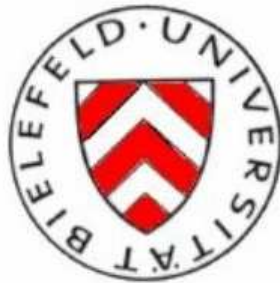# Memory Accuracy

A 7-Tesla fMRI Approach to Memory Accuracy

– Retrieval, Monitoring and Control Processes –

Dissertation to Achieve a Doctoral Grade

of Natural Sciences (Dr. rer. nat.) in Psychology

Department of Psychology and Sports Science

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by

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If the human mind was simple enough to understand, we'd be too simple

to understand it

(Emerson M. Pugh)

to Heiner Jaspers

Acknowledgments

Bielefeld, 2010

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Abbreviations

AAL   Automated Anatomical Labeling

ACC   anterior cingulate cortex

ACC-   low memory accuracy

ACC+   high memory accuracy

BA   Brodmann area

BOLD   blood oxygenation level-dependent

CS   contention scheduler

DLPFC   dorsolateral prefrontal cortex

DRM   Deese-Roediger-McDermott

e.g.   for example

EEG   electroencephalography

EM   episodic memory

EPI   echo planar imaging

ERP   event-related potential

et al.   et alii

etc.   et cetera

FDR   false discovery rate

Fig.   Figure

fMRI   functional magnetic resonance imaging

FOV   Field of view

FWE   familywise error

FWHM   Full Width Half Maximum

HERA   hemispheric encoding / retrieval asymmetry

HRF   hemodynamic response function

IFG   inferior frontal gyrus

ISI   inter-stimulus-interval

L   left hemisphere

LPFC	lateral prefrontal cortex
LTM	long-term memory
LTS	long term store
max	maximum
MDM	magnetic dipole moment
MHz	megahertz
min	minimum
mm	millimeter
MNI	Montreal Neurological Institute
MP-RAGE	magnetization prepared, rapid acquisition gradient echo
MR	magnetic resonance
MRI	magnetic resonance imaging
ms	milliseconds
MTG	middle temporal gyrus
MTL	medial temporal lobe
p	probability
Pa	assessed probability
PET	positron emission tomography
PFC	prefrontal cortex
Prc	response criterion probability
PRS	perceptual representing system
QTY	quantity
R	right hemisphere
REMO	retrieval mode
RF	radiofrequency
SAS	supervisory attentional system
SD	standard deviation
sec.	seconds
SFG	superior frontal gyrus
SM	semantic memory

SMG	supramarginal gyrus
SPI	serial-parallel-independent
SPM	Statistical Parametric Mapping
SPSS	Statistical Package for the Social Sciences
STM	short-term memory
STS	short term store
TE	echo time
TI	inversion time
TR	repetition time
VLPFC	ventrolateral prefrontal cortex
WM	working memory

1 Preface

When considering the contribution of subject-controlled processes to memory performance, it is important to distinguish between two different properties of memory: quantity and accuracy. Koriat and Goldsmith have shown that these two properties have received rather different emphasis in current research practices. With the quantity-oriented and accuracy-oriented approaches to memory, two fundamentally different ways of thinking about memory have been introduced. This is reflected by a distinction between two different memory metaphors. The storehouse metaphor assesses memory as a storehouse depositing items for a later retrieval and is therefore defined in terms of the number of items that can be recovered (Markowitsch, 1994, 2008). The correspondence metaphor defines memory in terms of its capability to represent past events, rather than just in terms of the quantity of items that are remembered and therefore are remaining in store (Koriat & Goldsmith, 1996b).

According to Koriat and Goldsmith, experimental memory research is quantity-oriented, while in everyday-life the importance of the accuracy-oriented conception preponderates. A simple example that illustrates the difference of both approaches is related to eyewitness reports: according to the quantity-oriented approach it would be important how much information about an offender can be retrieved while the accuracy-oriented approach concerns the question whether essential information can be remembered like facial features of an offender (Koriat & Goldsmith, 1996b).

The paradigm of Koriat and Goldsmith concerns three different phases of recall in which different monitoring processes proceed. In the retrieval phase subjects are presented with memory questions and are forced to answer each of them, even if they have to guess. In the monitoring phase the monitoring process is activated, hence subjects are requested to rate their confidence of whether the retrieved item is correct or not. In the control phase subjects are free to decide whether to bet on the

correctness of their answer or not (volunteering or withholding). This memory paradigm allows a separated evaluation of quantity and accuracy.

In the current study, the memory paradigm was modified and implemented into a 7 Tesla functional magnetic resonance imaging (fMRI) design to examine the neuropsychological correlates of retrieval, monitoring and control processes as well as memory accuracy.

The first section of the theoretical background gives an overview of the different classifications of human memory and the associated brain structures are illustrated focusing mainly on episodic memory. False memories are introduced in a second section with special emphasis on the different forms and the neural correlates. The third part of the theoretical background concerns the different approaches to executive functions and the accordant brain correlates. Finally, memory accuracy and memory quantity and the different approaches will be presented with a short overview of metamemory. The memory paradigm of Koriat and Goldsmith is introduced and the neural correlates of memory accuracy are highlighted.

The empirical part starts with questions and hypotheses related to the brain correlates of the different memory processes according to the memory paradigm. Subsequently, the participants, the applied neuropsychological tests and methods are presented. This is followed by a detailed description of the pre-scanning procedure, the experimental design, and the Post-Scanning Questionnaire. In the following, an introduction and explanation of the functional magnetic resonance imaging technique is given. The empirical part closes with the description of the results along the three major areas: neuropsychological data, behavioral data, imaging data and the verification of the hypotheses.

In the last part, the different contrasts that were developed for the fMRI group analyses are discussed for the whole sample size, respectively. The different contrasts comprise the retrieval phase, the monitoring phase, and the control phase

in light of comparisons within and between these processes. Finally, the neural correlates of memory accuracy and inaccuracy are presented. The chapter ends with a general discussion.

Examples of the clarification and information forms, the pre- and post-scanning procedure, and the experimental design with stimulus sentences used in the neuroimaging experiment, an overview of the subject's head motion as well as an overview of the Brodmann areas are given in the Appendices A to G.

2 Theoretical background

The aim of the current study is to implement the model of the strategic regulation of memory accuracy and memory quantity performance by Koriat and Goldsmith into a fMRI design to investigate the neural correlates connected with the three main processes: retrieval, monitoring, and control and moreover the brain areas related to memory accuracy.

The first section of the theoretical background gives an overview of the different classifications of human memory concerning processes, time, content, and neural correlates.

Subsequently, false memories are introduced, presenting different forms of false memories including Schacter's seven sins of memory and the accordant neural correlates. Afterwards, a short introduction of executive functions and the associated neural correlates is given. Finally, the memory paradigm of Koriat and Goldsmith is illustrated with special emphasis on metamemory.

2.1 Memory

Memory can be characterized concerning different aspects. First of all, the divergent processes during the memorization of new information are highlighted. Afterwards, memory is defined related to the distinction along the time axis and then a description of the different memory stores is given. The content of memories is subsequently described with the help of a classification into different systems. Finally, the neural correlates of (episodic) memory are focused.

2.1.1 Memory processes

It is necessary to classify the different stages of information processing in memory over time, before describing the complex ways of information processing within the different memory systems (Schneider & Fink, 2007).

When new information is gathered, it is first registered by sensory systems followed by encoding and consolidation processes. Afterwards, it is stored and can be retrieved at any time (Figure 1). All of these processes are variable. This means that during the process of retrieval, for example, information can be re-encoded or re-consolidated (Buckner, Wheeler & Sheridan, 2001; Walker & Stickgold, 2006).

| Registration | → | Encoding | → | Consolidation | → | Storage | → | Retrieval |
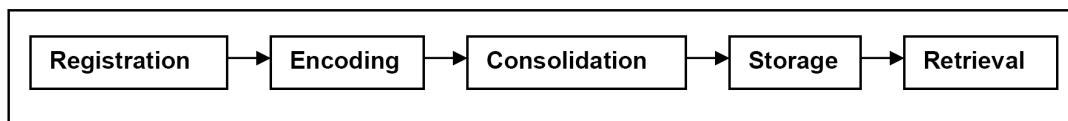
Figure 1: Illustration of the main processes from registration of new information to retrieval (modified from Markowitsch, 2003b).

The first perception of information via special receptors is defined as registration. Visual, auditory, olfactory or gustatory information is filtered which makes it easier to discriminate between relevant and non-relevant information. This is an important function to process an amount of information (Markowitsch, 2003b).

After this, memories are formed by engaging with an object or performing action which takes place during the encoding process. This operation leads to a representation of the accordant object or action within the brain and is referred to a specific internal code (Walker & Stickgold, 2006). The result of that process is a memory trace which is also named "engram".

One can distinguish between two different encoding processes. During intentional encoding information is consciously prepared for storage, whereas incidental encoding means that information is unconsciously processed by means of binding and association (Markowitsch, 2003b). Dependent on the cognitive effort (Addis, Wong & Schacter, 2007) and due to the depth and manner of processing (Craik & Lockhart, 1972; Craik & Tulving, 1975; Lockhart, 2002) certain information may be encoded better than other.

When a specific memory becomes resistant to interference from concurrent factors this is the result of a consolidation process. This operation needs no further practice and happens just through the simple passage of time (McGaugh, 2000). Moreover, it is related to a deeper encoding and embedding of information. In addition, it enables the transfer to long-term memory (LTM) for a long-ranging storage which implies a stable representation of information in the nervous system (Markowitsch, 2003b). This process is very mutable and can last over some minutes to hours or even years (McGaugh, 2000). Some researchers assume that consolidation mainly takes place while sleeping (Stickgold & Walker, 2005; Walker & Stickgold, 2006). It is supposed that consolidation involves different phases of post-encoding memory processing. Each phase is connected with specific brain states like wake or sleep, or even to specific stages of sleep (Stickgold, Whidbee, Schirmer, Patel & Hobson, 2000; Muellbacher, Ziemann, Wissel, Dang & Kofler, 2002; Walker, 2005).

One has to keep in mind that only previously successful storage will lead to an accurate reproduction of information during the stage of retrieval. Besides, memories are stored in different places within the associative cortices, simultaneously (Markowitsch, 2003b; Mesulam, 1994). Many different factors can influence memory retrieval from LTM.

Two components are crucial for successful retrieval, namely a feeling of familiarity as well as the context, during which the information was coded (Yonelinas & Levy, 2002). Moreover, two other elements have an important impact on the process of retrieval. This is on the one hand "ecphory" (recovery of stored information) and the other one is known as episodic "retrieval mode" (REMO) (Lepage, Ghaffar, Nyberg & Tulving, 2000).

We all know that memory retrieval is sometimes untrustworthy which has different reasons. It happens that past experiences are not correctly or not at all remembered. Also, one may feel very sure that certain information is stored somewhere in memory but it is absolutely unable to access and retrieve it. It even occurs that events are

recalled that never happened, at least never occurred in that manner (Kühnel et al., 2008; Schacter, 2001, 2003). In the section about false memories this phenomenon will be explained in more detail (2.2).

2.1.2 Time dependent memory

Consistent with our understanding of information transience is the classification of memory as time dependent. Some information last for just a few minutes, others last for any length of time, and some information last forever (Markowitsch, 1999).

This is in line with the idea of serial information processing, in which memory is divisible hierarchically into three main stores (Figure 2) (Atkinson & Shiffrin, 1967; Markowitsch, 1999). The first store is called ultra short-term memory or sensory memory. The second store reveals a strong connection to working memory (WM) and is known as short-term memory (STM).

The third one is defined as LTM and functions as a permanent memory store (Markowitsch, 2003b; Squire & Zola-Morgan, 1991).
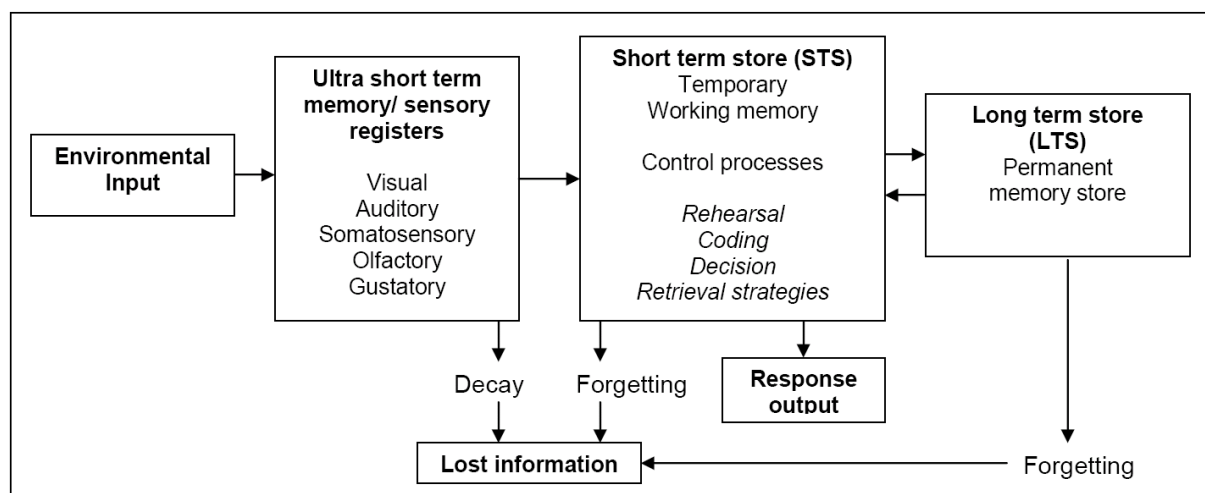
Figure 2: Processing of information through the memory system as devised by Atkinson and Shiffrin (1967).

Sensory memory has a duration of about 50-500 milliseconds and is defined as the maintenance of information along the sensory registers (Loftus, Duncan & Gehrig, 1992; Markowitsch, 2003b). Information is transferred from these registers into STM which is a temporary store with a limited capacity of 7 +/- 2 chunks (Miller, 1973; Miller & Desimone, 1994). There are also studies that report a lower capacity with about four chunks (Conners, Rosenquist, Sligh, Atwell & Kiser, 2006).

If information in STM is not further processed it will remain in this store for some minutes and then fades away. If processes like rehearsal, coding, decision, and retrieval strategies are well conducted in STM, there is a great probability that the information will be transferred into LTM (Baddeley, 1998).

It is assumed that LTM exhibits unlimited capacity and therefore especially facts and episodic events can be stored for a long time (Emilien, 2004). Information from STM that is transferred to LTM will not disappear but will remain for years (Waugh & Norman, 1965).

Free recall tasks, in which subjects are presented with lists of unrelated words and subsequently are asked to reproduce as many words as possible in an unspecific order, strengthen the evidence against a unitary view of memory. Further arguments in favor of at least two systems arise from the difference between STM and LTM concerning storage capacity and the rate of input and retrieval (Baddeley, 1998). Moreover, STM storage is relying on phonological coding compared to LTM which is more influenced by semantic facts (Baddeley, 1998; Vallar, Di Betta & Silveri, 1997; Papagno & Vallar, 1995).

In contrast, there is strong evidence against a unitary view of memory. This bases on studies with patients suffering memory impairment. The case of K.C., who suffered brain damage after a motorcycle accident, has been investigated for many years (Rosenbaum et al., 2005). The most famous case concerning this topic was introduced in 1975. The patient H.M. had undergone an operation in order to medicate his epilepsy. After the surgery he was not healed, but suffered from severe anterograde amnesia. Even though his STM was intact, H.M. could not transfer new

events to long-term memory (Scoville & Milner, 1957). The consequence of these cases concerns the supposition that LTM may be severely impaired while STM remains intact. This is in line with serial information processing according to the modal model, because here the STM plays a crucial role. This means that without being processed in STM information would never reach LTM (Baddeley, 1998).

In contrast, the case K.F., who's STM was impaired while his LTM appeared to be quite normal (Markowitsch, 1999; Shallice & Warrington, 1970) intensifies evidence for a distinction between STM and LTM. The assumption that STM is impaired while LTM is maintained supports parallel information processing in contrast to the before mentioned serial information processing. This model highlights that information is not processed sequentially as hypothesized by Atkinson & Shiffrin as well as Craick & Lockhart, but is processed rather simultaneously by several different parts of the memory system.

The concept of working memory is a more dynamic system with an actively transformation and process of different kinds of information while STM describes a kind of "passive temporary memory store" (Emilien, 2004). WM is a special form of STM and plays an important role in diverse cognitive skills (Adams & Gathercole, 2000), reading skills (Conners, Atwell, Rosenquist & Sligh, 2001; Conners et al., 2006), comprehension (Rosenquist, Conners & Roskos-Ewoldsen, 2003), reasoning, and planning (Baddeley, 1992; Wickelgren, 1997). Baddeley and Hitch define working memory as a three-component system (Figure 3) (Baddeley, 2003).
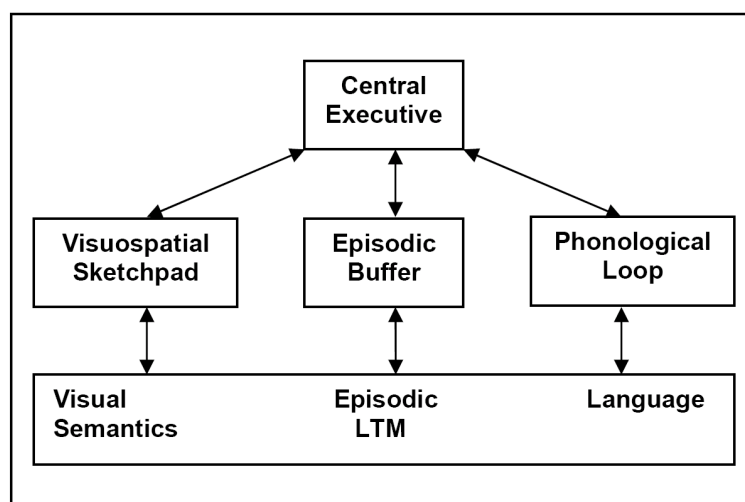
Figure 3: The current model of working memory (modified from Baddeley, 2003).

The main structure is the central executive (attentional controller) which can be described as a limited attentional relay station. It is supported by two subsystems. The first subsystem is the visuospatial sketchpad holding information about what is processed visually. Spatial and visual information is manipulated like for example remembering colors and shapes, or the speed or rather the location of objects. The visuospatial sketchpad also plays a role in planning of spatial movements like driving and parking a car on a parking area (Baddeley, 1986, 1992, 2000).

The second subsystem is the articulatory loop (phonological loop) which processes auditory information and language and can be divided into two different parts. One part is related to phonological store responsible for the maintenance of auditory information for an approximate duration of two seconds. On the other hand, the articulatory control system refers to rehearsal of information within the phonological store and therefore provides stabilization for any length of time (Schneider & Fink, 2007). The differentiation of the two "loops" is well reserved by now (Baddeley, 2002; Della Salla, Gray, Baddeley, Allamano & Wilson, 1999; Rosenquist et al., 2003; Baddeley, 1998).

Studies of WM normally use dual-task techniques with interesting results. When participants had to remember and recite a several-digit number, their accuracy of recalling or recognizing lists of words was not impaired (Baddeley, 2001; Baddeley, Lewis, Eldridge & Thomson, 1984). Beyond that, it was found that learning lists of words is more successful when subjects code the information both phonologically and visual-spatially (Baddeley, 2003). A fourth component that has not yet been introduced was implemented into the WM model: the episodic buffer. This system is capable of storing information in a multi dimensional code. As the name suggests it is comparable to episodic long-term memory with one exception, namely the temporary bounding. The episodic buffer is controlled by the central executive and constitutes a temporary gateway between the phonological loop, the visuospatial sketchpad, and LTM (Baddeley, 2000).

Even though being least understood, the central executive is considered to be the most complex component of WM (Baddeley, 1998; Baddeley & Della Sala, 1996). It was hypothesized by Baddeley that the central executive comprises several subcomponents that support at least four separate functions like "the coordination of separate task performances, switching retrieval strategies for tasks (such as in random generation), selectively attending to a particular stimulus while simultaneously inhibiting a separate stimulus, and manipulating information sourced from the temporary stores" (Hester & Garavan, 2005). According to Hester (2005), working memory processing of information and performance of traditional executive functions like suppression of prepotent responses are related. A connection was found between the active processing required for WM and inhibitory control (Roberts, Hager & Heron, 1994). Moreover, it was reported that selective visual attention can be influenced by working memory load. This constitutes another example for the relationship between WM and response selection (de Fockert, Rees, Frith & Lavie, 2001) and furthermore for the connection between WM and executive functions.

Another classification which is also time dependent is related to a differentiation into old and new memories. This is specifically relevant to amnesic patients. If dysfunctions are related to new memories the encoding of new information and long-term acquisition is influenced. In this memory model an arbitrary time point in life is set and memories that occur after this point are classified as anterograde amnesia (Markowitsch, 2003b; Pritzel, Brand & Markowitsch, 2003).

Dysfunctions that involve events that happened previous to that time point are called retrograde amnesia. This term is used for patients being incapable to retrieve long-term acquired information that was already stored (Figure 4).
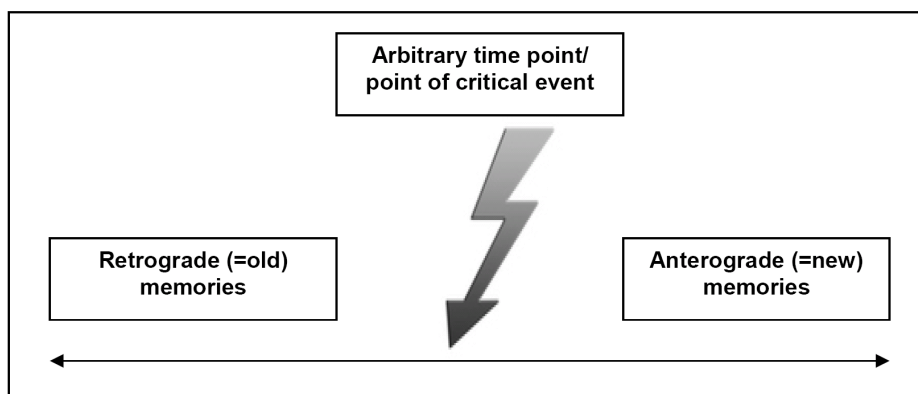
Figure 4: Classification of retrograde and anterograde amnesia (modified from Brand & Markowitsch, 2003).

In contrast to patients the terms are also used for healthy subjects in order to describe older and recent memories. There is a phenomenon that is called Ribot's Law which is supported by symptoms of some but not all patients. This concept is related to retrograde amnesia (Ribot, 1881) and assumes a specific time-gradient: recent memories are more likely to be lost than the more distant memories, also referred to as "first in last out" (Markowitsch, 1999, 2003b; Pritzel et al., 2003).

2.1.3 Content dependent memory

There are two different theories concerning the classification of the content of memories that became widely accepted: Squire (1987) distinguished declarative and non-declarative memory in contrast to Tulving and Markowitsch assuming five different long-term memory systems. According to Tulving and Markowitsch, the memory systems involve procedural memory, priming, semantic memory (SM), episodic memory (EM), and perceptual memory, whereas the latter was introduced more than 30 years later (Tulving, 2005; Markowitsch, 2003a).

A distinction between "declarative" and "non-declarative" ("procedural") memory is supposed in Squire's model (Squire et al., 2004). During retrieval and depending on the level of consciousness two components are differentiated.

Declarative memory is connected with facts (semantic memory) and personal experiences (episodic memory) that are consciously retrieved. In comparison to that, non-declarative memory plays an important role concerning motor skills, cognitive operations, and simple classical conditioning that influences behavior without being aware of it (Figure 5) (Pritzel et al., 2003; Squire, 1987). Synonymous to declarative and procedural the terms explicit and implicit can be used (Schacter, 1987).

Mainly data of amnesic patients support evidence for this division (Huff, Corkin & Growdon, 1986; Parkin, 1990; Schacter, 1987). The reason for this is the fact that procedural memory is normally spared in amnesia while declarative memory which is directly accessible to consciousness, is impaired. It has to be noted that the distinction between semantic-episodic and declarative-procedural memory was ambiguous for any length of time.
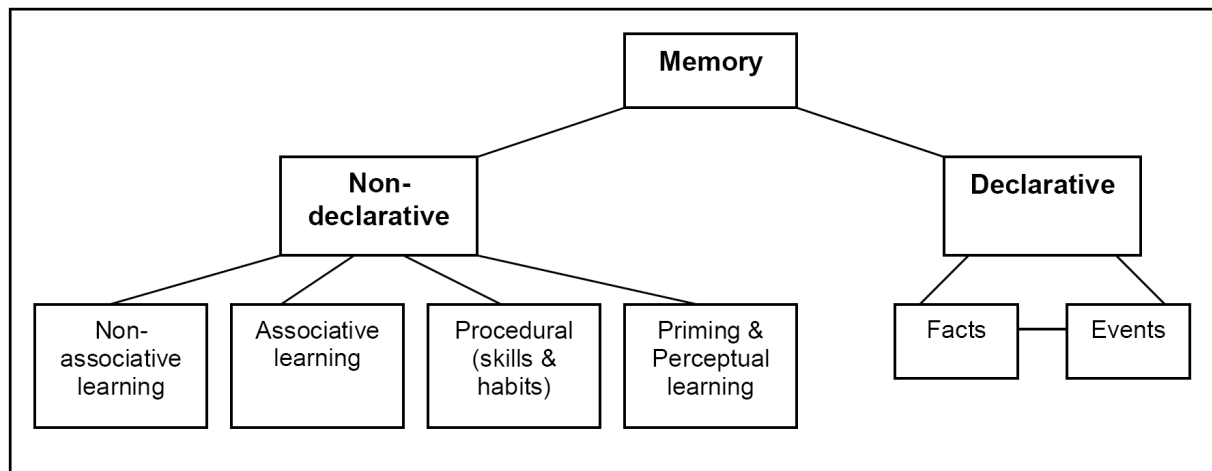
Figure 5: Declarative and non-declarative memory (modified from Squire et al., 2004).

In contrast to two distinct subsystems, Tulving and Markowitsch present five hierarchically organized memory systems that are called procedural memory, priming, semantic memory, episodic memory, and perceptual memory which are illustrated in Figure 6.
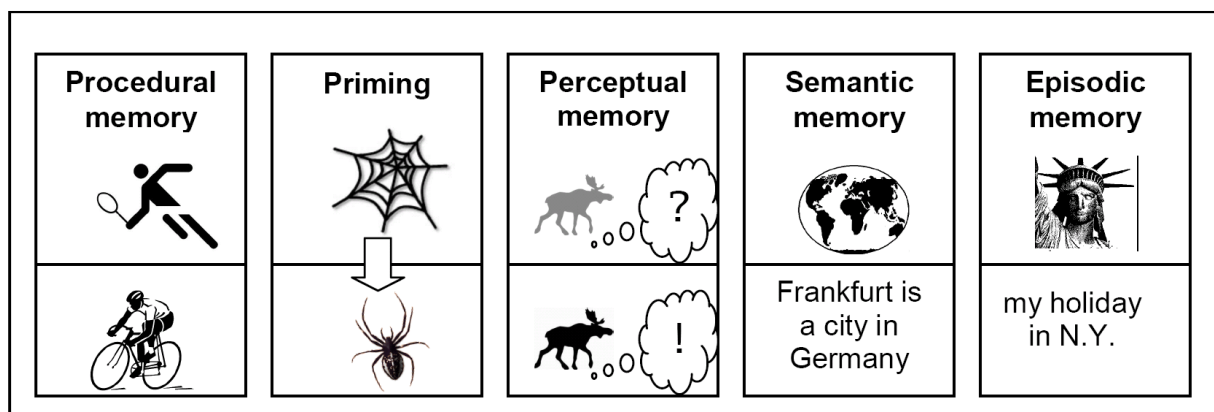
Figure 6: The five memory systems with examples (modified from Reinhold & Markowitsch, 2007).

The five subsystems are interacting with each other and are working parallel with the episodic memory and semantic memory constituting the highest levels.

Processes of procedural memory are characterized as skilled behavioral and cognitive procedures without any cognition (Tulving, 1995). Priming is a special form of perceptual learning. Certain stimuli exhibit an increased sensitivity because of prior experience occurring outside of conscious awareness (Thöne-Otto & Markowitsch, 2004; Markowitsch, 2003b; Tulving, 1995). Providing the estimation of newly gained information concerning familiarity or novelty is executed by the perceptual memory.

Semantic memory is also called the memory of facts, meanings, understandings, and common knowledge about the world. It maintains the possibility of thinking and executing cognitive operations. It is thought that SM does not depend on context and personal relevance. This independence on the other hand is accompanied by the disability to recall the time and context of encoding (Tulving, 1995).

Finally, the episodic memory comprises unique personal experiences (e.g. times, places, associated emotions, events) and helps individuals to remember personal events. These memories are embedded in a network of other personal incidences in subjective time (Tulving, 1995). Beyond all and incomparable to any other memory system, the episodic memory includes our entire personal autobiography.

Semantic and episodic memory represent the category of declarative memory which is one of the two major divisions in memory (Tulving, 1984; Tulving & Schacter, 1990).

The unique relationship between episodic, semantic, and perceptual memory is revealed by the serial-parallel-independent (SPI) model (Tulving, 1995). It is hypothesized that there is a process specific relation among the cognitive systems. This means that a piece of information is encoded serially and stored in parallel. In addition, the retrieval of information is independent (Figure 7) (Tulving, 1995, 2001; Tulving & Markowitsch, 1998).
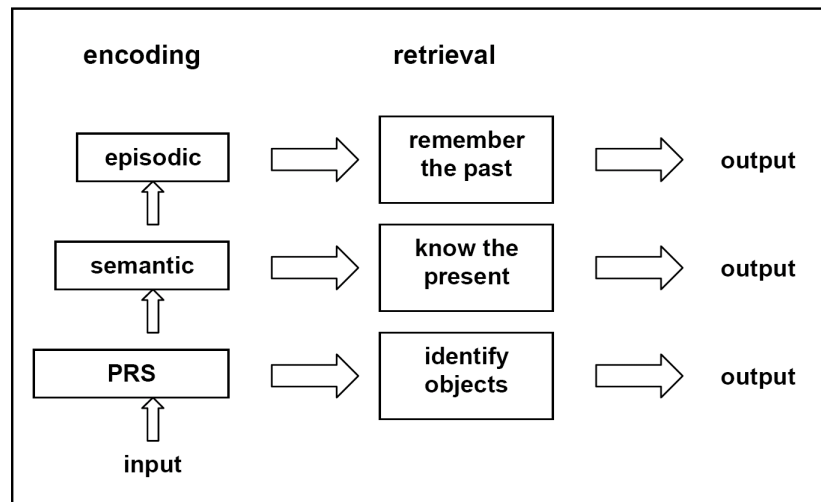
Figure 7: Serial-parallel-independent (SPI) model among three large memory systems: perceptual (PRS), semantic and episodic memory (modified from Tulving, 2001).

A hierarchical classification of the three memory systems is assumed by Tulving.

1.) The perceptual system constitutes the lowest level and episodic memory reflects the highest level. In the perceptual system new information is received in terms of perceptual features and objects, is then stored and prepared (perceptual representing system = PRS) (Tulving & Schacter, 1990).

2.) The semantic system also receives and stores information but with main focus on facts and knowledge of the world.

3.) The episodic memory system is defined as processing of both objects and facts extended to the self in a subjective time.

The SPI highlights that the encoding of information concerning these three systems runs serially. On the other hand, the storage proceeds separately within the different systems. It is supposed that storage is parallel which is in line with the procedure of independent retrieval: retrieval from one system need not have any influence or connection regarding retrieval from any other system (Tulving, 2001).

Not all perceived information can be further processed and reaches the semantic or episodic memory system; however the quality of encoding depends on individual

cognitive effort (Hasher & Zacks, 1979) as well as depth and manner of processing (Craik & Lockhart, 1972; Craik & Tulving, 1975; Lockhart, 2002).

2.1.4 Episodic memory

Episodic memory is defined as "memory for personally experienced events" or "remembering what happened where and when" whereas semantic memory comprises "general facts of the world" (Tulving, 2001).

When episodic memory is defined, three different issues have to be highlighted: autonoetic awareness, subjectively sensed time, and sense of self (Tulving, 2001). These three concepts will shortly be declared in the following.

Healthy humans are able to maintain and express their experiences for the whole life once they are stored in the course of subjectively apprehended time, thanks to autonoetic consciousness ("chronesthesia") (Tulving, 2002, 2005). This concept includes a backward orientation into the past which enables humans to travel mentally back to their past and consciously re-experience former events ("remembering"). Moreover, it comprises a forward orientation into the future ("thinking about" / "imaging") (Addis et al., 2007; Tulving, 2001). The term autonoetic implies a special kind of consciousness. This consciousness permits humans to be aware of the subjective time, in which events have occured (Tulving, 2002). In addition, the episodic memory involves a remembering "self" that exists in the present as well as in subjective time (Markowitsch et al., 2000; Tulving, 2002, 2005; Wheeler, Stuss & Tulving, 1997).

Many researchers are engaged with a view of memory that is not only concerned with the capacity of individuals to re-experience past episodes, but rather investigates the ability to simulate or "pre-experience" events in the future (Atance & O'Neill, 2001, 2005; Buckner & Carroll, 2007; Hancock, 2005; Suddendorf & Busby, 2005; Suddendorf & Corballis, 1997; Schacter & Addis, 2007; Tulving, 2005).

Evidence suggests that mental time travel into the past and future are related. This comprises an evolutionary advantage which is supposed to be the ability to access the future (Dudai & Carruthers, 2005; Suddendorf, 2003; Suddendorf & Corballis, 1997; Tulving, 2005).

It was introduced by Schacter (2007) that the future is never a precise repetition of the past. To imagine future episodes it is crucial to have a system that refers to elements of the past while retaining the general sense of what has happened. This system is capable to extract, recombine, and reassemble flexibly these elements in a way that provides simulation, imagination or "pre-experience" (Atance & O'Neill, 2001) of events that have never occurred before in the way we imagine them (Schacter & Addis, 2007). This concept is known as constructive episodic simulation hypothesis. The system bases on constructiveness rather than on reproduction (Schacter & Addis, 2007). This view is supported with Tulvings concept of "mental time travel" which comprises projecting oneself into both the past and the future (Tulving, 2002, 2005).

On the one hand it is an advantage and usually adaptive for the organism that memory is constructive, on the other hand just this makes memory prone to error: confabulation, intrusion, and false recognition are examples for memory distortions. These distortions of memory are summarized as false memories and will be introduced in detail in section 2.2. The following section gives a short overview about the neural correlates that are connected with episodic memory.

2.1.5 Neural correlates of episodic memory

Thanks to the development of neuroimaging techniques like electroencephalography (EEG), positron emission tomography (PET), magnetic resonance imaging (MRI), and functional magnetic resonance imaging it became possible to obtain a better understanding and to gain deeper insights into the relevant brain structures of memory also in healthy individuals. The following section broaches the issue of

neural correlates connected with the different memory processes that were introduced previously (Figure 8).

