visual feedback	green colored amount of gain or loss, total capital as bar	green or red colored amount of profit or costs, total capital as exact sum
Auditory feedback	gain: jingle of cash machine, loss: dull tone	gain: quickly passing truck, loss: noise of traffic jam

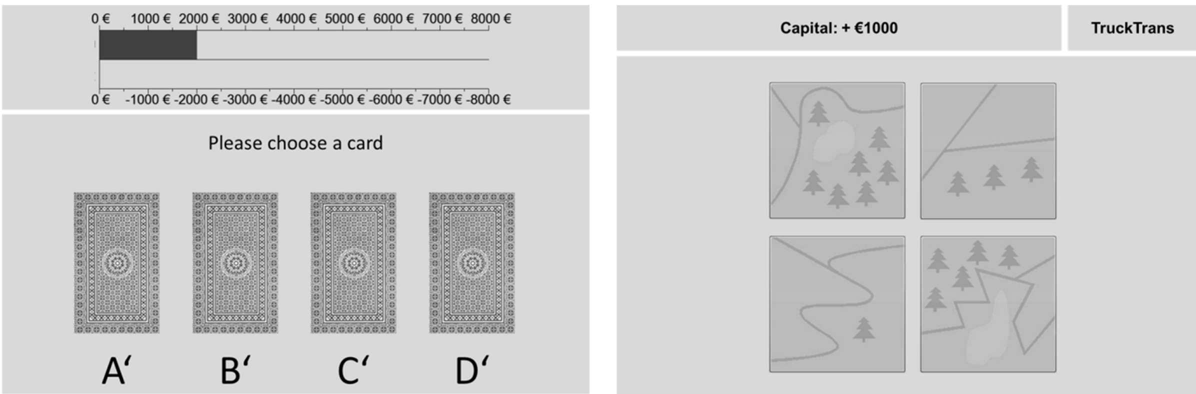

Figure 15. The left part of the picture shows the interface of the IGT, the right part the interface of the TDF-IGT.

Both provide four alternatives, and information about the money capital, but no information about the number of trials. After each decision the subjects are informed about their gain and thereafter about their loss (if there is a loss). Differences between the tasks are the arrangement of alternatives (vertically arranged in the IGT; grid-like arranged in the TDF-IGT), the visualization of the money capital (with a bar in the IGT; as number in the TDF-IGT), and the presentation of gain and loss amounts (displayed above the cards in the IGT; displayed in a pop-up window in the TDF-IGT).

Measures. According to the convention performance in the IGT and the TDF-IGT is measured by block-wise net scores in five blocks of 20 trials each and by an overall net score (number of advantageous – number of disadvantageous choices).

7.5.1.3. Statistical analyses

The methods for the statistical analyses were the same as in Experiment 1 and 2.

7.5.2. Results

Again, the first step was to control for effects of the sequence of task administration. A repeated measures ANOVA with performance in each block (net scores of the five blocks) and task (IGT, TDF-IGT) as within subject factors and sequence (IGT first, TDF-IGT first) as between subject factor was computed. We found no significant interaction between the block-wise net scores and sequence, $F(3.13, 119.10) = 2.02$, $p = .112$, $\eta_p^2 = .05$. The between subject effect of sequence was also not significant, $F(1, 38) = 1.35$, $p = .252$, $\eta_p^2 = .03$. Therefore, the data were analyzed independent of the sequence of task administration.

The groups' learning curves in the two tasks are depicted in Figure 16. Overall, in both tasks there was an ascending preference for the advantageous alternatives, but the learning curves are slightly different. Descriptively, in the IGT performance increases steadily, while in the TDF-IGT performance increases particularly between block 1 and 2.

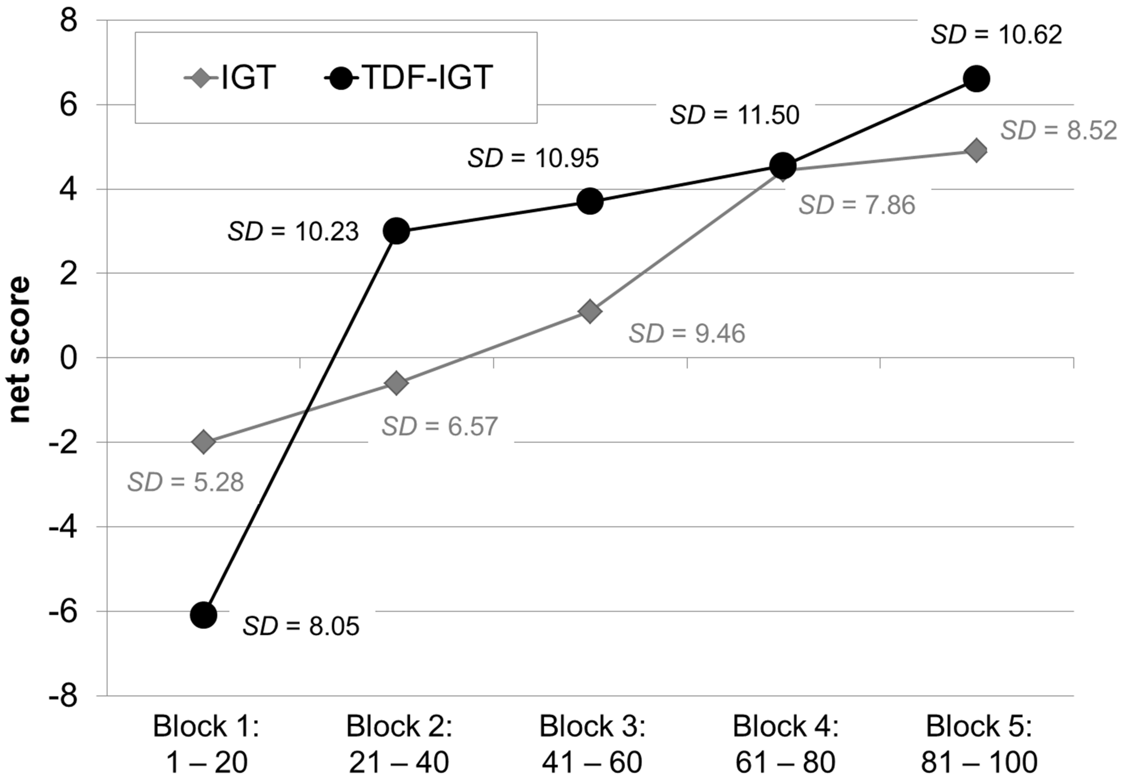

Figure 16. The figure shows the learning curves of the IGT and the TDF-IGT.

