False memories

A study of false recognitions caused by a stimulus film using functional magnetic resonance imaging (fMRI)

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Presented by
Sina Kühnel

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Contents

Abbreviations

AC-PC	anterior commissure–posterior commissure
ANOVA	analysis of variance
BA	Brodmann area
c	response bias
cf.	confer
d’	discriminability index
EEG	electroencephalography
df	degree of freedom
DRM	Deese-Roediger-McDermott
e.g.	for example
EPI	echo planar imaging
F	variance ratio distribution
Fig.	Figure
fMRI	functional magnetic resonance imaging
FOV	field of view
FWHM	full-width at half-maximum
GLM	General Linear Model
HERA	hemispheric encoding/retrieval asymmetry
HIPER	hippocampal encoding/retrieval
i.e.	that is
LTD	long-term depression
LTP	long-term potentiation
MANOVA	multivariate analysis of variance
MNI	Montreal Neurological Institute
MR	magnetic resonance
MRI	magnetic resonance imaging
p	probability
PET	positron emission tomography
PRS	perceptual representing system
PTSD	post-traumatic stress disorder
REMO	retrieval mode
RT	response time
s	seconds
SAS	supervisory attentional system
SAT	speed-accuracy trade-off
SD	standard deviation

SPI	serial–parallel–independent
SPM	Statistical Parametric Mapping
SPSS	Statistical Package for the Social Sciences
TE	time of echo (echo time)
TOT	tip-of-the-tongue
TR	time of repetition

1 Introduction

The brain never sleeps – every moment, information is perceived, analysed, and classified regarding its value for the current state of oneself. The estimation of events and the resulting behaviour are strongly related to the memories of past experiences. It is a circle that memories shape current behaviour, and that new information also affects old memories. Thus, it is impossible to disentangle past experiences and present behaviour. In this study, the phenomenon of false memories, i.e. memories of events that never happened or happened in a different way, are investigated. False memories can influence ones attitude towards life, to common and specific situations, and towards other people.

In chapter **2** theory about memory in general and false memories in particular are presented. The first section (**2.1**) introduces the theoretical background to 'normal' memory to facilitate the understanding of false memories' theories, explanations, and paradigms. This includes classification of memory regarding processes, time, content, and the neural substrate. The second section (**2.2**) of the theoretical background gives up-to-date knowledge regarding false memories. This includes the introduction of theories and classifications of false memories as well as task paradigms. Subsequently, the results of previous neuroimaging studies are reported.

Chapter **3** presents questions and hypotheses. A number of questions were formulated from the survey of the theoretical background. These questions lead to four hypotheses being developed that form the basis of this study. The first hypothesis expounds that a film, which mirrors everyday life, will provoke false recognitions. The second hypothesis states that two different causes of false recognitions can be distinguished. The third hypothesis says that longer response times indicate false and shorter response times correct recognitions. The fourth hypothesis deals with the underlying neural patterns of correct and false recognitions and states that these two recognition forms can be discriminated in the brain.

In chapter **4** the applied methods, the subjects, and the procedures are introduced. The first section (**4.1**) describes the development of a film paradigm, with which the hypotheses were tested. The film paradigm consists of a learning phase and a recognition task. During the learning phase the subjects view a film containing everyday scenes. The recognition task presents pictures directly from the film (one set) as well as closely related ones (two sets). The demographical data of two investigated groups of healthy subjects of the study is given (**4.2**). In addition, similarities and differences of the film paradigm procedure between these two groups are presented (**4.3**). Furthermore, the event-related functional magnetic resonance imagining (fMRI) procedure, which was used to detect changes in neural activity in the brain of the subjects of the second group during their recognition task (**4.4**) and the statistical method 'signal detection theory' (**4.5**) are briefly explained. The latter one is a procedure to investigate the degree of uncertainty whilst making a forced 'known/unknown' or 'yes/no' decision.