Encoding (and consolidation) processes in episodic memory are related to different brain structures. Particularly parts of the medial temporal lobe, the medial diencephalon, and the basal forebrain (partially) are important regions in these processes (Brand & Markowitsch, 2003). The cingulate gyrus and the amygdala are noteworthy when emotional toned information is encoded. Both areas belong to the limbic system, are interconnected by tracts, and belong to two separable but interrelated circuits: the Papez circuit and the basolateral-limbic / amygdaloid circuit (Markowitsch, 2000b). Due to the fact that information has to pass these structures for long-term storage these limbic system structures are also known as "bottleneck" structures (Markowitsch, 2005).
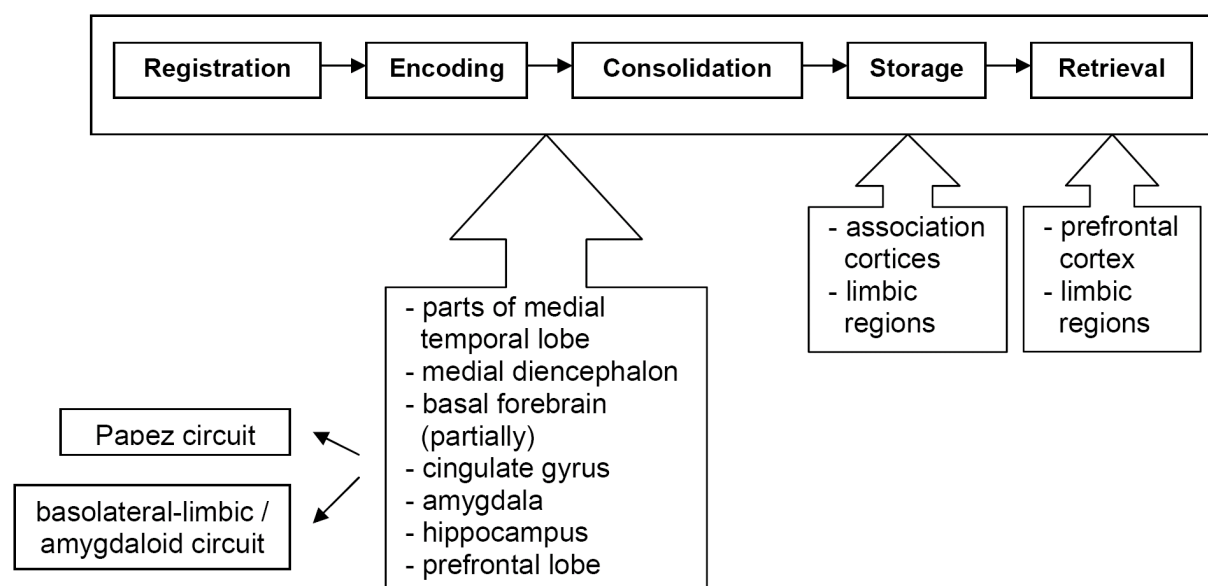
Figure 8a: Memory processes and neural correlates (modified from Markowitsch, 2003b).

The Papez circuit comprises different brain structures and pathways (hippocampal formation, fornix, mammillary bodies, mammillothalamic tract, anterior thalamic

nuclei, thalamo-cortical pedunculi, subiculum of the hippocampal formation). The main structures are illustrated in Figure 8a.

The previous assumption of this circuit being particularly involved in processing of emotional information (Papez, 1995) is now replaced by the supposition that the Papez circuit is responsible for a general transfer into long-term stores (no matter whether the material is emotionally toned or not) (Markowitsch, 2000b). It is rather relevant for cognitive aspects of memory processing (Markowitsch, 2003b).
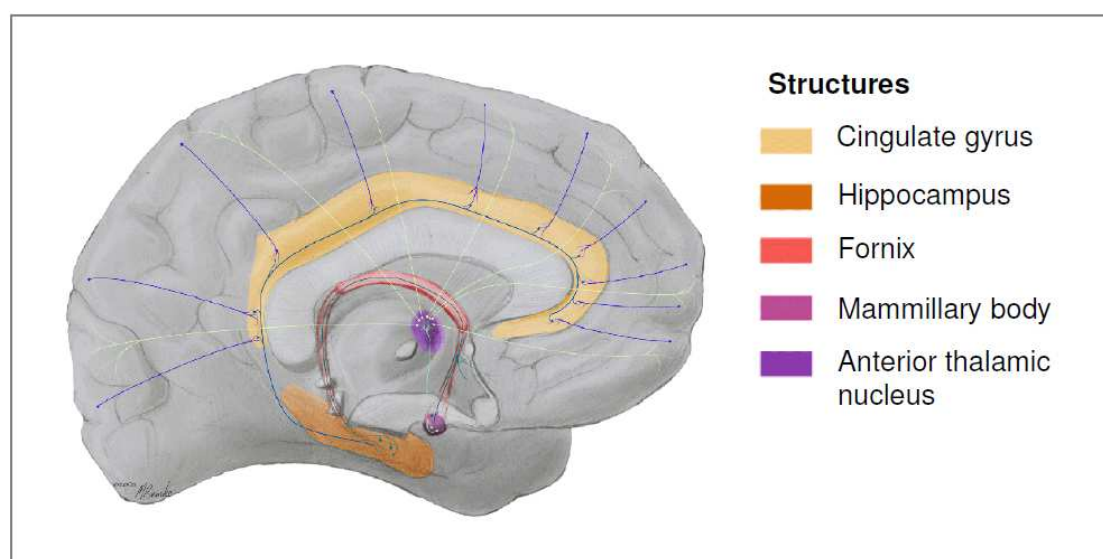
Figure 8b: Main structures of the Papez circuit.

In contrast, the basolateral-limbic circuit is assumed to be responsible for encoding and consolidation of emotional memories with the amygdala as a key structure (Phelps, 2006). The amygdaloid circuit includes the amygdala, ventral amygdalofugal projection, mediodorsal thalamic nucleus, anterior thalamic pedunculi, area subcallosa of the basal forebrain and bandeletta diagonalis (Markowitsch, 2000b, 2005). Even though both circuits are self-contained they interact with each other (Markowitsch, 2003b). When presenting the limbic system, the hippocampus has to be highlighted as holding a special importance for episodic memory functions

(Markowitsch, 2003b; Fletcher, Frith & Rugg, 1997; Greenberg et al., 2005). The rostral part of the hippocampus is particularly supposed to be engaged with encoding of episodic information (Lepage, Habib & Tulving, 1998).

Frontal and mainly prefrontal sections were found to play an important role (Fletcher et al., 1997; Markowitsch, 2005). The dorsolateral region and the orbitofrontal or ventral parts of the prefrontal lobe are also connected with certain aspects of encoding.

For storage of episodic information structures of the limbic system are important, namely the hippocampal formation and the amygdala (Markowitsch, 2003b, 2005). When information is emotionally toned, the amygdala is all the more included (Cahill, 2000; Cahill, Haier et al., 2001; Fujiwara & Markowitsch, 2006; Markowitsch, 2000b; Hoscheidt, Nadel, Payne & Ryan, 2010). Additionally to the limbic system, wide areas of association cortices with their huge number of neurons and multifaceted synaptic conjunctions are supposed to be significantly involved in memory storage. These areas are even considered as the principle cellular processes of storing information (Bailey & Kandel, 1995; Kandel, 2001; Markowitsch, 2003b, 2005). In general, information is presumed to be represented in a widespread network within the cerebral cortex (Markowitsch, 2003b).

Another region is discussed to be essential for the retrieval of episodic information stored in long-term memory, namely the prefrontal cortex (PFC) (Tulving, Kapur, Craik, Moscovitch & Houle, 1994; Markowitsch, 2005). The HERA model (hemispheric encoding / retrieval asymmetry) highlights a hemispheric asymmetry of the integration of the prefrontal cortex concerning encoding and retrieval of episodic memory (Habib, Nyberg & Tulving, 2003). The right prefrontal cortex is more involved in episodic retrieval, without comparable participation of left PFC. In contrast, the left prefrontal cortex is specialized for encoding of episodic information, without comparable activation in right hemispheric prefrontal regions (Fletcher et al., 1997; Habib et al., 2003; Tulving et al., 1994). Until now, no consensus has been achieved

concerning the laterality of the involvement of PFC in episodic vs. semantic memory retrieval.

Besides the prefrontal cortex, for the retrieval of episodic memories limbic structures, like hippocampal formation, the parahippocampal gyrus, and the amygdala are necessary, too (Fink et al., 1996; Haist, Bowden & Mao, 2001; Levine, 2004; Markowitsch, 2005; Moscovitch et al., 2005; Steinvorth, Levine & Corkin, 2005; Svoboda, McKinnon & Levine, 2006). The concurrence of these structures might depend on recent compared with remote memories (Piefke, 2003) and / or on age and gender (Piefke & Fink, 2005; Piefke, Weiss, Markowitsch & Fink, 2005).

Taken together, these sections emphasized different approaches to memory. Human memory was presented with regard to different processes in terms of a distinction along the time axis, and concerning different content. The memory system that more or less defines our personality and comprises our personal past was introduced, namely the episodic memory. Lastly, the different neural correlates of memory were illustrated. Even though memory has been defined clearly arranged, the reality draws a different picture. Memory is a highly complex process that involves several brain structures as well as the role of several neurotransmitters.

Due to the fact that memory is highly complex and constructive it is also fault-prone. The next chapter deals with the phenomenon that for example people remember events that never happened at all, namely false memories.

2.2 False memories

"False memory is a condition in which a person's identity and interpersonal relationships are centered around a memory of traumatic experience which is objectively false but in which the person strongly believes" (Lynn & McConkey, 1998).

False memories are known as recollections that are either divergent from true memories or that are completely false and invented by the subjects and involve events that have never happened at all (Schacter, 1999). False memories lead to the assumption that remembering is a rather constructive process instead of an accurate and exact reproduction of experienced events (Schacter & Curran, 2000). To experience false memories it doesn't make any difference whether one is very young or very old, or whether one suffers from any dysfunction or not (Tulving, 2001).

One of the first researchers studying memory illusions phenomena was Bartlett. He did a lot of research concerning the memory abilities of students. In one experiment, he asked a group of students to read an Indian folktale („The War of the Ghosts"). Subsequently, the participants had to recall the content at different time intervals. Bartlett found errors of omission and various errors of commission. Subjects manipulated the content by changing or adding details to the story to make it more rational and consistent (Bartlett, 1932). This is connected with the influence of schema consistency on contradictory information. Participants report greater false memory for schema-inconsistent items than schema-consistent items (Nemeth & Belli, 2006). A schema is defined as an organized knowledge structure or an individual model of the world that reflects personal knowledge, past experiences, and beliefs about different themes (Baddeley, 1999). On the one hand, schemata are very useful in relation to economy of time and effort, because the amount of information that has to be processed is reduced. If all experience would be memory preserved instead of compressing information into a gist-like representation, the

system would overload and lose its flexibility and its speed of processing (Schacter, 2001).

On the other hand, a schema can also be misleading by creating false memories as demonstrated in Bartlett's study.

Eyewitness testimony is strongly related to research concerning false memories. It was shown that eyewitness memory is often inaccurate in many different ways. A lot of experiments reveal that memory can be significantly manipulated by the manner of interviewing an eyewitness after a certain event. The misinformation effect, for example, concerns misleading information presented after the encoding of an event which is mistakenly remembered as being part of the original incident.

It is relatively easy to change special features of memories for previously experienced events and therefore create false episodic memories. It is even possible to implant completely false memories (Loftus, 1996; Nourkova, Bernstein & Loftus, 2004; Loftus, 2005). This depends on the individual ability of imagining the events, the verification by family members, and certain plausibility (Pezdek & Hodge, 1999; Pezdek, Blandon-Gitlin & Gabbay, 2006).

One important technique to create false memories is the Deese-Roediger-McDermott (DRM) paradigm (Deese, 1959; Roediger & McDermott, 1995). In this design, subjects see word lists (e.g. note, sound, piano, sing, radio, band, melody, horn, concert, instrument, symphony, jazz, orchestra, art, rhythm) consisting of associates which reveal a certain relation to a non-presented critical word (e.g. music). Subsequently, subjects have to accomplish a recognition test consisting of studied words that are presented in a random order and non-studied words (Graham, 2007): when subjects response "familiar" to a semantically similar lure (e.g. music) related false alarms occur. Unrelated false alarms occur when subjects response "familiar" to a novel word that has no associative or semantic relation to the before studied words e.g. spider) (Melo, Winocur & Moscovitch, 1999). This method aims at investigating

certain aspects of false memories under controlled circumstances and is very popular (Foley & Foy, 2008; Marsh & Dolan, 2007; Coane & McBride, 2006).

The next section deals with three established forms of false memories: confabulation, intrusion, and false recognition followed by certain theories trying to explain the occurrence of false memories. Afterwards a short overview regarding the neural correlates of false memories will be given.

2.2.1 Forms of false memories

Confabulation, intrusion, and false recognition are the three most reported forms of false memories (Figure 9) (Schacter, Norman & Koutstall, 1998).

Confabulation is the tendency to fill in gaps in one's memory with fabrications that one believes to be facts, furthermore, one confuses imagination with memory, and / or one confuses true memories with false memories ("The American Heritage Dictionary of the English Language", 1992). In its classical form, confabulation is defined as the involuntary falsification of memory occurring in clear consciousness in association with an organically derived amnesia (Berlyne, 1972; Kaplan & Sadock, 2000). Confabulation was first described by the Russian psychiatrist Sergei Korsakoff in 1889 in alcoholic amnesic patients. He has described a special kind of memory deficit in people who have had abused alcohol in their past. His patients have had no recollection of former events and have filled the gaps spontaneously with invented and therefore fictitious stories (Korsakoff, 1996; Dalla Barba, Cipolotti & Denes, 1990). It may also be possible that confabulations are described as true memories but confused in both time and place (Kopelman, 1987).

According to different authors a distinction can be made between spontaneous and provoked confabulations which may be due to different cognitive mechanisms. Momentary (provoked) confabulations are related to intrusions in memory tests and are produced in response to questions, for compensating the gaps in memory. Spontaneous confabulations are connected with executive dysfunction or a source memory deficit and are consisting of wish-fulfilling characteristics (Kessels, Kortrijk,

Wester & Nys, 2008; Gündoğar & Demirci, 2007; Schnider, von Däniken & Gutbrod, 1996; Kopelman, 1987; Metcalf, Langdon & Coltheart, 2007).
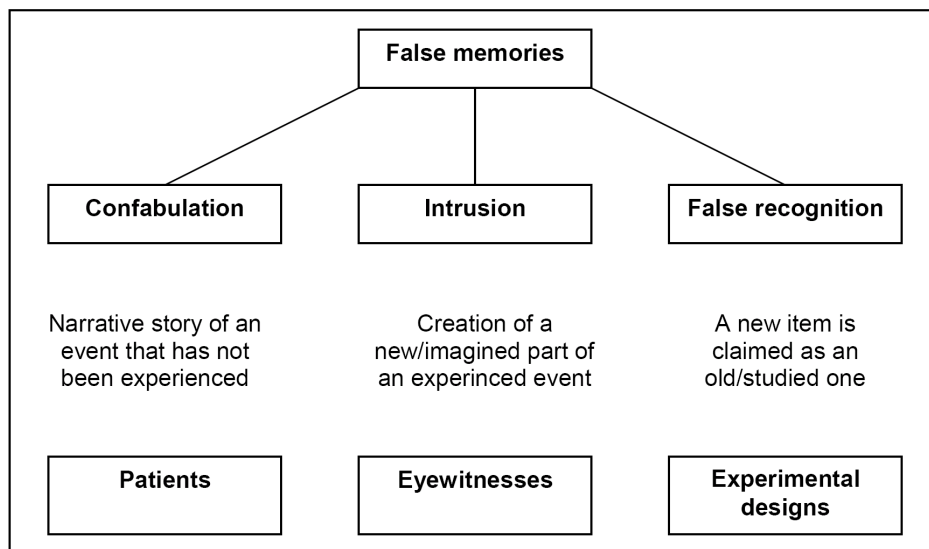
Figure 9: Three main forms of false memories with examples for the main research areas (modified from Kühnel et al., 2008).

Certain dissociation between spontaneous confabulation, provoked confabulation, and false memories is assumed (Kessels et al., 2008). Confabulating patients often report personal events, mostly in the form of a detailed description. The only possibility to verify or falsify those events is a conversation with relatives.

Other kind of false memories are intrusions. Subjects sometimes intrude details from a narrative description of an event (experienced by someone else) into their reports of a truly experienced visual (personal) event (Lindsay, Allen, Chan & Dahl, 2003). This form of false memories plays a role regarding witnesses and crime. It has been examined how a crime schema influences the types of details witnesses recall over a series of interviews at different times. Witnesses use their schemata to interpret ambiguous information and therefore make more schema-consistent intrusions and less correct responses. Subjects unconsciously intrude details which have not been

witnessed at all and they are more likely to report false memories that involve supposed conscious recollection (Tuckey & Brewer, 2003).

The third form of false memories is false recognitions which occur when novel items are mistakenly classified as familiar. In an experiment healthy controls studied lists of semantically related words. Afterwards, participants showed extremely high levels of false recognition to non-studied lures that were semantic associates of studied list words (Schacter et al., 1998).

False memory occurs amongst others in experiments, when subjects show false recognition after they have studied words that were semantically or perceptually related to a new presented item (related false alarms) as described by Schacter. Errors might also occur, however, when items are presented that appear to be unrelated to before studied items (unrelated false alarms) (Garoff-Eaton, Slotnick & Schacter, 2006). The forecited Deese-Roediger-McDermott (DRM) paradigm has been applied to explore false recall and false recognition. Thus, it provides the opportunity of both: to induce high value of falsely recognized lures (like previously studied words) and to provoke false recall of critical lures (Melo et al., 1999). Among other forms the described types of false memories are the most common ones.

The next paragraph examines the neural correlates that were found to be connected with false memories.

2.2.2 Neural correlates of false memories

In the previous section the interrelation between true and false memories was described from the behavioral point of view. The following paragraph presents a short overview concerning the neural correlates that are connected with retrieval of false memories.

When presenting neural correlates of false memories in contrast to true retrieval, medial temporal regions as well as frontoparietal areas have to be highlighted. A recent study found that true memory was connected with diffusion anisotropy in the

inferior longitudinal fascicle which is assumed to be the major connective pathway of the medial temporal lobe. In contrast, retrieving false items was connected with the superior longitudinal fascicle connecting frontoparietal structures (Fuentemilla et al., 2009). This is supported by a different study, presenting that high-confidence responses were related to medial temporal lobe activity when true items were recognized. Frontoparietal activity in high-confidence responses were identified in the case of false recognition. The authors emphasize that correlation analyses could present that medial temporal lobe (MTL) and frontoparietal regions play complementary roles during episodic retrieval (Kim & Cabeza, 2007).

Different research showed that medial temporal lobe activity (including the hippocampus) during recognition of false targets was similar to recognition of true targets, suggesting that MTL is a contributing factor to false memory (Cabeza, Rao, Wagner, Mayer & Schacter, 2001; Schacter et al., 1996; Schacter & Addis, 2007).

True recognition and related false recognition are connected with similar patterns of neural activity and include, beside the medial temporal lobe, also activity in the prefrontal cortex and the parietal cortex (Garoff-Eaton et al., 2006). This is supported by the finding that high confidence in false recognition is related to familiarity which is linked to these two areas (Kühnel et al., 2008; Eichenbaum, Yonelinas & Ranganath, 2007). This is maintained by the result of comparisons which indicated greater activation during true than false recognition in left temporoparietal regions (Abe et al., 2008).

Moreover, it was reported that left PFC was involved in both true and false memory formation activities which is consistent with evidence that semantic elaboration, which has been associated with left PFC, tends to enhance both true and false remembering (Kim & Cabeza, 2007). In contrast to these similarities between true and false recognition, differences have been observed in the ventromedial prefrontal cortex which was associated with more activity for false recognition in comparison with true recognition.

The PFC plays an important role for both encoding and retrieving episodic memories (Brand & Markowitsch, 2008) and is important regarding executive functions like strategic search, monitoring, verification, and organization of the automatic output from MTL structures (Moscovitch & Nadel, 1998).

Furthermore, the role of the frontal lobes was examined (Turner, Cipolotti, Yousry & Shallice, 2008). Even though activation was evident in all of the trials of an experiment, it increased during false compared to true recognition (Schacter et al., 1996). Further evidence can be gained in patient studies concerning confabulation, because confabulation is supposed to be associated with an impairment of the ventromedial aspect of the frontal lobes and basal forebrain (Melo et al., 1999). In contrast, Okado and Stark revealed that the left parietal cortex and left frontal regions did not differ between true and false memory retrieval (Okado & Stark, 2003).

Similar activation of the hippocampal region was found during true as well as during false recognitions (Cabeza et al., 2001). More specifically, the right anterior hippocampus was activated during false recognition relative to correct rejection and pretending to know (Abe et al., 2008). In contrast, the parahippocampal region revealed differentiated activation during retrieval of true items, but not during false recognitions (Cabeza et al., 2001) which is in line with the results of another study, reporting that activity in the (posterior right) parahippocampal region was more intensive for true compared to false memories (Okado & Stark, 2003).

Another region, playing a role concerning false memories is the anterior cingulate cortex. It was discovered that activity was greater for false than for true memories in right anterior cingulate gyrus (Okado & Stark, 2003). The ACC was additionally found to be engaged with conflict monitoring processes (Botvinick, Cohen & Carter, 2004).

The findings concerning neural correlates of false memories are quite ambiguous. Some results are related to the idea that false memories are associated with an inaccurate output from MTL due to an impairment of the monitoring function of the

prefrontal cortex. To summarize, several studies show that true and false recognition is related to the same network of brain activity. These are regions that are commonly activated by episodic retrieval tasks, like for example dorsolateral / anterior prefrontal, medial parietal, and medial temporal areas (Koriat & Goldsmith, 1996c). There is no characteristic structure that can be identified as inalienable for false memories. If differences are found they normally base on a different degree of activation associated with true or false recognitions (Kühnel, 2006).

The next section deals with executive functions which are supposed to explain behavior and refer to higher-level cognitive abilities. They are assumed to guide complex behavior over time by planning, decision-making, and self-monitoring.

2.3 Executive functions

In the literature executive functions are reported to be strongly connected with memory accuracy (Davidson & Glisky, 2002; Glisky, Rubin & Davidson, 2001). Moreover, individual differences in executive functions seem to play an important role in memory accuracy (Rhodes & Kelley, 2005). In the following section executive functions and the most important theories are introduced. Subsequently, the accordant neural correlates will be illustrated.

The term executive function contains different cognitive abilities like planning, cognitive flexibility, initiating appropriate actions, inhibiting inappropriate actions, and decision-making (Stuss & Knight, 2002). Executive functions are defined as metacognitive processes and allow us to adapt to changing situations as well as to perform a task for a certain amount of time (Jurado & Rosselli, 2007).

There is no unique definition of executive functions hence different components are described by different authors. Still, there is no consensus whether executive functions belong to a basal mechanism or whether different executive functions are correlated with each other but generally separable (Jurado & Rosselli, 2007). The SAS-model (supervisory attentional system) as well as the working memory model suggest a "supervisory system" or "central executive" which can override automatic responses (Norman, 1986; Baddeley, 1996).

In contrast, it is assumed that executive functions can be reduced to less independent basic mechanisms (Miyake et al., 2000). This is supported by the view that there are five different executive components comprising basic as well as rather complex integrative functions (Smith & Jonides, 1999).

2.3.1 Different approaches to executive functions

Miyake and colleagues examined the separability of three often postulated executive functions, namely mental set shifting (cognitive flexibility), information updating and

monitoring, and inhibition of prepotent responses. Their results suggest moderate correlations between these functions hence it is important to recognize both the unity and diversity of executive functions (Miyake et al., 2000).

Set shifting describes the ability to shift back and forth between multiple tasks, mental sets or operations (Monsell, 1996). It is also defined as "attention switching" or "task switching" (Miyake et al., 2000). According to Monsell, set shifting is supposed to be a "candidate executive function" which on the one hand might explain failures of cognitive control in brain-damaged patients. On the other hand it might illustrate laboratory tasks in which participants are asked to shift between actions (Monsell, 1996).

Moreover, Miyake et al. emphasize that models of attentional control like SAS (Norman, 1986) often presume that the ability to shift between actions is strongly connected with executive control. Hence, set shifting not only concerns engaging and disengaging appropriate task sets. There is evidence that individual differences in set shifting are also related to the ability to execute a new operation in consideration of proactive interference or negative priming (Miyake et al., 2000).

Inhibition concerns the ability to suppress predominant or automatic responses. The Stroop paradigm, for example, is a characteristic inhibition task, because one has to inhibit the intention to give an automatic answer (i.e., naming the color word). This kind of inhibition is a typical executive function and is also defined as "internally generated act of control" (Logan, 1994). There are many different forms of inhibition. According to the concept introduced by Miyake et al. (2000), inhibition is defined as the intentional suppression of inappropriate responses.

The authors emphasize that their concept of inhibition has to be separated from "reactive inhibition" which is connected with phenomena like negative priming or inhibition of return. The main difference is supposed to be the fact that inhibition according to Miyake is actually intended, in contrast to reactive inhibition which is assumed to be a residual after-effect of processing that is not usually intended

(Logan, 1994). Even though both kinds of inhibition may be connected with each other, they are conceptually separable (Miyake et al., 2000).

Monitoring of working memory representations is strongly connected with the concept of working memory (Jonides & Smith, 1997; Lehto, 1996).

It is about monitoring and coding new information concerning its relevance for a certain task by replacing old and therefore no longer relevant information with recent more relevant items (Morris & Jones, 1990).

The main purpose of monitoring is an active manipulation of relevant information in working memory, rather than passively store information (Miyake et al., 2000).

Smith and Jonides (1999) hypothesize that WM is divided into two main components: the short-term storage (involving active maintenance of a limited amount of information for a matter of seconds) and executive processes that operate on the contents of storage.

Even though the topic is still debated, there is evidence that executive functions comprise

- focusing attention on relevant information and processes and inhibiting irrelevant ones ("attention and inhibition")

- scheduling processes in complex tasks which requires the switching of focused attention between tasks ("task management")

- planning a sequence of subtasks to accomplish some goal ("planning")

- updating and checking the contents of working memory to determine the next step in a sequential task ("monitoring")

- coding representations in working memory for time and place of appearance ("coding").

It was found that each of these executive processes may be selectively impaired in patients with prefrontal damage (Smith & Jonides, 1999).

Norman and Shallice (1986) propose that single, general executive components are not sufficient for explaining actions. Moreover, they assume in their SAS model an

influence of willed control. It uses an attentionally limited controller, namely the supervisory attentional system which is responsible for more complex cognitive operations. The presented system comes with the ability to organize, coordinate, and monitor (with attention and awareness) schemata to accomplish new and complex tasks. Furthermore, it comprises a general-purpose planning component that is capable to adapt to novel domains. The SAS is strongly connected with the main component of the working memory concept (Baddeley & Hitch, 1974), namely the central executive (Pezullo, 2007).

The executive system according to Norman and Shallice (1980) is defined as two central components within a selection-for-action system. The contention scheduler (CS) is presumed to mediate the effect of the environment (this may 'trigger' certain actions) on the selection of automatic or routine actions. When the CS is triggered it controls the inhibition of rival actions (different actions may be triggered at once) to select the most appropriate outcome. The SAS is expected to influence non-routine situations when certain actions have to be modified or suppressed because of a new encounter or decision-making process (Bell, 2004). Therewith, the SAS provides a flexible adaptation to environmental conditions.

2.3.2 Neural correlates of executive functions

Executive functions are discussed to be particularly located in the frontal lobes since brain damage in this area is strongly connected with deficits in executive functions (Smith & Jonides, 1999; Godefroy, Jeannerod, Allain & Le Gall, 2008; Huey et al., 2009). There is evidence from neuropsychological and neurophysiological research suggesting that shifting between tasks or mental sets involves the frontal lobes, e.g. an event-related potential (ERP) study has shown that shifting between two different tasks activated frontal as well as occipital and parietal regions (Moulden et al., 1998). Moreover, it was found that frontal lobe impairments are correlated with perseveration or repeating the same response several times, even when it is clearly no longer appropriate which is construed in terms of difficulty in shifting mental set

(Luria, 1966; Stuss & Benson, 1986). Besides, results reveal that patients with damage to the left frontal lobes exhibit shifting impairment compared to the matched controls (Rogers et al., 1998; Miyake et al., 2000). Within the frontal lobe there is one area playing a crucial role in executive functioning, namely the prefrontal region.

The prefrontal cortex can be divided into different subcomponents hence it is still discussed controversially whether a classification should specify domains or functions. While the domain-specific model hypothesizes that different areas are specified on different contents, the function-specific model assumes that the prefrontal cortex (PFC) of primates has traditionally been classified into at least three main subdivisions: lateral, medial, and ventral (orbitofrontal) that deal with different functions (Tanji, Shima & Mushiake, 2007; Funahashi, 2001).

A major debate regarding the lateral PFC concerns the question whether it is unitary or heterogeneous in function. Evidence for a functional specialization within the PFC comes from lesion studies (Curtis & D'Esposito, 2004).

The lateral PFC can be divided into a ventrolateral and a dorsolateral part hence both parts of the PFC are viewed as having two distinct origins of structural differentiation. The ventrolateral PFC (VLPFC) is involved in active retrieval and information selection, also defined as first-order executive processes. Compared to this, the dorsolateral part is related to higher-order executive components of behavioral planning, including monitoring, manipulation, and integration of different information (Tanji & Hoshi, 2008). It was reported that monitoring is connected with working memory which is discussed to be associated with the dorsolateral portion of PFC (Goldman-Rakic, 1996; Smith & Jonides, 1999).

This paragraph has dealt with different approaches to executive functions and the connected neural correlates. To say it short and simple, who we are and how we plan and then execute those plans is basically determined by the frontal regions of our brain.

The next section will present the memory paradigm according to Koriat and Goldsmith. Memory accuracy and memory quantity will be explained and the concept of metamemory will be introduced. Finally, the neural correlates of memory accuracy will be highlighted.

2.4 Memory accuracy

When considering the contribution of subject-controlled processes to memory performance, it is important to distinguish between two different properties of memory: quantity and accuracy (Klatzky & Erdelyi, 1985; Stern, 1904). As Koriat and Goldsmith have shown, these two properties, as well as subject control, have received rather different emphasis in current research practices (Koriat & Goldsmith, 1994, 1996a, 1996b).

With the quantity-oriented and accuracy-oriented approaches to memory two fundamentally different ways of thinking about memory are introduced. The main difference is revealed by a distinction between two different memory metaphors: the storehouse and the correspondence metaphor (Koriat & Goldsmith, 1996b).

According to Koriat and Goldsmith (1996), experimental memory research is quantity-oriented. In contrast, everyday-life is designed by the importance of the accuracy-oriented conception.

In the following both approaches to memory will be introduced with special emphasis on the accuracy-oriented approach, hence it constitutes the fundament of the current work.

2.4.1 Quantity-oriented approach

A typical laboratory task concerns the presentation of words which have to be memorized. Memory performance is measured in terms of the words that can be recalled out of the total number of words that were presented. The so called list learning paradigm is strongly connected with the storehouse metaphor and memory is defined as an information-storage place. Memory is assessed input-bound which means that after the input it is measured how much of it was recovered in the output and how much was lost. When free-recall performance is scored, false answers (commission errors) are often ignored. In this concept forgetting is defined as information loss, indicated by the number of input items that can not be remembered.

It makes no difference whether the word "weapon" is remembered and the word "hat" is forgotten or vice versa. The only thing that matters concerning the storehouse metaphor is how much is remembered and not what is remembered. This reflects the difference between quality and quantity and these attributes of the storehouse conception leads to a quantity-oriented approach to memory. The quantity-oriented approach treats memory as something that can be "counted" (Goldsmith, Koriat & Weinberg-Eliezer, 2002; Koriat, Goldsmith & Pansky, 2000; Koriat & Goldsmith, 1994).

In contrast, the accuracy-oriented approach defines memory as something that can be counted on – this concept will be introduced in the following.

2.4.2 Accuracy-oriented approach

In contrast to the quantity-oriented approach, there is a second way of defining memory performance; one that eventually more represents everyday memory. For example, an eyewitness is interviewed concerning some details of a crime. In this concept, the quantity of items is more incidental hence the basic information required is the correspondence between the subjects report and the facts that actually happened. In contrast to the rather concrete storehouse metaphor, the correspondence metaphor is more abstract. Here, memory is measured in terms of its accordance with previous happenings. In comparison to the quantity-oriented approach, forgetting is defined as a loss of correspondence. Also, what is recovered plays a crucial role: it makes a difference whether a witness remembered that a defendant had a weapon but forgot that he wore a hat. The evaluation of memory correspondence is output-bound and assesses the correlation between input and output. In this concept, accuracy can be measured only for what a subject reported earlier, and not for what is omitted. These features characterize an accuracy-oriented approach to memory. Memory is defined as something that can be counted on and concerns the extent to which memory reports can be trusted (Koriat & Goldsmith, 1994, 1996a; Koriat et al., 2000). Keeping this in mind, it is obvious that the output-

bound assessment of memory accuracy is particularly suited to situations such as eyewitness testimony, in which a high importance is placed on obtaining memory reports that can be relied on (Deffenbacher, 1991; Koriat & Goldsmith, 1996c).

2.4.3 Quantity and accuracy

This differentiation between quantity and accuracy and therewith between input- and output-bound measures is well reflected in the following example concerning eyewitness reports: witness A is able to remember the names of three out of five people that were presented earlier and reaches 60% quantity. If only these three persons were really presented before, witness A achieved 100% accuracy. Witness B declares four names and reaches a higher quantity performance of 75% which at the same time reduces the accuracy to 75%.

Input-bound measures are concerned with what a rememberer fails to report, whereas output-bound emphasize what a rememberer does report (Koriat & Goldsmith, 1996c).

Input-bound (quantity) and output-bound (accuracy) evaluations are only under free-report conditions operationally distinguishable and mediated by the report option. The report option determines whether the rememberer has to answer all items or not. In a forced-report design, memory quantity and accuracy measures are equivalent, because the likelihood of remembering each input item (quantity) is equal to the likelihood that each reported item is correct (accuracy). Only under free-report conditions, in which rememberer are given the option (implicitly or explicitly) either to volunteer or to withhold information (e.g. respond with "I don't know") (Neisser, 1988) accuracy and quantity measures can differ significantly (Koriat & Goldsmith, 1996c). This is a general situation in everyday life. It is important to notice that people prefer to withhold potential incorrect information and favor to provide information of which they think is correct (Klatzky & Erdelyi, 1985; Koriat & Goldsmith, 1994).

Input- and output-bound memory evaluation may differ significantly hence the amount of input items is normally higher than the number of volunteered answers (Koriat & Goldsmith, 1996c).

The report option and its characteristic traits will be described in more detail in the next paragraph.

2.4.3.1 Report option

On the one hand, the option to report is important, because it facilitates operational differentiation between memory accuracy and quantity. On the other hand, it directly influences memory accuracy. Memory accuracy performance increases, when subjects are allowed to control their memory reporting. From this it follows that the improved accuracy leads to a corresponding decrease of quantity performance (Koriat & Goldsmith, 1994, 1996c).

During recognition as well as forced-report conditions, subjects are confronted with a set of memory questions and subsequently are forced to answer each of them, even if they have to guess. In contrast, under free-report conditions, subjects are allowed to withhold their answer, when they are not sure whether it is correct. Moreover, in open-ended memory questions, rememberer have two options to increase the accuracy of what they report. One of the two possibilities is the report option allowing subjects to decide whether to volunteer or withhold certain information. The other one is control over grain size which involves choosing the level of detail (precision) or generality (coarseness) concerning the accordant information (Goldsmith & Koriat, 1999, Koriat & Goldsmith, 1996c; Goldsmith et al., 2002).

Koriat and Goldsmith report different laboratory experiments in which always the same "paradoxical" pattern was obtained: Forced recognition leaded to an increase in quantity performance and a decrease in accuracy performance compared to free recall.

In the case when test format and report option were dispersed from each other, it was found that the increase of recognition quantity performance depended on the

test format. On the other hand, the increase of recall accuracy was justified by the possibility of free report. Two consequential results can be presented: recognition and recall accuracy measures are almost the same in free-report conditions, in which subjects have equal opportunity to screen their answers. In addition, for both the recall and the recognition test formats, free-report accuracy performance was significantly better. In sum, the report option reveals a crucial factor in the evaluation of memory accuracy (even in a laboratory research context and regardless of the particular format of the test) (Koriat & Goldsmith, 1996c).

2.4.3.2 Bonus system – payoff

Koriat and Goldsmith hypothesize that subjects are able to regulate their memory accuracy according to special situations. An explicit pay-off schedule was used with the intention to motivate accurate responding (bonus system). Free-report participants were either given a high accuracy incentive which was defined as gaining a bonus for each correct answer but losing the complete bonus if only one answer was incorrectly volunteered. A moderate incentive was represented in a balance between gain and loss of bonus. Subjects were very sensitive for the level of accuracy incentive and enhanced their accuracy significantly (for both recall and recognition testing) when a strong incentive was provided (Goldsmith et al., 2002; Koriat & Goldsmith, 1996c). The increase in memory accuracy came along with a decrease in quantity performance. Experiments, examining quantity-oriented memory performance discovered that the implementation of a bonus system did not increase quantity. An experimental group received bonus points for correctly recognized items and a control group did not get any recompense. No significant difference between both conditions could be found (Roediger & Payne, 1985).