In both the net scores increase in later trials, but the courses of the two curves slightly differ.

In order to compare the learning patterns in the two tasks a repeated measures ANOVA was computed with performance in each block and with task as within subject factors. This showed a significant interaction between block and task, $F(3.13, 122.10) = 3.85$, $p = .010$, $\eta_p^2 = .09$. The single pair comparisons between the bock-wise net scores in the IGT and their analogues in the TDF-IGT showed no significant differences, ps > .015 (please note that the Bonferroni corrected significance threshold was $p = .01$).

To test whether the learning effect that is known from the IGT-literature was present in both tasks, we computed repeated measures ANOVAs with the IGT data and the TDF-IGT data separately. In the IGT the effect of block was significant, $F(2.82, 110.13) = 8.06$, $p < .001$, $\eta_p^2 = .17$. The single pair comparisons were significant when comparing the net scores of the first three blocks with net scores of the last two blocks, ps < .039 (only the comparison between block 3 and 5 failed to reach significance, $p = .062$). The comparisons among the net scores of the first three or the last two blocks, respectively, were not significant, ps > .193.

In the TDF-IGT the analysis also showed a significant effect of block, $F(4, 156) = 17.48$, $p < .001$, $\eta_p^2 = .31$. The single pair comparisons between the blocks were significant when comparing block 1 with the other blocks, *ps* < .001, but not between all other block-pairs ps > .560. In conclusion, the ANOVA indicates that there is a learning effect similar to the one that is known from studies using the IGT. The single pair comparisons show that the main improvement of decision-making performance took place within the course of the first two blocks.

The overall net scores in the IGT and the TDF-IGT are shown in Figure 17. The two net scores were descriptively comparable and did not differ significantly $t(39) = -0.63$, $p = .533$, $d = 0.12$.

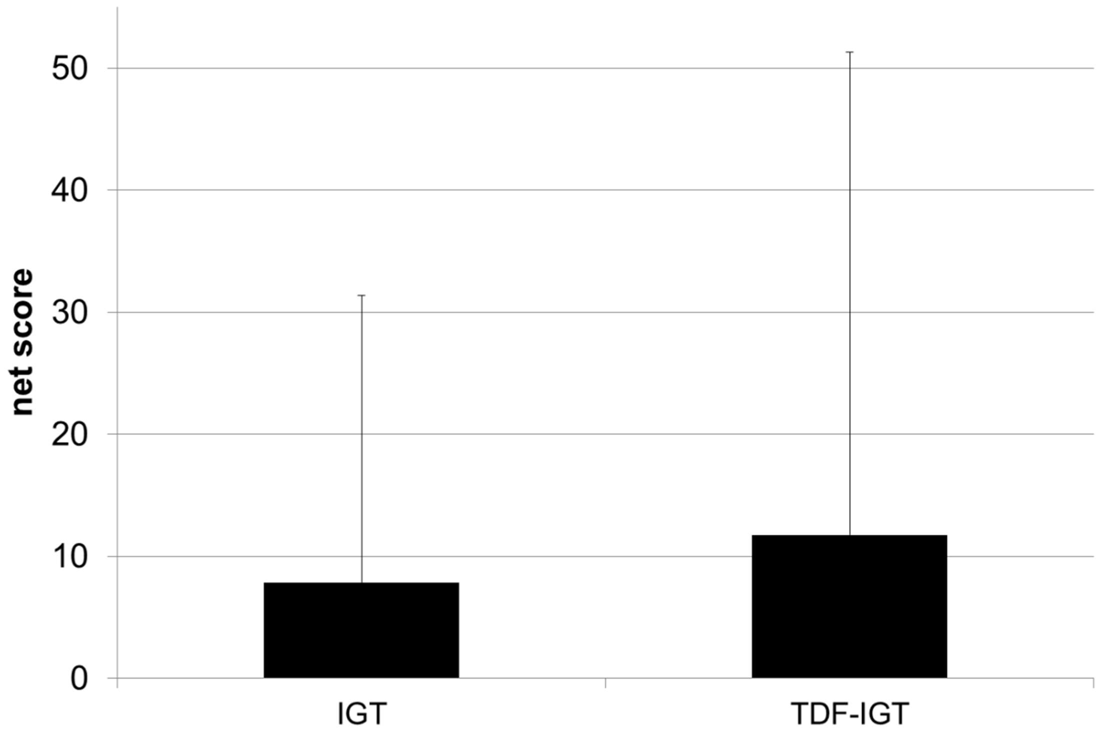

Figure 17. The figure shows the mean net scores of the IGT and the TDF-IGT.

The net score of the TDF-IGT is descriptively higher, but the difference was not significant, and the effect was very small. The error bars represent standard deviations.

The correlations between the variables of the IGT and the TDF-IGT can be found in Table 14. When interpreting the results of the correlations, the sample sizes have to be kept in mind, which are small for correlation analysis. The correlations reflect the slight differences in the block-wise learning curves. Between the analogue blocks the correlations are mostly very low and not significant. However, when regarding the entire table, it can be seen that except three correlations, all coefficients are positive, indicating that generally decision-making performance in the IGT was positively related to the performance in the TDF-IGT.

Table 14. Correlations between the net scores of the original IGT and the TDF-IGT.