The results sections, which are given in chapter **5**, are structured regarding behavioural and neuroimaging data. The behavioural data is separately presented for the two groups and further organised after the given hypotheses (**5.1**). The neuroimaging results are introduced with respect to four analysis steps, starting with correct and false recognitions across all investigated stimuli, followed by contrasts between studied and unstudied stimulus sets, contrasts between the three sets, and ending with contrasting single stimulus sets with baseline condition (**5.2**).

In chapter **6** the discussion of the formulated hypotheses is given by considering behavioural and neuroimaging results. The behavioural results of the two investigated groups are discussed. At the beginning, the film paradigm is discussed regarding the hypothesis if this paradigm caused false recognitions (**6.1**). It follows the discussion of the results of the two unstudied stimulus sets, which represented the two different causes of false recognitions (**6.2**). The third section deals with the revealed response times (**6.3**). The section of the neuroimaging results (**6.4**) is divided in two different parts. In the first part, correct and false recognitions across all three picture sets are discussed. In the second part, the results of the other three analysis steps are interpreted. The revealed increases in neural activity in the brain are sorted and discussed regarding their anatomical affiliation. At the end of this section, a summary of the neuroimaging data is given with a special attention to correct and false recognitions and findings of previous studies.

Finally, in chapter **7** the conclusions of this study are presented by evaluating the film paradigm. Moreover, possible future directions for this work are discussed.

The appendices show all used pictures of the recognition task (**A**), additional statistical analyses to demonstrate that the behavioural results of the first group can be discussed along with the ones of the second group (**B**), and a map, which shows the Brodmann areas of the human brain (**C**).

2 Theoretical background

In this study, the phenomenon of false memories, more specifically the occurrence of false recognitions, is investigated. False memories are defined as memories of events that did not happen or were distorted, caused by additional information, internally or externally generated. During the last decades, most of the research of false memories focussed on episodic memories. These are memories for personally experienced events. More recently studies have also investigated false memories for semantic information, which contains general knowledge. To understand the occurrence of false memories, it is necessary to gain an overview of the processes of 'normal' or true memories.

The first part of this chapter will present the different classifications of true memory regarding processes, time, content, and neural correlates. The second part will shed light on the phenomenon of false memories. This includes definitions of the different forms of false memories, theoretical explanations, Schacter's seven sins of memory, paradigms for investigation, and at the end also neural correlates.

2.1 Memory

"In neural network models, there are no specific locations with unique addresses for memory records. Rather, memories are captured by patterns of activation spread over many neuron-like units and links between them." (Haberlandt, 1999, p. 167)

Memory is the most fascinating development of evolution. The ability to learn new information and to adapt to behaving in new (environmental) situations is a basic requirement for life. Memory is introduced here with the focus on human memory, even though some animal studies are also discussed for a better grasp of some of the conclusions. Memory is classified with regards to different aspects. Firstly, the sequence of processes during the memorisation of new information is examined. Then, the distinction along the time axis during the acquisition of information is introduced, followed by a description of the different memory stores that last from a few milliseconds till almost infinity. The content of memories is a further aspect, along which memories are classified into different systems. The further development of neuroimaging techniques concentrated the focus more on the underlying neural correlates of memory, which are explained in the final section (**2.1.4**).

2.1.1 Memory processes

New information is registered via the sensory systems. It is then encoded, over the time consolidated, stored, and can be retrieved later on (Fig. 1). These cognitive operations are not fixed. For example, during the process of retrieval, information is also re-encoded and re-consolidated, respectively.

Figure 1: Illustration of the main processes from registration of information till memory retrieval (modified from Markowitsch, 2003a)

During the registration process of new information via the five sensory channels (visual, auditory, somatosensory, olfactory, and gustatory), selective processes take place. An initial filtering of the huge amount of miscellaneous data enables discrimination between relevant and non-relevant information regarding the actual situation. For example, when a person attends a lecture the most important information is what the lecturer says and not what other students may say nearby. A selection at this early stage allows effective handling of an abundance of information. Former experiences can help to distinguish between important and unimportant details in a complex environment.