One can conclude from that: "memory accuracy performance is under strategic control, whereas memory quantity performance is not". Moreover, strong incentives can lead to very accurate memory reports (Goldsmith et al., 2002; Koriat & Goldsmith, 1996c).

The paradigm of Koriat and Goldsmith allows a separated evaluation of quantity and accuracy. Memory performance depends on the individual competence of controlling the correctness of given answers to volunteer correct and withhold incorrect answers. The assumption that memory performance is influenced by self-directed decision processes is widespread and one has to mention the signal-detection theory in this context. The signal-detection theory concerns the possibility to quantify the ability to discern between signal and noise. The theory emphasizes that there are different conditions determining how individuals detect a signal and what the individual threshold levels will be. These thresholds are influenced by subjective experience, expectations, physiological state, etc. (Heeger, 1997).

Many memory researchers intend to diminish individual variations in self-directed processing. As Koriat and Goldsmith accentuate, it is very unsatisfactory to reduce subject's control, at least from an accuracy-oriented point of view. This is why they tried to expand the main principle of the signal-detection theory to free-report situations (Klatzky & Erdelyi, 1985) and concurrently enhanced it with concepts and ideas gained from metamemory. The paradigm of Koriat and Goldsmith is based on the concept of metamemory which will be introduced in the following.

2.4.4 Metamemory

Metamemory means "thinking about thinking" and is defined as what people "know" about their memory and the extent to which this knowledge is appropriate (Metcalfe & Shimamura, 1994). The memory paradigm according to Koriat and Goldsmith bases on the concept of metamemory. Nelson and Narens define metamemory as an executive that instigates, manages, and controls cognitive functions in memory (Nelson & Narens, 1990).
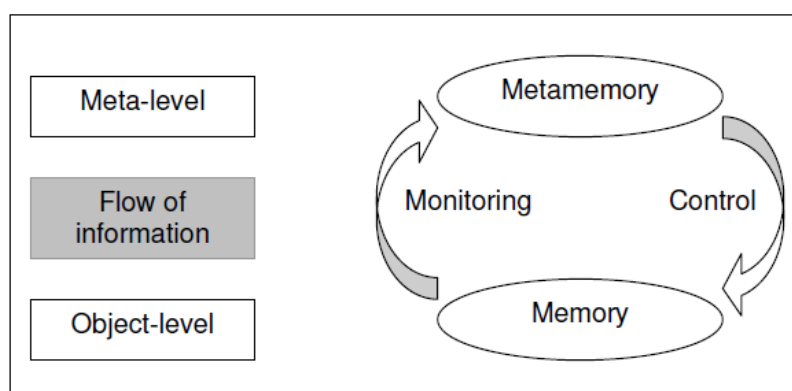
Figure 10: Hierarchical organization of metamemory with meta-level, object-level and flow of information (modified from Nelson & Narens, 1990).

They postulate three abstract different principles. The first principle states that cognitive processes are split into two specifically interrelated levels called meta-level and object-level. The second principle declares that the meta-level contains a dynamic model of the object-level.

Finally, the third principle predicates that there are two dominance relations, called "control" and "monitoring" which are defined in terms of the direction of the flow of information between the meta-level and the object-level. The basic structure of metamemory is shown in Figure 10.

Theoretical and empirical treatments require a differentiation between two separate but related functions, namely monitoring and control (Barnes, 1999; Koriat & Ben-zur, 1988). In the context of free-report memory performance, a monitoring mechanism is assumed that subjects revert to when they evaluate the correctness of a certain memory response. The following control mechanism influences whether to volunteer the best available candidate answer (Koriat & Goldsmith, 1996c; Barnes, 1999). When reporting information from memory, people invoke monitoring and control processes to screen out information that is likely to be wrong (Goldsmith et al., 2002). It is supposed that the control mechanism is regulated by the monitoring output and depends on functional incentives and situational conditions. These concepts are

implemented into the paradigm of Koriat and Goldsmith which is described in the next chapter.

2.4.5 Memory paradigm according to Koriat and Goldsmith

Koriat and Goldsmith established a framework to examine how monitoring and control processes can be used to regulate memory accuracy and quantity performance under free-report conditions (Figure 11). As highlighted by the authors, this model is independent of the characteristics of memory retrieval processes and is adaptive to both recall and recognition (Koriat & Goldsmith, 1996c).
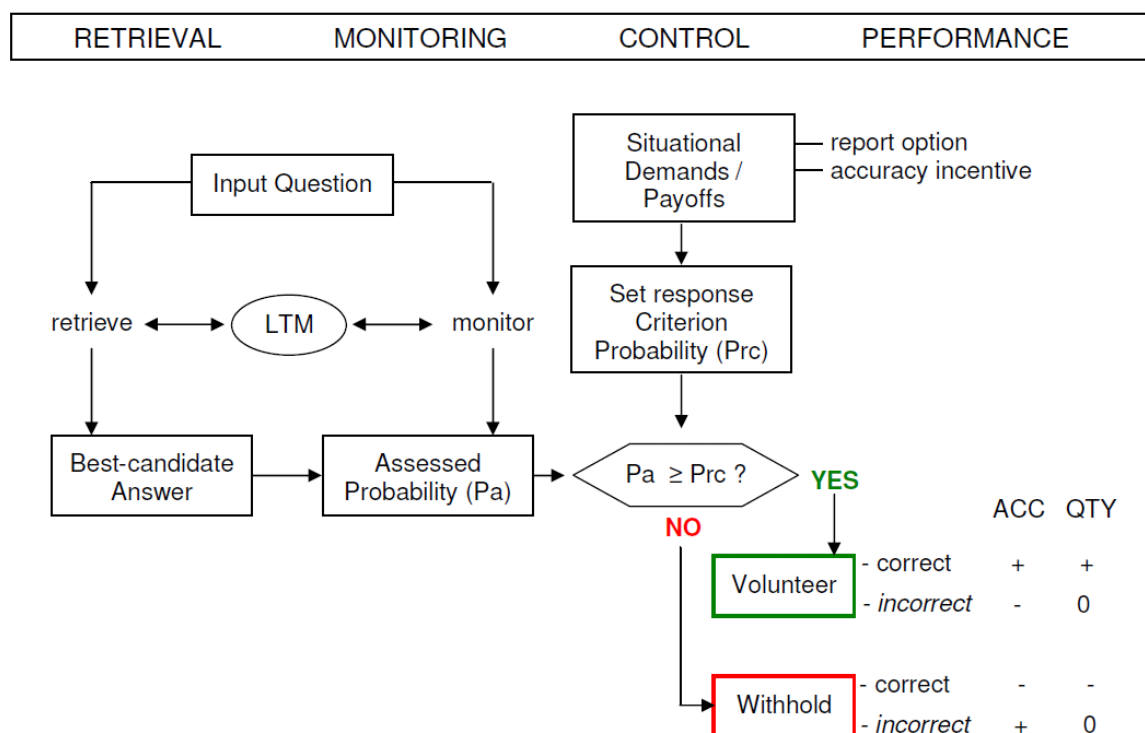
Figure 11: A schematic model of the strategic regulation of memory accuracy and memory quantity performance. Performance effects are signified by plus (+ = increase), minus (- = decrease), and zero (0 = no effect). LTM = long-term memory, ACC = accuracy, QTY = quantity, Pa = assessed probability, Prc = response criterion probability (modified from Koriat & Goldsmith, 1996c).

During the retrieval phase the pieces of information are evaluated concerning correctness by means of monitoring. Koriat and Goldsmith point out that the combination of retrieval and the subsequent monitoring process together with the estimated probability (Pa = assessed probability of being correct) is a "best-candidate" answer. Dependent on the results of monitoring, the control process then observes which information to volunteer and to withhold by comparing the assessed probability with the present response criterion probability (Prc). When the assessed probability exceeds the response criterion probability, a particular answer is volunteered, but is withheld otherwise. The Prc threshold depends on implicit or explicit payoffs and the gains for providing correct answers relative to the costs of giving wrong answers (Goldsmith et al., 2002).

According to the memory paradigm, the contributions of monitoring and control to free-report memory performance depend on mainly three factors: the monitoring effectiveness defines to which extent the assessed probabilities successfully differentiate correct from incorrect candidate answers and therewith plays a crucial role in weighing the relative payoffs for accuracy and quantity to achieve an optimal criterion setting. The control sensitivity concerns the degree to which volunteering or withholding of answers is actually sensitive to the monitoring output. Finally, the response criterion setting is related to the Prc level that is set in accordance with the incentive to be accurate (→ payoff schedule). The Prc is set individually, hence an increase in Prc is expected to raise memory accuracy to the disadvantage of quantity. According to Koriat and Goldsmith, the strategic control of memory performance should require the rememberer to weigh the relative payoffs for accuracy and quantity in reaching an optimal criterion setting (Koriat & Goldsmith, 1996c). They moreover note that both the benefits and the costs of this strategic control depend critically on the rememberers monitoring effectiveness.

2.4.6 Neural correlates of memory accuracy

Kensinger et al. (2005) aimed at identifying the processes that were related to accurate memory assignment for emotional and neutral items. They report activity in a region centered in the left anterior hippocampus that was related to accurate retrieval for both emotional and neutral Items. Accurate retrieval concerning only emotional items was found to activate the right amygdala / periamygdaloid cortex and the left orbitofrontal cortex, whereas neutral items revealed activation of the lateral inferior prefrontal cortex and the right posterior hippocampus.

It is supposed that the hippocampus plays a role in retrieval of particular contextual details required for accurate memory attribution. This finding is in line with previous studies that emphasize the important role of the anterior hippocampus in successful retrieval of contextual details associated with an encoding episode (Hoscheidt et al., 2010; Dobbins, Rice, Wagner & Schacter, 2003; Eldridge, Knowlton, Furmanski, Bookheimer & Engel, 2000; Wheeler & Buckner, 2003).

The authors conclude that activity in regions implicated in prior studies of episodic retrieval corresponded with accurate retrieval regardless of the item's emotional content (Kensinger & Schacter, 2005). Furthermore, a recent study discussed differential blood oxygenation level-dependent (BOLD) responses as a function of accuracy in the left hippocampus (Mendelsohn, Furman & Dudai, 2010). A previous study revealed activity in the left anterior prefrontal cortex which was assumed to be connected with the retrieval of perceptual details (Ranganath, Johnson & D'Esposito, 2000). In addition, activity in the left parietal cortex is related to the amount of contextual information that is retrieved (Cabeza, 2001; Henson, Rugg, Shallice, Josephs & Dolan, 1999; Henson, 1999; Wheeler, 2004). The authors discuss activity in the posterior cingulate and inferior temporal gyrus in correlation with retrieval of contextual information hence they argue that these regions are important for mental imagery and visual processing (D'Esposito et al., 1997; Malouin, Richards, Jackson, Dumas & Doyon, 2003; Simons, Graham, Owen, Patterson & Hodges, 2001).

Kensinger et al. (2005) report that activity in the amygdala / periamygdaloid cortex and orbitofrontal cortex corresponds with accurate memory attributions for emotional information.

The lingual gyrus was recently introduced to be an area reflecting activity during correct in contrast to incorrect (lag) judgments (Greve, Doidge, Evans & Wilding, 2010).

This section provided a survey of memory accuracy in general and in contrast to memory quantity. Moreover, the report option and the bonus system were described. Due to the fact that the memory paradigm according to Koriat and Goldsmith bases on metamemory functions, the concept of metamemory was introduced and finally, the memory paradigm was presented.

In the next paragraph questions and hypotheses are established which arose out of the presented information about episodic memory, false memories, executive functions, and in the first instance the memory paradigm according to Koriat and Goldsmith.

3 The present study – questions and hypotheses

The aim of the current study is to implement the model of the strategic regulation of memory accuracy and memory quantity performance by Koriat and Goldsmith into an fMRI design. The neural correlates connected with the three main processes like retrieval, monitoring, and control as well as memory accuracy and memory performance are investigated. Relationships between the different memory processes and executive functions as well as false memories are examined.

To complement the imaging results, behavioral data for the presented stimuli were acquired during the scanning procedure and will be analyzed.

3.1 Questions

The questions for the topics above are as follows:

- Are there differences in neural activation connected with retrieval (correct versus incorrect), monitoring (high confidence versus low confidence), and control (volunteering versus withholding) processes?
- To which extent do the different contrasts represent similarities and differences?
- Do retrieval and memory accuracy reveal comparable neural correlates?
- Are monitoring and control processes connected with executive functions?
- Is there a relation between memory inaccuracy and false memories?

The hypotheses that arise from these questions are introduced in the following.

3.2 Hypotheses

According the previously presented questions, the following eight hypotheses are enunciated.

Hypothesis 1

During the retrieval phase brain activity differs with regard to giving a correct in contrast to an incorrect answer. Correct responding is related to memory-specific areas like prefrontal and temporal regions and particularly the hippocampus. Moreover, the neural activation pattern of correct retrieval is similar to brain activation connected with memory accuracy as defined by Koriat and Goldsmith.

First of all, it is supposed that the current material is encoded and stored in episodic long-term memory and is finally retrieved from this memory system. The contemplated regions constitute the basic network for episodic memories. As mentioned earlier (see section 2.1.5), the prefrontal cortex is assumed to play an important role in the retrieval of episodic information stored in long-term memory (Tulving et al., 1994; Markowitsch, 2005). In addition, the network comprises limbic structures playing a role in emotional episodic memory retrieval (Fink et al., 1996; Haist et al., 2001; Levine, 2004; Markowitsch, 2005; Moscovitch et al., 2005; Steinvorth et al., 2005; Svoboda et al., 2006). Especially the left hippocampus should reveal activation during the retrieval of correct statements since previous studies reported this region to be connected with correct retrieval or rather accuracy (Habib & Nyberg, 2008; Mendelsohn, Furman & Dudai, 2010). Due to the fact that the left medial temporal lobe was presented to play a role in memory retrieval of recently learned information (Cabeza & Nyberg, 2000; Frankland & Bontempi, 2005; Sybirska, Davachi & Goldman-Rakic, 2000) and particularly in the comparison between misses and correct rejection, its involvement in correct retrieval is strongly assumed

(Takahashi, Kenichi & Kim, 2008). Correct retrieval is defined as either correct rejection or hit, in contrast to incorrect retrieval which is characterized as either false alarm or miss.

> **Hypothesis 2a**
>
> **During the monitoring phase brain activity differs with respect to giving a high confidence rating in contrast to a low confidence rating.**
>
> **Due to its relationship to executive functions, high confidence ratings will activate frontal regions and particularly the ventrolateral PFC as well as regions that are involved in correct memory retrieval, like the medial temporal lobe, including the hippocampus and parahippocampal gyrus.**

As introduced in chapter 2.3, the term executive function contains different cognitive abilities like cognitive flexibility, monitoring, or decision-making (Stuss & Knight, 2002).

During high confidence rating, a certain memory is retrieved and afterwards a decision has to be taken to judge it with 100% confidence. Executive functioning is strongly related to activation in the frontal lobes (Smith & Jonides, 1999; Godefroy et al., 2008; Huey et al., 2009) (see 2.3.2). Most notably, the ventrolateral prefrontal cortex plays an important role in first-order executive processes that comprise active retrieval and information selection (Tanji & Hoshi, 2008). High confidence rating will additionally reveal brain activation that is characteristic for correct memory retrieval, because a certain memory is assumed to be subjectively correct when a judgment of 100% confidence is given. These regions are specifically the left hippocampus (Habib & Nyberg, 2008; Mendelsohn et al., 2010), parahippocampal gyrus (Fink et al., 1996; Haist et al., 2001; Levine, 2004; Markowitsch, 2005; Moscovitch et al., 2005; Steinvorth et al., 2005; Svoboda et al., 2006), and the medial temporal lobe

(Cabeza & Nyberg, 2000; Frankland & Bontempi, 2005; Sybirska et al., 2000; Takahashi et al., 2008) (see section 2.1.5).

Hypothesis 2b

Low confidence ratings reveal a higher demand for cognitive functions and attention. Due to the uncertainty about the retrieved memory, more cognitive effort has to be investigated in memory retrieval. Brain activity is particularly associated with prefrontal regions like dorsolateral prefrontal cortex. In addition, it is connected with parietal areas as well as limbic and temporal regions.

Low confidence is assumed to be associated with a higher requirement of cognitive functions and therefore activates a broad pattern of neural correlates. During the low confidence rating it is assumable that the access to the according memory is impaired. This leads to an increase in cognitive effort that is needed for possible memory retrieval. Besides activation in temporal and limbic regions and particularly the hippocampal formation and the parahippocampal gyrus that are related to memory retrieval (Fink et al., 1996; Haist et al., 2001; Levine, 2004; Markowitsch, 2005; Moscovitch et al., 2005; Steinvorth et al., 2005; Svoboda et al., 2006), neural correlates are supposed to reveal activation that are linked to higher-order executive functions. Due to the assumed complex cognitive process during low confidence ratings, brain activation is additionally revealed in the dorsolateral PFC (DLPFC). This region is connected with higher-order executive components of behavioral planning, including monitoring, manipulation, and integration of different information (Tanji & Hoshi, 2008). Low confidence rating is moreover associated with frontal and parietal brain activation which was also found during shifting between different tasks (Moulden et al., 1998; Luria, 1966; Stuss & Benson, 1986; Rogers et al., 1998; Miyake et al., 2000).

> **Hypothesis 3a**
>
> **During the control phase brain activity differs relative to volunteering or withholding the accordant response.**
>
> **Volunteering a response provokes neural activation in the dorsolateral and ventral medial PFC as well as in the cingulate cortex.**

Volunteering is defined as betting on a certain memory and comprises the desire to maximize the outcome resulting from the chosen decision. According to the experimental design, volunteering a correct response results in an increase of bonus points whereas the risky side action is the loss of bonus points being the consequence of incorrect responses. The prefrontal cortex is thought to play a crucial role in both motivation and executive processes (Pochon et al., 2002). As already explained above, the dorsolateral PFC is more involved in higher-order executive components like WM and planning (Tanji & Hoshi, 2008; Pochon et al., 2002). It was found that beside cingulate cortex and basal ganglia, the DLPFC is related to the value of expected reward and actual outcome. Thus, the dorsolateral prefrontal cortex is likely to be a part of the broader network involved in adaptive decision-making. Imaging studies have also shown that the activation in the dorsolateral prefrontal cortex is modulated by the amount of monetary reward (Lee & Seo, 2007).

The ventral PFC and to some degree the ventral medial areas are related to reward sensitivity and motivation (Pochon et al., 2002). This region was also found to play a central role in decision-making under risk (Lee & Seo, 2007). The posterior cingulate cortex was detected to be activated by (expected) reward (Lee & Seo, 2007; Pochon et al., 2002). Moreover, the anterior cingulate and dorsolateral prefrontal cortex were reported to correlate with two fundamental executive processes, namely selective attention and task management (Smith & Jonides, 1999).

Hypothesis 3b

Withholding information is associated with response inhibition expressed by neural activation in ventrolateral PFC in conjunction with a more extensive frontoparietal network. Moreover, brain areas reveal activation that are known for memory retrieval.

When a certain response is not volunteered but withheld, no bonus points can be gained or lost. Withholding is associated with response inhibition which is assumed to be an important executive function (Miyake et al., 2000). The relevant brain areas for response inhibition include the ventrolateral PFC, mainly in the right hemisphere often in conjunction with a more extensive frontoparietal network (Walther, Goya-Maldonado, Stippich, Weisbrod & Kaiser, 2010; Garavan, Ross & Stein, 1999; Konishi et al., 1999; Aron, Robbins & Poldrack, 2004). Due to the fact that the accordant memory is not volunteered it is supposed to be rather fragile and cognitive effort is needed to retrieve that memory which provokes neural activity in memory specific regions.

Hypothesis 4

Monitoring and control processes exhibit a strong relationship. Both depend on a certain memory and require a high degree of cognitive function which leads to neural activation in frontal brain regions and particularly the dorsolateral portion of the PFC. In addition, the anterior cingulate cortex along with medial temporal areas provoke activation.

During the confidence judgment, subjects monitor their recognition and make a subjective rating about their previous memory performance. Based on this, the according response is either volunteered or withheld. Monitoring as well as control is

correlated with decision-making processes. The main purpose of both phases is assumed to be an active manipulation of relevant information in working memory (Miyake et al., 2000). This connection to working memory is supposed to be associated with the dorsolateral portion of PFC (Goldman-Rakic, 1996; Smith & Jonides, 1999).

Furthermore, an increase in confidence at recognition was found to be associated with bilateral activation in the anterior and posterior cingulate cortex along with medial temporal regions (Moritz, Gläscher, Sommer, Büchel & Braus, 2006). Monitoring is one of many different executive functions (Tanji & Hoshi, 2008). An executive control network was reported which amongst others, showed activation of the anterior cingulate (ACC) (Fan, McCandliss, Fossella, Flombaum & Posner, 2005). The ACC was additionally found to play a role in conflict monitoring processes (Botvinick et al., 2004).

Hypothesis 5a

Even though being differently operationalized, memory accuracy provokes brain activity in similar or even the same areas as correct memory retrieval, namely prefrontal and temporal regions and particularly the left hippocampus.

There are different ways to define memory accuracy. Here it is operationalized as withholding an incorrect answer, according to the memory paradigm introduced in 2.4.5. Correct memory retrieval defined as giving a correct answer is, from the behavioral point of view, rather the opposite of withholding an incorrect response, because conflictive cognitive functions are required. Due to the fact that both evoke the same consequence, namely the excellence of the accordant memory, the same brain regions will reveal neural activation. Characteristic areas are prefrontal (Tulving et al., 1994; Markowitsch, 2005) and temporal regions and particularly the left hippocampus (Habib & Nyberg, 2008; Mendelsohn et al., 2010) and the medial

temporal lobe (Cabeza & Nyberg, 2000; Frankland & Bontempi, 2005; Sybirska et al., 2000) (see also Hypothesis 1).

> **Hypothesis 5b**
>
> **Memory inaccuracy is defined as volunteering an objectively false and subjectively potentially correct answer and is therefore connected with false memories. Memory inaccuracy provokes a diffuse neural network, involving frontoparietal and temporoparietal regions, the MTL, and the anterior cingulate cortex.**

Memory inaccuracy is defined as volunteering incorrect answers. Due to the fact that objectively false memories are volunteered points out that individuals may believe in their correctness which is one of several definitions of false memories. This is in line with the assumption that when an accordant memory is not volunteered it is supposed to be rather fragile. Although there is no characteristic brain region reliably connected with false memories but rather a broad and diffuse network it is assumable that memory inaccuracy is related to this pattern. However, relevant brain regions comprise frontoparietal structures that were identified concerning false recognition (Fuentemilla et al., 2009). In addition, greater activation was found in temporoparietal regions during true in contrast to false recognition (Abe et al., 2008). Furthermore, the anterior cingulate cortex is related to false memories since it was reported that activity was greater for false than for true memories (Okado & Stark, 2003). Finally, the MTL is thought to constitute a contributing factor to false memory (Cabeza et al., 2001; Schacter et al., 1996; Schacter & Addis, 2007).

4 Method

For this study twenty-nine healthy subjects were shown a short video-tape and performed an approximately 2 hours lasting neuropsychological testing battery afterwards. To err on the side of caution that participants understood the instruction appropriately they performed a kind of quiz as a preparation for the scanning procedure.

Subsequently, the subjects were scanned with functional magnetic resonance imaging concerning the content of the film and completed a post-scanning debriefing. In the following section, the demographical data of the subjects are introduced and the utilized materials are presented. Moreover, the basics of functional magnetic resonance imaging are illustrated. Furthermore, a description of the image acquisition, processing and data analysis of data gained by fMRI are given.

4.1 Participants

24 subjects (12 male [mean age = 26, SD = 2.8, min = 22, max = 31 years], 12 female [mean age = 24.13, SD = 3.4, min = 20, max = 30 years]) without prior history of neurological or psychiatric diseases and with normal or corrected to normal vision participated in the study which was approved by the local ethics committee. All participants (mean age = 25, SD = 3.2, min = 20, max = 31 years) were right-handed, as assessed by the Edinburgh inventory (Oldfield, 1971), and native speakers of German. Female and male subjects did not significantly differ concerning their mean age (female versus male, T = .55, p = .592). Demographic data of the subjects are illustrated in Table 1.

Table 1: Demographic data of the participants.

	Mean age	SD	min	max
Female	24.13	3.4	20	30
Male	26	2.8	22	31
overall	25	3.2	20	31

Additionally, subjects underwent neuropsychological testing including working memory, long-term memory, visuo-constructive abilities, executive functioning, and attention. IQ measures were accomplished using age-specific short versions of the "Leistungsprüfsystem".

All subjects received course credits or were paid 20 € (plus the sum they gained for correct volunteering during the scanning procedure) for their participation.

Written informed consent was obtained from all participants prior to the examination and all subjects were examined exclusively by the author.

From originally 29 subjects, three female and two male participants were removed from the fMRI analysis due to their head motion during scanning which exceeded four mm (see Appendix D). Due to the fact that the study design included an fMRI Scan, all subjects had to fulfill inclusion and exclusion criteria listed in Table 2.

Table 2: Inclusion and exclusion criteria for the fMRI examination.

Inclusion criteria	Exclusion criteria
- right-handed	- claustrophobia
- healthy	- indelible metal inside the body
- 18-35 years of age	- tattoos
- German as first language	- permanent make-up
	- pacemaker
	- defective vision (and no contacts)
	- neurological or psychotic diseases

4.2 Neuropsychological data

Subjects underwent an extensive neuropsychological testing battery assessing the main cognitive functions like anterograde memory, working memory, visuospatial construction ability, executive functioning, intelligence, and attention to control for possible between-subject differences in overall neuropsychological performance.

Personality features were controlled by the revised version of the Freiburg Personality Inventory – Revised (Fahrenberg, Hampel & Selg, 2001). Depressive symptoms were evaluated with the Beck Depression Inventory (Beck & Steer, 2005). The BSI was used as a self-report inventory of psychopathology and psychological distress (Derogatis, 1993).

The Trail Making Test (Reitan, 1958), the FAS (Lezak, 1995), and the Game of Dice Task (Brand et al., 2002) were implemented to assess executive functioning. To evaluate the verbal long-term memory, the Verbal Learning and Memory Test (in the german version: "Verbaler Lern- und Merkfähigkeitstest") (Helmstaedter, Lendt & Lux, 2001) was applied. Moreover, the ROCF (Rey-Osterrieth Complex Figure) Test (Osterrieth, 1944) was used.

4.2.1 Neuropsychological testing battery

In the following, each neuropsychological procedure is presented as a brief summary. An overview of the different neuropsychological tests investigated as well as the according succession is illustrated in Table 3.

4.2.1.1 Memory

A) VLMT Auditory Verbal Learning Test –German version– (Helmstaedter et al., 2001): Anterograde memory

The VLMT is used to measure special aspects of episodic and working memory. Subjects are confronted with a word list including fifteen different words and have to learn as many words as possible which is followed by immediate free recalls. The

whole procedure is repeated four times. After the fifth free recall, a different fifteen-item interference word list is presented. The interference word list is used to test working memory performance and has to be recalled only one time. This is immediately followed by a sixth free recall of the previous word list.

30 minutes later, the first word list has to be remembered in a delayed free recall. Subsequently, a recognition task has to be executed. To rate recognition performance, the subjects are confronted with a sixty item word list. This includes both words of the original word list and the interference word list. In addition, it comprises words with a semantic or phonological similarity to the words of the first list and subjects are required to specify whether a word was on the original list, or whether it was a completely new word. To generate verbal memory performance, several scores are calculated. The estimation of immediate free recall is characterized as the number of correctly recalled words of the first recall. Learning memory performance results from the sum of correctly recalled target words of trial one to five. An estimation of proactive interference is produced by the mean number of correctly recalled words, whereas the first free recall of the first list causes retroactive interference.

An indicator of verbal delayed memory performance is on the one hand the delayed free recall after thirty minutes and on the other hand, the number of correct recognized words. The number of incorrectly recalled target words of the trials one to five, measures intrusions.

B) Rey-Osterrieth Complex Figure Test (ROCF) (Osterrieth, 1944): Anterograde memory (especially for visuospatial construction ability and visual memory)

The ROCF involves three test conditions. First of all, subjects are instructed to copy the complex figure from the original. It has to be noted that the figure has to be drawn as accurate as possible maintaining the relations. This is followed immediately by a free recall trial. About 30 minutes later a delayed free recall is administered.

A copy score which presents the accuracy and measures visual-constructional ability is included in the measure of performance. Furthermore, the time for copying the figure is evaluated. Both, the immediate and delayed free recall scores involve the amount of information that remained over the time interval (Strauss & Sherman, 2006).

4.2.1.2 Working Memory

A) Wechsler Memory Scale – Revised

WMS-R; Subtest: Digit Span (Härting et al., 2000): Measure of different memory functions

The WMS-R subtest digit span comprises two parts. In the first run, numbers are said in one second intervals in a monotone voice. The participant has to remember all numbers of one trial and has to recall them afterwards, in the right order (digit span forward). In the second run, again numbers are presented and the subject is required to recall the numbers in the reverse order. In both runs the number of correctly recalled digit spans is assessed. Both parts demand for attention and memory recall, but the second part also requires a higher cognitive load.

4.2.1.3 Executive Functioning

A) The Trail Making Test A and B (Reitan, 1958): Measure of attention, speed of information processing and mental flexibility

The Trail Making Test is separated into two parts, Trails A and Trails B. In "Trails A" subjects are confronted with encircled numbers that are distributed across a sheet of paper in a random order. A line has to be drawn to connect the numbers in the correct order beginning with number 1 and ending with number 25.

In "Trails B" the sheet of paper comprises encircled numbers ranging from 1 to 13 and encircled letters ranging from letter "A" to letter "L". The numbers and letters have to be connected with a line consecutively but in an alternating order.

In both trials participants are instructed to work as quickly as possible without lifting the pencil off the sheet of paper. The examiner has to correct errors immediately. The time in seconds that subjects needed for completion of each of the two parts constitutes the scoring. Both parts demand for perceptual tracking of a sequence and speeded performance, but B also requires divided attention (Strauss & Sherman, 2006).

B) "FAS"-task and "animals" task (Lezak, 1995): Executive functioning

The "FAS"-task assesses lexical word fluency while the "animals" task measures verbal semantic fluency.

In the "FAS"-task, subjects have to list as many words as possible within one minute per letter. The words are starting with F, A or S as an initial letter. Moreover, participants are advised not to name proper nouns, e.g. persons, cities, states. In addition, each word should only be named once and it is not allowed to use several words including the same "word stem". In sum, three different scores are calculated to rate subjects' performance. The general performance score comprises the number of correctly named words. Further scores concern rule violations and word repetition. The word repetition score is calculated by the number of words that have been named repeatedly.

The "animals" task evaluates verbal semantic fluency. Within one minute subjects have to enumerate as many different animals as possible. In this trial, the initial letter does not mind. Participants are advised to name animal species (e.g. shark) and genus (e.g. fish). Again, three scores indicate the subjects' performance.

C) The Game of Dice Task (Brand et al., 2004): Measure of risk-taking behavior

The Game of dice task evaluates the risk-taking behavior in a gambling situation. A virtual single die and a shaker are used. Participants are instructed to increase their fictive starting capital of 1000 € within the following 18 throws of the die. Before each trial, subjects have to choose a single number or a combination of numbers (two,

three, or four numbers). The specific gains and losses depend on the probability occurrence of a choice. The amount of risk associated with each choice is obvious, because the winning probability of each choice can be established on the basis of the ratio of occurrence (1:6, 2:6, 3:6, and 4:6). The choices of one or two numbers (probability of winning less than 50% and high gains but also high penalties) are defined as risky, whereas the choices of three and four numbers are classified as non-risky.

4.2.1.4 Attention

A) d2 Test (Brickenkamp, 1998): Measures selective attention and mental concentration

The test form comprises a landscape layout of 14 test lines with 47 characters in each line. Each character consists of a letter "d" and "p" marked with one, two, three or four small dashes arranged either above or below the letter. The Participant is required to scan the lines as fast as possible and cross out all occurrences of the letter "d" with two dashes while ignoring all other characters.

After an interval of 20 seconds it has to be started at the beginning of the next line, with the instruction to always work from left to right. In sum, the test takes about 8 minutes.

One scoring key concerns identifying errors of omission (missing characters that should have been crossed out) and the other one is related to identifying errors of commission (crossing out characters that should not have been crossed out).

Further scores involve the total number of processed items, the percentage of errors, and the total number of items processed minus errors.

4.2.1.5   Intelligence

A) Leistungsprüfsystem (Horn, 1983): Measures different kinds of intelligence

For short diagnoses the subtests LPS – 1, LPS – 2, LPS – 4, and LPS – 12 are administered which have an approximate duration of 20 minutes and reveal a high correlation with IQ.

Each of the subtests consisted of about 40 items. Every item comprises either words or a series of digits and letters with one exception according to a basic rule or a correct word. Participants are required to identify the wrong element in respectively different time limits, like two minutes for LPS – 1, three minutes for LPS – 2, eight minutes for LPS – 4, and two minutes for LPS – 12. The number of correctly performed items is assessed.

4.2.1.6   Handedness

A) Edinburgh Handedness Scale (Oldfield, 1971): Assesses hand dominance

The Handedness Scale is a measurement scale which is applied to detect the dominance of a person's right or left hand in everyday activities. The scale comprises questions like e.g. with which hand a ball is thrown. The inventory can either be used by an observer assessing the person, or by a person self-reporting hand use.

4.2.1.7   Affective Disorder

A) Beck Depression Inventory

BDI (Beck & Steer, 2005): Measure of the severity of self-reported depression in adolescents and adults

The BDI involves 21 item self-report ratings for measuring the presence and severity of characteristic attitudes and symptoms of depression in adults and adolescents. Subjects rate the current depressed mood regarding four different options, scored from 0 to 3. The greater severity of a given depressive symptom is reflected by increasing scores. The maximum score is 63, whereas totals between zero and ten

imply no depressive symptoms and are inconspicuous. Furthermore, scores from 11 to 17 reveal mild to moderate depression. Sums of 18 and more exhibit clinical relevance constituting severe depression (Strauss & Sherman, 2006).

4.2.1.8 Personality

A) Freiburg Personality Inventory – Revised

FPI (Fahrenberg et al., 2001): Assesses personality

The Freiburg Personality Inventory – Revised measures personality on 12 different dichotomized dimensions. The dimensions include life satisfaction (confident / content versus dissatisfied / sorrowful), social orientation (socially responsible / cooperative versus self-dependent / self-oriented), achievement motivation (ambitious / competitive versus unmotivated), inhibition (inhibited / insecure versus self-confident / sociable), excitability (excitable / sensitive versus calm / placid), aggressiveness (aggressive / assertive versus chary / controlled), stress (stressed / strained versus not feeling stressed / strained), physical complaints (many complaints / psychosomatic tendencies versus few complaints / no psychosomatic tendencies), worries about health (fear of diseases / health-conscious versus being free of health worries / robust), openness (willing to admit minor weaknesses and violations of everyday conventions versus oriented to social norms / giving a socially desirable impression), extraversion (extraverted / impulsive versus introverted / prudential), and neuroticism (emotionally labile / many problems and bodily complaints versus emotionally stable / self-confident). The subscale openness presents a validity scale.

Socially desirable response tendencies are revealed by low results (standard scores one to three). According to Fahrenberg this means that the interpretation of all other responses is limited.

B) Brief Symptom Inventory (Derogatis, 1993): Evaluates psychopathology and psychological distress

The Brief Symptom Inventory is a self-report instrument and consists of 53 items which concern nine symptom dimensions, namely somatization, obsession-compulsion, interpersonal sensitivity, depression, anxiety, hostility, phobic anxiety, paranoid ideation, and psychoticism; and additionally three global indices of distress like global severity index, positive symptom distress index, and positive symptom total. The current or past level of symptomatology, intensity of symptoms, and the number of reported symptoms is assessed respectively by the global indices of distress. The general severity index (GSI) is an indicator of the current level of distress by combining information on the numbers of symptoms and the intensity of perceived distress. Again, the positive symptom distress index (PSDI) measures the intensity of symptoms, corrected for the numbers of symptoms. Finally, the positive symptom total (PST) gives information about the number of symptoms that were reported (Derogatis & Melisaratos, 1983).

Table 3: The order of measures of cognitive functioning.