		TDF-IGT					
		Block 1	Block 2	Block 3	Block 4	Block 5	net score
IGT	Block 1	**-.14**	-.01	.11	.06	-.37*	-.08
	Block 2	.30	**.19**	.13	.14	.07	.21
	Block 3	.01	.06	**.04**	.03	.01	.03
	Block 4	.27	.33*	.39*	**.29**	.19	.38*
	Block 5	.20	.29	.32*	.23	**.40***	.38*
	net score	.21	.29	.32*	.24	.14	**.31***

* $p \leq .05$ (two-tailed)
** $p \leq .01$ (two-tailed)

7.5.3. Discussion

The results of Experiment 3 suggest that the features of the IGT can also be integrated within the cover story of the TDF. As known from IGT studies (e.g., Fernie & Tunney, 2006; Turnbull et al., 2005; De Vries, Holland, & Witteman, 2008), there was an ascending learning curve reflecting the increasing preference for the advantageous alternatives albeit the absence of explicit information about the rules for gains and losses. This indicates that the main underlying learning process of making advantageous decisions by processing the feedback about previous outcomes seems to be measured by the TDF-IGT.

7.6. General Discussion and Conclusion

The overarching question of the three studies was whether it is possible to base frequently used standard decision-making tasks on the common story line of the TDF, in a way that the TDF versions of the tasks measure the same underlying construct as the original tasks. Although, there were some differences in decision-making behavior when comparing the original task data with the data gathered using TDF versions, it can nevertheless be concluded that the same constructs were measured. The results show that in all tasks the main patterns that characterize the decision-making behavior of brain-healthy subjects in the original tasks could also be observed in the TDF versions. In the two tasks measuring decision-making behavior under risk conditions the subjects showed the typical pattern characterized by more frequent choices of the advantageous decision options and less frequent choices of the disadvantageous decision options (e.g., Brand, Fujiwara, et al., 2005; Schiebener et al., 2011; Sinz et al., 2008; Zamarian et al., 2008). In the additional Experiment 3 it was also observed that the core of decision-making behavior under conditions of ambiguity, as normally measured using the IGT, was also present in the TDF-IGT: Participants learned to avoid the disadvantageous options and instead chose the advantageous options (e.g., Bechara et al., 1996, 1997; Turnbull et al., 2005). Given that these patterns emerged, the observed differences in behavior do not weaken the main conclusion. These differences are probably due to the fact that the TDF story is more complex or due to differences in the user interface (e.g. style of probability presentation, style of feedback presentation).

However, of course, these minor behavioral differences need to be regarded when interpreting decision-making behavior in TDF tasks in future studies and when testing the framework for clinical application. In the tasks measuring decision making under risk, it seems that the behavior of healthy subjects includes slightly more risk taking than in the original tasks (reflected by more disadvantageous decisions in the TDF-GDT and more gambles in the TDF-PAG task). In the task measuring decision making under ambiguity, it is possible that the course of the learning curve in the TDF-IGT slightly differs from the course in the IGT.

In summary, the results indicate that the cover story of the TDF is appropriate for setting up tasks to measure human decision-making behavior. In the future the framework therefore can be applied in experimental research with healthy participants and patient groups. Additionally, the TDF may also be tested with regard to its potential as a practical diagnostic tool. In this context the framework could be useful when aiming at investigating patients with more than one decision-making task. For example, neuropsychologists may aim at characterizing the reasons for a patient’s problems with decision making and whether the problems originate from impairments in specific domains, such as in feedback processing, finding advantageous long term strategies, or handling simple probabilities. Then variants of the TDF can be applied, each of which tapping specifically one of the demands, while the general scenario, in which the different tasks take place can be kept stable.

In experimental research the uncounted possibilities for modifying the TDF can also be useful, enabling researchers to systematically and flexibly vary certain attributes of the decision situation while keeping all other aspects stable. Thus, the framework allows investigating the cognitive and emotional mechanisms of decision making in interaction with controlled situational variations. Furthermore, the TDF can be applied to examine decision-making behavior in patients with pathological gambling without the influence of explicit gambling cues. The prominent strengths of the TDF are as outlined in the aims of this work, the (1) adaptability for different questionings, (2) the flexible cover story, (3) that is reality oriented, (4) is poor in typical gambling-cues, and as has been shown in the three studies, (5) is able to project the main features of standard neuropsychological gambling tasks.

8. Summary of the studies' main results

The three studies in this thesis provided new empirical data on specific theoretical and methodological topics of the neuropsychological literature on decision making. Study 1 investigated the involvement of different executive subcomponents in decision making under risk conditions. The results pointed out that particularly subcomponents that seem to be responsible for strategic management of behavior predict decision making. Basic situation processing components affect decision-making performance indirectly, mediated by the strategy managing functions. The executive component that is responsible for flexibly reacting to changing task requirements was not related to decision-making performance. Moreover, the results indicated that the subcomponents of executive functions are organized hierarchically and act in concert in directing the decision-making process.

Study 2 investigated the role of explicit performance goals for decision making in a situation allowing high strategic control. It was found that explicit goals caused more advantageous decision making when comparing subjects with explicit goals to subject without explicit goals. This effect seemed to be caused by the goal setting rather than the goal-monitoring process. Regarding the literature on goal setting, it appears reasonable that the process of goal setting triggers a more strategic and calculative cognitive approach toward the evaluation of the attributes of the decision-making situation. Therefore goal setting seems to lead to more advantageous decisions from the beginning of the decision task. However, higher goals were related to more risky decisions and particularly very high, unrealistic goals were associated with less advantageous decision making.

In Study 3, the TDF, a new framework for decision-making tasks has been tested. In three Experiments the participants' behavior in original standard task were compared with the behavior in TDF tasks. In these the main features of the original tasks have been projected to the story line of the TDF. The results showed that the behavior in the TDF versions was very similar to the behavior in the original tasks. The main patterns of behavior (e.g., preference for the saver alternatives in the GDT or a learning effect in the IGT) could also be observed in the TDF versions. Thus, it can be concluded that the TDF versions measure the same underlying constructs as the original tasks.

9. General Conclusion

The results of the three conducted studies have novel implications for theory as well as for research practice and clinical application. These implications do not only focus on the topic of decision making under risk conditions but also the question for the organization of executive subcomponents. In the following, the broader conclusions for our understanding of decision making and executive functions are discussed. Furthermore, outlooks to future research are provided, and possible limitations of the conclusions are explained. (Please note that detailed discussions of the specific results can be found in the discussion sections of the three studies.)