After the registration, information is transferred through the encoding process into a specific internal code. A new memory trace is created for the information in the brain. This memory trace is also named *engram*. Encoding processes are further differentiated into intentional and incidental encoding processes (Craik & Lockhart, 1972; Craik & Tulving, 1975).

Intentional encoding occurs when new information is consciously processed. For example, someone studies for an exam and aims actively to understand complex issues. On the other hand, incidental encoding happens without our direct awareness of the information. A good example was given by a study where subjects were asked to distinguish words in a list considering whether they represent a living or a non-living object (Kapur et al., 1994). Later, during an unheralded recognition task subjects recognised 75% of the words correctly. This result indicates that the subjects incidentally encoded most of the words during the decision task. The phenomenon of incidental encoding is further known from commercials. For example, when we see an advertising spot that shows a specific product and simultaneously a catchy melody is playing in the background. Even though the product is what watchers should encode the melody is incidentally encoded. Later on, the melody, which should only enhance the encoding of the product, might be remembered even more easily than the specific product.

How well information is encoded depends on the ‘depth of processing’ effect, formulated by Craik and Lockhart (1972). If information is processed in a way that the meaning of it is encoded, it is called ‘deep’ or semantic encoding. For example, when subjects are instructed to decide if a presented word is abstract (e.g. love) or concrete (e.g. book)

(Demb et al., 1995). If only the general characteristics of the information is processed the encoding is 'shallow'. For example, when subjects are instructed to distinguish if two underlined letters in a word are in a alphabetically order or not (Fletcher, Stephenson, Carpenter, Donovan, & Bullmore, 2003).

Consolidation describes the process of linking newly registered and encoded information with older reactivated memories (Tronel, Milekic, & Alberini, 2005). This process enhances the stability of the new memory formation. The process of consolidation can take place over a period of minutes to hours, even years (McGaugh, 2000) and connects several steps, including stabilisation, enhancement, and integration. The process of consolidation is further distinguished in synaptic and system consolidation (Dudai, 2004). Synaptic consolidation describes changes that take place within the first minutes and hours after the registration of information. The system consolidation, which follows after the first synaptic changes, influences old memories by connecting these with the new information. Consolidation is suggested to be mainly processed while sleeping (Stickgold & Walker, 2005; Stickgold, 2005; Spencer, Sunm, & Ivry, 2006; Walker & Stickgold, 2006).

Storing of memories in form of the introduced engrams is processed by a broad neural network. Memories are not stored self-contained but simultaneously, at different places within the associative cortices (Mesulam, 1994). For example, the last lecture that someone attended, which combines a multitude of information. The specific knowledge of the lecture is stored as semantic memory, but perhaps besides that something special was witnessed like a lecturer's funny joke. The information is stored as a complex episodic event. The same event is stored within different memory systems, but the single elements of the event are still connected with each other. This also happens with the different modalities of an event, the visual information is stored in the visual cortex, the auditory information in the auditory cortex, and so on.

Retrieval of memories can be initiated by a 'trigger', which reactivates memory traces. A trigger can be any information, which initiates a recall of a specific memory. For example, when someone sees a travel agency it initiates memories of recent holidays. A cue stands for a specific stimulus that activates the specific memory. For example, an advertisement for a vacation in Mexico activates memories of a trip to this country including specific episodes and details, i.e. cued recall. In this example the trigger, as well as the cue, were externally perceived. However, they can also be produced internally, for example, when someone takes a walk and muses about the last year, that triggers the memory of vacations, which brings forth specific memories of one holiday. A trigger can also be the instruction of an experimenter to a subject to recall words of a previously studied list, i.e. free recall. A further form of retrieval is the recognition of information. For example, recognising previously studied words out of a sample containing also new words.