Neuropsychological tests
RCFT – copy
RCFT – immediate
VLMT (1 – 5, interference, short recall)
d2
Edinburgh Handedness Inventory
RCFT – delayed
Digit span
VLMT (7, recognition)
LPS
GDT
"FAS"

"animals"
TMT A and B
BDI
FPI
BSI

4.3 Materials

4.3.1 Videotape

A short film with emotional material was used to create a controlled experience that encompassed features of real-life events. The film was named "The New Cat" and had an approximate duration of 6 minutes. The film by Ziv Shachar was used as stimulus material in the research project "The assessment of eyewitness memory: a multi-componential, correspondence-oriented approach" and was therefore translated from Hebrew into German. The videotape was shown on a computer screen that was 13" in size and for a consistent and adequate volume extern boxes were used. The videotape was presented about 2 hours prior to the scanning phase and consisted of many scenic details, well suited for the fMRI procedure.

The film was about a man who loves dogs but has problems with keeping them in the house because they make dirt. He decides to have a cat at home but gets very shortly in trouble with this, because he treats the cat like a dog. After only one day, the cat jumps from the window sill and is run over by a car. The woman who drove the car and the chief character fall in love with each other and they bury the cat together. They move in together and the woman gives a dog to the man as a present (for screenshots see Figure 12).

None of the participants indicated having seen the video before and subjects were not informed that their memory of the film would be tested at a later stage.

Figure 12: Six exemplary screenshots of the film "The New Cat".

4.3.2 Statements

180 statements concerning the story of the film were constructed, of which one half concerned true details and the other half contained incorrect details of the film. Moreover, all true and all false statements were consistently related to different categories, like content, perception, and action to allow for standardization. The statements were phrased as shortly as possible (with a range between 6 and 10 words) for subjects not having trouble to read it on the screen inside the scanner. For an overview of all statements and the order used in the fMRI presentation see Appendix C.

4.4 Pre-Scanning Procedure

To familiarize the subjects with the experimental set-up, they executed a presentation of neutral statements adapted to the presentation inside the scanner. Some of the 45

statements were true and some of them were false e.g. "elephants have thick skin" (see Appendix B for the statements). Subjects performed the pre-testing-learning phase on the same PC the video-tape was shown earlier and used the numbers "1", "2", and "3" of the PC keyboard to answer. It was important that subjects deliberated on the statements to get used to the available time slot, respectively. The instruction was analogical to the fMRI scanning procedure (see 4.4). The procedure was important to make sure that subjects internalized the instruction and automated pushing the buttons to assure an accurate scanning procedure. All participants reached the required cut-off value which was saved in a txt file and was therefore disposable for an evaluation. The evaluation of the accordant cut-off is presented in Appendix B.

For stimulus presentation and response collection, the software Presentation 9.0 (Neurobehavioral Systems, Albany, CA, USA; http://www.neurobs.com) was used.

4.5 Experimental task – fMRI

The task included in this study design required the subjects to evaluate correct and incorrect statements from the videotape they saw before (see Figure 2). It has to be noted that during the videotape audiovisual material was shown, whereas the fMRI-Scanning involved only written statements. In this way, the statements were never presented before and the studied material had to be mentally reconstructed, before being answered. This is comparable with eyewitness testimony hence witnesses may have seen a crime and subsequently, when they appear in court, have to respond verbally.

In sum, 180 statements appeared on a computer screen in a random order. Each statement had to be assessed concerning its quality as being correct or incorrect (retrieval phase). This was accompanied by a confidence rating offering three increments, namely 100% confidence, 75% confidence, and 50% confidence (monitoring phase). For further analyses it was decided to differentiate between high (100%) and low confidence (combining 50% and 75%) only. Subsequently, subjects

had to choose whether to volunteer or to withhold the answer (control phase). Volunteering consisted of expressing the will to bet on the correctness of the given answer. An explicit bonus system was implemented to motivate accurate responding. If an answer was correctly volunteered one bonus point could be earned or lost if an incorrect answer was volunteered. Of course, when deciding for withholding the response, no bonus points were awarded irrespective of the correctness of the answer. A formula was developed in which the amount of bonus points was evaluated and multiplied by .075 to achieve the according sum in Euro. From this, a certain amount of money resulted being disbursed to the participants (see Appendix B).
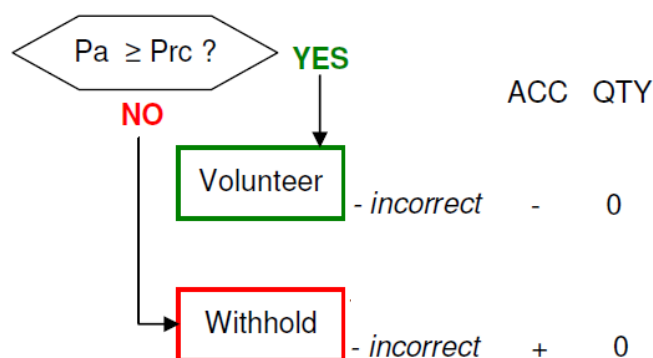
Figure 14: Memory accuracy and inaccuracy according to the memory paradigm.

For the baseline a fixation cross was presented to complete the foregone sequence and attract attention for the next sequence (see Figure 13B).

Finally, memory accuracy was defined as withholding an incorrect answer, whereas memory inaccuracy was related to volunteering an incorrect answer (see Figure 14).
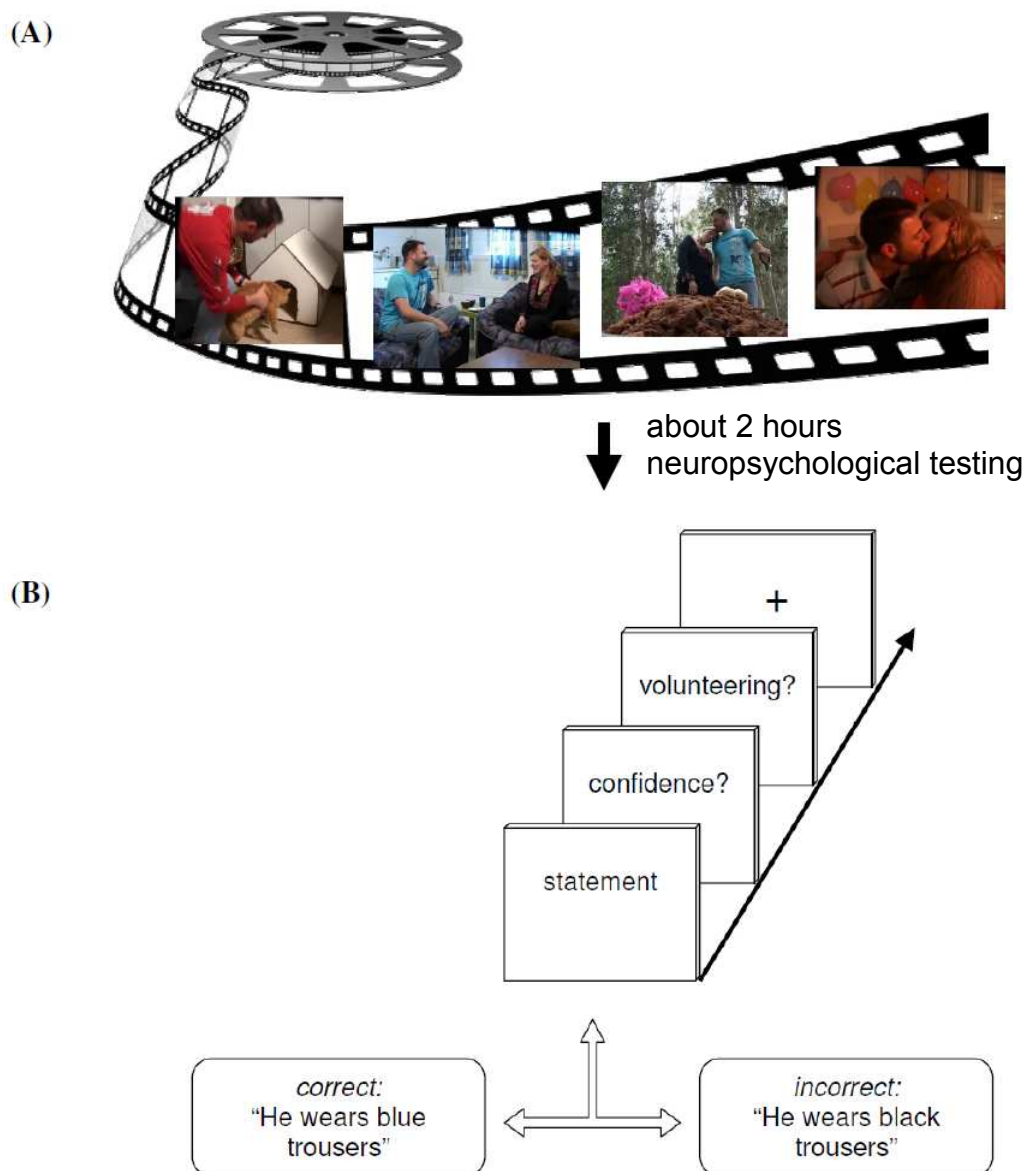
Figure 13: Experimental design:
(A) The encoding session consisted of watching a 6-min emotional film in a quiet room. After about 2 hours the scanning procedure occured.
(B) An exemplary sequence during the fMRI scanning

During the fMRI measurement, subjects made their choices using three fingers of their right hand (index finger, middle finger, and ring finger) on a three button response device, called lumitouch (see Figure 15). Random jitter was included to prevent correlation of event regressors (for further explanation see 4.7.1.3). For this,

statements were presented between three and five seconds, and the confidence retrieval, the question for volunteering / withholding as well as the fixation cross were illustrated between two and three seconds.

The whole run took about 43 minutes. In order to prevent head movements throughout the scan, the experiment was divided into two consecutive scans, each containing one half of the statements. Each run lasted an average of 17 min. For stimulus presentation and response collection, the software Presentation 9.0 (Neurobehavioral Systems, Albany, CA, USA; http://www.neurobs.com) was used. During the fMRI experiment, the stimulus display was back-projected onto a screen mounted on a custom head coil.
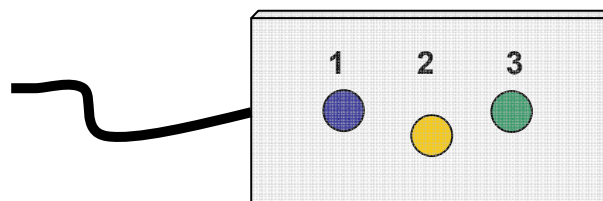
Figure 15: Illustration of the lumitouch. Individuals were requested to push the accordant buttons on the lumitouch, whereas the button functions were as follows: left / blue = the statement is correct, right / green = the statement is incorrect; left / blue = 100% confidence, middle / yellow = 75% confidence, right / green = 50% confidence; left / blue = volunteering, right / green = withholding, middle / yellow = fixation cross).

4.6 Post-Scanning Questionnaire

Immediately after scanning, subjects completed the post-scanning debriefing with questions concerning the fMRI procedure. The questionnaire involved questions about the presentation of the statements, the confidence rating, and volunteering and withholding during the scanning procedure. Participants had to rate the effort to (A) identify the statements on the screen, (B) to read the statements in the given time-slot, (C) to rate the statements as either correct or incorrect and (D) to choose the accordant buttons on the lumitouch. Concerning the confidence rating, subjects were

required to rate the effort to (A) estimate the sureness related to each statement, (B) to give the confidence rating in the given time-slot, and (C) to choose the three different buttons on the lumitouch. Finally, individuals were requested to rate the effort to (A) volunteer or withhold the accordant answer, (B) to give the answer in the given time-slot, and (C) to choose the two different buttons. Each response had to be evaluated on a scale ranging from one to five with 1 = very easy, 2 = easy, 3 = moderate, 4 = difficult, and 5 = very difficult.

Moreover, subjects were asked whether they used any strategies. For more details see Appendix E.

4.7 Fundamentals of functional magnetic resonance imaging

Functional magnetic resonance imaging has quickly become a popular tool for measuring brain function. In the following, the fMRI procedure is presented, including the main principles about MRI and fMRI. Moreover, block designs and event related designs are described and the problem concerning head motion during the scanning procedure will be introduced.

Subsequently, a brief overview of image acquisition and image processing is given.

4.7.1 Physiological background

4.7.1.1 MRI

During MRI the response of hydrogen molecules is measured. The hydrogen nucleus is most commonly used, because of its ability to give strong MRI signal and due to the fact that there are many of them in the human brain (Buxton, 2002; Hashemi, Bradley & Lisanti, 2004; Horowitz, 1995; Jezzard & Clare, 2001). Hydrogen nuclei are positively charged particles that spin around their axis. A magnetic field is produced, when an electrically charged particle moves. Each hydrogen nucleus in the brain can be defined as a vector which represents the strength and direction of

the magnetic field of the hydrogen nucleus produced by its spinning around its axis. This vector is also known as the Magnetic Dipole Moment (MDM) (Buxton, 2002; Hashemi et al., 2004; Horowitz, 1995; Jezzard & Clare, 2001). When the brain is outside of a magnetic field, the MDM's of the hydrogen nuclei are not aligned and point in different directions. Instead, when the brain is in a magnetic field, the MDM's of the hydrogen nuclei align themselves in the direction of the main magnetic field (the amount depends on the strength of the magnetic field). For example, in a 1.5 Tesla magnetic field, 4.5 MDM's per million align themselves in the direction of the main magnetic field (Morris, 1986). In addition, when the brain is arranged in a magnetic field, the MDM's of the hydrogen nuclei start to precess. The frequency of this precession differs related to the type of nucleus and depends on the strength of the magnetic field. For example, in a magnetic field of 1.5 Tesla the frequency of precession for the MDM's of hydrogen nuclei will be 64 MHz (64,000,000 revolutions per second) and in a magnetic field of 3 Tesla the frequency of precession will be 128 MHz (Jezzard & Clare, 2001; Horowitz, 1995). In a second step when measuring the MRI signal the radiofrequency (RF) pulse is applied. The RF pulse is an electromagnetic wave that results from the brief application of an alternating current perpendicular to the direction of the main magnetic field. This is why it is also called 90° RF-pulse (Buxton, 2002; Hashemi et al., 2004; Horowitz, 1995; Jezzard & Clare, 2001). Normally, the 90° RF-pulse 'tips' the MDM's in the x-y plane. After this, the 90° RF-pulse ends and the MDM's return to their original orientation after a certain amount of time which is known as relaxation (Buxton, 2002; Hashemi et al., 2004; Horowitz, 1995; Jezzard & Clare, 2001). The RF-pulse inserted energy into the system which is released when the MDM's return from the 'tipped' state to their original lower energy state. The release of energy is called relaxation and comprises the radiofrequency signal that is measured during MRI (Buxton, 2002; Hashemi et al., 2004; Horowitz, 1995; Jezzard & Clare, 2001).

The MDM of a hydrogen nucleus consists of two components, namely the amplitude in the z-axis and the amplitude in the x-y plane. After the RF-pulse was applied, the

amplitude in the z-axis is zero while the amplitude in the x-y plane is maximal. In contrast, during relaxation the amplitude in the z-axis increases while the amplitude in the x-y plane decreases. This indicates that the relaxation of the MDM's of the hydrogen nuclei includes two components. The increase along the z-axis of the MDM's is named T1 relaxation while the decrease in the x-y plane of the MDM's is called T2 relaxation (Buxton, 2002; Hashemi et al., 2004; Horowitz, 1995; Jezzard & Clare, 2001). A T1 weighted signal or a T2 weighted signal can be achieved by changing certain scanner parameters. If the time from RF-pulse to measurement of the signal (TE = time of echo) is kept short as well as the time between two successive RF-pulses (TR = time of repetition), the difference in T1 for the different tissues is maximized and the according scan is called a T1 weighted scan. These scans are obtained with a TE of approximately 20 ms and a TR of approximately 500 ms. Due to the fact that these scans reveal good contrast between grey and white matter, they are used for anatomical scans.
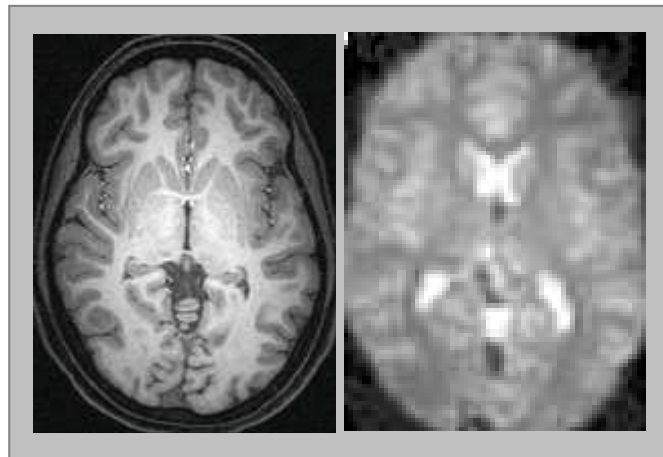
Figure 16: T1 and T2-weighted signals: on the left: anatomical T1-weighted image, on the right: functional T2-weighted image.

In comparison, if the TE as well as the TR is long, the difference in T2 for the different tissues is maximized and the accordant scan is called a T2 weighted scan.

Here, a TE of approximately 80 ms and a TR of approximately 2000 ms is used. T2 weighted scans lesions appear very bright and this makes them well suited for pathological scans. Moreover, the T2* signal is the most commonly measured in BOLD fMRI, because the T2 signal is relatively insensitive to inhomogenity in the magnetic field (Jezzard & Clare, 2001; Horowitz, 1995). See Figure 16 for a comparison of the two kinds of signals.

After a MRI signal is measured it has to be transformed into a 3D image of the individual brain. Three magnetic gradients which are oriented orthogonal to each other are used to evaluate the unique contribution of each part of the brain to the MRI signal. The slice select gradient is oriented along the z-axis, the frequency-encoding gradient is oriented along the x-axis, and the phase-encoding gradient is oriented along the y-axis (for example) (Buxton, 2002; Hashemi et al., 2004; Horowitz, 1995; Jezzard & Clare, 2001). The z-axis runs from head to foot, the x-axis runs from ear to ear, and the y-axis runs from nose to back of the head (see Figure 17).
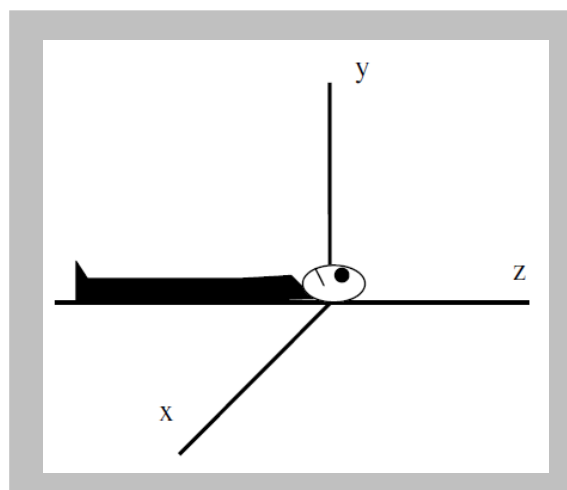
Figure 17: An exemplary view of the three coordinate axes.

The slice-select gradient is applied to select the slice position in the direction of this gradient (x-direction). After the application of the slice-select gradient, the MRI signal still contains information about the entire slice. To determine the contribution of each

individual point in a slice (commonly referred to as a pixel or voxel), the frequency-encoding gradient and phase-encoding gradients are used. Normally, as many phase-encoding (and therefore frequency-encoding) steps as there are rows in the slice are performed.

4.7.1.2 fMRI

MRI which is used for structural scans of the brain can also be applied to look at functional activity of the brain, in which case it is referred to as functional magnetic resonance imaging (fMRI). FMRI uses MRI equipment to measure the level of oxygen in the blood in response to task activation and therefore the changing neural activity (Raichle, 2001).

The type of scanning technique most commonly used to obtain fMRI images is echo planar imaging (EPI). EPI is a very rapid imaging technique. This comprises many advantages in MRI, because faster scans can reduce motion-related artifacts and problems in MR images. The most important practicability of this technique is in the dynamic study of the brain activity related to blood volume changes (BOLD) (Bandettini, Wang, Hinks, Rifosky & Hyde, 1992; Kwong & Wisskoff, 1992; Ogawa et al., 1992).

The BOLD fMRI technique quantifies changes in the inhomogenity of the magnetic field which are the outcome of changes in the level of oxygen in the blood (blood oxygenation) (Detre & Wang, 2002; Heeger & Ress, 2002; Ogawa et al., 1992).

Deoxyhemoglobin is the form of hemoglobin without oxygen contained within the red blood cells. It has magnetic properties and can cause an inhomogenity in the magnetic field by which it is surrounded. In contrast, oxyhemoglobin is the form of hemoglobin with oxygen also include in the red blood cells. Oxyhemoglobin exhibits nearly no magnetic properties meaning that is has hardly any influence on the magnetic field. This is why a high level of deoxyhemoglobin in the blood will lead to a greater field inhomogenity which causes a decrease of the fMRI signal (Detre & Wang, 2002; Heeger & Ress, 2002; Ogawa et al., 1992). The function of the BOLD

fMRI signal against time in response to a temporary increase in neuronal activity is called hemodynamic response function (HRF) (Heeger & Ress, 2002).

After an initial decrease ("initial dip") a large increase in the BOLD fMRI signal follows which achieves its maximum after about 6 seconds (Fox, Raichle, Mintun & Dence, 1988).
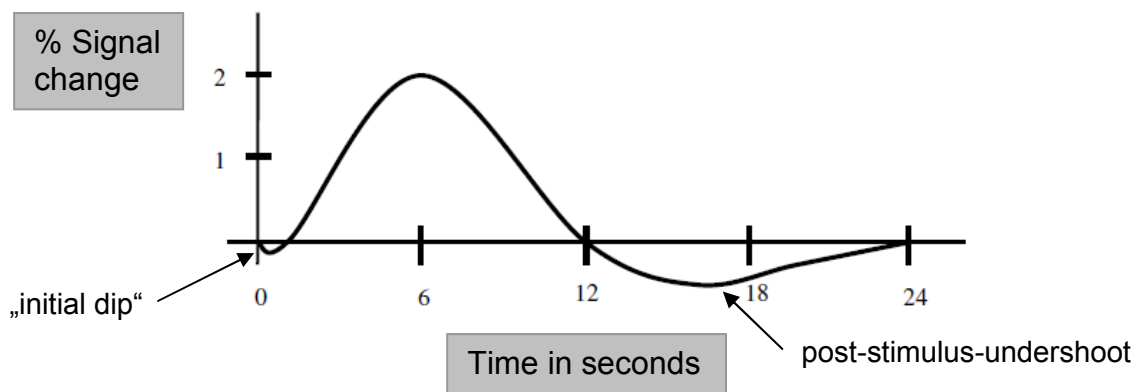
Figure 18: The BOLD fMRI signal against time (BOLD response).

The increase occurs, because of an oversupply of oxygen-rich blood. This leads to a large decrease in the relative level of deoxyhemoglobin which causes the increase in the BOLD fMRI signal. The level of deoxyhemoglobin returns to the normal state and the BOLD fMRI signal first has an initial undershoot after approximately 24 seconds and then decays until it has reached its original baseline level; this is also called BOLD response and is illustrated in Figure 18 (Heeger & Ress, 2002).

4.7.1.3 Block versus event-related fMRI designs

In this paragraph, two different kinds of experimental designs that are used in fMRI research will be presented, namely block designs and event related designs. Moreover, some advantages and disadvantaged will be discussed.

Block designs: this design is also known as boxcar (Aguirre & D'Esposito, 2000). A characteristic feature is the fact that two or more conditions are alternated in blocks. Each block consists of particular fMRI scans and one block only comprises one certain condition.

20-60 sec
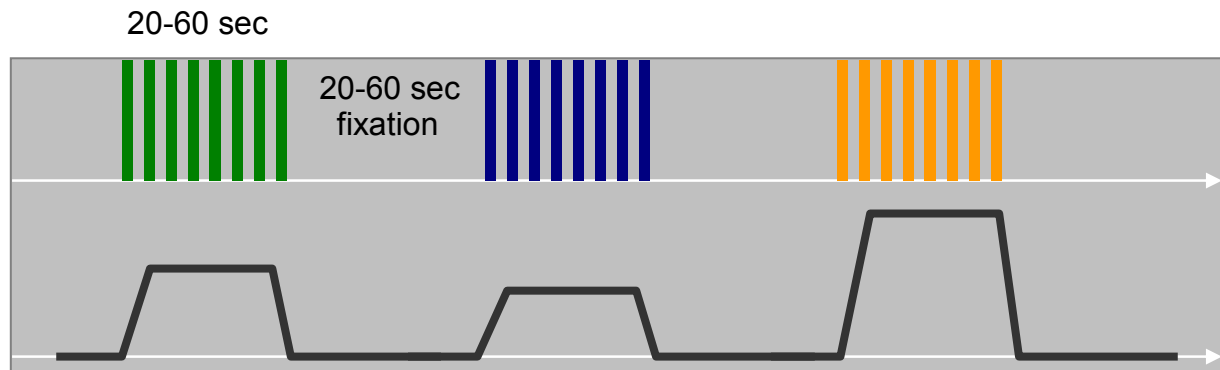
Figure 19: Schematic illustration of a block design. In this example 3 different stimuli are represented.

The main advantage concerns its statistical power: the increase of fMRI signal in response to a stimulus is additive. When lots of stimuli are presented rapidly the amplitude of the HRF increases. Moreover, when each block is alternated with a rest condition a maximum amount of variability can be reached (Aguirre & D'Esposito, 2000). A main disadvantage is related to the fact that stimuli types can not be randomized within a block which makes the type of stimulus predictable and subjects realize the according order of events (see Figure 19) (Aguirre & D'Esposito, 2000; Donaldson & Buckner, 2001).

Event related designs: this design estimates the course of the HRF related to each stimulus presentation (see Figure 20). Therefore, the different HRF's that concern a single type of stimulus are averaged.
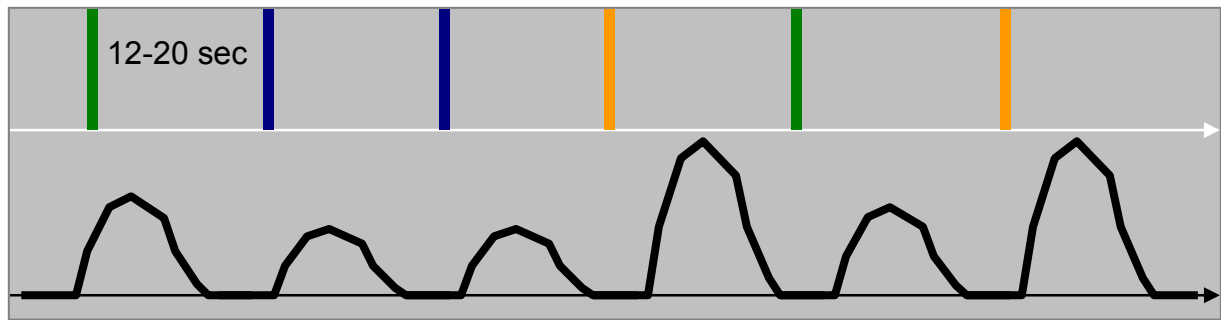
Figure 20: Schematic illustration of a fixed interval event related design. Again, 3 different stimuli are represented.

On the one hand, this is more realistic, but on the other hand the statistical power is very low, because the signal change in the BOLD fMRI signal of single stimulus presentation is small (Aguirre & D'Esposito, 2000; Donaldson & Buckner, 2001).

One important disadvantage of event related design is its low statistical power. Although it is possible to improve the power either by introducing latency jitter (Dale, 1999) or by implementation of null events (Friston, Holmes, Price, Büchel & Worsley, 1999; Josephs & Henson, 1999) it is still not comparable with block designs. A latency jitter can easily be applied by replacing a fixed inter-stimulus-interval (ISI) with a variable ISI (see Figure 21). In this case the duration of the ISI according to an exponential distribution is randomized (Dale, 1999). The alternative to latency jitter is the introduction of null events. Here, instead of an event, no stimulus is presented.
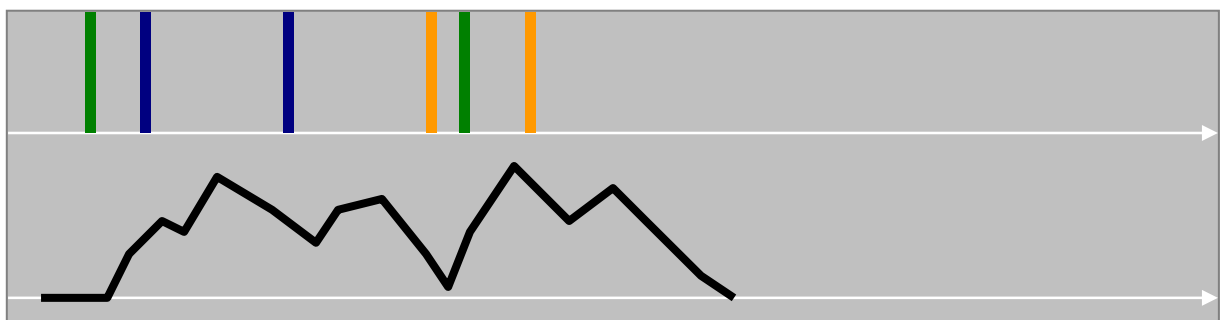
Figure 21: Schematic illustration of a rapid event related design with variable ISI (latency jitter).

Nevertheless, event related designs have many advantages as illustrated in Table 4. First of all, the main advantage is that randomization of trials is possible. Trials of the same type do not have to be grouped any longer (Aguirre & D'Esposito, 2000; Donaldson & Buckner, 2001). This means that the response to an event is neither systematically influenced by prior events, nor is it confounded by differences in the subject's cognitive state. Habituation, anticipation, and strategy effects are minimized which increases the power to draw valid conclusions from an experiment.

Moreover, event related designs make it possible to remove certain trials (Donaldson & Buckner, 2001). Events can be categorized post hoc related to the subject's behavior. Another advantage concerns the fact that some experimental problems cannot be blocked. Event related designs can focus the response to an infrequently occurring stimulus appearing in a series of frequently occurring stimuli (odd-ball experiments) (Donaldson & Buckner, 2001).

Even blocked stimuli can be evaluated as distinct events. This leads to a potentially more accurate model (Price, Veltman, Ashburner, Josephs & Friston, 1999).

Table 4: Advantages of event related designs.

Advantages
1. Flexibility and randomization
2. Post hoc sorting
3. Rare or unpredictable events can be measured
4. Treating blocks as events

4.7.1.4 Head motion

Motion, particularly head motion of participants, influences the quality of anatomical and functional data critically (Brammer, 2001; Wood & Henkelman, 1985). When anatomical data is obtained, it takes a few minutes to record data from the entire head. During this time it is fundamental that the participant remains stock-still. Head

motion in this procedure will affect the three-dimensional representation of the brain. Head motion can occur within or between slices. If it emerges within slices, the consequence is fuzziness or image repetition that extends across the entire image. If it occurs between slices, the result is a staggering of image edges as soon as the slices are assembled in order to obtain a three-dimensional representation of the data. A high level of head motion in an anatomical data set evokes inaccuracies in morphological measurements and difficulties in overlaying functional data onto anatomical structure. This cannot be corrected satisfactorily. In contrast to anatomical data, for functional data it is even more important to control for head movements, because signal changes due to the BOLD effect are very small (Kwong & Wisskoff, 1992). There are possibilities to correct for artifacts evoked by head movement, in the form of mathematical algorithms. They can be used after the data collection, although strong movements cannot be corrected. Head motion that occurs during the scan causes brain tissue being scanned in different physical locations inside the magnetic field. If this happens, the signal from a certain volume of tissue won't be collected at the same field strength which is not due to differences in activation. These signal changes will interfere with signal changes from the functional brain response which confounds the functional signal over time. According to this, head movement during functional imaging is an important problem of any fMRI study (Hunt & Thomas, 2008).

4.7.2 Image acquisition and MR Technical Parameters

Functional MR images were acquired on a Siemens Magnetom Investigational Device 7T syngo MR B15 with echo planar imaging (EPI) capability. Head motion was restricted using expandable foam pads that surrounded the head. Stimuli were presented on a screen. Multislice T2*-weighted echoplanar images were achieved from a gradient-echo sequence with the following parameters: repetition time (TR) = 3000 ms, echo time (TE) = 29 ms, field of view (FOV) = 230 mm, flip angle = 76°, slice thickness = 4mm. 30 axial slices were oriented in the plane of the anterior –

posterior commissure and covered the whole brain. For each subject, additional high-resolution anatomical images were acquired using the 3D T1-weighted magnetization prepared, rapid acquisition gradient echo (MP-RAGE) sequence with the parameters: TR = 2300 ms, TE = 3.93 ms, inversion time (TI) = 1100 ms, flip angle = 12°, FOV = 256 x 256 mm, matrix size = 1.0 x 1.0 x 1.0, 160 slices with a thickness of 1 mm (Poser, Koopmans, Witzel, Wald & Barth, 2010; Poser & Norris, 2009).

4.7.3 Image processing and data analysis

In the following the different steps of data analyses and their consequences will be presented. It has to be noted that only those processes that were used for the analyses in this study will be introduced in more detail. For an overview see Figure 22.
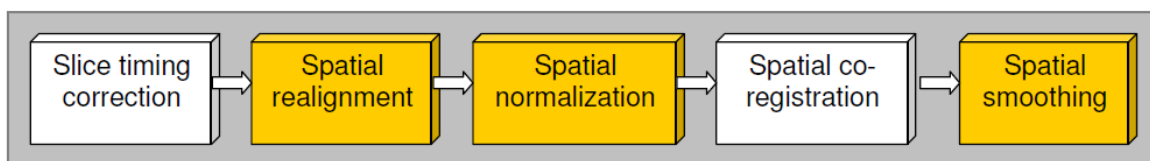
Figure 22: The different steps of data analyses with those highlighted in yellow that were performed in this study.

Slice timing correction: In this step the dataset is temporally adjusted. During the scan slices of the functional images are acquired throughout the TR. This is why the BOLD signal concerns different layers of the brain at different time points. Without correcting for slice timing, it might seem as though the same change in the BOLD fMRI response starts at an earlier time for slices that are acquired later in time than for slices that are acquired earlier when, in fact, it was just sampled from the later one at a point closer to the peak of its HRF. To avoid this problem, the individual slices of a volume have to be adjusted in the temporal domain. A temporal correction

for the differences in acquisition time between the slices is carried out which is called slice timing correction (Smith, 2001).

Spatial realignment: Of course subjects are previously instructed not to move during the scan and usually head constraint is used to minimize movement, anyhow certain head movement always happens (see section 4.7.1.4). The main outcome is that the same voxel does not necessarily represent the same location in the brain throughout time (Ashburner & Friston, 2000, 2003; Brammer, 2001). This may lead to two different problems. On the one hand, movements might be correlated with task performance resulting in false activations after the statistical analysis. Even if the movement is not correlated with task performance, they will add noise in the signal which leads to a decrease in the statistical power (Ashburner & Friston, 2000, 2003; Brammer, 2001). The correction for movement artifacts is done for each subject separately.

The realignment adjusts also for apparent movement (an artifact arising from the scanner). Due to the fact that the fMRI scanner heats up throughout the time it seems as though the head drifts slightly. After realignment, the amount movement of each subject is diagrammed in a coordinate system.

Spatial normalization: Normally datasets are not only evaluated for one single subject, but for a larger sample. Obviously, all brains differ concerning orientation, size, and shape. This is why these features of the brains of individual subjects are changed to match the orientation, size, and shape of a standard brain (Ashburner & Friston, 2000, 2003). There are advantages to make the divergent brains more alike. Comparisons over and between different subjects are only possible, when the same voxels in the brain represent the same anatomical location. In addition, when different brains are mapped to a specific standard brain, communication of different anatomical regions and the accordant effects are more standardized. This matching of individual brains to a standard brain is known as spatial normalization (Ashburner & Friston, 2000, 2003; Jenkinson & Smith, 2001).