9.1. Decision making under risk

The first two studies described in this thesis were conducted with the aim to gather empirical data about the mechanisms involved in decision making under risk. The main question was which subcomponents of the central executive system direct the decision-making process. Additionally, the effects of explicit goals in a decision situation, which allowed increased strategic control, were investigated. Based on the new results of this thesis and on empirical data that has been reported in the literature (see 3.1.3 and Table 3), a revised version of the model by Brand and colleagues (2006) can be suggested. The new version that will be described in the following contains four central changes: (1) the involvement of situational conditions, (2) an enhanced description of the mainly operating and interacting executive subcomponents, (3) the definition of three possible routes to the decision, and (4) a readjustment of the focus, concentrating on the *active* cognitive and emotional processes. In the following the four changes will be explained in detail. Thereafter, the model as a whole will be explained, in order to describe the steps that can be supposed to direct decision making under risk (for a graphical representation of the model please refer to Figure 18 on page 150).

(1) The first specification of the model concerns the involvement of situational conditions. In the original model (Brand et al., 2006), influence of the attributes of the decision situation on cognitive processes in decision making were assumed. These were mainly concentrated on the characteristics of the decision task itself, but not on other situational conditions. Recent studies demonstrated that additional information about the decision situation can affects decision-making performance in interaction with the cognitive abilities of the individual. As has been outlined before (see e.g., 3.1.3) supporting as well as

misleading information can interact with executive- and working memory functions in predicting decision-making performance (Schiebener et al., 2012; Schiebener, Wegmann, et al., under review). The results of Study 2 in this thesis additionally pointed out that explicit goals can affect decision-making performance and risk taking. It is suggested that when goals are realistic they trigger increased effort and efficiency in the cognitive processes that guide decision making. This idea is in line with the theory on goal setting (Locke & Latham, 2002), which assumes explicit goals to trigger enhanced execution of mechanisms that are directed by the central executive system and involved in the decision-making process. Given that the role of situational influences has been reported in the literature and in Study 2, situational conditions and influences are added to the model. It is now suggested that situational influences can affect the executive processes in decision making. The inclusion of situational conditions to the new model is also in line with the PTF (Finucane & Lees, 2005), which assumes that characteristics of the task (such as the amount of strategic control it allows), characteristics of the decision maker (such as the individual level of executive abilities), and external influences (such as the presence of explicit goals) interact in determining the decision-making competence.

(2) The main aim of this thesis was to provide an enhanced description of the role of executive subcomponents in decision making under risk. In the original model it has been stated relatively generally that executive functions should be involved in strategy development. While the original model only suggested that executive functions are involved in the development and application of a decision-making strategy, it has now been identified which functions are involved and how they probably interact. Study 1 could show for the first time that not all subcomponents influence decision making to the same amount. The results suggest that the cognitive processes that precede and accompany decision making are directed by hierarchically organized executive components. Thus, the role of executive functions is more specifically described in the new version of the model. Furthermore, the definitions of the possible interactions between executive processes, decision strategy, and decision-making behavior are specified in more detail.

It is now suggested that the role of executive functions is ascribable to three components: working memory, situation processing functions, and strategy management functions. Working memory stands for the active maintenance of information that can originate from external resources (e.g., the information about the decision situation, involving options, gains and losses or additional information) as well as internal resources (e.g., knowledge about probabilities retrieved from long-term memory). This information is processed in working memory and manipulated under the direction of the two executive components: situation processing and strategy management. These are suggested to operate on a hierarchically superior level compared to working memory. Situation processing directs attention on relevant information, inhibits processing of irrelevant information and codes information into the working memory buffers. Strategy management is allocated on the highest level of the suggested hierarchy. This component is thought to direct the usage of information about the decision situation as well as about feedback events. It is also responsible for planning and monitoring a current decision-making strategy. Furthermore, strategy management functions probably direct the activities of the situation processing functions by managing towards which information the attention needs to be directed or which information can be inhibited. The result of this interaction of the subcomponents can be an action plan for decision-making behavior: A decision strategy, for which the behavioral steps are represented in working memory. The decision-making strategy can give direction to the situation processing component because the character of the strategy can require specific processes guided by situation processing. These may involve focusing attention on specific parts of the decision task, inhibiting irrelevant information, and inhibiting inappropriate behaviors. For example, attention is focused on alternatives that have been chosen for the first decisions. Inhibition may be required to ignore the high possible rewards of very risky alternatives not involved in the planned strategy. Moreover, inhibition should also be important to inhibit impulsive deviations from the strategy (regarding the role of impulsivity as a personality facet refer also to Bayard, Raffard, et al., 2011).

The results of Study 1 yielded the support for these differential roles of situation processing and strategy management. The data supported the idea that the two functions are distinguishable executive subcomponents. Nevertheless, the data also supported the assumption that the two functions interacted in directing decision making. They were closely related, and situation processing did not directly affect decision-making performance, but mediated by strategy management. These adaptions in the revised model are also in accordance with the results of previous studies pointing out the crucial role of executive functions in decision making under risk. This has especially been found when the decision situation allowed for development, monitoring, and revision of calculative long-term strategies (e.g., Brand, Heinze, et al., 2008; Brand, Fujiwara, et al., 2005). Thus, it is reasonable to assume that the strategy management function fulfills a directive role in decision making.

(3) The third specification in the new model is the definition of three possible routes to the decision, instead of two possible routes as described in the original model. The original model suggested a cognitive route and an emotional route. Both are still represented in the new version of the model. In this, the cognitive route starts in working memory, with the representation of information from internal and external resources. It continues with situation processing and strategy management to the decision strategy. The decision strategy and the actual state of its execution in behavior are represented in working memory, which thereby provides the link between the cognitive representation of the strategy and its realization in behavior (as suggested in theoretical models of working memory, e.g., Baddeley & Hitch, 1974; Baddeley, 2003). In the visualization (Figure 18) this route is represented by the arrows between the executive components, leading to the decision strategy, and then entering working memory and going on towards the decision. The emotional route integrates the emotional signals from the body periphery. The emotional signals can be used to base the next decision on intuitive hunches and guesses, without cognitive processes involved. Additionally, emotional feedback processing can also support the cognitive processes because the emotions can receive a representation in working memory. In other words, a person should be able to realize his/her emotions (e.g., negative emotion after a loss) and can therefore consciously revise the actual decision-making strategy. The cognitive and the emotional route have been adopted from the original model given that studies have found support for the role of both (see e.g., 3.1.2, 3.1.3, Study 1, and Brand, Grabenhorst, et al., 2007; Labudda et al., 2007; Starcke et al., 2011).