Retrieval is often strongly associated with a feeling of familiarity that stimulates the retrieval process. Besides the judgement of the familiarity of an item (e.g. a word), a second process is needed for the correct retrieval of specific information. The event/context, during which the information was encoded, also has to be recollected. Both processes, familiarity and recollection (cf. dual-process model, Yonelinas & Jacoby, 1994), have to merge for a successful retrieval of memories (Yonelinas, 2002). A method to distinguish between these two processes is the 'remember/know paradigm', introduced by Tulving (1985). Subjects are instructed to respond with 'remember' when they can truly recollect the context of learning the stimulus. For example, they not only remember the word but also the ones before and after. If they are unable to remember the context of learning the stimulus but are still sure to have learnt it they are instructed to respond with 'know'. This paradigm can be used to analyse similarities and differences between familiarity and recollection processes (Yonelinas & Jacoby, 1995; Giovanello, Keane, & Verfaellie, 2006). These two processes also activate different regions in the brain, which will be presented later in section **2.1.4.3**.

Two further important elements of the retrieval process have to be distinguished, namely 'ecphory' and 'retrieval mode' (REMO). Ecphory was introduced by Tulving (1983) as the interaction between retrieval cues and stored information, which leads to a successful retrieval of a memory (Steinvorth, Corkina, & Halgren, 2006). REMO describes an 'online' holding of older memories that enables the evaluation of new information as 'retrieval cues' and finally yields a conscious recollection of an event (Lepage, Ghaffar, Nyberg, & Tulving, 2000).

During the retrieval of memories the processes of re-encoding or re-consolidation can take place (Buckner, Wheeler, & Sheridan, 2001; Stickgold & Walker, 2005). By retrieving old information, this information is also newly encoded and thereby strengthened. Current information, which is perceived during the retrieval process, can be linked with the older memories. Afterwards, a modified version of the old memory is (re-)encoded and stored (Tulving, 2001). Furthermore, prior memories can be interlinked with each other during the processes and can at this point be changed. Unfortunately, it is nearly impossible to distinguish between an original memory and a later transformed one. The implications of these memory deformations will be explained in detail in the section **False memory (2.2)**.

2.1.2 Relation between memory and time

The classification of memory along the time axis demonstrates a hierarchical system of three main stores (Atkinson & Shiffrin, 1968). The first one is referred to as the ultra-short-term memory or the sensory store. The second one is called short-term memory, which is strongly linked with the working memory system. The third store is the long-term memory. Figure 2 shows this multi-store model of memory with the processes among and the dependencies between them.

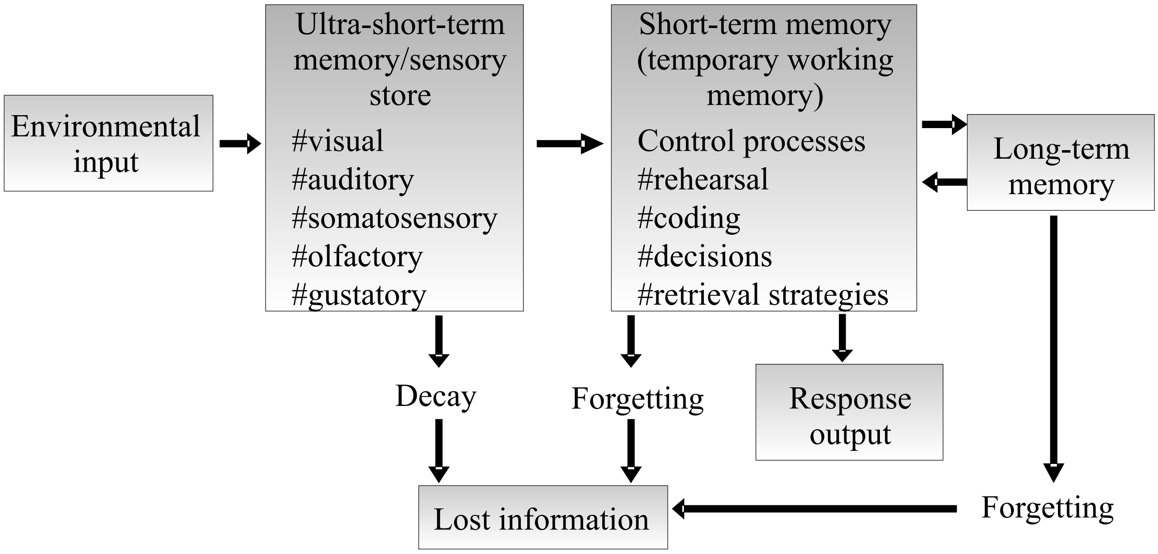


Figure 2: Multi-store model connecting the serial information processing along the time (modified from Atkinson & Shiffrin, 1968)