Spatial co-registration: Is the alignment of scans from different modalities. This means that EPI fMRI scans are repositioned until they are in the same position as a reference EPI fMRI scan. Co-registration might support spatial normalization. The high resolution anatomical scan is more detailed than the fMRI scans, so normalization of the high resolution anatomical scan to a standard brain often leads to better results than matching the fMRI scans to the standard brain (Ashburner & Friston, 2003; Jenkinson & Smith, 2001).
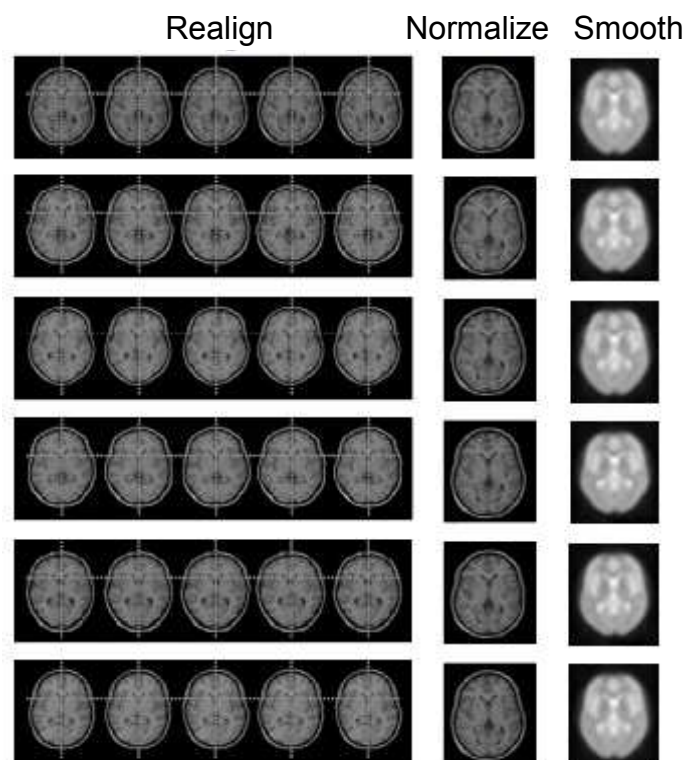
Figure 23: The different qualities of fMRI data according to the different analyses steps.

Spatial smoothing: Means to spatially blur images. This process has different advantages like for example an increase of the signal to noise ratio due to removing high spatial frequencies. Furthermore, comparisons across subjects are easier, because during smoothing the small frequency differences are removed. Again, due to smoothed data it is easier to achieve the requirements for applying Gaussian Field Theory to correct for multiple comparisons in the ensuing statistical analysis. The

reason for this is that data are more normally distributed (Smith, 2001). In general, smoothing is executed by convolving the 3D volume with a 3D Gaussian kernel. This means that each data point is multiplied by a curve in the shape of a 3D distribution. The shape of the smoothing curve is defined by the Full Width Half Maximum (FWHM). This is the width of the curve at half of the maximum and is usually defined in millimeters. The analyses steps that were executed in this study are depicted in Figure 23 related to the accordant fMRI images. Functional volumes were analyzed with SPM5 (Statistical Parametric Mapping; Wellcome Department of Imaging Neuroscience, London, UK; http://www.fil.ion.ucl.ac.uk/spm) implemented in MATLAB 7 (The Mathworks Inc., Natick, MA, USA).

The images were realigned, normalized into the Montreal Neurological Institute (MNI) coordinate space and smoothed with a 5 x 5 x 5 mm Gaussian kernel (full width half maximum).

Parameter estimates of the resulting general linear model were calculated for each subject and each voxel. For population inference, a second level analysis was performed, using the contrast estimates for the simple effect of each experimental condition.

Differential contrasts of interest were calculated according to the experimental factors retrieval phase (correct answer versus incorrect answer, and vice versa), monitoring phase (high confidence versus low confidence, and vice versa), and control phase (volunteering versus withholding, and vice versa) as well as retrieval phase versus monitoring phase (and vice versa), retrieval phase versus control phase (and vice versa), and monitoring phase versus control phase (and vice versa) to assess differential modulation of the BOLD signal induced by each factor. To detect only memory accuracy (without an overlap to quality) according to the model of Koriat and Goldsmith (see Figure 14) the factor memory accuracy was calculated: high memory accuracy (withholding an incorrect answer leads to an increase in memory accuracy)

versus low memory accuracy (volunteering a correct answer leads to a decrease in memory accuracy) (and vice versa).

The statistical threshold for within- and between-group comparisons was set to p < .001, corrected for multiple comparisons at the cluster level.

4.7.4 Localization of Activations

SPMT maps resulting from the group analysis were superimposed onto a group mean MR image which was calculated from the normalized anatomical T1-images of each subject (see above). Standard stereotactic coordinates of voxels showing local maximum activation were determined within areas of significant relative changes in neural activity associated with different experimental conditions. Maxima were anatomically localized and labeled with an anatomical SPM5 toolbox, namely AAL which refers to the Automated Anatomical Labeling map which is a 3-dimensional map containing 116 brain regions co-registered to standard MNI space. MNI coordinates refers to a standard brain imaging coordinate system developed by the Montreal Neurological Institute (Tzourio-Mazoyer et al., 2002).

5 Results

In the following section, the results of the current study are presented. The statistical analyses were performed with the program SPSS (Statistical Package for the Social Sciences', Version 15.0 for Windows). The imaging data was analyzed with SPM5 which was implemented in MATLAB 7.

5.1 Presentation of the results

First of all, the results of the neuropsychological testing battery will be introduced. Afterwards the behavioral data is depicted with regards to the Post-Scanning Questionnaire and the responding behavior during the fMRI scanning procedure. Finally, the results of the imaging data are presented. At the end of the section the hypotheses will be verified.

5.1.1 Neuropsychological Tests

A summary of the percentile ranks, means, and standard deviations is presented in Table 5. Individual neuropsychological data were within the range of reference population norms for all tests which were administered (see Methods). There was no evidence for neurological or psychiatric impairment and subjects showed normal to above performance in the different memory tests.

Table 5: Results of the neuropsychological tests and the questionnaire battery.

Domain / test	Percentile rank	Means (N = 24)	SD	Min	Max
ANTEROGRADE MEMORY					
Rey-Osterrieth-Figure					
Copy	99	35.96	.19	35	36
delayed recall (30 min.)	78	29.38	4.78	19	36
Auditory Verbal Learning Test (VLMT = German: Verbaler Lern- und Merkfähigkeitstest) -German Version-					
Trial 1	78	8.38	2.1	4	13
Trial 1-5	57	58.00	5.1	42	60
WORKING MEMORY					
Wechsler Memory Scale – Revised					
Subtest: digit span					
original order	46	7.91	1.78	5	12
reverse order	52	6.97	1.79	3	12
EXECUTIVE FUNCTIONING					
Trail Making Test					
A (duration)	64	2.62	5.93	11	37
B (duration)	61	46.27	8.93	28	66
FAS-Test					
F – A – S	49	43.06	1.74	19	57
"animals"	67	27.10	6.35	16	40
Game of dice task	59				
risky		2.79	3.89	0	17
non-risky		15.21	3.89	1	18

ATTENTION					
d2 Test	61				
speed		528.34	48.99	445	613
concentration		191.38	36.42	86	247
INTELLIGENCE					
Leistungsprüfsystem					
1 and 2 (general education)	63	45.76	9.48	27	67
4 (reasoning)	82	29.62	3.49	23	36
12 (academic performance)	65	27.17	3.07	21	34
Beck Depression Inventory	Cut-offs:				
	12: mild to moderate depression	4.13	3.94	0	12
	18: severe depression				
Freiburg Personality Inventory – Revised					
life satisfaction		5.66	1.76	2	9
social orientation		5.86	1.71	3	9
achievement motivation		4.59	1.45	2	9
inhibition		4.24	1.38	2	7
excitability		4.28	2.17	0	9
aggressiveness		3.97	2.09	0	9
stress		3.93	2.34	0	9
physical complaints		4.00	2.63	0	9
worries about health		4.48	2.06	0	8
openness		5.62	1.72	2	9

extraversion	5.17	1.37	3	7
neuroticism	4.45	2.01	0	8
Brief Symptom Inventory				
GSI	.28	.22	.02	.74
PSDI	1.17	.23	1.00	1.81
PST	11.76	8.19	1	32

5.1.2 Post-Scanning Questionnaire

A summary of the results is presented in Table 6. Subjects rated the questionnaires concerning the responding during the scanning procedure mainly as very easy and easy. Participants had no difficulties to perform the instruction appropriately.

Table 6: Results of the Post-Scanning Questionnaire.

Domain	Means (N = 24)	SD	Min	Max
STATEMENTS				
identification	1.65	.67	1	3
speed	2.17	.93	1	4
rating	2.96	.78	1	4
buttons	1.64	.66	1	3
CONFIDENCE RATING				
rating	2.48	.69	1	4
speed	2.34	.77	1	4
buttons	2.01	.85	1	4
VOLUNTEERING / WITHHOLDING				
rating	2.01	.76	1	3

| speed | 1.97 | .73 | 1 | 4 |
| buttons | 1.65 | .81 | 1 | 4 |

5.1.3 Behavioral data

The behavioral data was gained during the scanning procedure and comprise the response behavior of the subjects related to the experimental task (see section 4.5). Parametric methods were applied in the case of normally distributed data. For the differential contrasts defined in the fMRI experiment T-tests for paired samples were executed. T-tests revealed that subjects responded to the statements mainly correctly (retrieval phase: correct answer versus incorrect answer, T = 23.59, p < .001). During retrieval process, different responding pattern can be distinguished: (A) to assume a true statement (hit), (B) to decline a true statement (miss), (C) to decline a false statement (correct rejection), and (D) to assume a false statement (false alarm).
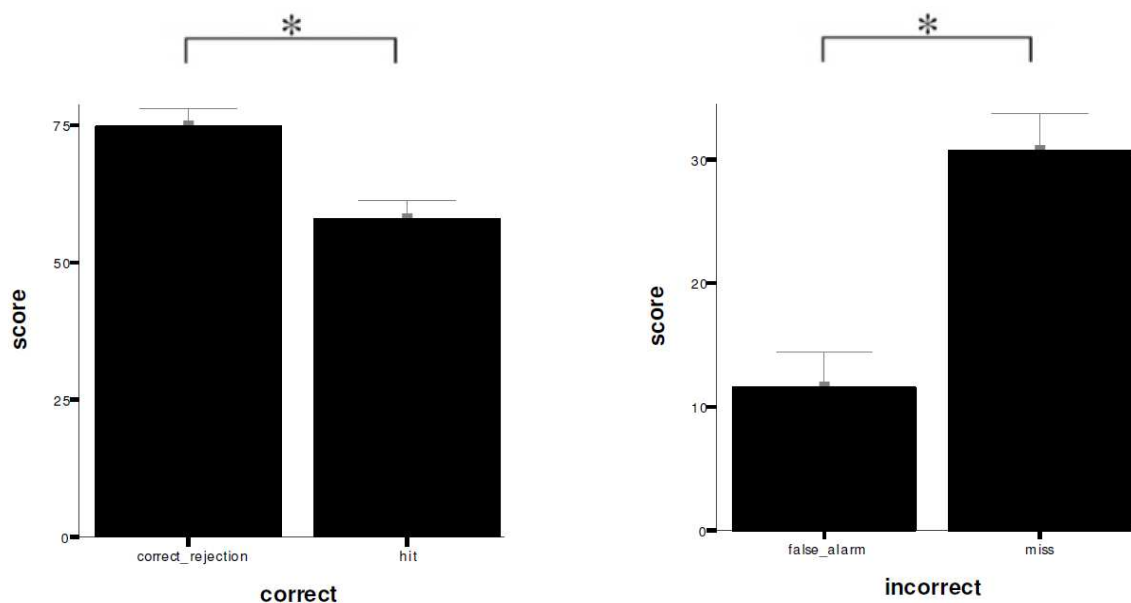
Figure 24: Comparison of mean ratings (+ SD) concerning correct (correct rejection versus hit) and incorrect (false alarm versus miss) retrieval.
* = statistical significance (p < .001)

The results show that when a statement was answered correctly this was a consequence of correct rejection significantly more often than it was resulting from a hit (correct rejection versus hit, T = 6.56, p < .001). When a statement was answered incorrectly this was because of a miss significantly more often than it was due to a false alarm (miss versus false alarm, T = 8.57, p < .001). The results are illustrated in Figure 24.
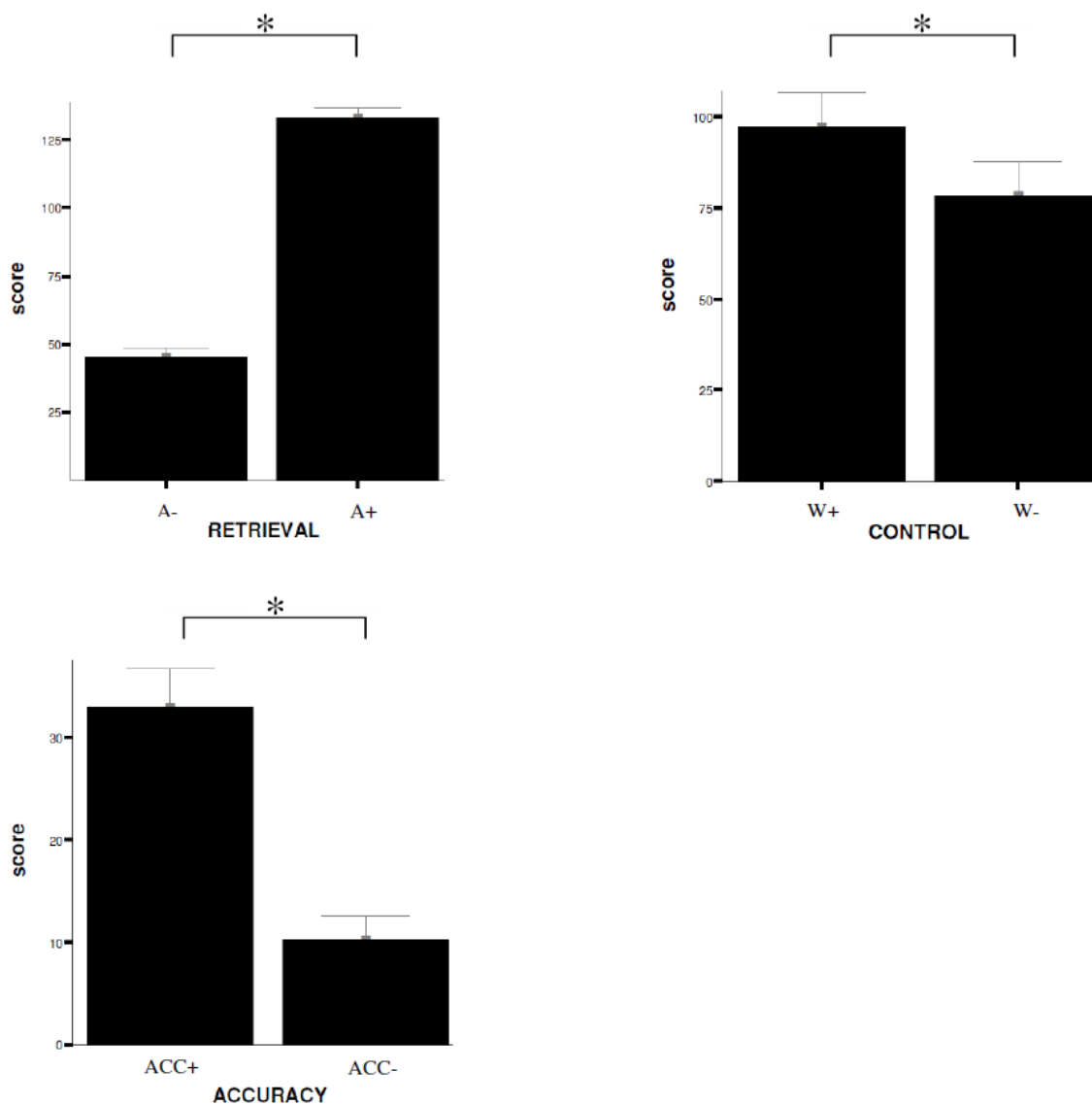
Figure 25: Comparison of mean ratings (+ SD) given by the subjects on items during scanning procedure for the different experimental conditions, retrieval phase, control phase, and memory accuracy.
W+ = volunteering; W- = withholding; SD = standard deviation; * = statistical significance (p < .001 and p < .05 for control)

No significant difference can be reported for the confidence rating of the statements (monitoring phase: high confidence versus low confidence, T = -1.43, p = .16). Moreover, the analyses reveal that subjects rather volunteered an answer instead of withholding it (control phase: volunteering versus withholding, T = 2.1, p < .05). Participants showed respectively a significant increase in memory accuracy (high memory accuracy versus low memory accuracy, T = 9.18, p < .001). The results of the behavioral data are depicted in Figure 25.

5.1.4 Neuroimaging data

The functional magnetic resonance imaging data were analyzed across 12 female and 12 male subjects. Only contrasts with statistically significant increases in neural activity entered the analysis.

In the following sections, the different contrasts are presented consecutively. The tables show the region labels, hemispheres, and the x-, y-, and z-coordinates. The coordinates are standardized MNI coordinates, referring to the local maxima within each area of activation. MNI coordinates concern a standard brain imaging coordinate system developed by the Montreal Neurological Institute. Brain regions will be presented that are within the boundaries of the AAL atlas. AAL refers to the Automated Anatomical Labeling map which is a 3-dimensional map containing 116 brain regions co-registered to standard MNI space.

For all contrasts the so-called "glass brains" are illustrated. These are projections of significant activations onto representations of the standard stereotaxic space, which was defined by Talairach and Tournoux (1988). Additionally, images were included that present the local maxima of areas of significant relative increase in neural activity, which were displayed superimposed on MRI sections to detail the functional anatomy of the activations and their relationship to underlying structural anatomy.

5.1.4.1 Retrieval phase (correct > incorrect responding)

The main effect of correct (relative to incorrect) answers reveals significant differential bilateral activations of the precuneus, left hippocampus, the insula, left middle temporal gyrus (MTG), and right lingual gyrus (p < .001, uncorrected). The reverse contrast (incorrect > correct) does not show any differential activation. Data are displayed in Table 7 and Figure 26.

Table 7: Group activations for the contrast between correct > incorrect retrieval.

Anatomical region	Side	MNI coordinates		
correct > incorrect		x	y	z
Precuneus	L	-14	-48	40
	R	14	-16	36
Hippocampus	L	-20	-36	0
Insula	L	-36	-32	22
Lingual gyrus	R	10	-40	2
Middle temporal gyrus	L	-42	-50	8
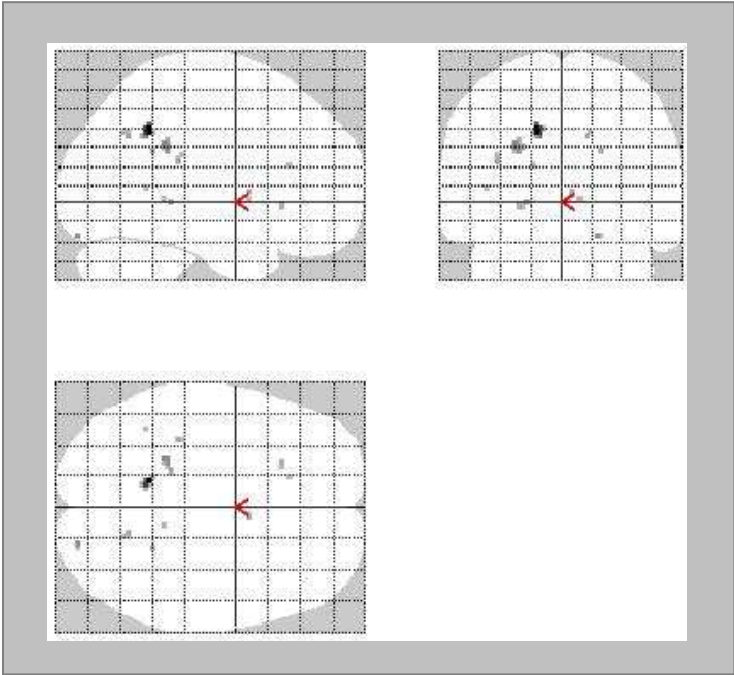
Figure 26a: Retrieval phase: relative increases in neural activity associated with correct > incorrect retrieval. Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space ("glass brains"). The MNI coordinates for each activated cluster are presented in Table 7. P = posterior; A = anterior; L = left; R = right.

Figure 26b: Relative increases in neural activity associated with correct > incorrect retrieval superimposed in terms of colour on MRI sections to depict the functional anatomy of the activations and their relationship to the underlying structural anatomy. The exact coordinates of the local maximum is indicated by x, y, and z-Talairach coordinates. Increased neural activity was seen amongst others in left hippocampus (x = -20, y = -36, z = 0).

5.1.4.2 Monitoring phase (high confidence versus low confidence)

Areas of significant differential activation revealed by high confidence (relative to low confidence) are located bilateral in the fusiform gyrus, left lingual gyrus, and the left parahippocampal gyrus ($p < .001$, uncorrected). The reverse contrast (low confidence > high confidence) demonstrates, amongst others, bilateral activation of the hippocampus, the angular gyrus, precentral gyrus, lingual, middle occipital, inferior parietal and postcentral gyri, putamen, Rolandic operculum, different temporal and frontal and occipital regions, the left precuneus, and the right insula ($p < .05$, FDR corrected). At $p < .05$, FWE corrected the left precuneus is activated. See Table 8 and Figure 27 for detailed information.

Table 8: Group activations for the contrast between high versus low confidence.

Anatomical region	Side	MNI coordinates		
high > low confidence		x	y	z
Fusiform gyrus	R	34	-48	-4
	L	-34	-50	-10
Parahippocampal area	L	-28	-42	-6
Lingual gyrus	L	-32	-48	-2
low > high confidence				
Precuneus	L	-8	-50	36
	L	-2	-56	30
	L	-2	-64	24
Cuneus	L	-2	-80	28
	R	12	-96	10
Middle temporal gyrus	L	-44	-52	4
	L	-52	-62	4
	L	-52	-42	10
	R	56	-62	2
	R	54	-68	14
	R	62	-54	12

	R	52	-52	10
	R	60	-50	0
	R	58	-36	-8
Superior temporal pole	L	-44	22	-18
	L	-54	12	-8
Superior temporal gyrus	R	62	-50	20
	L	-60	-30	22
	L	-52	-34	10
	R	38	-32	12
	R	56	-44	20
Inferior temporal gyrus	R	58	-60	-6
Fusiform gyrus	L	-32	-24	-26
Insula	R	40	0	0
	R	44	18	0
	R	36	-12	22
	R	36	-18	4
Middle occipital gyrus	R	52	-68	26
	R	30	-72	22
	R	38	-72	16
	R	36	-84	30
	L	-24	-86	10
	L	-32	-88	14
Superior occipital gyrus	L	-14	-84	22
Inferior occipital gyrus	R	30	-86	-16
Parahippocampal area	L	-22	-26	-20
Hippocampus	R	24	-20	-16
	L	-30	-6	-26
Putamen	L	-22	12	0
	L	-30	2	-2
	R	22	14	-2
Inferior frontal gyrus, pars opercularis	L	-52	12	6
	L	-34	24	-12

	L	-52	14	20
	L	-58	12	16
Inferior frontal gyrus, pars triangularis	L	-44	40	0
	L	-46	32	16
Superior frontal gyrus medial	L	2	36	38
Superior frontal gyrus	L	-24	54	6
Middle frontal gyrus	L	-38	24	40
Supramarginal gyrus	L	-48	-44	34
	L	-56	-52	34
	L	-52	-30	24
Postcentral gyrus	R	-40	-32	10
Lingual gyrus	L	-14	-56	-10
	L	-16	-68	-6
	R	14	-60	-8
Precentral gyrus	R	54	-4	40
	L	-42	-2	30
Postcentral gyrus	L	-46	-12	38
	R	58	-22	42
	R	54	-16	40
Posterior cingulate cortex	L	-6	-44	8
Middle cingulate cortex	R	6	-16	34
	R	10	-30	32
Calcarine sulcus	L	-12	-80	12
	L	-14	-66	4
	L	-14	-72	8
Inferior parietal gyrus	L	-54	-48	50
	L	-46	-58	46
	L	-42	-56	48
	R	32	-42	52
	R	58	-48	40
Rolandic operculum	R	50	-18	12
	R	52	-10	18

	R	46	-12	20
	L	-60	-6	12
Angular gyrus	R	56	-48	30
	R	50	-66	40
	L	-46	-58	34
Paracentral lobule	R	16	-42	50
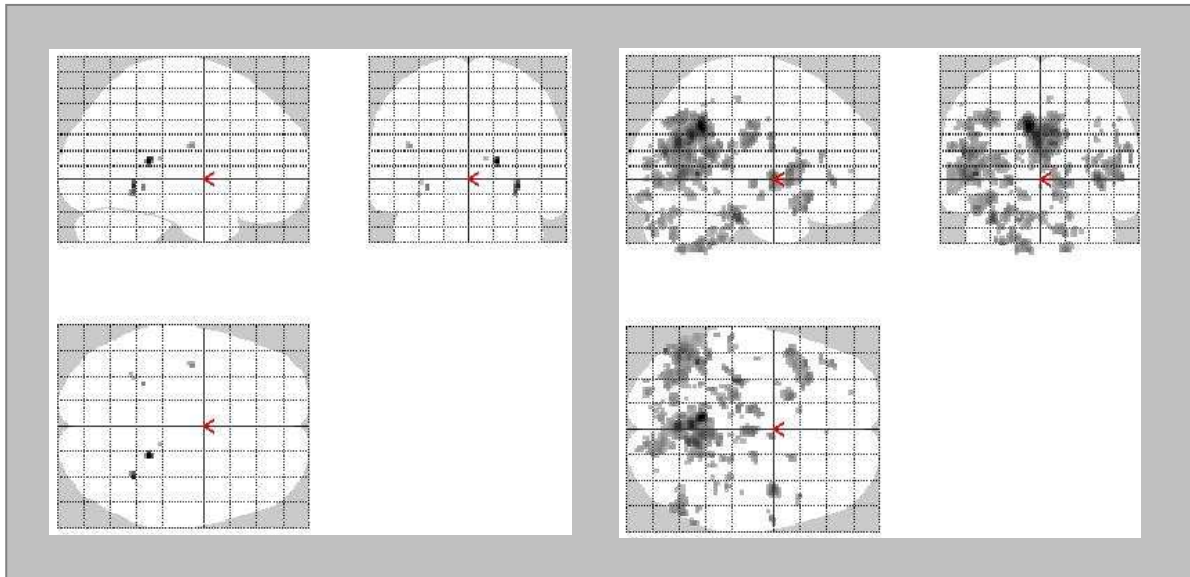
Figure 27a: Monitoring phase: relative increases in neural activity associated with confidence rating. On the left: high > low confidence, on the right: low > high confidence. The MNI coordinates for each activated cluster are presented in Table 8. P = posterior; A = anterior; L = left; R = right.
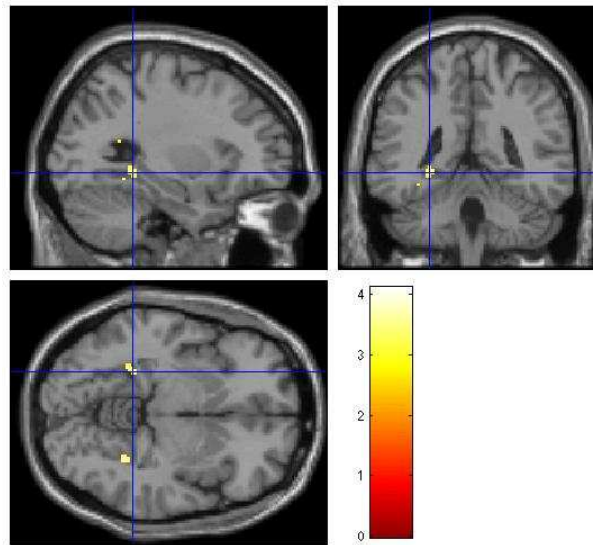
Figure 27b: Relative increases in neural activity associated with high > low confidence superimposed in terms of colour on MRI sections to depict the functional anatomy of the activations and their relationship to the underlying structural anatomy. The exact coordinates of the local maximum is indicated by x, y, and z-Talairach coordinates. Increased neural activity was seen amongst others in left parahippocampal area (x = -28, y = -42, z = -6).
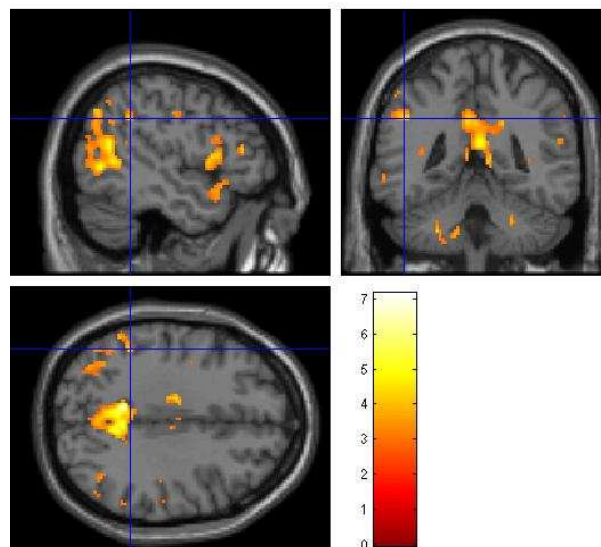
Figure 27c: Relative increases in neural activity associated with low > high confidence superimposed in terms of colour on MRI sections to depict the functional anatomy of the activations and their relationship to the underlying structural anatomy. The exact coordinates of the local maximum is indicated by x, y, and z-Talairach coordinates. Increased neural activity was seen amongst others in left supramarginal gyrus (x = -48, y = -44, z = 34).

5.1.4.3   Control phase (volunteering versus withholding)

Brain areas revealed by volunteering (relative to withholding) show bilateral activation of temporal, frontal, and cingulate regions, namely of the middle temporal gyrus, superior temporal pole, left middle frontal, and left inferior frontal cortex (pars opercularis), left precuneus, and the right posterior cingulate cortex ($p < .001$, uncorrected). The reverse contrast, namely withholding (relative to volunteering), reveals bilateral activation of the hippocampus, left caudate nucleus, left Heschl region, and the left postcentral gyrus ($p < .001$, uncorrected) which is demonstrated in Table 9 and Figure 28.

Table 9: Group activations for the contrast between volunteering versus withholding.

Anatomical region	Side	MNI coordinates		
volunteering > withholding		x	y	z
Superior temporal pole	R	44	20	-24
	L	-48	10	-22
Middle temporal gyrus	R	50	0	-26
	L	-52	-46	12
Posterior cingulate cortex	R	6	-38	10
Middle cingulate cortex	R	12	-40	48
Middle frontal gyrus	L	-22	48	26
Inferior frontal gyrus, pars opercularis	L	-36	12	14
Precuneus	L	-10	-44	46
withholding > volunteering				
Heschl region	L	-44	-14	6
Hippocampus	L	-28	-18	-16
	R	28	-16	-22
Caudate nucleus	L	-14	-8	18
Postcentral gyrus	L	-54	-10	24
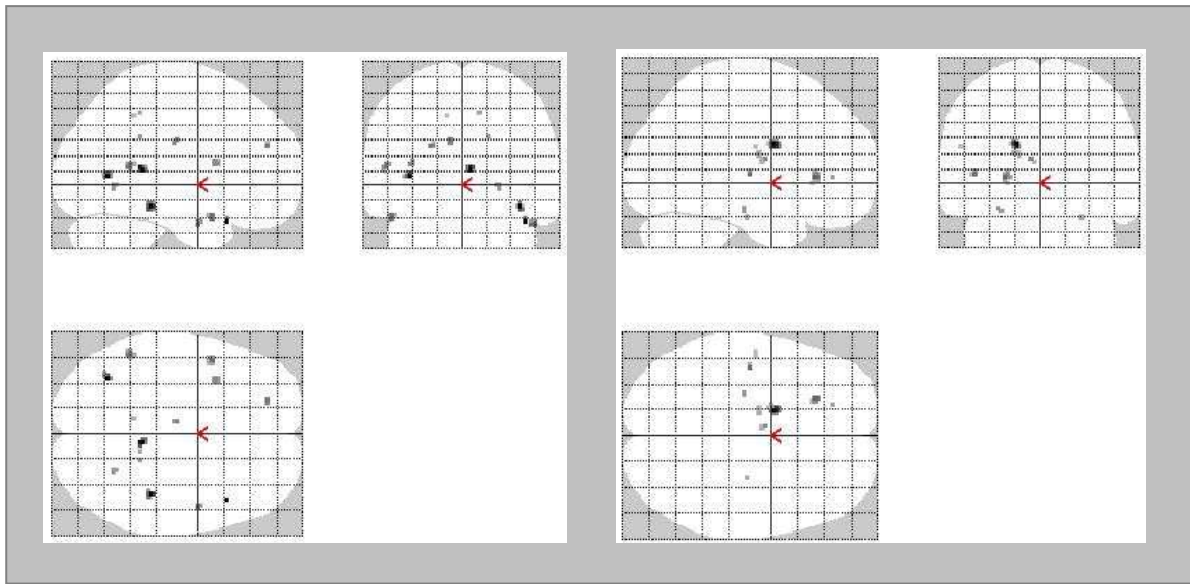
Figure 28a: Control phase: relative increases in neural activity associated with the control phase. On the left: volunteering > withholding, on the right: withholding > volunteering. The MNI coordinates for each activated cluster are presented in Table 9. P = posterior; A = anterior; L = left; R = right.
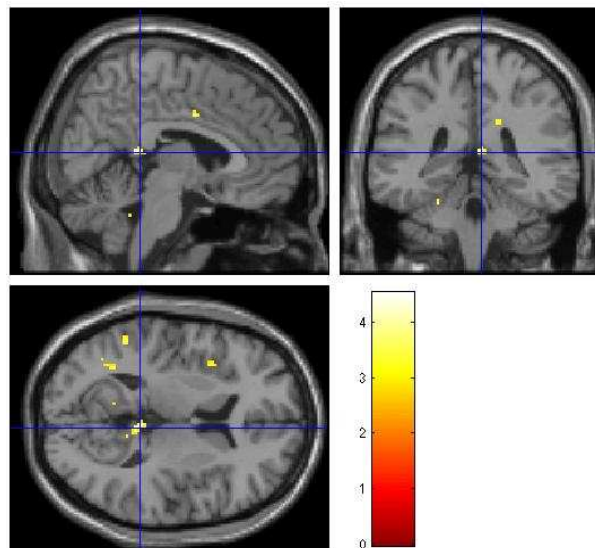
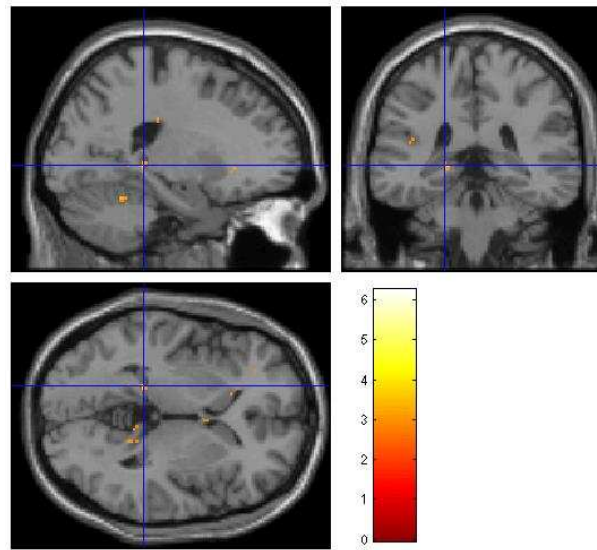Figure 28b: Relative increases in neural activity associated with volunteering > withholding superimposed in terms of colour on MRI sections to depict the functional anatomy of the activations and their relationship to the underlying structural anatomy. The exact coordinates of the local maximum is indicated by x, y, and z-Talairach coordinates. Increased neural activity was seen amongst others in right posterior cingulate cortex (x = 6, y = -38, z = 10).
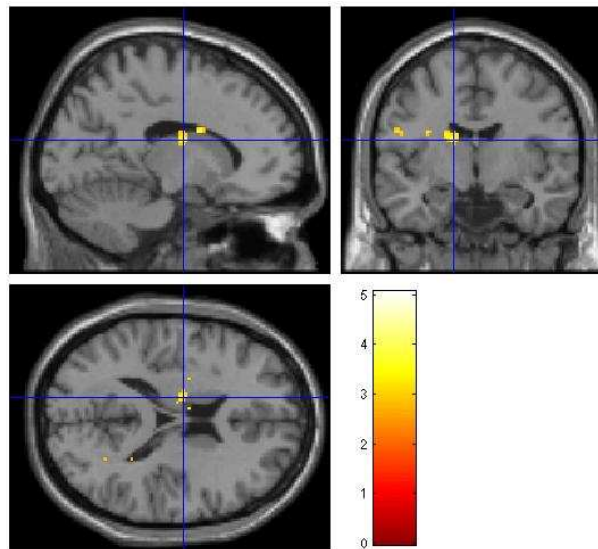
Figure 28c: Relative increases in neural activity associated with withholding > volunteering superimposed in terms of colour on MRI sections to depict the functional anatomy of the activations and their relationship to the underlying structural anatomy. The exact coordinates of the local maximum is indicated by x, y, and z-Talairach coordinates. Increased neural activity was seen amongst others in left caudate nucleus (x = -14, y -8, z = 18).