In addition to these two routes, a third route is suggested. This leads directly from working memory to decision making, without the involvement of higher level executive processes and the development of a decision-making strategy. By adding this route it is taken into account that a person does not necessarily have to plan and apply a decision-making strategy. It is also possible to make decisions without an explicit strategy (as developed on the cognitive route) and without being guided by emotional signals of the body periphery that have been learned from the feedback of previous trials (as suggested on the emotional feedback route). On a theoretical level, it is reasonable to assume the third route because it should be possible to make decisions without consciously developing a strategy before. This assumption is also in line with the finding that some individuals make decisions under risk without performing calculative operations that would lead to an explicit strategy (Brand, Heinze, et al., 2008). Additionally, it is not necessary for making decisions that the executive control functions that are required to develop a strategy are intact. It is also possible to make decisions with very reduced or impaired executive control functions as has been demonstrated in studies with patient groups (e.g., Brand, Fujiwara, et al., 2005; Brand, Labudda, et al., 2004; Delazer et al., 2007; Euteneuer et al., 2009; Sinz et al., 2008).

(4) Additionally, the focus of the model is readjusted. The new model more clearly concentrates on to internal processes that can be called active. These are active processes of working memory and executive control and of emotional reactions. In the original model the passive component “long-term memory” had been involved because it had been assumed that information from long-term memory can be retrieved to support strategy development. For example, such information might be knowledge about probabilities, numbers, or experiences with other decision situations. Although, studies have so far not investigated the role of long-term memory for decision making under risk it is reasonable that such knowledge from long-term is involved in decision making. However, long-term memory was removed from the model because it is regarded as a passive memory system (e.g., Atkinson & Shiffrin, 1968; Baddeley, 2003) and therefore cannot be regarded as an active component in the decision-making process. Therefore, the role of long-term memory is only implicitly addressed in the new version of the model by assuming that working memory not only holds representations of information from external resources (e.g., information about decision options) but also retrieves and maintains information from internal resources (e.g., from long-term memory).

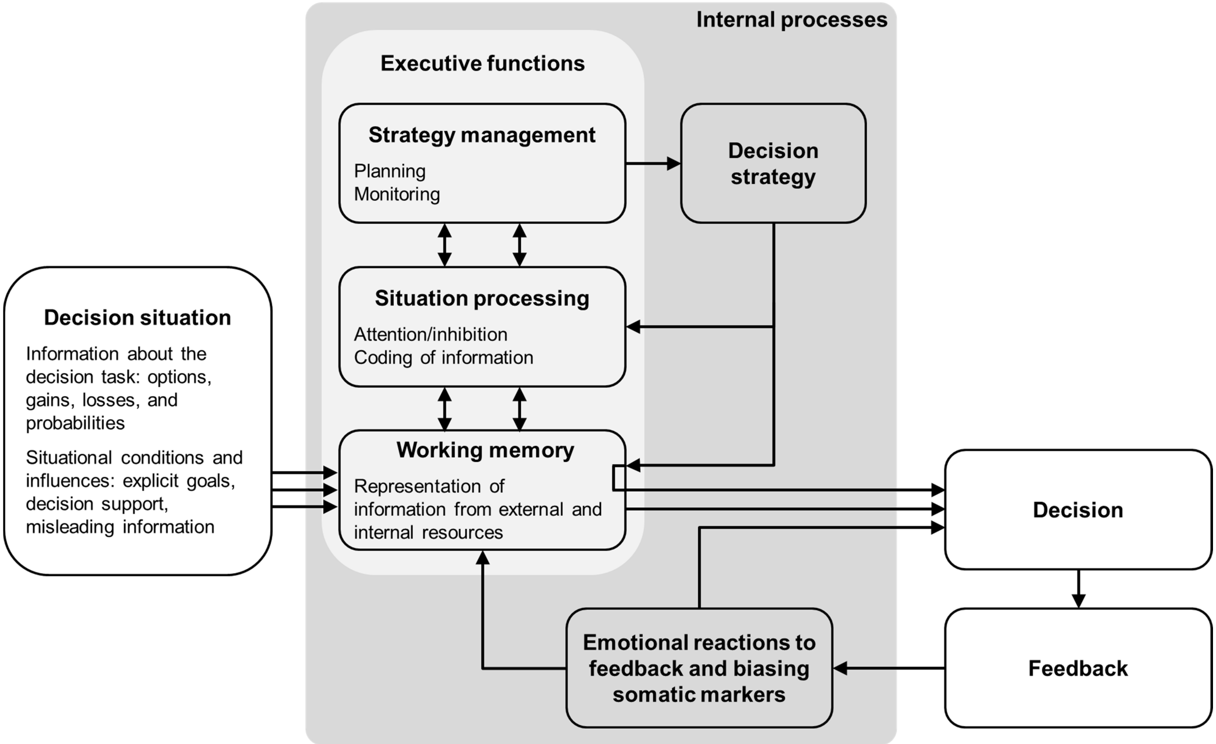

Figure 18. The proposed revised version of Brand's model of decision making under risk (Brand et al., 2006).

The main difference in comparison to the original model is the description of interactions between different executive functions, which are supposed to direct the decision-making process. Additionally, situational conditions and influences such as additional information or explicit goals are suggested to affect the neurocognitive processes in decision making.