2.1.2.1 Ultra-short-term, short-term and working memory

Information is ‘stored’ and pre-processed in the ultra-short-term memory. The ultra-short-term memory is also referred to as the sensory store because of the modality-specificity of it. It processes information that were perceived via the visual, auditory, somatosensory, olfactory, and gustatory sensory channel. Most of the research focuses on the *iconic* (visual) (Sperling, 1960) and *echoic* (auditory) (Treisman, 1964) stores because of their easier accessibility, contrary to the somatosensory, olfactory, and gustatory stores.

The information persists briefly (several milliseconds) in the ultra-short-term memory (e.g. G. R. Loftus, Duncan, & Gehrig, 1992). The processed information passes then to the short-term memory, which lasts longer than the ultra-short-term memory, by up to several seconds (Waugh & Norman, 1965). The short-term memory is limited by the amount of information it can process in parallel. The capacity of the mental storage ranges between four and eight chunks, earlier research stated, on average, seven chunks (G. A. Miller, 1956), more recent studies narrowed it down to four chunks (Cowan, 2001).

A chunk decodes a word, a number or any other single perceived information. During free recall tasks, it was found that the first and the last few items of a list are usually more easily and better recalled than the remaining items in the middle (e.g. Demaree, Shenal, Everhart, & Robinson, 2004). This outcome was named the primacy and recency effect, respectively. A further limitation of the short-term memory is the length of the single chunks (Baddeley, Thomson, & Buchanan, 1975). Baddeley and colleagues named this the 'word length effect', which says that short words are accessible for a longer time than longer words. A recent study confirmed the influence of both factors for the short-term memory capacity (Chen & Cowan, 2005).

As a special form of the short-term memory system, Baddeley and Hitch (1974) introduced the working memory system. Working memory is an active system, which analyses and evaluates information over a restricted period of time. It interlinks the perception of information with the long-term memory and the resulting actions (output). The working memory consists originally of the central executive and two temporary storage systems: the phonological loop and the visuospatial sketchpad. More recently, a fourth component of the working memory was proposed, the episodic buffer (Baddeley, 2000). Figure 3 shows the revised multi-component working memory system (Baddeley, 2003b).