5.1.4.4   Monitoring versus retrieval

The main effect of monitoring (relative to retrieval) demonstrates significant differential bilateral activations of the inferior occipital gyrus, precuneus, middle temporal gyrus, left middle cingulate cortex, left anterior and posterior cingulate cortex as well as left middle and superior frontal gyri ($p < .001$, uncorrected), see Table 10 and Figure 29. The reverse contrast, retrieval (relative to monitoring), does not reach statistical significant activation.

Table 10: Group activations for the contrast between monitoring > retrieval.

Anatomical region	Side	MNI coordinates		
monitoring > retrieval		x	y	z
Precuneus	R	6	-52	20
	R	12	-58	24
	L	-6	-54	8
Middle cingulate cortex	L	-12	-50	36
	L	0	-32	36
Posterior cingulate cortex	L	-6	-36	30
Anterior cingulate gyrus	L	0	40	10
	L	-2	38	12
Inferior occipital gyrus	L	-34	-86	-8
	R	36	-80	-4
Middle occipital gyrus	R	40	-76	2
Middle frontal gyrus	L	-34	44	16
Superior frontal gyrus medial	L	-2	56	22
Middle temporal gyrus	L	-48	-70	18
	L	-40	-54	12
	R	50	-72	2
	R	50	-50	4
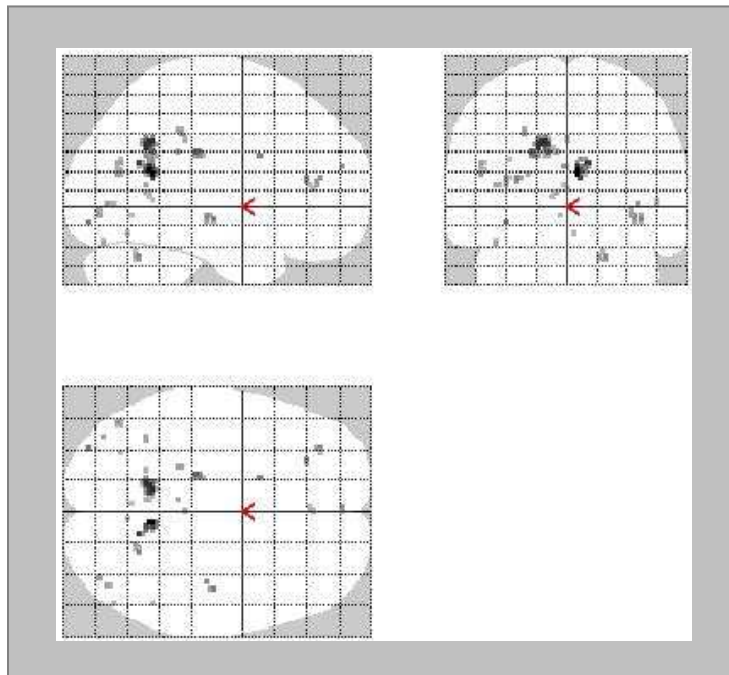
Figure 29a: Relative increases in neural activity associated with monitoring > retrieval. The MNI coordinates for each activated cluster are presented in Table 10. P = posterior; A = anterior; L = left; R = right.
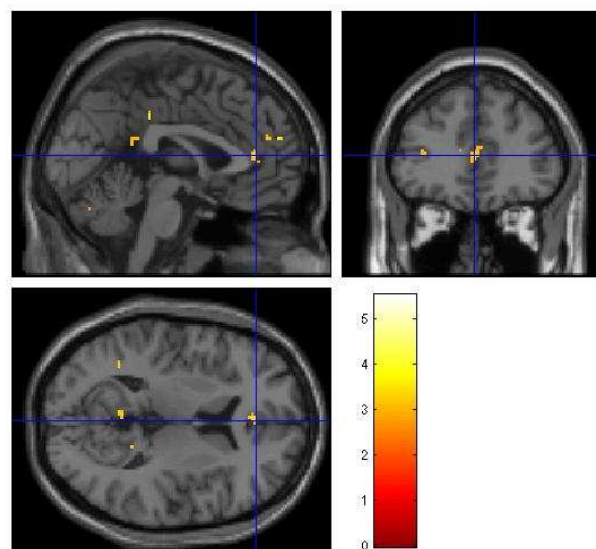
Figure 29b: Relative increases in neural activity associated with monitoring > retrieval superimposed in terms of colour on MRI sections to depict the functional anatomy of the activations and their relationship to the underlying structural anatomy. The exact coordinates of the local maximum is indicated by x, y, and z-Talairach coordinates. Increased neural activity was seen amongst others in left anterior cingulate cortex (x = 0, y = 40, z = 10).

5.1.4.5   Control versus retrieval

Areas of significant differential activation revealed by control (relative to retrieval) are located in the left middle frontal gyrus, left middle temporal gyrus, right fusiform gyrus, right putamen, right Rolandic operculum, and the right superior temporal gyrus (p < .001, uncorrected) Table 11 and Figure 30. Again, the reverse contrast, retrieval (relative to control) does not show any differential activation.

Table 11: Group activations for the contrast between control > retrieval.

Anatomical region	Side	MNI coordinates		
control > retrieval		x	y	z
Middle temporal gyrus	L	-42	-68	20
	L	-52	-46	8
Superior temporal gyrus	R	42	-34	12
Middle frontal gyrus	L	-32	44	16
Fusiform gyrus	R	34	-50	-4
Rolandic operculum	R	40	-32	18
Putamen	R	28	-16	4
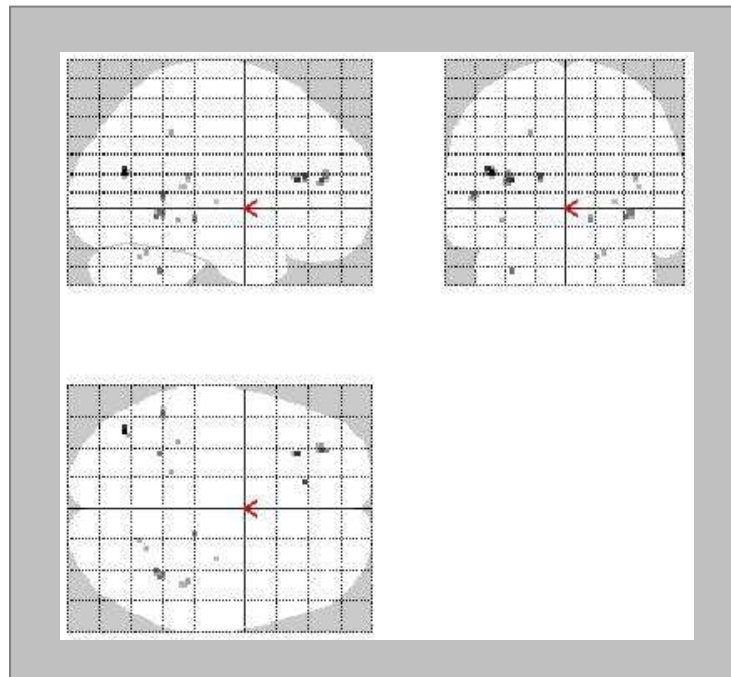
Figure 30a: Relative increases in neural activity associated with control > retrieval. The MNI coordinates for each activated cluster are presented in Table 11. P = posterior; A = anterior; L = left; R = right.
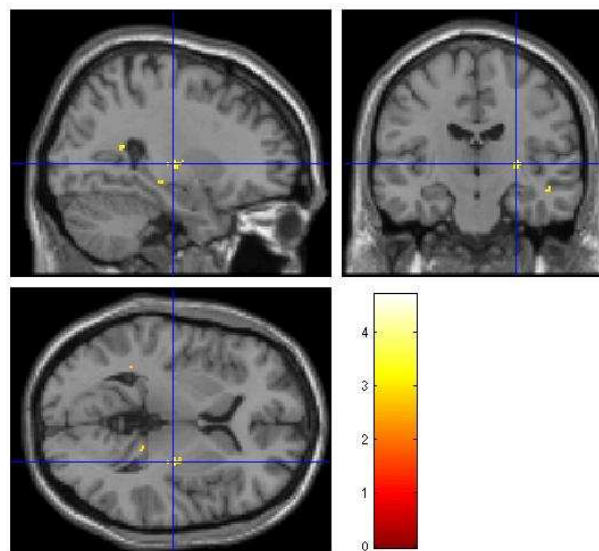
Figure 30b: Relative increases in neural activity associated with control > retrieval superimposed in terms of colour on MRI sections to depict the functional anatomy of the activations and their relationship to the underlying structural anatomy. The exact coordinates of the local maximum is indicated by x, y, and z-Talairach coordinates. Increased neural activity was seen amongst others in right putamen (x = 28, y = -16, z = 4).

5.1.4.6 Monitoring versus control

The main effect of monitoring (relative to control) reveals significant activation of the right superior temporal gyrus (p < .001, uncorrected). Due to the fact that only one region reached statistical significance this contrast will not be discussed here. The reverse contrast, control (relative to monitoring) does not reveal any significant activation.

5.1.4.7 Memory accuracy

The main effect of memory accuracy (relative to low memory accuracy) presents significant differential bilateral activations of the superior temporal gyrus, the supramarginal gyrus (SMG), left hippocampus, left Heschl region, the right superior temporal pole, middle temporal gyrus, and the right precuneus (p < .001, uncorrected) which is illustrated in Table 7a and Figure 10a. The reverse contrast, low accuracy (relative to high accuracy), reveals activation only in the left hemisphere, namely the insula, and the superior frontal gyrus (p < .001, uncorrected) which is illustrated in Table 12 and Figure 31.

Table 12: Group activations for the contrast between high versus low memory accuracy.

Anatomical region	Side	MNI coordinates		
accuracy > inaccuracy		x	y	z
Superior temporal gyrus	L	-52	-28	12
	L	-60	-30	14
	R	62	-22	12
Superior temporal pole	R	52	4	-2
Middle temporal gyrus	R	48	-38	4
Hippocampus	L	-24	-40	0
Supramarginal gyrus	R	58	-38	32
	R	56	-36	34

	L	-62	-24	16
Heschl region	L	-32	-28	6
Precuneus	R	12	-42	46
inaccuracy > accuracy				
Superior frontal gyrus medial	L	2	50	22
	L	0	46	32
	L	-8	60	8
Superior frontal gyrus	L	-14	60	8
Insula	L	-36	26	4
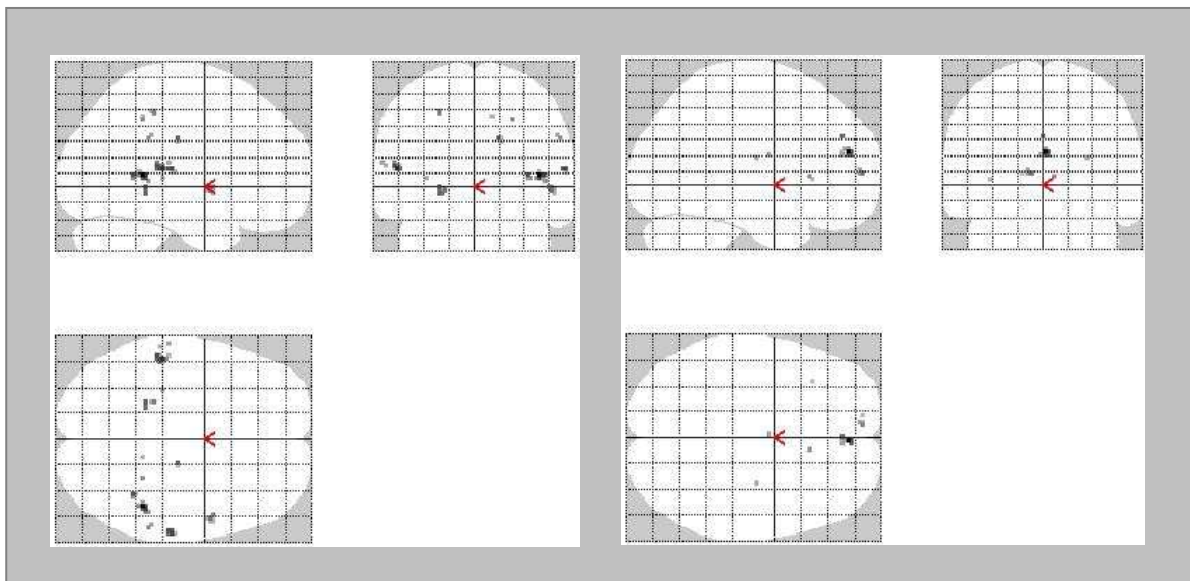
Figure 31a: Memory accuracy: relative increases in neural activity associated with high and low memory accuracy. On the left: memory accuracy, on the right: memory inaccuracy. The MNI coordinates for each activated cluster are presented in Table 12. P = posterior; A = anterior; L = left; R = right.
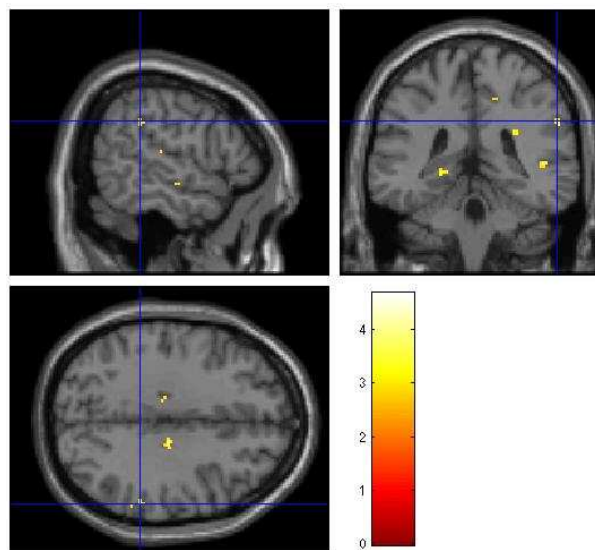
Figure 31b: Relative increases in neural activity associated with high memory accuracy > low memory accuracy superimposed in terms of colour on MRI sections to depict the functional anatomy of the activations and their relationship to the underlying structural anatomy. The exact coordinates of the local maximum is indicated by x, y, and z-Talairach coordinates. Increased neural activity was seen amongst others in right supramarginal gyrus (x = 58, y = -38, z = 32).
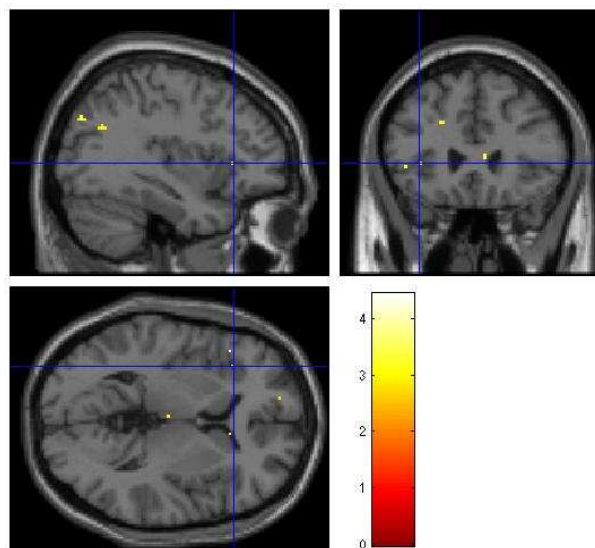
Figure 31c: Relative increases in neural activity associated with low memory accuracy > high memory accuracy superimposed in terms of colour on MRI sections to depict the functional anatomy of the activations and their relationship to the underlying structural anatomy. The exact coordinates of the local maximum is indicated by x, y, and z-Talairach coordinates. Increased neural activity was seen amongst others in left insula (x = -36, y = 26, z = 4).

5.2   Verification of the hypotheses

Hypothesis 1

During the retrieval phase brain activity differs with regard to giving a correct in contrast to an incorrect answer. Correct responding is related to memory-specific areas like prefrontal and temporal regions and particularly the hippocampus. Moreover, the neural activation pattern of correct retrieval is similar to brain activation connected with memory accuracy as defined by Koriat and Goldsmith.

Despite little deviance Hypothesis 1 is confirmed which is supported by the results described in 5.1.4.1 and 5.1.4.7. Correct memory retrieval was found to be connected with the left hippocampus, a region that also plays an important role in episodic memory retrieval. It was assumed that the left medial temporal lobe is associated with correct retrieval and the comparison between misses and correct rejection. This is in line with the finding that subjects gave more correct than incorrect answers which resulted significantly more often from correct rejection instead of a hit. When incorrect answers were given, this resulted basically from a miss instead of a false alarm as presented in section 5.1.3. In comparison to memory accuracy it can be reported that identical neural correlates were found which is presented in Hypothesis 5a. Prefrontal activation was not affirmed.

Hypothesis 2a

During the monitoring phase brain activity differs with respect to giving a high confidence rating in contrast to a low confidence rating.

Due to its relationship to executive functions, high confidence ratings will activate frontal regions and particularly the ventrolateral PFC as well as regions that are involved in correct memory retrieval, like the medial temporal lobe, including the hippocampus and the parahippocampal gyrus.

Hypothesis 2a can be partly verified. Predicted activation was only found in the parahippocampal gyrus as illustrated by the results in 5.1.4.2. Instead of frontal neural activity, fusiform gyrus, and lingual gyrus revealed significant activation.

Hypothesis 2b

Low confidence ratings reveal a higher demand for cognitive functions and attention. Due to the uncertainty about the retrieved memory, more cognitive effort has to be investigated in memory retrieval. Brain activity is particularly associated with prefrontal regions like dorsolateral prefrontal cortex. In addition, it is connected with parietal areas as well as to limbic and temporal regions.

As shown in the results in section 5.1.4.2, Hypothesis 2b can be affirmed. Activation was found in temporal regions, namely the middle, superior, and inferior temporal gyrus. Related to limbic regions neural activity was found in the middle and posterior cingulate cortex, the hippocampus and additionally in the parahippocampal area. A diffuse left-hemispheric frontal network revealed significant activation, comprising precentral gyrus as well as inferior, superior, and middle frontal gyrus and as

hypothesized the dorsolateral prefrontal cortex. Parietal activation was related to supramarginal gyrus, postcentral and angular gyrus, and paracentral lobule.

Hypothesis 3a

During the control phase brain activity differs relative to volunteering or withholding the accordant response.

Volunteering a response provokes neural activation in the dorsolateral and ventral medial PFC as well as in the cingulate cortex.

Concerning activation in the cingulate cortex, Hypothesis 3a is confirmed. The results in section 5.1.4.3 present neural activity in the middle and posterior cingulate cortex. In addition, activation of prefrontal cortex was limited to the dorsolateral and orbitofrontal prefrontal cortex.

Hypothesis 3b

Withholding information is associated with response inhibition expressed by neural activation in ventrolateral PFC in conjunction with a more extensive frontoparietal network. Moreover, brain areas reveal activation that are known for memory retrieval.

Due to activation in unpredicted brain regions, Hypothesis 3b can be partly approved. As shown in the results 5.1.4.3 bilateral activity can be reported for the hippocampus and the caudate nucleus being related to memory retrieval. Prefrontal activation was not found.

> **Hypothesis 4**
>
> **Monitoring and control processes exhibit a strong relationship. Both depend on a certain memory and require a high degree of cognitive function which leads to neural activation in frontal brain regions and particularly the dorsolateral portion of the PFC. In addition, the anterior cingulate cortex along with medial temporal areas provoke activation.**

When contrasting monitoring (for results see section 5.1.4.4) as well as control (for results see section 5.1.4.5) against retrieval it can be reported that both processes provoke activation in the same areas, namely left middle temporal gyrus and left middle frontal gyrus.

Neural activity in the anterior and posterior cingulate can only be reported for monitoring (against retrieval) and not, as predicted, for both processes. Due to these findings, Hypothesis 4 is basically affirmed.

> **Hypothesis 5a**
>
> **Even though being differently operationalized, memory accuracy provokes brain activity in similar or even the same areas as correct memory retrieval, namely prefrontal and temporal regions and particularly the left hippocampus.**

The results in 5.1.4.1 and 5.1.4.7 reveal that in the main Hypothesis 5a is confirmed. Indeed, prefrontal regions did not reveal significant activation but for all that, the presented activation pattern is strongly related to correct memory retrieval. The right precuneus, left hippocampus, and middle temporal gyrus are also reported when correct information is retrieved.

Hypothesis 5b

Memory inaccuracy is defined as volunteering an objectively false and subjectively potentially correct answer and is therefore connected with false memories. Memory inaccuracy provokes a diffuse neural network, involving frontoparietal and temporoparietal regions, the MTL, and the anterior cingulate cortex.

Against the previous prediction, memory inaccuracy was not directly related to frontoparietal and temporoparietal regions, the MTL, and the anterior cingulate cortex which disproves Hypothesis 5b. Instead, activation was found left-hemispheric in the superior frontal gyrus (SFG) and the insula as illustrated in the results (5.1.4.7).

6 Discussion

In the following chapter, the results are discussed in the context of previous research on identifying the brain mechanisms connected with retrieval, monitoring, and control processes according to the memory paradigm of Koriat and Goldsmith (1996). Moreover, brain regions are discussed that are connected with memory accuracy.

The maxima of all brain regions showing differential event related responses to retrieval, monitoring, and control processes as well as memory accuracy are shown in Tables 7 – 12.

6.1 Discussion of the different contrasts

Below the behavioral data and the fMRI responses of selected regions are discussed that were predicted on the basis of previous findings for the different contrasts, respectively.

6.1.1 Retrieval process (correct versus incorrect responding)

During the retrieval process (correct > incorrect responding) a significant effect was identified in the behavioral rating: subjects gave more correct than incorrect answers, which was in general a consequence of correct rejection (instead of a hit). When incorrect answers were given, this resulted basically from a miss (instead of a false alarm). This finding indicates that subjects were able to correctly discriminate between correct and incorrect answers and, moreover, responded rather carefully, avoiding risky decisions.

When responding correctly instead of giving false answers brain activation was found particularly in areas that are known to be connected with memory. In agreement with previous studies, activation was found in the left hippocampus during correct retrieval (in contrast to incorrect retrieval). Different studies highlight the important role of the anterior hippocampus in successful retrieval of contextual details (Hoscheidt et al.,

2010; Dobbins et al., 2003; Eldridge et al., 2000; Wheeler & Buckner, 2003). This finding supports the results of a recent study of Mendelsohn discussing differential BOLD responses as a function of accuracy in the left hippocampus for correct factual statements in contrast to incorrect factual statements (Mendelsohn et al., 2010). The authors postulate, amongst others, activation in left hippocampus and posterior cingulate cortex / precuneus as a function of accuracy. This is in line with the current results because in both correct retrieval and high memory accuracy the left hippocampus and the precuneus revealed activation. Meanwhile it is approved that the hippocampus plays an important role in detailed and vivid memory recall, even though its contribution to retrieval is still under controversial discussion (Gilboa, Winocur, Grady, Hevenor & Moscovitch, 2004; Gilboa, 2006; Maguire, 2001).

In this study the results indicate that particularly the left hippocampus seems to play an important role at least for correct memory retrieval.

Another interesting finding concerns the bilateral activation of the precuneus in combination with the hippocampus. This result is related to the finding of hippocampal connectivity to the left precuneus in a recollection network (in contrast to familiarity) (Dörfel, Werner, Schaefer, von Kummer & Karl, 2009). Moreover, the authors found blood oxygen level-dependent activations during "remember" and "know", for example, in the left middle temporal gyrus, insula, precuneus, and the hippocampus. These areas were connected with correct recognition of items as compared with correct rejection. The previous study found activation in exactly these brain regions associated with correct retrieval as compared with incorrect retrieval. Besides, activity in the left parietal cortex (which comprises the precuneus) is related to the amount of contextual information that is retrieved (Cabeza, 2001; Henson et al., 1999; Henson, 1999; Wheeler, 2004). The statements that were presented and retrieved in the current study concerned perception, action, and content related information in equal parts. Due to the left parietal activation it is assumable that subjects mainly retrieved content specific statements correctly.

Besides its role in memory retrieval (Maddock, Garrett & Buonocore, 2001; Piefke, Weiss, Zilles, Markowitsch & Fink, 2003; Lundstrom et al., 2003), the precuneus is referred to be associated with imagination in general (Cavanna & Trimble, 2006) and mental imagery during retrieval of visual information (Fletcher et al., 1995, 1996). According to Maddock et al. (2001) precuneus functions are not restricted to the retrieval of visual information. He highlights that this brain area is likely to be implicated in polymodal imagery associated with successful memory retrieval, as well. This can be approved by the current findings, because it is well assumable that subjects retrieved those memories correctly which they were able to imagine.

The left insula was found to play a role in correct recognition in contrast to false recognition (Kühnel, 2006; Dörfel et al., 2009) which is also supported by the current results. A meta-analysis of functional neuroimaging experiments concerning emotion processing reported a particular and consistent involvement of the insular (and anterior cingulate) cortex in emotional recall and imagery as well as effortful emotional task performance (Phan, Wager, Taylor & Liberzon, 2002). Due to the fact that some statements were emotionally toned and other statements were rather neutral; this result might indicate that subjects are emotionally engaged in recall of correct events.

A recent study found the left medial temporal lobe to be connected with memory retrieval and essentially in the comparison between misses and correct rejections (Takahashi et al., 2008). This result is reflected in the current study insofar as the fMRI contrast related to correct versus incorrect retrieval was represented by correct rejections versus misses in the behavioral data. It is assumable that the MTL plays a rather differentiated role concerning correct and incorrect memory retrieval.

A study of Cabeza underlines the fact that the MTL can be dissociated. They used fMRI to investigate the different types of memory traces recovered by the medial temporal lobe. In contrast to the current results, they investigated true and false recognition. Whereas true recognition may be comparable to correct retrieval as

defined in the current study, false items are not comparable to incorrect retrieval as used here. The authors found the hippocampus to be similarly activated for true and false items. In addition, the parahippocampal gyrus was more activated for true than for false items (Cabeza, 2001).

In the present study subjects retrieved information that was recently learned before in the presented videotape. The medial temporal lobe was found to reveal certain importance concerning consolidation and particularly retrieval of recently learned items (Cabeza & Nyberg, 2000; Frankland & Bontempi, 2005; Sybirska et al., 2000).

Due to the current results one can assume a memory retrieval network including the left hippocampus, precuneus, left middle temporal gyrus, and eventually the left insula. This network plays an important role in memory accuracy and particularly in correct (in contrast to incorrect) memory retrieval.

In addition, activation was found in the lingual gyrus, an area that was recently presented to be significantly more active for correct than for incorrect (lag) judgments (Greve et al., 2010). Moreover, the right lingual gyrus revealed activation at correct rejection in contrast to hits (Kühnel, 2006) which might represent the present finding insofar as correct retrieval was rather represented by correct rejections instead of hits.

6.1.2 Monitoring process (high confidence versus low confidence)

The monitoring process (high confidence versus low confidence) revealed no significant effect in the behavioral rating during the scanning procedure. Subjects rated the statements with high confidence in comparison to low confidence as equal. The imaging data draws a different picture. When contrasting high (subjective) confidence against low confidence, activation was located in the fusiform gyrus and the parahippocampal area as well as the lingual gyrus.

It was found that activity in occipital regions and the posterior parahippocampal region is greater for true than false memories. This was hypothesized, because those areas process perceived and imagined stimuli in a systematic way. The perceived

stimuli contain richer sensory details that lead to greater activation of the occipital region (Okado & Stark, 2003). It is conceivable that subjective confidence in recognition memory would be high with vivid remembering of specific contextual details. Occipito-temporal activation in fusiform gyrus were found during retrieval of visual stimuli (Wheeler & Buckner, 2003) which indicates the imagination of the accordant memory. The occipital regions and the posterior parahippocampal region revealed activation when a high confidence rating was given which might point out that the accordant item is better remembered. Activation of the parahippocampal gyrus may strengthen this assumption hence this area is amongst others characteristic for correct memory retrieval (Fink et al., 1996; Haist et al., 2001; Levine, 2004; Markowitsch, 2005; Moscovitch et al., 2005; Steinvorth et al., 2005; Svoboda et al., 2006). This stands to reason, because high confidence was defined as 100% secureness. It is assumable that subjects only rated items with high confidence when the accordant statement was actually subjectively and objectively correct. This is also comparable to the results that the early visual processing regions (lingual / fusiform gyri) are stronger activated for true / correct in contrast to false recognitions (Slotnick & Schacter, 2004).

The reverse contrast, namely low confidence (in contrast to high confidence) revealed activation of similar areas, and in addition a broad pattern of diffuse frontal, temporal, parietal, occipital, and limbic activation. Interestingly, a recent fMRI-study also reported brain areas common to high and low confidence recognition, indicating contribution of these regions to both high and low confidence recognition activity (Kim & Cabeza, 2009).

Significant neural activity was additionally found in the posterior and middle cingulate cortex. Activation in cingulate regions concerning comparisons of high versus low confidence judgments were also described by Chua and colleagues (Chua, Schacter, Rand-Giovannetti & Sperling, 2006).

Henson et al. asked volunteers to make one of three judgments to each presented word during recognition. Subjects had to judge whether they recollected seeing it during study (R judgments), whether they experienced a feeling of familiarity in the absence of recollection (K judgments), or whether they did not remember seeing it during study (N judgments). The R and N judgments can be assumed to be analogical to the high and low confidence rating in this study. Henson found increases for N judgments (in contrast to R judgments) in the middle and superior frontal gyrus, insula, amygdala, precuneus, inferior parietal gyrus, and middle temporal gyrus (Henson et al., 1999). Except for the amygdala exactly the same areas were found to be activated in the current study when participants rated statements with low confidence. It is actually easy to imagine that subjects rated a statement with low confidence when they did not remember the accordant item appropriately. It is important to note here that in a study about false memories (Kühnel, 2006) very similar brain regions evoked activity during false recognition, namely left middle occipital gyrus, left posterior cingulate gyrus, left middle frontal gyrus, right middle temporal gyrus, fusiform gyrus, and inferior frontal gyrus (IFG). Moreover, in the previous study, the right precentral gyrus revealed activation when contrasting all false recognitions against all correct recognitions. This region can also be reported in this study. This might point out to the idea that low confidence ratings are correlated with specific kind of memories that may be of a similar quality as certain forms of false memories.

Further activation was found in superior temporal and inferior parietal cortex in the region of the supramarginal and angular gyrus. These regions are related to language comprehension (van Buren, Fedio & Frederick, 1978) and were found to be involved in semantic comprehension of words (Démonet et al., 1992; Démonet, Price, Wise & Frackowiak, 1994; Stoeckel, Gough, Watkins & Devlin, 2009) and sentences (Sakai, Hashimoto & Homae, 2001). It is possible that subjects laid more emphasis and concentration in recalling the presentation of the written statements when they did not remember the content.

Roughly spoken it is reasonable to consider that temporal areas are associated with a confidence rating in general, whereas specific frontal regions (inferior frontal gyrus (IFG), superior and middle frontal gyrus, paracentral lobule, precentral gyrus) are associated with low confidence.

This mainly left-hemispheric frontal activation pattern might reflect a relationship to executive control processes (Kim & Cabeza, 2009). The connection to executive control processes is also consistent with the notion that higher activity at IFG was found to be correlated with higher risk aversion (Christopoulos, Tobler, Bossaerts, Dolan & Schultz, 2009). In this study design subjects had to decide whether to choose the 100% confidence or 50% confidence option. When choosing 50% confidence subjects made no commitment and there was no risk at all.

Further activation was found in the superior frontal gyrus which is related to Brodmann area (BA) 10. This area is supposed to play a role in strategic processes involved in memory retrieval and higher cognitive function (Burgess, Gilbert & Dumontheil, 2007). Moreover, the SFG is thought to contribute to higher cognitive functions and particularly to working memory (Du Boisgueheneuc et al., 2006).

Additionally, activation was found in the dorsolateral prefrontal cortex which is also assumed to be related to higher-order executive components including behavioral planning, like monitoring, manipulation, and integration of different information (Tanji & Hoshi, 2008) and which is even connected with working memory.

This result again intensifies the connection to executive control processes in decisions under uncertainty. It can be suggested that when subjects are uncertain about a memory they investigate more effort in memory retrieval which requires higher cognitive functions and executive control processes. Again, cingulate cortex activation was also revealed in generation tasks (Abrahams et al., 2003) which might point to enhanced attentional demands like for example task switching (Swainson et al., 2003) which is also connected with higher cognitive functions. Activation of the insula may be interpreted in terms of effortful task performance (Phan et al., 2002).

These results are correlated with a rather ambivalent activation pattern compared to high confidence, which was previously assumed to be linked to certainty about the according memory.

In summary, much more and differential brain areas are activated when contrasting low against high confidence. One can assume from that difference that there are greater monitoring demands when memory judgments are less certain.

6.1.3 Control process (volunteering versus withholding)

The control process (volunteering versus withholding) induced a significant effect in the behavioral rating during the scanning procedure: subjects rather volunteered an answer instead of withholding it which is comprehensible due to the fact that each correctly volunteered answer was rewarded with a bonus. The imaging data revealed differential activation for volunteering and withholding suggesting that the two domains utilize at least partially distinct sets of cognitive processes.

Volunteering was defined as betting on a certain memory. In the current design volunteering a correct response resulted in an increase of bonus points with the risky side action that a potential loss of bonus points resulted from incorrect responses. If an answer was volunteered, particularly temporal and frontal as well as middle and posterior cingulate areas and the precuneus reveal activation. Surprisingly, activation for volunteering is very similar to the neural correlates of monitoring (in contrast to retrieval) which is also represented by activation of the middle temporal gyrus, posterior cingulate cortex, middle cingulate cortex, left middle frontal gyrus, and precuneus. It can be concluded that volunteering is subject to monitoring processes.

Aside from that, both processes depend on the strengths of the underlying memory trace. According to the quality of the memory trace a certain confidence rating is given and, in the control phase, an answer is volunteered or withheld (Belli, Lindsay, Gales & McCarthy, 1994; Bradfield, Wells & Olson, 2002; Busey, Tunnicliff, Loftus & Loftus, 2000; Shaw & Zerr, 2003; Yonelinas, 1994). This interconnection to memory accounts for the detected neural correlates that are known to play a role in memory

retrieval, like limbic structures (cingulate cortex) (Fink et al., 1996; Haist et al., 2001; Levine, 2004; Markowitsch, 2005; Moscovitch et al., 2005; Steinvorth et al., 2005; Svoboda et al., 2006) and the medial temporal lobe (Cabeza & Nyberg, 2000; Frankland & Bontempi, 2005; Sybirska et al., 2000).

The posterior cingulate and the DLPFC were found to reveal activation in connection with (expected) reward (Lee & Seo, 2007; Pochon et al., 2002). Moreover, the dorsolateral prefrontal cortex belongs to a broader network that is connected with adaptive decision-making. It was found that activation in the dorsolateral prefrontal cortex is modulated by the amount of monetary reward (Lee & Seo, 2007).

Due to the fact that both regions were detected to be activated when answers were volunteered, it is supposable that subjects decided to volunteer strategically, because they knew about the (amount of) potential reward.