After these changes, the process of decision making is in the new version of the model compiled as visualized in Figure 18. In the first step, information about the decision situation is perceived and obtains a representation in working memory. This can include features of the decision task, as well as situational conditions and additional influences. This external information can be combined with information from internal resources, including general reasoning strategies, knowledge about probabilities, and numbers or mathematical operations. From this point on, there are two possible routes to the decision. The simplest route is the route that leads directly to a decision without developing a strategy (the decision maker simply decides without extensive cognitive operations or calculative strategies). On the other possible route cognitive operations, guided by subcomponents of executive functions, lead towards a decision strategy. In the situation processing component attention control is engaged to direct the attention on the relevant information of the decision situation, which is coded and maintained in working memory (e.g., available decision options, or probability information), while access of irrelevant information is inhibited (e.g., environmental information that do not contribute to the understanding of the decision task). Based on these preparations by the basic situation processing functions, higher level strategy management can operate. This is responsible for planning a first decision-making strategy. For example, a decision maker may plan to start with medium risk in the first decision and also plan to see whether this will lead to success. The planed decision strategy can retroactively influence the situation processing operations (e.g., attention is directed to moderately risky alternatives). A representation of the strategy is maintained in working memory together with the relevant information for applying the strategy (e.g., a representation of the alternative that is supposed to be chosen first). Thereby, the working memory representation of the current state of the strategy leads to the first decision. At this point inhibition may be required for preventing interference by irrelevant information as well as for inhibiting inaccurate behavior, such as an unplanned decision for a possibly short termly rewarding, but highly risky options (e.g., in order to reach an unrealistically high goal quickly). It has to be kept in mind that all these processes involved in strategy development and application can also be influenced by particular situational conditions. For example, the calculation of probabilities or the evaluation of risks may be affected by supporting or misleading information from external resources. Furthermore, higher cognitive effort, involving increased executive control in strategy development, may be triggered by explicit goals. In case of intact behavioral control the first decision is made according to the developed strategy. If there is feedback about the decision's outcome, this can then be processed cognitively and/or emotionally. On the cognitive route the feedback information receives a representation in working memory. Again, it is possible to directly make a new decision without involving higher cognitive control for strategy management. Moreover, the two executive subcomponents can be incorporated to control cognitive processing of the feedback. In this case, strategy management operations, particularly monitoring functions, direct the operation of the situation processing component. This focusses attention on the strategy-relevant information (e.g., the height of the gain or loss and the resulting new money balance). Based on this information, strategy management functions realize monitoring of the success of the currently applied decision-making strategy. When evaluating the success of the strategy, situational information may be taken into account (e.g., for verifying the accuracy of supporting information). Monitoring of the feedback may result in different processes: continuing with the current strategy, developing a plan for further validation of the current strategy, or in planning the application of a revised/new strategy.

Finally, the emotional processing of feedback can also affect decision-making behavior. On the emotional route, reward or punishment is experienced. This experience initiates the creation of somatic markers that can enact anticipations of emotional consequences of future decisions (see also chapter 3.1.2 and further literature, e.g., Bechara, 2011a; A. R. Damasio, 1994). Based on this emotional function the next decision may be made, also without involving cognitive operations. However, the cognitive and the emotional route are supposed to interact, whilst emotional experiences can support reasoning strategies as well as planning and monitoring of decision-making strategies (as also signified in the model of decision making under ambiguity; Bechara et al., 1997).

The results of this thesis do not only have theoretical implications for the model of decision making under risk conditions but can also be interpreted in relation to the PTF (Finucane & Lees, 2005) as well as in relation to dual process theories (J. S. B. T. Evans, 2003; Kahneman, 2003). Referring to the structure of the PTF, the role of specific person characteristics for decision-making competence was investigated in Study 1, the role of a potentially relevant context characteristic was investigated in Study 2, and variations in task characteristics were realized in Study 3. Particularly, the first two studies found support for the role of individual differences and context characteristics for decision making. However, these results and the findings reported in the literature (see chapter 3.1) indicate that there is still room for data based specifications in the PTF. Although the framework has intentionally been formulated relatively generally, it seems that it would be structured more systematically when also regarding specifications as they have been made in the model of decision making under risk. First, as already mentioned in the theoretical background (see chapter 3.1.1), the PTF does not explicitly incorporate a theoretical model of cognitive processing and behavioral control in the person characteristics section. The results of Study 1 and other findings (see chapter 3.1.3) suggest that individual differences in neurocognitive functions could be involved as important examples of person characteristics. Particularly working memory and subcomponents of executive processing seem to be systematically involved in decision making. Given that this seems to apply especially in decisions under risk conditions but to a lesser degree in decisions under ambiguity (see 3.1 and Starcke et al., 2011; Turnbull et al., 2005) the PTF may also profit from referring to the role of different types of decision situations in its task characteristics section. Second, the PTF may also refer to the role of explicit goals on decision making in the context characteristics section. The results of Study 1 and other studies (Hassin et al., 2009; D. Knight et al., 2001; Schiebener et al., 2012) supported the idea that goals can affect decision-making performance. It appears reasonable that goals are substantially involved in decision making in the laboratory as well as in everyday life. Therefore goals should be regarded in a general framework for predicting decision-making competence.

Future studies may further investigate the assumptions in the PTF that individual differences in person characteristics and variations in situational conditions determine decision-making performance in interaction. Thanks to several neuropsychological studies (see chapter 3.1 and Study 1) fundamental abilities for making advantageous decisions under ambiguity and risk have been described. In contrast, general psychological studies have often observed effects of situational influences on decision making. However, little is known about the potentially moderating effect basic neuropsychological functions on the influences situational variations can have on decision making (e.g., effects of anchors, framing, task complexity, or decision support; see e.g., Appelt et al., 2011; Englich et al., 2006; Schiebener et al., 2012; Tversky & Kahneman, 1981).

The results of this thesis and the specifications in the model of decisions under risk conditions may also help to answer the question on the role of intuitive System 1 and cognitive System 2 processes in decision making (J. S. B. T. Evans, 2003; Kahneman, 2003). In particular mainly the role of System 2 associated functions for decision making under risk was investigated in this thesis. The results of Study 1 clear assign a role of System 2 processing to advantageous decision making under risk conditions. The study showed that higher level executive control functions are fundamentally involved in this type of decisions. This can be interpreted as an indicator for controlled and arduous cognitive processing in decision making. Consequently, the results are in line with previous findings suggesting decision making under risk to tap to a considerable extend into System 2 processing (Brand, Heinze, et al., 2008; Brand, Laier, et al., 2009; Starcke et al., 2011).

Principally, the results of Study 2 are also in line with this idea. It may be possible that goals positively affected decision-making performance in general, because they triggered increased inclusion of cognitively demanding System 2 processes into the development of a decision-making strategy. In future studies, it would be interesting to investigate the effect of goals on the choice of intuitive vs. cognitively controlled decision-making strategies. It may be thinkable that persons who normally tend to rely on intuitive decision-making strategies switch to calculative strategy development, if they have an explicit performance goal. In other words, it would be interesting to work out whether explicit goals affect the choice of one of the routes as they are suggested in the revised model of decision making under risk conditions.

Beside the theoretical implications, these new insights into the decision-making process have implications for clinical application and for research on decision making. The finding of Study 1, that lower level executive functions affect decision-making mediated by higher, strategy managing functions, indicates that advantageous decision making can rely on the integrity of more than one executive subcomponent. Therefore, impairments in decision making as they have been reported for patient populations can probably result from defects in basal attention/inhibition and coding functions as well as from defects in higher planning and monitoring functions. Likewise, one mechanism that might explain disadvantageous behavior may be dysfunctional goal-handling. This implies handling the conflict between the desire to attain ambitious goals and the necessity to decide conservatively in order to be sure not to lose too much stake. The involvement of conflict management in decision making under risk has also been suggested by Labudda and colleagues (2008). They reported activations in the anterior cingulate cortex during decisions involving conflicts between possible high gains with low winning probabilities and possible low gains with high winning probabilities (Labudda et al., 2008).

The new findings of this thesis should be attended in the development of therapy programs and cognitive training programs for patients with problems in decision making. General cognitive training programs such as NEUROvitalis (Baller, Kalbe, Kaesberg, & Kessler, 2010) already imply executive functioning trainings. If suchlike trainings would also aim toward specific practices on decision-making competence, these may clearly address lower and higher level executive functions and their interaction. Additionally, practices for handling situational conditions may be taken into account. For example, these practices may educate against misjudgments of probabilities (as for e.g. reported in Schiebener et al., 2012) or disadvantageous handling of goals (Study 2).

The results of Study 3 have primarily practical implications for decision-making research. The newly developed framework for decision-making tasks, the TDF, may fill a methodological gap in the measurement of decision-making competence. The new framework establishes the opportunity to measure decision making in a more application oriented scenario, allowing to manipulate task characteristics pointedly (e.g. the amount of ambiguity or the task's complexity) while keeping other conditions stable. Thus, the TDF should help to approach further theoretical advances, for example additional specifications of the model of decision making under risk. Moreover, it appears recommendable to validate the TDF as a diagnostic tool, in order to detect problems with decision making in individuals with neurological or psychiatric diseases. A rather secondary implication of Study 3 is of theoretical nature. The model of decision making under risk implicitly assumes that decision-making behavior remains stable in different scenarios, as long as the core information about the decision situation stay the same (involving the number of alternatives, probabilities and heights of gains and losses, as well as additional information, such as supporting or misleading information). The results of Study 3 support this assumption. The main patterns of decision-making behavior were very similar in the original tasks and their TDF versions, which shared the main situational information.

The current findings may inspire future research on decision making. Primarily, more empirical testing of the model of decision making is needed, in order to attain specifications in further domains. In particular studies, which investigate the role of individual differences in cognitive functions for the choice of decision-making strategies are rare. Several strategies are known to be applied in decisions under risk, such as probability matching, maximization, gamblers fallacy, or win-stay-loose shift (see e.g., Gal & Baron, 1996; Nowak & Sigmund, 1993; P. Rogers, 1998; West & Stanovich, 2003). However, whether and how neurocognitive mechanisms predict strategy usage is relatively unclear. Future studies may investigate executive functions and situational conditions, as well as their interactions, as possible predictors of strategy choice and strategy adaption.

Furthermore, studies on the exact role of working-memory are rare. Although relationships between working memory and performance in decisions under risk have already been reported (Schiebener, Wegmann, et al., in press; Starcke et al., 2011), the interaction between working memory capacity, buffering functions and the information-manipulating central executive functions need further attention in order to extent the description of the neurocognitive processes of decision making.

Further research is also required concerning the effects of goal mechanisms on decision-making performance. Although, the findings in Study 2 provided reasonable conclusions that lead to theoretical progress, data on this topic remains scarce. It may be investigated in the future, whether the effect of goal setting is moderated by executive functions and whether goals affect the choice of specific decision-making strategies. This would theoretically be in line with the finding in Study 2, which has shown that it should be the cognitive process of goal setting, which triggers the internal mechanisms that are responsible for the improvement of decision-making performance.

Besides the research that is required to reach further specifications of the model, research is required to test whether there are other domains that are systematically involved in decision making under risk. Particularly, as described in the literature overview (3.1.3) some specific cognitive processes have been found to be associated with decision making performance (e.g., logical thinking, handling of simple probabilities, or the tendency toward calculative processing; Brand, Heinze, et al., 2008; Brand, Laier, et al., 2009; Schiebener et al., 2011). Furthermore, associations with scattered personality facets have been reported (e.g., subcomponents of impulsivity or perfectionisms; Bayard, Raffard, et al., 2011; Brand & Altstötter-Gleich, 2008). However, it may be possible that such domains rather moderate the relationship between executive functions and decision making instead of being main predictors of decision making (as reported by Brand, Laier, et al., 2009; Schiebener et al., 2011).

Upcoming research should also profit from the development and evaluation of the TDF. This can be applied in several contexts, involving general judgment and decision-making research with healthy individuals, as well as research with patient populations. Particularly, two topics may be investigated systematically with the TDF in future studies. The first topic is the level of ambiguity. As outlined previously (3.4), there are several studies which have reported differential amounts of cognitive and emotional processing involved in decisions under risk versus decisions under ambiguity (Brand, Grabenhorst, et al., 2007; Brand, Recknor, et al., 2007; Drucaroff et al., 2011; Y.-T. Kim et al., 2011). Other studies found impairments in patient populations in one type of decision situation, but not in the other (Bayard, Abril, et al., 2011; Bayard et al., 2010; Rossi et al., 2010). The competencies in decisions under risk and under ambiguity were often investigated with tasks that differed in more attributes than only the amount of ambiguity, which undermines the theoretical conclusions (see 3.4 and Introduction of Study 3). With the TDF the level of ambiguity could be varied by systematically providing and withholding explicit information about possible gains, losses, and their probabilities, while holding the general scenario, the number of options, and the number of decision trials stable. The second topic is the level of situational complexity. The TDF might be used to manipulate the number of decision options in decisions under risk and under ambiguity. By this means the cognitive and emotional processes, as well as strategy choice in situations of varying complexity could be investigated. While studies have already shown that participants more often applied heuristic, non-compensatory strategies when the situation's complexity was increased (Payne, 1976), the neurocognitive mechanisms involved in the ability to make advantageous decisions in very complex situations are still relatively unclear. In future research, it may be examined which neuropsychological processes realize the cognitive strategies that reduce the complexity, or whether the reliance on intuitive hunches and guesses may increases with more decision options.