In addition, activation in the left middle and inferior frontal gyrus might suggest a connection to working memory which was found in previous studies (McCarthy et al., 1991; Rypma, Prabhakaran, Desmond, Glover & Gabrieli, 1999). Working memory is a special form of STM and is related for example to diverse cognitive skills (Adams & Gathercole, 2000), reasoning, and planning (Baddeley, 1992; Wickelgren, 1997). It is quite obvious that volunteering is provided by these or similar processes and is modulated by higher cognitive functions. According to the memory paradigm of Koriat and Goldsmith a certain memory has to be retrieved and monitored concerning its quality (Goldsmith et al., 2002). Dependent on the results of the monitoring, in the control process it is decided which information is volunteered and finally the outcome of volunteering has to be balanced.

When a response was withheld, no bonus points could be gained or lost. This was connected with activation in parietal and temporal regions and also the caudate nucleus. This is quite surprising, because due to the task demands which were assumed to be connected with control processes like executive functioning, rather frontal and prefrontal brain activity would have been expected to reveal activation

(Hedden & Gabrieli, 2010). The relevant brain areas for response inhibition which are supposed to be related to withholding an answer include the ventrolateral PFC, mainly in the right hemisphere often in conjunction with a more extensive frontoparietal network (Walther, Goya-Maldonado, Stippich, Weisbrod & Kaiser, 2010; Garavan, Ross & Stein, 1999; Konishi et al., 1999; Aron, Robbins & Poldrack, 2004).

Instead, activation was found in areas that play a differential role in (episodic) memory retrieval like bilateral activation of the hippocampus (Tulving & Markowitsch, 1998).

This might point out that subjects were more concentrated on the re-retrieval of the appropriate memory instead of response selection / inhibition (Robbins, 2007). This may be caused by the design specification, because subjects had only very short time to answer and there might have been a time overlap in neural activity to the retrieval process. It is supposable that withholding an answer is related to a rather fragile memory and cognitive effort is needed to retrieve that memory which then arouses neural activity in memory specific regions.

In addition, activity was identified in the left caudate nucleus which is part of the basal ganglia. The basal ganglia circuit is known to play a role in different motor activities (Lehéricy et al., 2006) and is moreover modulated by the frontal lobes (Cavedini, Gorini & Bellodi, 2006). The caudate nucleus was detected to be activated in tasks that require preparation and selection of a sequence of movements based on information stored in working memory, new learning, and planning (Lehéricy et al., 2006). Furthermore, it can be reported that the basal ganglia and particularly the caudate nucleus is essential for some forms of learning-related plasticity. It is additionally suggested that the basal ganglia are parts of a brain-wide set of adaptive neural systems promoting optimal motor and cognitive control (Graybiel, 2005). This is in line with the fact that when withholding a memory, different cognitive functions proceed. Cognitive effort increases to retrieve the according memory and responding

behavior has to be inhibited depending on the quality of the memory to eliminate the risk of volunteering an incorrect answer and loosing bonus points as a consequence.

Studies of patients with neurodegenerative diseases highlight the role of the basal ganglia in habit learning. There are studies that have identified the role of the basal ganglia in stimulus-response learning (Packard & Knowlton, 2002).

It is assumed that during learning, basal ganglia and medial temporal lobe memory systems (including the hippocampus as a primary component) are activated simultaneously and, depending on the learning situation, there is competitive interference between these two systems (Packard & White, 1991).

A more recent study reported that the caudate nucleus contributes to behavior with regards to the excitation of correct action schemata as well as the selection of appropriate sub-goals which base on an evaluation of action-outcomes (Grahn, Parkinson & Owen, 2008).

One can suppose from these findings and the fact that both the hippocampus and the caudate nucleus evoked activation in this experiment that subjects might have learned to use special strategies like for example to always withhold the answer when a memory was uncertain.

6.1.4 Monitoring versus retrieval process

The contrast between monitoring and retrieval caused temporal, occipital, parietal, and frontal brain activation, and moreover bilateral activation of the precuneus and differential left cingulate cortex areas. While during the retrieval phase subjects rated each statement as correct or incorrect, the monitoring phase was defined as giving a high or low confidence judgment. During the confidence judgment, subjects monitored the retrieved memory and made a subjective judgment about it. It is quit obvious that monitoring and retrieval processes are related with each other. According to Chua et al. confidence judgments are believed to be based on the strengths of the underlying memory trace, ease of retrieval, and also on study specific heuristics and test conditions, and finally on the subject's own memory

(Chua, Schacter & Sperling, 2009; Belli, Lindsay, Gales & McCarthy, 1994; Bradfield, Wells & Olson, 2002; Busey, Tunnicliff, Loftus & Loftus, 2000; Shaw & Zerr, 2003; Yonelinas, 1994).

An imaging study reported an increase in confidence at recognition related to bilateral activation in the anterior and posterior cingulate cortex along with medial temporal regions (Moritz et al., 2006). In the current study the same regions revealed activation during the monitoring process which in this design additionally includes low confidence ratings. One can assume from this that those regions are connected with an increase in confidence but also, as shown by the present results, with confidence rating in general.

According to Vandekerckhove, the posterior cingulate cortex is involved in evaluative functions (Vandekerckhove, 2004). This fits well to the finding of left posterior cingulate activation in association with monitoring, because judging high and low confidence is a typical evaluative process.

As reported previously, monitoring is part of executive functions (Tanji & Hoshi, 2008). These are mediated by the cingulate cortex and parts of the prefrontal cortex (amongst other regions) (Carter et al., 1998) and comprise for example effortful behavior, attention, and control of inhibitory acts (Fletcher et al., 1996; Markowitsch, Vandekerckhove, Lanfermann & Russ, 2003; van Nieuwenhuis, Yeung, den Wildenberg & Ridderinkhof, 2003). In the present study activation was reported in the anterior, middle and posterior cingulate cortex as well as prefrontal regions, namely the left middle frontal gyrus (BA 13, orbitofrontal prefrontal cortex) and the left superior frontal gyrus (BA 9, dorsolateral prefrontal cortex). Additionally, activation of the anterior cingulate cortex may support the relationship between monitoring processes and executive functions; hence the dorsal part of the ACC is connected with the prefrontal cortex which plays a crucial role in executive functioning. A recent study found a kind of executive control network which showed activation of the anterior cingulate cortex together with other brain areas (Fan, McCandliss, Fossella, Flombaum & Posner, 2005). Beyond that, the anterior cingulate and dorsolateral

prefrontal cortex were presented to correlate with selective attention and task management, two fundamental executive processes (Smith & Jonides, 1999). This supports the strong relationship between the monitoring process as defined in this study and executive functions.

The anterior cingulate cortex is moreover related to different and multiple processes like, for example, response selection, anticipation, arousal, visual imagery, and re-experiencing (Cabeza & Nyberg, 1997; Fletcher et al., 1996; Markowitsch, 2000a). This is quite interesting since it is assumable that during the monitoring phase subjects selected the according response from the retrieval process, anticipated the outcome, and it stands to reason that the accordant memory content was visually imagined during the monitoring phase. This may be affirmed by the fact that occipital regions revealed neural activation, namely the inferior and middle occipital gyrus including BA 18 where visual processing occurs.

Above all, it was hypothesized that monitoring is connected with working memory in the form of an active manipulation of relevant information in working memory (Miyake et al., 2000). The relationship to working memory was believed to be associated with the dorsolateral portion of PFC (Goldman-Rakic, 1996; Smith & Jonides, 1999). Due to the finding that the dorsolateral prefrontal cortex showed activation one can assume that monitoring in the form of confidence rating is supported by working memory mechanisms.

Furthermore, activation was identified in the precuneus and the medial temporal lobe, two regions that were already extensively discussed concerning their connection to memory retrieval (Maddock et al., 2001; Piefke et al., 2003; Lundstrom et al., 2003; Cabeza & Nyberg, 2000; Frankland & Bontempi, 2005; Sybirska et al., 2000; Takahashi et al., 2008).

One may conclude from these findings that even though monitoring and retrieval are strongly connected with each other which is mainly mediated by memory characteristic brain regions, the former is characterized by a higher demand for cognitive performance.

6.1.5 Control versus retrieval process

According to our results, the control phase (in contrast to retrieval) revealed (amongst others) the same neural activation as monitoring (in contrast to retrieval). These regions are the left middle temporal gyrus which was found to be connected with memory (Dörfel et al., 2009) and the left middle frontal gyrus.

This finding supports the assumption that monitoring and control are related processes and moreover in consideration of middle temporal gyrus activation both processes reveal a connection to memory retrieval. This is in line with the idea that not only the monitoring process is based on the accordant memory quality, but the control process depends on this memory trace, too. However, the outcome of both processes is again based on a recognition process (Chua et al., 2009).

The middle frontal activation might indicate the connection to executive functions (Kim & Cabeza, 2009). However, it is surprising that no further frontal activation can be reported as it was originally expected.

In addition, different right hemispheric activation was found, namely amongst others a part of the striatum. Here, it is interesting to note that the caudate nucleus was discussed in the context of withholding an answer (see section 6.1.3). When looking at the control process in general which comprises withholding and volunteering, the putamen revealed activation. The caudate nucleus and putamen are the main input nuclei to the basal ganglia and receive axons from nearly all parts of cortex (Grahn et al., 2008).

The putamen, nucleus accumbens and caudate nucleus constitute the ventromedial striatum which is part of the limbic loop that receives frontal input from the orbital and medial prefrontal cortex (Haber, Fudge & McFarland, 2000; Kunishio & Haber, 1994). In contrast, an associative loop involves the head of caudate and most rostral putamen; receiving input from the dorsolateral prefrontal and posterior parietal cortex (Parent, 1990; Parent & Hazrati, 1995). One can conclude from this that maybe the lack of prefrontal activation is moderated or even compensated by the putamen.

It was assumed that control processes require a high degree of cognitive function, however, the current results indicate that the putamen appears, in contrast to the caudate nucleus, to support cognitive functions in a more limited way (Grahn et al., 2008). This is in line with the definition of the different processes, because withholding an answer is more specific than the control process in general which combines both withholding and volunteering.

6.1.6 Memory accuracy

High memory accuracy (in contrast to low memory accuracy) was here defined as withholding an objectively incorrect answer in contrast to volunteering an incorrect answer according to the memory paradigm of Koriat and Goldsmith introduced in 2.4.5. The behavioral data revealed that significantly more items were connected with high memory accuracy then with inaccuracy (see section 5.1.3).

It has to be noted that even though correct retrieval and memory accuracy seem to be identical at first sight, conflictive cognitive functions are required. Both processes were defined and operated very different in this study, since correct retrieval implied identifying a correct item as correct whereas memory accuracy meant withholding an incorrect answer. On the other hand, both processes evoke the same consequence, namely the excellence of the accordant memory. This is why it was hypothesized that, amongst others, the same brain regions will reveal neural activation, namely predominantly memory characteristic regions.

The present neural activation related to memory accuracy included the middle temporal gyrus, left hippocampus, and right precuneus.

The important role of the medial temporal lobe, (including the hippocampus and the parahippocampal gyrus) in memory performance has been known since the mid-1950s (Frankland & Bontempi, 2005; Scoville & Milner, 2000). The connection between the left hippocampus and accuracy was already found earlier (Mendelsohn et al., 2010) and is supported by the current results. Moreover, it was reported that activation in left hippocampus and posterior cingulate cortex / precuneus are a

function of accuracy (Mendelsohn et al., 2010) which was already discussed in section 6.1.1 concerning correct memory retrieval. A recent study also found activity in a region centered in the left anterior hippocampus that was related to accurate retrieval for emotional as well as neutral items (Kensinger & Schacter, 2005).

At this point it is important to highlight that exactly the same activation pattern was found when correct memory retrieval proceeded (see section 6.1.1). For this reason the previous assumption that there is a memory network related to correct retrieval and accurate memory is even strengthened. This network includes the hippocampus, the precuneus, and the middle temporal gyrus. Beyond that, one can conclude from the current results that the left hippocampus mediates the excellence of memory, independent of design specifications and the way of operationalizing.

In addition, the superior temporal gyrus and supramarginal gyrus revealed bilateral activation related to memory accuracy. These regions were found to play a role in visual word recognition (Hart, Kraut, Kremen, Soher & Gordon, 2000). Better performance in tasks requiring cross-modal conversions of visual / auditory words was also found to be correlated with activation in the supramarginal gyrus (Booth et al., 2003). Furthermore, the SMG is considered to play an important role in verbal working memory (Clark et al., 2000). It is suggested that the activation of the SMG (in combination with the middle frontal gyrus) is related to the executive control of goal-setting in planned behavior (Clark et al., 2000). The supramarginal gyrus (part of Brodmann area 40) is furthermore a region in the inferior parietal lobe that is involved in reading both in regards to meaning and phonology. The authors conclude that SMG contributes to reading regardless of the specific task demands. They assume that this may be connected with automatically computing the sound of a word (Stoeckel et al., 2009).

Accordingly, in the context of memory accuracy one can assume that the observed areas are associated with retrieval of semantic and language-related information (Kircher, Brammer, Williams & McGuire, 2000; Lee, Robbins, Graham & Owen, 2002) and moreover one could suggest that the activation is related to verbal working

memory processes like actively holding sentences in mind. This is explainable with regard to the way of operating memory accuracy, because certain information was firstly retrieved then monitored, and finally the decision was reached to withhold the information.

During the decision process the retrieved memory is certainly actively held in mind and due to the fact that the accordant items in this study design were short statements, the connection to verbal and language-related processing is obvious. Maybe the fact that information is held in mind verbally and is processed in a language-related way is an important contribution to memory accuracy. This assumption is also underlined by the fact that none of these regions revealed activation concerning memory inaccuracy.

The reverse contrast, inaccuracy or low memory accuracy (in contrast to high memory accuracy), was defined as volunteering incorrect answers. It was shown in the behavioral data (see section 5.1.3) that low memory accuracy occurred relatively rarely. The imaging data presented that only the left superior frontal gyrus and the left insula demonstrated neural activation.

Activation of the left superior frontal gyrus was also found to play a role at low confidence ratings. It is important to note that the given answers were objectively incorrect which means that subjects did not necessarily know about the incorrectness of the according item when they decided to volunteer. The region was previously reported to be connected with strategic processes involved in memory retrieval and higher cognitive function (Burgess et al., 2007), and is supposed to be related to working memory (Du Boisgueheneuc et al., 2006). The connection to cognitive functions and strategic processes as well as working memory may be explained by the fact that subjects were not completely convinced by the correctness of their answer when they volunteered it and calculated the probability of gaining or loosing bonus points. This fits well to the finding that the same region revealed activation when low confidence ratings were given.

Moreover, one can assume from the results that uncertainty and inaccuracy may belong to related underlying processes whereas no relationship to false memories can be reported.

In addition, neural activity was related to the left insula (see Figure 40). Mohr and colleagues determined the role of the insula finding that this region was consistently associated with risky behavior (Mohr, Biele & Heekeren, 2010; Weller, Levin, Shiv & Bechara, 2009). Furthermore, the insula was found to be predominantly active in the presence of potential loss (Mohr et al., 2010). Low memory accuracy was defined as volunteering an incorrect answer – if presuming that subjects unconsciously anticipated the incorrectness of their decision the before mentioned finding would be downright in accordance with the current experimental design hence subjects knew that incorrect decisions resulted in a loss of bonus points.

Different findings suggest that the insula along with medial posterior cingulate cortex is involved in the estimation of the predictability of stimuli (Blakemore, Rees & Frith, 1998) – a process that might be related to the cognitive process of calculating the probability of gaining or loosing bonus points.

Besides, the insula, together with the claustrum, is believed to be associated with the integration of motivational, sensory, emotional, and mnemonic information via reciprocal claustro-neocortical and its claustrolimbic connections (Kühnel, 2006; Markowitsch, Irle, Bang-Olsen & Flindt-Egebak, 1984). Thus, the activation in the insula might reflect the processing of the retrieved statements and the monitoring as well as the decision process of being motivated to volunteer a subjective potentially correct answer. This is in line with the previous finding that activation of the insula was also found in low confidence ratings which was connected with monitoring as well as cognitive effort and interpreted in terms of effortful task performance (Phan et al., 2002).

6.2 General discussion

The aim of the current study was to modify and implement the memory paradigm of Koriat and Goldsmith into a 7 Tesla fMRI design to examine the neuropsychological correlates of retrieval, monitoring, and control processes as well as memory accuracy.

Twelve healthy men and women were examined with functional magnetic resonance imaging concerning the different neural correlates connected with retrieval, monitoring, and control processes as well as memory accuracy according to the memory paradigm. Variable consequences can be drawn from the results of this experiment. The different phases are distinguishable related to their activation pattern of the neural correlates. In the following, the main findings related to the different processes will be summarized and implications for future research will be given.

From the behavioral results revealed by the retrieval process one can assume that correct and incorrect retrieval can be differentiated. Concerning the imaging data it is to note that only the contrast between correct and incorrect retrieval reached significance. It is strongly assumable that correct and incorrect retrieval evoke different activation pattern, so future research should investigate this contrast with a larger number of participants. As it was hypothesized, the retrieval process activated memory relevant brain regions, particularly the hippocampus. Even though it is assured that the hippocampus is important for detailed and vivid memory recall, its contribution to retrieval is still debated controversially (Gilboa et al., 2004; Gilboa, 2006; Maguire, 2001). The current results suggest that particularly the left hippocampus plays an important role at least for correct memory retrieval. The role of the hippocampus related to incorrect memory retrieval according to the memory paradigm still needs to be examined.

Moreover, correct memory retrieval presented similar brain activation as memory accuracy. In this study it was assumed that both correct memory retrieval and memory accuracy are similar phenomena, because both evoke the same

consequence, namely the quality of the accordant memory. This needs to be clarified and verified since both were operationalized differently and presumably require different cognitive functions.

However, the results reveal a memory network comprising the left hippocampus, precuneus, and the left middle temporal gyrus. According to the current experiment this network is involved in both memory accuracy and correct memory retrieval. At this point, it has to be emphasized that there are many different ways to define and operationalize memory accuracy. It would be interesting to study whether another definition of memory accuracy and a different paradigm would also lead to the same neural activation which would approve the hypothesized memory network.

The monitoring process was characterized by very diverse neural correlates connected with high and low confidence, respectively. Against the hypothesis, no prefrontal activation was found when high confidence ratings were given. This is surprising and may be caused by the fact that high confidence was only defined as 100% confidence, meaning that subjects were very sure about the memory and maybe did not really need to monitor the answer.

The reverse contrast was related to 50% confidence. The assumption that low confidence ratings reveal a higher demand for cognitive and monitoring functions due to the uncertainty about the memory was affirmed. One can assume from the results that due to the fact of being activated in both contrasts, temporal areas are associated with a confidence rating in general. In contrast, specific frontal regions are associated with low confidence which reveals the greater monitoring demands when memory judgments are less certain.

Because of the design specification and the fact that fMRI technique was used it was not possible to apply a very precise graduation like a range between 1% and 100%. Indeed, in a future experiment a 75% confidence alternative should be analyzed. It is assumable that this rating reveals an even higher demand for cognitive effort and monitoring functions, because of being less explicit.

When dissecting the two different control processes, namely volunteering and withholding, it becomes obvious that both domains are related to different cognitive demands. In this design correct volunteering was rewarded with a bonus, whereas incorrect volunteering caused a loss of bonus. According to the behavioral data, subjects were engaged with this system because they rather volunteered an answer to increase their reward instead of withholding it.

It was found that the activation pattern connected with volunteering was similar to the one related to monitoring. It is reasonable to conclude that volunteering is subject to monitoring processes. Moreover, the relationship is explainable, because both processes rely on the same memory that in the end decides on the confidence rating and the fact whether the answer is volunteered or not.

The results related to volunteering indicate activation of the dorsolateral prefrontal cortex which was found to be modulated by the amount of monetary reward (Lee & Seo, 2007). This interconnection can be clarified in future studies by varying the bonus system in different ways. Koriat and Goldsmith differed in their research between high and moderate incentives. In the current study, a moderate accuracy incentive was used, namely a balance between gain and loss of bonus. It would be interesting to analyze the activity of the DLPFC in connection with high accuracy incentive which implied gaining a bonus for each correct answer but losing the complete bonus if only one answer was incorrectly volunteered.

In contrast, withholding an answer did not cause any consequence concerning gaining or loosing bonus points. Against the assumption of frontoparietal and particularly (ventrolateral) prefrontal areas being activated, the neural correlates concern brain regions which are known for memory retrieval. It was already discussed previously that this may be a consequence of the design specification since there was only a very small space of time to answer which might have caused an overlap in neural activity to the retrieval process. Maybe prefrontal activation will be detected, if the time to answer is expanded in a future experiment giving subjects the possibility to actively select or inhibit the accordant response.

The results suggest that participants might have learned to use certain strategies, like withholding the response when being uncertain about the outcome which is assumed to be deduced by activation of the hippocampus and the caudate nucleus (Grahn et al., 2008). Future research should be carried out in order to examine this relationship.

Moreover, it was investigated whether the different processes are generally distinguishable or whether they bear resemblance to each other. Against the background of this question, it was assumed that monitoring and control processes exhibit a strong relationship. Before discussing the similarities and differences, the two processes monitoring and control are presented separately.

The monitoring phase was defined as giving either a high or low confidence judgment. The present results ascertain that monitoring is part of executive functioning and working memory processes which was mainly reflected by activation of the dorsolateral prefrontal cortex (Goldman-Rakic, 1996; Smith & Jonides, 1999) and the anterior cingulate (Fan et al., 2005). Evidence suggests that during the monitoring process participants selected the according response from the retrieval process and the according memory was visually imagined which is supported by brain activation of the inferior and middle occipital gyrus and activation in memory characteristic regions. In sum, it is assumable that monitoring and retrieval processes as defined by Koriat and Goldsmith are related mechanisms, whereas monitoring features a higher demand for cognitive performance.

The control process included either volunteering a response or withholding it. A connection to executive functions was only revealed by middle frontal activation. It is remarkable that no further frontal activity can be reported.

Due to the fact that activity was found in the ventromedial striatum, and more precisely, the putamen which receives (via the limbic loop) frontal input from the orbital and medial prefrontal cortex (Haber et al., 2000; Kunishio & Haber, 1994) as well as from the dorsolateral prefrontal and posterior parietal cortex (Parent, 1990; Parent & Hazrati, 1995) it could be possible to expect that maybe the lack of

prefrontal activation is moderated or even compensated by activation of the putamen. This suggestion should be ascertained in future experiments.

One can conclude from the described results that monitoring and control evoke different neural activity. In addition, monitoring is connected with executive functions and cognitive performance more clearly than the control process.

On the other hand both processes were found to show overlapping neural correlates, namely the left middle temporal gyrus and the left middle frontal gyrus. Interestingly, the MTG was reported to be related with memory (Dörfel et al., 2009). It is reasonable to conclude that the relationship between monitoring and control is constituted by the association to memory. This coherence is explained by the presumption that both are based on the underlying memory quality which in turn determines the outcome of the accordant process, meaning that high memory quality might lead to high confidence rating and volunteering the particular response, whereas low memory quality might arouse a low confidence rating and withholding the answer.

The respectively reverse contrasts like retrieval against monitoring and against control as well as monitoring versus control did not reach statistical significance. Maybe different and more meaningful results for those contrasts can be reached when utilizing different fMRI parameter or a larger sample size.

Concerning memory accuracy two different assumptions were drawn. On the one hand it was suggested that high and low memory accuracy differs from each other. On the other hand it was hypothesized that high memory reveals similar activation as correct memory retrieval. Both suppositions were approved. High memory accuracy was assessed as withholding an incorrect answer in contrast to volunteering an incorrect answer. The behavioral data point out that the responses of the participants revealed high accuracy more often than low accuracy (see section 5.1.3). The neural activation pattern related to memory accuracy included the middle temporal gyrus, left hippocampus, and right precuneus, areas that are known to play a role in memory functions (Frankland & Bontempi, 2005; Scoville & Milner, 2000). It was

even found that activation in left hippocampus and posterior cingulate cortex / precuneus are a function of accuracy (Mendelsohn et al., 2010; Kensinger & Schacter, 2005). As introduced earlier, the idea of memory network consisting of the hippocampus, the precuneus, and the middle temporal gyrus which is assumed to be crucial for correct and accurate memory performance seems to be confirmed. However, the relationship between correct retrieval and memory accuracy has to be analyzed in future studies.

According to Koriat and Goldsmith, strong incentives can lead to very accurate memory reports. Participants are very sensitive for the level of accuracy incentive and are able to enhance their accuracy significantly when a strong incentive is provided (Goldsmith et al., 2002; Koriat & Goldsmith, 1996c). It would be interesting to explore in the future whether the described memory network can still be replicated when a high accuracy incentive is offered.

Furthermore, the role of the left hippocampus in correct retrieval and memory accuracy has to be highlighted. It is assumable from the current results that the left hippocampus mediates the excellence of memory, independent of design specifications and the way of operationalizing.

Additionally, activation was found in the superior temporal gyrus and supramarginal gyrus. It is conceivable that these regions are connected with retrieval of semantic and language-related information (Kircher et al., 2000; Lee et al., 2002) and therewith are associated with verbal working memory processes like actively holding sentences in mind. It can be concluded that holding information in mind and processing it in a language-related way is one important contribution to memory accuracy.

In contrast, low memory accuracy, or inaccuracy, was defined as volunteering incorrect answers. The behavioral data reveals that low memory accuracy occurred significantly less often than memory accuracy. Brain activation was limited to the left superior frontal gyrus and the left insula. The left SFG is assumed to be associated with strategic processes involved in memory retrieval, higher cognitive function (Burgess et al., 2007), and working memory (Du Boisgueheneuc et al., 2006). In

addition, the SFG showed activation at low confidence ratings. This might indicate that the participants were not completely convinced by the correctness of their response when they volunteered it and calculated the probability of gaining or loosing bonus points. And, it was concluded that uncertainty and inaccuracy may belong to related underlying processes.

Insula activity was interpreted in terms of risky behavior (Mohr et al., 2010; Weller et al., 2009) and potential loss (Mohr et al., 2010). Furthermore, it was suggested that the insula together with medial posterior cingulate cortex is connected with the estimation of the predictability of stimuli (Blakemore et al., 1998)

This result points out that subjects maybe unconsciously anticipated the incorrectness of their decision, because they knew that incorrect decisions resulted in a loss of bonus points which may be interpreted as a sign of risky behavior.

In the current study results were deduced from a group of 24 male and female young adults with a mean age of 25 years. It would be interesting to examine to what extent and in which way the neural correlates of retrieval, monitoring, and control processes as well as memory accuracy change depending on age effects. Even though, differential results are reported concerning memory performance and aging (Light & Singh, 1987; Kessels, Boekhorst & Postma, 2005; Daffner et al., 2010) it seems to be obvious that memory accuracy decreases in older adults. In the main, episodic long term memory is affected from that decline (Buckner, 2004; Grady, 2008; Piefke & Fink, 2005). Due to the finding that the accuracy of episodic memories is related to LTM and executive functions (Piefke, 2008; Piefke & Fink, 2005) it is strongly assumable that a study with older people will reveal different neural correlates compared to the current results. Moreover, it would be informative to investigate the effects of differential rewards (moderate versus strong incentive) and the according influence on memory accuracy in older people.

Furthermore, the question arises whether neural correlates of male and female participants would be distinguishable from each other and to what extent these gender differences would influence the results. It seems to be supported that there are distinctions related to memory regulated by gender. A recent fMRI study examined autobiographical memory retrieval in male and female subjects and found that beside activation common to men and women, neural correlates differed in consideration of gender. In males, brain activation was connected with the left parahippocampal gyrus, whereas neural correlates of females were associated with the right dorsolateral cortex and right insula. According to the authors, the different results illustrate gender-specific cognitive strategies related to autobiographical memories (Piefke et al., 2005).

Evidence suggests that men and women reveal different performance concerning spatial and verbal cognitive abilities (Halpern, 1992). In spatial and verbal memory tasks it has been shown that females were more successful in verbal tasks while males revealed better performance in the spatial domain (Halpern, 1992; Vecchi & Girelli, 1998; Mekarski, Cutmore & Suboski, 1996). In this context it would be fundamental to analyze the utilized statements more precisely. In the current experimental design the correct and incorrect statements were consistently related to different categories, like content, perception, and action. It could be contributing to explore in what way males and females evoke differences related to the neural correlates of correct and incorrect retrieval depending on the three categories. It has to be noted as limitation of this study that very specific kind of material was used, namely a short film with more or less emotional content.

Admittedly, much more statements as well as larger groups of male and female participants would be needed to reach statistical significant results.

7 Conclusion

Investigation of functional brain correlates during retrieval, monitoring, and control processes as well as memory accuracy was conducted by 7 Tesla fMRI in 12 male and 12 female healthy subjects.

The main aim of this study was to investigate memory accuracy as well as the related processes in the framework of Koriat and Goldsmith memory paradigm. The results suggest a memory network including the left hippocampus, the precuneus, and the left middle temporal gyrus. It was found that this network is involved in both memory accuracy and correct memory retrieval, even though both were defined relatively different in this experiment. In terms of eyewitness reports this network might play an important role someday, since it might point to giving accurate and correct evidence for example in court. However, much more and differential experiments are needed to replicate and verify this neural activation pattern.

Moreover, the results suggest that the left hippocampus plays an important role in correct as well as accurate memory retrieval which sheds light on the controversial discussion concerning the hippocampus and its contribution to memory retrieval.

One can assume from the results related to monitoring process that temporal areas are associated with a confidence rating in general, whereas specific frontal regions were associated with low confidence which reveals that monitoring demands increase when memory judgments are less certain.

The control phase included volunteering or withholding a response. According to the current findings it is reasonable to conclude that volunteering is subject to monitoring processes whereas withholding an answer is not. In addition, volunteering caused activity of the dorsolateral prefrontal cortex. This relationship can be assumed to be modulated by the amount of monetary reward.

Withholding an answer was correlated with neural activation which is concerned with memory retrieval and brain activity of the hippocampus and the caudate nucleus indicating that participants might have learned and used different strategies.

In summary, the results connected with the three different processes, namely retrieval (correct versus incorrect), monitoring (high confidence versus low confidence), and control (volunteering versus withholding) point to the fact that the different sub-processes are independent from each other; hence very diverse cognitive demands are made.

In addition, it was examined in the current study to what extent the different processes are distinguishable or related to each other. It is reasonable to suggest that monitoring is part of executive functioning and is related to working memory processes which points to the fact that particularly attention processes play a crucial role concerning monitoring of memory functions. Compared to the retrieval phase one can conclude that both processes are linked to each other, indeed monitoring exhibits a higher demand for cognitive performance.

In contrast, related to control process a connection to executive functions was only reflected by middle frontal activation and was indirectly revealed by activation of the putamen. Similar activity of both processes was revealed by the left middle temporal gyrus, and the left middle frontal gyrus. It is reasonable to conclude from the results that the connection between monitoring and control is mediated only by memory.

Beside its contribution to the previously introduced memory network, memory accuracy aroused brain activation of the superior temporal gyrus and supramarginal gyrus. One can assume from this result an association to verbal working memory processes and moreover it is reasonable to assume that holding information in mind and processing it in a language-related way leads to an increase in memory accuracy.

Low memory accuracy evoked left-hemispheric neural activation in the superior frontal gyrus and the insula and therewith no relationship to high memory accuracy can be reported. Instead, there is indication of cognitive function and working memory processes as well as a connection to risky behavior related to inaccuracy of memory retrieval.

It needs to be considered as limitation of this study that memory accuracy as well as inaccuracy was operationalized in a very narrow way. Particularly high memory accuracy was here operationalized very passively like not volunteering an incorrect answer.

It should be further investigated to what extent the results are repeatable when memory accuracy is defined in a different fashion.

In sum, this study succeeded in trying to implement the memory paradigm of Koriat and Goldsmith into an fMRI setting. It is possible to investigate the different memory processes separately and each of them is connected with specific neural correlates even though the same memory content is concerned, respectively.

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Appendix A – Clarification and information

Clarification and information

1. Information form for participants

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Informationsblatt für Probanden

Liebe Probandin, lieber Proband,

wir möchten Ihnen anhand dieses Informationsblattes den Zweck des Projektes und den Ablauf der Untersuchung näher erläutern.

Teilnahme

Die Teilnahme an der Untersuchung ist freiwillig. Sie können jederzeit und ohne Angabe von Gründen Ihre Einwilligung widerrufen, ohne dass dies mit Nachteilen für Sie verbunden wäre. Wichtig ist, dass Sie Rechtshänder sind, zwischen 18 und 35 Jahren alt sind, Ihre Muttersprache Deutsch ist, Sie eine normale (oder durch Kontaktlinsen korrigierte) Sehstärke haben und die Kriterien für die fMRI-Untersuchung erfüllen (siehe unten).

Kurzbeschreibung des Projektes

Das übergreifende Ziel des beantragten Projekts ist die Untersuchung der Genauigkeit des Gedächtnisses bei gesunden Versuchspersonen. Hierfür werden als Methoden umfangreiche neuropsychologische Untersuchungen, spezielle Verfahren zur Messung der Gedächtnisgenauigkeit und die strukturelle und funktionelle Kernspin- bzw. Magnetresonanztomographie (MRI, fMRI) zur Erfassung der anatomischen und neurofunktionellen Grundlagen des Gedächtnisses eingesetzt.

Wir möchten Sie im Laufe des Experiments bitten, zunächst einen kurzen Film anzuschauen und daran anschließend an einer neuropsychologischen Untersuchung teilzunehmen. In dieser Untersuchung werden verschiedene Gehirnfunktionen (z.B. Aufmerksamkeit, Gedächtnis, exekutive Funktionen) untersucht. Des Weiteren werden Ihnen verschiedene Fragebögen vorgelegt.

Außerdem bitten wir Sie, an einer kernspintomographischen Untersuchung teilzunehmen, die im Erwin L. Hahn Institut für Magnetresonanz in Essen stattfindet. Bei dieser Untersuchung wird Ihre Gehirnaktivität gemessen, während Sie bestimmte Denkaufgaben lösen.

Für Ihre Teilnahme bekommen Sie einen Geldbetrag von min. 20€ als Aufwandsentschädigung sowie die Bilder, die während der fMRI-Untersuchung von Ihrem Gehirn gemacht wurden (diese sind allerdings nicht für diagnostische Zwecke geeignet).

Kernspintomographische Untersuchung

Bei der kernspintomographischen Technologie werden keine körperlichen Eingriffe vorgenommen und die Untersuchung ist bei Einhaltung der Ausschlusskriterien (siehe unten) für den Körper nach heutigem Erkenntnisstand mit keinerlei gesundheitlichen Risiken verbunden. Sie wird in der klinischen Routinediagnostik weltweit eingesetzt. Im Gegensatz zu anderen diagnostischen Verfahren (z.B. Röntgendiagnostik) wird bei der Kernspintomographie **keine** Radioaktivität eingesetzt. Die Kernspintomographie basiert ausschließlich auf den magnetisierbaren Eigenschaften von Geweben.

MRT Ausschlusskriterien:

Da Sie sich währen der fMRI Messungen in einem starken Magnetfeld befinden, ist es wichtig, dass Sie vor der Untersuchung **alle metallischen Gegenstände** (z.B. Schmuck, Piercings) vom Körper **entfernen**. Falls Sie nicht entfernbare Metalle oder metallhaltige Substanzen bzw. Geräte im Körper haben (z.B. Herzschrittmacher, Medikamentenpumpe, Aneurismenclips, Prothesen, Metallimplantate) können Sie nicht an der Untersuchung teilnehmen. Wenn Sie nicht sicher sind, ob möglicherweise Implantate bei Ihnen metallisch sind, sollten Sie uns dies mitteilen, damit wir zusammen z.B. von Ihrem Arzt entsprechende Erkundigungen einholen können. Tätowierungen sind in Einzelfällen auch ein Ausschlusskriterium – hier wird nach Größe der Tätowierung, der Farbe und der Lokalisation entschieden.

Des Weiteren ist es wichtig, dass Sie nicht unter **Klaustrophobie** (Angst vor Enge) leiden.

Ablauf

In einer ersten Sitzung, wird Ihnen ein Film gezeigt woraufhin die neuropsychologische Untersuchung stattfindet. Unmittelbar danach wird die fMRI-Untersuchung durchgeführt und Sie werden danach gebeten einen Fragebogen auszufüllen.

Die zweite Sitzung wird genau eine Woche später stattfinden und es werden Ihnen erneut verschiedene Fragebögen vorgelegt.