Another important topic of future research may be real world decision making. So far, this has widely been neglected in judgment and decision-making research. While several studies, such as those reported in this thesis, have investigated the ability to make advantageous decisions in laboratory tasks and have been searching for predictors of task performance, the reports on associations with decision-making performance in real life have rather anecdotic character (e.g., in Bechara et al., 1994; Eslinger & Damasio, 1985). Despite the methodological problems that would probably undermine research on this topic, measures of real world decision-making performance should be developed and evaluated, in order to test the relationships between neurocognitive performance measures, decision making in the laboratory and decision making in real life.

9.2. Executive functions

Although, investigating the structure of executive functions was not the main aim of this thesis, the results of Study 1 have implications for the literature on the composition of the central executive system. As explained in detail in the theory section (3.2.2), the previous literature suggests that a hierarchical organization of the subcomponents may be reasonable (Miyake & Friedman, 2012; Smith & Jonides, 1999). The results of Study 1 support this assumption. Three latent dimensions were found in the data: Lower level situation processing functions, higher level task management functions (or "flexibility"), and strategy management functions. This finding is not only in line with the already discussed arrangements of subcomponents (suggested by Smith and Jonides (1999) or Miyake and colleagues (2000)) but is also in line with other theoretically supposed arrangements of subcomponents. For example Borkowsky and Burke (1996) suggested task analysis, strategy control, and strategy monitoring as executive components. Elliott (2003) suggested solving novel problems, modifying behavior in accordance with new information, generating strategies, and sequencing complex actions as executive subcomponents. These arrangements are comparable to those found in Study 1, given that they also suggest situational processing, handling of strategies, and flexibility as main contributors to cognitive and behavioral control. It should be noticed that the results of this thesis do not constitute another suggestion for a new definition of subcomponents. The subcomponent model suggested here should rather be regarded as an integrative approach, in which established theories of executive components are brought into line. The resulting model was tested with approved methods and in a situation, in which the functions were active and worked together: namely in directing decision-making behavior. In this situation, the components were found to act in concert, as had been expected on the theoretical level. Thus, there is theoretical and empirical support for this arrangement of subcomponents.

In future studies, the hierarchical interaction of the three components should be tested in samples of healthy participants and patients. Particularly, the interaction of the three components may be examined in patients, who are selectively impaired in one of the subcomponents. This may help to understand how the three functions differentially determine goal-directed behavior and thereby also determine the symptoms of the dysexecutive syndrome and the strategy application disorder (e.g., Burgess, 2000).

9.3. Limitations

Beyond the limitations that have been mentioned in the discussion sections of the three studies, there are two further aspects that may limit the conclusions that can be drawn from the results of the current thesis. First, all results are based on data from brain-healthy participants, who reported to have no psychiatric disorders. Therefore, the conclusions for patient populations are restricted. The role of different executive subcomponents and explicit goals would need to be tested in patient groups in order to test the validity of the conclusions for these groups. Given that only healthy participants attended the TDF study, the TDF should be carefully tested with patients in order to evaluate its value as a diagnostic tool. Second, the findings that have inspired the specification of the model are only based on one measure of decision making under risk, the GDT. Although, the task is a frequently used measure of strategic decision making under risk, it would be desirable to replicate the results in other decision-making paradigms.

10. The end

Finally, this thesis provides the prerequisite to give an answer to the introductory question that was raised at the beginning of this thesis. Which abilities does the consultant need to make an advantageous decision between the two routes for driving to the meeting at a commercial enterprise? One route would result in saving a lot of time in combination with a high financial gain, but the risk for traffic jam is high on this route. The other route is a detour. This will result in saving less time and achieving a lower financial gain, while the risk for traffic jam is lower. The results of the studies indicate that the consultant would need to focus attention on the relevant information, including the driving times, the probabilities for traffic jams, and their magnitudes as well as personal goals for the outcomes of this additional occupation. This information needs to be coded into a working memory representation allowing an estimation of the probabilities for their occurrence. If the consultant has an explicit goal, he/she may even increase the cognitive effort and exactly calculate the probabilities and account them with the possible resulting salaries. May be the consultant is experienced with this or comparable decision problems (he/she might not be in this trouble for the first time). In this case, the memories about the experiences could be chosen for recall in order to be maintained in working memory. The previously used decision strategy can then be evaluated and monitored with regard to its reasonability and the actual consequences that have followed the last times (e.g., traffic jams, monetary losses). This memory and the probability estimation may be judged with regard to the explicit goal for the attained financial outcome. Integrating this information should result in planning a revised strategy for the upcoming decision. If all these processes are completed successfully and if the goal is realistic and not too high, the consultant may plan to make the safer and most probably more advantageous decision: to take the detour which promises a positive monetary outcome together with a high probability to lose not too much time.

11. References

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12. List of tables

13. List of figures

14. Erklärung über die eigenständige Verfassung der vorgelegten Dissertation

Hiermit versichere ich, dass die vorgelegte Dissertation gemäß §9 der Promotionsordnung der Fakultät für Ingenieurwissenschaften der Universität Duisburg-Essen vom 9. Juni 2009 eine selbstständig durchgeführte und eigenständig verfasste Forschungsleistung darstellt und ich keine anderen als die angegebenen Hilfsmittel und Quellen benutzt habe. Die Arbeit hat weder in gleicher noch in ähnlicher Form einem anderen Prüfungsausschuss vorgelegen.

Datum ______________________ Johannes Schiebener, M.Sc. _______________________