Datenschutz

Die Bestimmungen des Datenschutzes werden eingehalten. Alle Untersuchungsergebnisse werden streng vertraulich behandelt. Die ärztliche und psychologische Schweigepflicht bleibt gewahrt. Die Einzelergebnisse werden anonymisiert verwaltet und weiterverarbeitet.

Wissenschaftliche Ergebnisse der Untersuchung werden möglicherweise in medizinisch-psychologischen Fachzeitschriften veröffentlicht. Durch die Anonymisierung der Daten ist aber keine Identifikation Ihrer Person möglich.

Für weitere Fragen zu der Studie stehen wir Ihnen jederzeit gerne zur Verfügung.

Prof. Dr. Hans J. Markowitsch   Dipl. Psych. Uda M. Risius

2. Consent form

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Liebe Probandin, lieber Proband,

da es sich in diesem Fall um eine sehr aufwändige und wichtige Studie handelt, möchten wir Sie bitten, im Vorfeld folgende Fragen ehrlich zu beantworten.

Name: _____   Vorname: _____   Geschlecht: _____

Geburtsdatum: _____   Geburtsort: _____   Familienstand: _____

Größe: _____   Gewicht: _____   (wichtig für die fMRI-Untersuchung)
_____

Schulbildung:
Hauptschule O   Realschule O   Gymnasium O   andere: _____
Schulabschluss: _____

Berufsausbildung:
Berufsschule: _____   Lehre: _____   Studium: _____
Derzeitige Berufstätigkeit: _____   frühere Berufstätigkeit: _____

_____

Ein- und Ausschlusskriterien

Sie…	ja	nein
…sind zwischen 18 und 35 Jahre alt		
…haben Deutsch als Muttersprache		
…sind Rechtshänder		
…haben eine normale Sehstärke (oder Kurzsichtigkeit)		
falls nicht: Sie haben Kontaktlinsen		

…haben Klaustrophobie (Angst vor Enge)		
…haben Piercings, die nicht entfernt werden können		
…haben Tätowierungen		
…haben eine (metallhaltige) Spirale		
…sind schwanger		
…haben neurologische oder psychiatrische Erkrankungen		
…haben medizinische Erkrankungen (z.B. Herz- und Kreislauferkrankungen, onkologische Erkrankungen)		
…nehmen zentral wirksame Substanzen ein (z.B. Schmerzmittel, Neuroleptika, Antidepressiva)		
…sind fMRI-tauglich (das heißt, kein: Herzschrittmacher, Medikamentenpumpen, Aneurisma, Clips, Metallimplantate, feste Zahnklammern, metallhaltige Schminke, Epilepsie)		
Bei Frauen: Tag der letzten Regelblutung: _____		

Ich habe alles verstanden und wahrheitsgemäß beantwortet.

_____
Unterschrift Proband(in)

Vielen Dank für Ihre Teilnahme!

Appendix B – Pre-scanning procedure

Pre-scanning Procedure

1. Instruction

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Instruktion für das Quiz

In dem folgenden Quiz werden Ihnen richtige und falsche Aussagen präsentiert. Das Quiz dient als Vorbereitungsphase für die fMRI-Untersuchung, daher ist es wichtig, dass Sie auf jede Aussage so schnell wie möglich reagieren. Bei der fMRI-Untersuchung werden Sie einen ähnlichen Schalter bekommen, wie er in der Instruktion zu sehen ist. Sie werden gebeten die PC-Tastatur zu verwenden. Die Auflösung für das Quiz bekommen Sie natürlich im Nachhinein ausgehändigt.

Bitte lesen die Aussagen und entscheiden sich dann, ob es sich jeweils um eine richtige oder falsche Aussage handelt.

Beispiel:

Der Fußball ist rund.

richtig   falsch
1   3

Wenn Sie denken, dass es sich um eine **richtige Aussage** handelt, drücken Sie bitte die **1** der Tastatur. Wenn Sie denken, dass es sich um eine **falsche Aussage** handelt, drücken Sie bitte die **3**. Falls Sie die Antwort einmal nicht wissen, raten Sie bitte.

Danach schätzen Sie bitte ein, wie sicher Sie sich bei Ihrer Entscheidung sind.

Beispiel:

Sicherheit?

sehr sicher   unsicher
halbwegs sicher
1   2   3
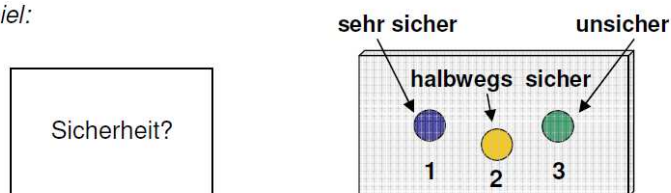
Wenn Sie **sehr sicher** sind, drücken Sie bitte die **1** der Tastatur, sind Sie **halbwegs sicher**, drücken Sie bitte die **2** und wenn Sie **unsicher** sind drücken Sie bitte die **3**.

Daraufhin werden Sie gefragt, ob Sie auf Ihre Aussage wetten wollen. Wenn Sie sich entscheiden auf Ihre richtige Aussage zu **wetten**, drücken Sie bitte die **1**. Für jede korrekte Antwort auf die Sie wetten, bekommen Sie 1 Punkt und für jede falsche Antwort auf die Sie wetten, wird Ihnen 1 Punkt abgezogen.

Sie können bei jeder Aussage erneut entscheiden, ob Sie wetten wollen oder nicht. Wenn Sie **nicht wetten** wollen, drücken Sie bitte die **3**.

Beispiel:

Vor jeder neuen Aussage wird Ihnen ein Fixationskreuz dargeboten, auf das Sie bitte durch Drücken der Taste **2** reagieren.

Beispiel:

Bitte antworten Sie immer so schnell wie möglich! Auch wenn Sie einmal nicht antworten, läuft die Präsentation automatisch weiter. Bitte geben Sie Ihre Antwort in diesem Fall nicht im Nachhinein, sondern machen Sie direkt mit der nächsten Darstellung weiter. ..

Während des Quizzes werden Sie aufgefordert, die instruierten Tastenbelegungen zu drücken – bitte tun Sie dies so schnell wie möglich, da wir hiermit überprüfen, ob Sie generell die richtigen Tasten benutzen. Geben Sie bitte auch hierfür eine Sicherheitseinschätzung ab, außerdem können Sie auch in diesem Fall auf Ihre Aussage wetten.

Viel Spaß beim Quiz!

2

2. Statements

Toronto ist die Hauptstadt von Kanada.
Luther nagelte seine Thesen an die Schlosstüre von Wittenberg.
Raben sind schlechte Eltern.
Tulpen kommen aus Holland.
Die Steinzeitmenschen lebten in Höhlen.
Bleistifte enthalten Blei.
Das Alter der Marienkäfer erkennt man an der Punktezahl.
Muskelkater entsteht durch feine Risse in den Muskelfasern.
Flugzeuge sinken in Luftlöchern ab.
Pflanzen können Fieber bekommen.
Der oberste Indianergott heißt Manitou.
Kricket ist ein typisch englisches Spiel.
Hornissen sind giftiger als Bienen.
Das Croissant wurde in Österreich erfunden.
Esel sind dumm.
Die Hauptstadt der USA ist New York.
Panther sind eine eigene Raubkatzenart.
Rot reizt Stiere.
Blindschleichen sind blind.
Wenn man den ganzen Körper mit Farbe anmalt, erstickt man.
Ali Baba ist der Anführer der 40 Räuber.
Katzen vertragen keine Milch.
Das Rad war die wichtigste Erfindung der Menschheit.
Erdbeeren sind Beeren.
Blut ist bei allen Tieren rot.
Karl May war nie im „Wilden Westen".
Cola ist gut bei Durchfall.
Platzangst ist die Furcht vor großen, leeren Plätzen.
Sydney ist die Hauptstadt von Australien.
Luxemburg ist das kleinste Land der EU.
Kleopatra war Ägypterin.
Mozart hieß mit Vornamen Wolfgang Amadeus.
Eisbären haben schwarze Haut.
Luft wiegt nichts.
Alle Katzen sind wasserscheu.
Die Freiheitsstatue steht in Paris.
Alle Geier fressen Aas.
Alle Säugetiere bringen lebende Junge zur Welt.
Der deutsche Regierungssitz ist Berlin.
Vampire gehören zu den Insekten.
Elefanten haben eine dicke Haut.
Die größte Pyramide der Welt steht in Mexiko.
Der 100-jährige Krieg dauerte 100 Jahre.
Wale sind Fische.
Im Wasser kann man nicht schwitzen.

3. Cut-off Evaluation

Cut-off Berechnung

Versuchsperson: Untersuchungsdatum:

_____

1. Baseline:
Drücken der 2. Taste ohne Auslassungen und Mehrfachdrücken:

Fehler: _____   0 – 1 – 2: | 2 |

3 – 4 – 5: | 1 |

≥ 6: | 0 |

2. Auslassungen:
Auslassungen bei Statements, Sicherheits-Ratings und Wetten:

Fehler: _____   0 – 1 – 2: | 2 |

3 – 4 – 5: | 1 |

≥ 6: | 0 |

3. Mehrfachdrücken:
Drücken von 2 oder mehr Tasten bei Statements, Sicherheits-Ratings und Wetten:

Fehler: _____   0 – 1 – 2: | 2 |

3 – 4 – 5: | 1 |

≥ 6: | 0 |

4. Testfragen:
Beantwortung der Fragen zur Tastenbelegung:

Nr.	Folie	Antwort	Richtig?
3	sehr sicher	1	
6	wetten	1	
8	falsch	3	
12	sehr sicher	1	
16	halbwegs sicher	2	
18	nicht wetten	3	
21	richtig	1	

24	wetten	1	
26	unsicher	3	
29	nicht wetten	3	
32	halbwegs sicher	2	
36	nicht wetten	3	
38	unsicher	3	
41	halbwegs sicher	2	
44	richtig	1	
48	sehr sicher	1	
51	unsicher	3	
54	wetten	1	
56	richtig	1	
60	falsch	3	
64	falsch	3	

Fehler: _____   0 / 1:   2

                              2:                    1

                           ≥ 3:   0

4. weitere Auffälligkeiten / Bemerkungen des Probanden:

_____

Berechnung:

4 – 8 Punkte: fMRI-Untersuchung (wenn keine weiteren Auffälligkeiten)

0 – 3 Punkte: kein fMRI !!!

4. Volunteering – payoff

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Berechnung Wettbetrag

auf Antwort gewettet + richtige Antwort = **+ 1 Punkt:** _____ (wet_r)

auf Antwort gewettet + falsche Antwort = **- 1 Punkt:** _____ (wet_f)

nicht gewettet   = **0 Punkte**

Umrechnungsformel:

$$\text{Bonus (in Euro)} = (\text{wet\_r} - \text{wet\_f}) * 0.075$$

_____ – _____ * 0.075 = _____ €

Ich _____ (Vorname, Name) habe den oben berechneten Betrag sowie eine Summe von 20 € Aufwandsentschädigung erhalten.

_____   _____
Ort, Datum   Unterschrift

EYEWITMEM

Appendix C – Experimental design

Experimental Design

1. Instruction

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Instruktion für die Untersuchung im fMRI

Im fMRI-Scanner werden Ihnen richtige und falsche Aussagen zu dem Film präsentiert, den Sie heute gesehen haben. Da es im Scanner keine Möglichkeit gibt, verbal zu antworten, bekommen Sie einen Tastschalter, mit dem Sie per Knopfdruck Ihre Antwort geben können.
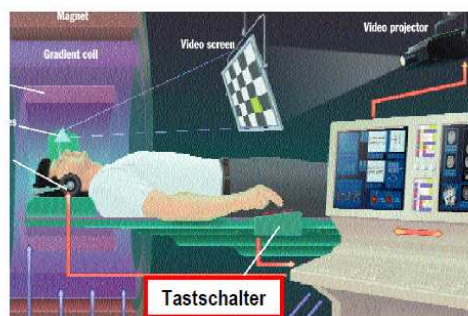
Das Antwortprinzip haben Sie bereits kennen gelernt, als Sie das Quiz durchgeführt haben, es wird aber im Folgenden noch einmal etwas genauer vorgestellt.

Bitte lesen die Aussagen und entscheiden sich dann, ob es sich jeweils um eine richtige oder falsche Aussage handelt

Beispiel:

Der Fußball ist rund.
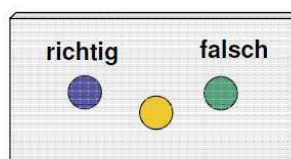
richtig   falsch

Wenn Sie denken, dass es sich um eine **richtige** Aussage handelt, drücken Sie bitte den **linken Knopf**. Wenn Sie denken, dass es sich um eine **falsche** Aussage handelt, drücken Sie bitte den **rechten Knopf**.

Danach schätzen Sie bitte ein, wie sicher Sie sich bei Ihrer Entscheidung sind.

Beispiel:

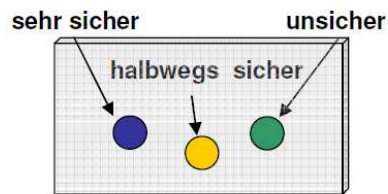Wenn Sie **sehr sicher** sind, drücken Sie bitte **linken Knopf.** Sind Sie **halbwegs sicher**, drücken Sie bitte den **mittleren Knopf** und wenn Sie **unsicher** sind drücken Sie bitte den **rechten Knopf.**

Daraufhin werden Sie gefragt, ob Sie auf Ihre Aussage wetten wollen.

Beispiel:
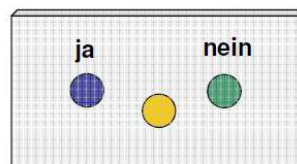
Wenn Sie sich entscheiden auf Ihre richtige Aussage zu **wetten**, drücken Sie bitte den **linken Knopf**. Sie können bei jeder Aussage erneut entscheiden, ob Sie wetten wollen oder nicht. Wenn Sie **nicht wetten** wollen, drücken Sie bitte den **rechten Knopf**.

Für jede korrekte Antwort auf die Sie wetten, bekommen Sie 1 Punkt und für jede falsche Antwort auf die Sie wetten, wird Ihnen 1 Punkt abgezogen.
Am Ende werden Ihre gesammelten Punkte in einen Geldbetrag umgerechnet. Sie können bis zu **13.50€** ausgezahlt bekommen.

Vor jeder neuen Aussage wird Ihnen ein Fixationskreuz dargeboten, auf das Sie bitte durch Drücken des **mittleren Knopfes** reagieren.

Beispiel:
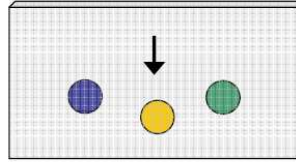
In den Aussagen zum Film wird der Hauptdarsteller als „er" und die Hauptdarstellerin als „sie" bezeichnet.

Bitte antworten Sie immer **so schnell wie möglich!** Die Präsentation läuft automatisch weiter, auch wenn Sie *nicht drücken.* Bitte versuchen Sie dies zu vermeiden, indem Sie in einem solchen Fall die Antwortalternative wählen, die Ihnen am ehesten als richtig erscheint.

Bitte bemühen Sie sich während des Scans *nicht* **zu bewegen**, da dies zu Verfälschungen führt und Ihre Daten unbrauchbar machen kann.

Wenn Sie Fragen zu der Instruktion oder dem Ablauf des fMRI-Scans haben, wenden Sie sich bitte an den Versuchsleiter.

Vielen Dank für Ihre Teilnahme!

2. Statements

Green = correct statement
Red = incorrect statement

H = action   P = perception   I = content

Number	Quality	Sentence
1.	P	Das Auto der Frau ist weiß
2.	I	Der neue Hund bestätigt die Einstellung des Hauptdarstellers.
3.	H	Er hat einen Mitbewohner.
4.	H	Er liest eine hebräische Zeitung
5.	H	Sie ist nach dem Unfall wütend.
6.	I	Die Freunde des Hauptdarstellers heißen Thomas und Malte.
7.	I	Der neue Hund ist anstrengend.
8.	I	Der Film heißt „Neue Katze".
9.	P	Sie trägt ein weißes Oberteil.
10.	P	Er hat einen Bart
11.	I	Freunde mit Hunden besuchen ihn am Wochenende.
12.	I	Am Grab küsst er die Frau.
13.	I	Das Pärchen kauft sich einen Hund.
14.	I	Er ruft den Rettungsdienst, als die Katze aus dem Fenster springt.
15.	H	Sie weint nach dem Unfall.
16.	H	Er gibt der Katze Vitamine.
17.	P	Sie ist blond
18.	I	Der neue Hund ist sehr pflegeleicht.
19.	H	Er gibt der Katze Hundefutter.
20.	H	Er putzt das Fenster mit einem Lappen.
21.	I	Er wurde schon einmal von einem Hund gebissen.
22.	I	Der neue Hund ändert die Einstellung des Hauptdarstellers.
23.	H	Sie und er unterhalten sich beim ersten Treffen.
24.	P	Sie trägt einen Rock.
25.	H	Er sieht sich Pärchen mit Hunden an.
26.	I	Sie ist völlig aufgelöst nach dem Unfall.
27.	I	Sie hat die Katze des Hauptdarstellers überfahren.
28.	P	Der neue Hund ist pflegeleicht.
29.	I	Er schläft nicht zusammen mit seiner neuen Katze ein.
30.	H	Er legt einen Hundeknochen auf das Grab.
31.	H	Er liest ein Buch.
32.	H	Sie sagt sie sei zu schnell gefahren.
33.	P	Es hängen Bilder über dem Fernseher.
34.	H	Er liest Zeitung auf der Toilette.
35.	H	Sie behauptet sie sei langsam gefahren.
36.	P	Er ist Roller gefahren.
37.	P	Die Gardinen des Hauptdarstellers sind kariert.
38.	H	Er bürstet seine neue Katze nicht.
39.	P	Die Katze ist braun-beige.
40.	H	Er spielt ein Videospiel.
41.	I	Es freut ihn nicht, dass der Hund mit im Bett schläft.
42.	I	Er verliebt sich in die Frau.
43.	P	Der Napf der Katze ist rot.
44.	I	Das Pärchen kauft sich einen neuen Hund.
45.	I	Das Paar schläft zusammen ohne den Hund im Bett.
46.	I	Der neue Hund heißt Bobby.
47.	H	Seine Freunde spielen in seinem Appartement mit Hunden.
48.	H	Er schläft mit der Katze im Bett.
49.	H	Seine Freunde essen Pizza in seinem Appartement.
50.	P	Beim Fahren trägt er keine Brille.
51.	P	Die Ballons im Raum haben verschiedene Formen.
52.	H	Er bietet der Katze Spaghetti zum Frühstück an
53.	P	In der Küche steht ein weißer Wasserkocher.
54.	H	Sie legt einen Strauß Blumen auf das Grab.
55.	I	Das Pärchen redet über die berufliche Laufbahn der Frau.
56.	P	In der Küche liegt eine Pfanne auf dem Herd.

57.	P	Der Staubsauger ist blau.
58.	P	In der Küche hängt ein Kronleuchter.
59.	H	Er gibt der Katze Katzenfutter.
60.	I	Er schreit die Frau an, als er sie sieht.
61.	I	Er rennt herunter, als die Katze aus dem Fenster springt.
62.	I	Die erste Nacht mit der neuen Katze war ein Horror.
63.	P	In der Küche ist ein Ventilator an der Decke.
64.	I	Sie möchte Kindergärtnerin werden.
65.	P	Es liegen Socken unter dem Bett.
66.	H	Er bietet der Katze Lasagne zum Frühstück an
67.	P	Auf dem Teppich liegt eine weiße Socke.
68.	I	Er hat ein Problem mit Hunden.
69.	I	Die Freunde des Hauptdarstellers heißen Thomas und Michael.
70.	H	Er steht nachdenklich unter der Dusche.
71.	I	Er fährt ohne Helm Roller.
72.	H	Er macht sich Gedanken beim Fernseher gucken.
73.	P	Der Teppich ist rot.
74.	H	Er telefoniert auf der Toilette.
75.	H	Sie klingelt nach dem Unfall an seiner Tür.
76.	I	Die Katze mag das Hundefutter nicht.
77.	H	Er spaziert mit dem neuen Hund.
78.	P	Der Teppich ist blau-grau
79.	I	Er hat eine Vorliebe für Katzen.
80.	P	Sie hat eine schwarze Hose an.
81.	I	Er wurde schon einmal von einer Katze gekratzt.
82.	H	Er liest eine englische Zeitung.
83.	H	Sie und er küssen sich beim ersten Treffen.
84.	I	Die Katze isst das Hundefutter.
85.	P	Im Wohnzimmer steht ein brauner Holztisch.
86.	I	Sie möchte weniger mit Kindern arbeiten.
87.	H	Er isst Kekse.
88.	I	Am Grab hält er die Hand der Frau.
89.	P	Die Decke des Hauptdarstellers hat ein Blumenmuster.
90.	H	Sie steht nach dem Unfall vor dem Auto.
91.	P	Im Bad hängen Postkarten an der Wand.
92.	I	Der Unfall wurde nicht von Passanten beobachtet.
93.	I	Die erste Nacht mit der neuen Katze war ein Erfolg.
94.	I	Es freut ihn, dass der Hund mit im Bett schläft.
95.	P	Sie hat einen Nasenpiercing.
96.	I	Das Paar schläft zusammen mit dem Hund im Bett.
97.	H	Sie ist Rektorin an einer Grundschule.
98.	P	Am Anfang trägt er ein T-Shirt von Nike.
99.	H	Er sperrt die Katze ins Bad.
100.	I	Er beerdigt die Katze.
101.	I	Das Pärchen hat sich zwei neue Hunde gekauft.
102.	P	Am Anfang trägt er ein T-Shirt von O´Neill.
103.	H	Die Katze ist ein Kater.
104.	H	Er wischt den Boden.
105.	P	Ein blaues Handtuch hängt auf der Toilette.
106.	P	Das Autokennzeichen der Frau ist weiß
107.	P	Der Staubsauger ist rot.
108.	P	Auf dem Teppich liegt eine Unterhose.
109.	H	Er gibt der Katze einen Wollknäuel.
110.	I	Der neue Hund heißt Kitty.
111.	I	Er fährt mit Helm Roller.
112.	I	Er hat eine Vorliebe für Kaninchen.
113.	P	Beim Fahren trägt er eine schwarze Brille.
114.	I	Die Katze isst das Hundefutter nicht.
115.	I	Das Pärchen redet über Politik.
116.	P	Er ist Fahrrad gefahren.
117.	H	Sie möchte Kindergärtnerin werden.
118.	H	Er fährt nicht ins Tierheim.
119.	H	Er sieht sich Hundevideos an.
120.	P	Das Hundehäuschen ist weiß.
121.	P	Die Katze ist schwarz.

122.	H	Er lädt sie auf einen Kaffee ein.
123.	I	Er wirkt verträumt als er die Frau sieht.
124.	H	Er saugt den Teppich.
125.	I	Er fährt mit der Katze zum Tierarzt.
126.	H	Er liegt nachdenklich auf dem Sofa.
127.	I	Sie hat den Hund des Hauptdarstellers überfahren
128.	H	Er putzt das Fenster mit Schaum.
129.	H	Der Kater ist eine Katze.
130.	P	Sie trägt Ohrringe.
131.	H	Er lädt sie zum Essen ein.
132.	H	Der neue Hund schläft im Bett des Pärchens.
133.	P	Die Gardinen des Hauptdarstellers sind gestreift.
134.	I	Die Katze mag das Hundefutter.
135.	P	Es stehen Schuhe unter dem Bett.
136.	P	Die Ballons im Raum sind rund.
137.	I	Er schläft zusammen mit seiner neuen Katze ein.
138.	I	Sie möchte viel mit Kindern arbeiten.
139.	I	Das Pärchen kauft sich eine zweite Katze.
140.	P	Sie hat keinen Pony.
141.	P	Der Napf der Katze ist silber.
142.	H	Er hat keinen Mitbewohner.
143.	P	Er hat keinen Bart.
144.	H	Er schläft beim Fernseher gucken ein.
145.	H	Er legt ein Katzenhalsband auf das Grab.
146.	P	Ein rotes Handtuch hängt auf der Toilette.
147.	P	Es hängen keine Bilder über dem Fernseher.
148.	P	Im Bad hängt ein Handtuch.
149.	I	Der Unfall wurde von Passanten beobachtet.
150.	P	Der neue Hund verwüstet die Wohnung.
151.	H	Er fährt ins Tierheim.
152.	I	Sie ist wütend nach dem Unfall.
153.	P	Als er auf sie trifft, trägt er ein türkises T-Shirt.
154.	P	Sie hat einen kurzen Pony.
155.	I	Der Film heißt „Nerviges Kätzchen".
156.	P	Sie trägt ein gemustertes Oberteil.
157.	I	Er geht mit seiner Katze spazieren.
158.	H	Er zeigt der Katze Bilder von Mäusen.
159.	P	Das Hundehäuschen ist braun.
160.	I	Er geht nicht mit der Katze spazieren.
161.	P	Als er auf sie trifft, trägt er ein rotes T-Shirt.
162.	H	Der neue Hund schläft in seinem Hundehäuschen
163.	H	Er liest Zeitung.
164.	P	Das Autokennzeichen der Frau ist gelb.
165.	H	Er zeigt der Katze Bilder von Hunden.
166.	P	Sie ist brünett.
167.	P	Das Auto der Frau ist gelb.
168.	I	Freunde mit Hunden besuchen ihn jeden Tag.
169.	H	Sie legt eine Blume auf das Grab.
170.	H	Er spaziert nicht mit dem neuen Hund.
171.	I.	Sie möchte Rektorin werden.
172.	P	Die Decke des Hauptdarstellers hat ein Leopardenmuster.
173.	H	Er isst Cornflakes aus der Schachtel.
174.	P	Im Wohnzimmer steht ein schwarzer Marmortisch.
175.	I	Er hat ein Problem mit Katzen.
176.	P	In der Küche steht ein Topf auf dem Herd.
177.	H	Er bürstet seine neue Katze.
178.	I	Er ruft die Polizei.
179.	P	In der Küche steht ein weißer Mixer.
180.	H	Er schaltet durch verschiedene Fernsehsender.

Appendix D – fMRI data

fMRI data

1. Head motion of the different participants

Proband	Run I			Run II		
	mm	diff.	degree	mm	diff.	degree
8_AS	1	1.5	0.5	0.6	1	1
	-0.5		-1.5	-0.4		-1
9_SH	1	2	0.6	3	4	1.5
	-1		-0.7	-1		1.5
10_JL	0.5	1	0.4	0.4	1	0.3
	-0.5		-0.4	-0.6		-0.2
11_MY	0.5	2.5	0.4	0.4	0.8	0.6
	-2		-0.4	-0.4		-0.4
12_KN	2	2.5	1.5	1.5	2	1
	-0.5		-0.5	-0.5		-0.5
13_LJ	2.5	3	2	1	2	1
	-0.5		-3	-1		-0.5
14_LM	1	2	1	1	2	1
	-1		-0.5	-1		-1
15_DZ	3	4	1	0.4	0.8	0.6
	-1		-1	-0.4		-0.2
17_SS	0.5	1.5	0.6	1.5	2.5	1
	-1		-0.4	-1		-0.5
18_SV	1.5	2	1	1	1.5	0.8
	-0.5		-1	-0.5		-0.2
19_TP	2	2.5	1	2	2.5	0.5
	-0.5		-1.5	-0.5		-1
20_LS	0.4	0.8	0.4	0.2	0.5	0.2
	-0.4		-0.6	-0.3		-0.3
21_SM	1.5	2	0.2	6	8	3
	-0.5		-0.6	-2		-1
22_JR	5	6	0.5	1	2.5	1
	-1		-2.5	-1.5		-1
23_MM	0.6	1	0.4	0.4	0.8	0.6
	-0.4		-0.4	-0.4		-0.4
24_KH	5	20	2	0.6	1	1
	-15		-8	-0.4		-0.5
25_EB	1.5	2.5	0.6	1	2	1
	-1		-0.4	-1		-1
26_NW	3	4	0.4	1	2	0.6
	-1		-0.6	-1		-0.4
27_MR	0.6	1	0.8	1.5	2.5	0.6
	-0.4		-0.2	-1		-0.4
28_SO	2.5	3	1	2	2.5	1
	-0.5		-1.5	-0.5		-0.5
29_LR	1	2	2	2	6	2
	-1		-0.5	-4		-2

30_PG	0.8 -0.2	1	1 -0.5	0.4 -0.6	1	1 -0.5
31_TF	0.8 -0.2	1	0.6 -0.4	0.4 -0.6	1	0.6 -0.4
32_MP	4 -1	5	2 -4	5 -1	6	1 -4
33_DH	1 -0.5	1.5	0.4 -0.4	1 -0.5	1.5	0.4 -0.4
34_EM	1 -1	2	1 -1	0.5 -2.5	3	1.5 -0.5
35_AA	1.5 -1	2.5	1 -0.5	2 -1	3	1 -1
36_SH	0.6 -0.2	0.8	0.3 -0.1	0.6 -0.2	0.8	0.3 -0.1
37_MK	1 -0.5	1.5	1 -1	1 -1	2	0.4 -0.4

⬛ = mehr als 4mm (von der Analyse ausgeschlossen)

Appendix E – Post-Scanning Questionnaire

Post-Scanning Questionnaire

1. Instruction

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Fragebogen zur Aufgabenstellung während der fMRI Messung

Liebe Probandin, lieber Proband,

mit diesem Fragebogen untersuchen wir, wie gut Sie die Aufgaben während der fMRI Messung bewältigen konnten und ob es während der Untersuchung irgendwelche Schwierigkeiten bei der Aufgabendurchführung gab.

Die Fragen müssen unmittelbar im Anschluss an die Untersuchung beantwortet werden. Bitte geben Sie Ihre Antworten mit Hilfe der 5-stufigen Bewertungsskala, die Sie unter jeder Frage finden, und antworten Sie bitte im Rückblick auf die Situation der Aufgabendurchführung während der fMRI Messung.

Die einzelnen Statements, das Sicherheits-Rating und die Frage ob Sie wetten wollen werden in diesem Fragebogen getrennt behandelt.

Kreuzen Sie bitte von den 5 vorgegebenen Antwortkategorien jeder Bewertungsskala jeweils diejenige an, die für Sie am besten zutrifft. Bitte überlegen Sie nicht lange bei jeder einzelnen Frage, sondern geben Sie Ihre Antworten spontan, und kreuzen Sie bitte bei jeder Frage eine Antwortkategorie an. Bei einigen Fragen werden Sie gebeten, Beschreibungen in eigenen Worten vorzunehmen. Bitte machen Sie von dieser Möglichkeit Gebrauch.

2. Statements

|	Statements	sehr leicht	leicht	mittel	schwierig	sehr schwierig
1.	Wie leicht/schwierig war es für Sie, die auf dem Bildschirm gezeigten Statements zu erkennen?					
2.	Wie leicht/schwierig war es für Sie mit der Geschwindigkeit der Abfolgen die einzelnen Statements zu lesen?					
3.	Wie leicht/schwierig war es für Sie, das einzelne Statement als richtig oder falsch einzustufen?					
4.	Wie leicht/schwierig war es für Sie, die entsprechenden Knöpfe für „richtig" oder „falsch" auszuwählen?					
5.	Haben Sie bei der Einschätzung der Statements auf bestimmte Strategien zurückgegriffen? ja: ___ nein: ___					
6.	Wenn ja, wie intensiv haben auf diese Strategien zurückgegriffen?					
7.	Beschreiben Sie bitte, welche Strategien Sie verwendet haben:					
8.	Hat sich der Anteil Ihrer Strategien im Verlauf des Experiments verändert (z.B. mehr Strategien am Anfang als gegen Ende des Experiments, oder umgekehrt)? ja: ___ nein: ___					
9.	Wenn ja, beschreiben Sie diese Veränderung bitte:					

3. Confidence-rating

	Sicherheits-Rating	sehr leicht	leicht	mittel	schwierig	sehr schwierig
10.	Wie leicht/schwierig war es für Sie anzugeben, wie sicher Sie sich bei jeder einzelnen Aussage sind?					
11.	Wie leicht/schwierig war es für Sie in der vorgegebenen Zeit Ihr Sicherheits-Rating abzugeben?					
12.	Wie leicht/schwierig war es für Sie, die 3 entsprechenden Knöpfe für das Sicherheits-Rating auszuwählen?					
13.	Haben Sie beim Sicherheits-Rating auf bestimmte Strategien zurückgegriffen? ja: ___ nein: ___					
14.	Wenn ja, wie intensiv haben auf diese Strategien zurückgegriffen?					
15.	Beschreiben Sie bitte, welche Strategien Sie verwendet haben:					
16.	Hat sich der Anteil Ihrer Strategien im Verlauf des Experiments verändert (z.B. mehr Strategien am Anfang als gegen Ende des Experiments, oder umgekehrt)? ja: ___ nein: ___					
17.	Wenn ja, beschreiben Sie diese Veränderung bitte:					

4. Volunteering / withholding

	Wetten	sehr leicht	leicht	mittel	schwierig	sehr schwierig
18.	Wie leicht/schwierig war es für Sie anzugeben ob Sie auf Ihre Aussage wetten wollen oder nicht?					
19.	Wie leicht/schwierig war es für Sie, sich in der vorgegebenen Zeit für oder gegen das Wetten zu entscheiden?					
20.	Wie leicht/schwierig war es für Sie, die 2 entsprechenden Knöpfe für / gegen das Wetten auszuwählen?					
21.	Haben Sie beim Wetten auf bestimmte Strategien zurückgegriffen? ja: ___ nein: ___					
22.	Wenn ja, wie intensiv haben auf diese Strategien zurückgegriffen?					
23.	Beschreiben Sie bitte, welche Strategien Sie verwendet haben:					
24.	Hat sich der Anteil Ihrer Strategien im Verlauf des Experiments verändert (z.B. mehr Strategien am Anfang als gegen Ende des Experiments, oder umgekehrt)? ja: ___ nein: ___					
25.	Wenn ja, beschreiben Sie diese Veränderung bitte:					

Appendix G – Brodmann areas

Brodmann areas
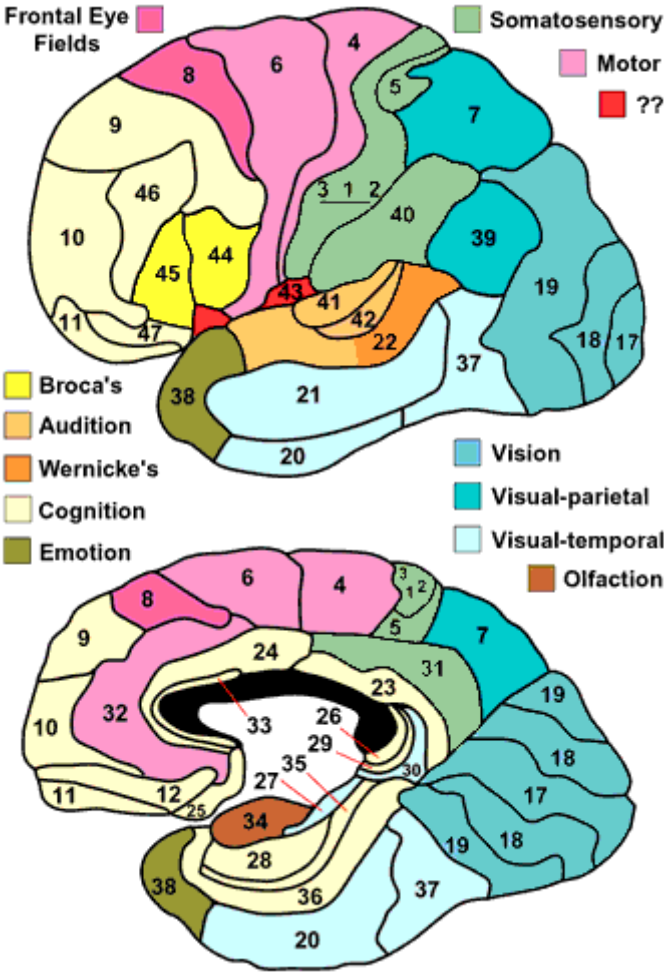
Declaration

I hereby certify that this thesis entitled

"Memory Accuracy

A 7-Tesla fMRI Approach to Memory Accuracy
– Retrieval, Monitoring and Control Processes –"

is my own work. No other materials and methods beside the ones cited were used. This thesis has not been submitted in this or another form at any other university or faculty.

_____   _____

Date   Signature