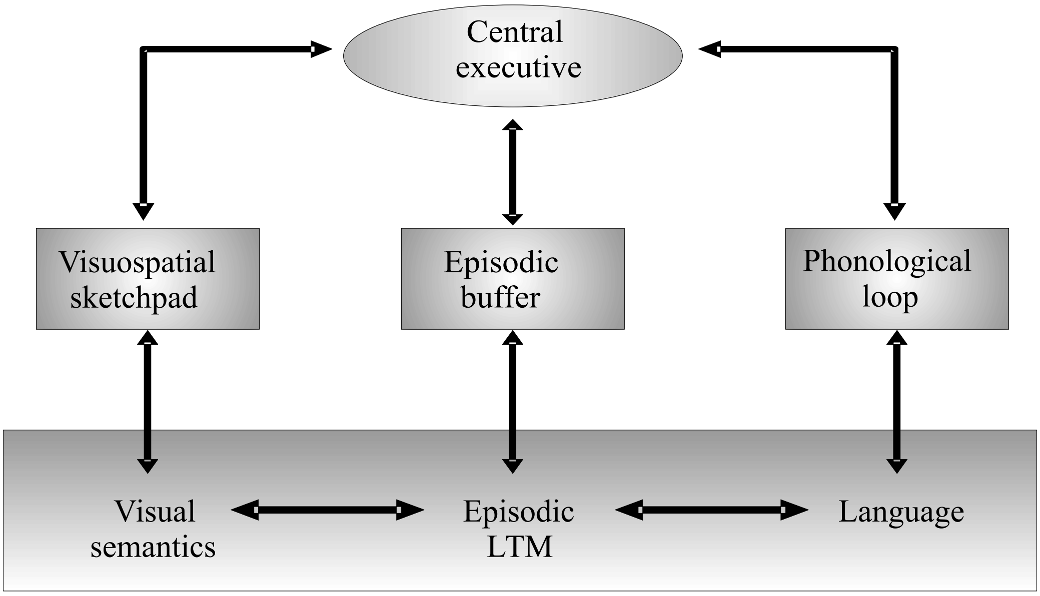


Figure 3: The multi-component working memory system (modified from Baddeley, 2003b); LTM = long-term memory

The visuospatial sketchpad processes visual data, holds transitional images and manipulates the information. These operations enable the production of a designated action. An example is driving a car that combines a flow of visual information that has to be quickly interpreted. The visuospatial sketchpad is also a possible measure to acquire non-verbal intelligence, which is important in several scientific fields, for example architecture (Verstijnen, van Leeuwen, Goldschmidt, Hamel, & Hennessey, 1998). The visuospatial sketchpad is restricted in capacity, which normally ranges between three and four chunks.

The phonological loop processes auditory information and language. One component of the loop is the phonological store that allows an upholding of information traces for a few seconds before they vanish. An example is reading a telephone number, which has to be rehearsed before it can actually by typed in a phone. The second component of the phonological loop is an articulatory rehearsal process that takes place within the phonological store. The articulatory rehearsal process is comparable to subvocal speech, which describes the finding that only thinking about speaking without the production of any sounds is connected with slight movements of the speech muscles (Paulesu, Frith, & Frackowiak, 1993). The phonological loop is therefore of high relevance for language learning (Baddeley, 2003a). New words are temporarily represented in the phonological store whereas the rehearsing process in the articulatory system facilitates the production of unfamiliar syllables. The phonological loop is similar to the visuospatial sketchpad limited in capacity to three to four chunks.

The third component, the episodic buffer, is analogous to the episodic long-term memory but contrary to it with a temporary bounding. It is able to integrate information from the central executive and the episodic long-term memory, and via these components further information from the phonological loop and the visuospatial sketchpad. Therefore, it buffers between those systems and provides a unitary representation of episodes (Baddeley, 2000).

The central executive, as the main structure of the multi-component working memory system, describes a limited attentional relay station. Though it is the main component of working memory, the central executive system is the least understood. One important part of the central executive is the supervisory attentional system (SAS) developed by Norman and Shallice (1986). The SAS functions as a controller with limited attentional capacity between routine sequences and situational adequate action beyond the routine. For example, when the same route to work is driven every day but one day a stop is necessary at a pharmacy, which is located slightly aside, the SAS has to override the routine sequence of the usual route to enable the adequate action.

In conclusion, the control processes within the short-term memory system are not only responsible for the forwarding of information from the ultra-short-term memory store to the long-term memory store. They are also actively involved in retrieval processes and mediation of information from the long-term memory to the response output.

2.1.2.2 Long-term memory

The long-term memory store absorbs all information that traversed the short-term memory. It seemed to be limitless regarding the amount of information that can be stored. The time span also appeared to be infinite. The long-term memory integrates separate memory systems, which will be explained thoroughly in the next section (**2.1.3**).

A further classification regarding the time is mainly used for amnesic patients and refers to their ability to store new, or retrieve old memories from the long-term memory store (Fig. 4). Patients who are unable to remember their pasts are referred to as retrograde amnesic. On the other hand, anterograde amnesia, describes patients who are unable to memorise any new event. They are literally stuck in time.

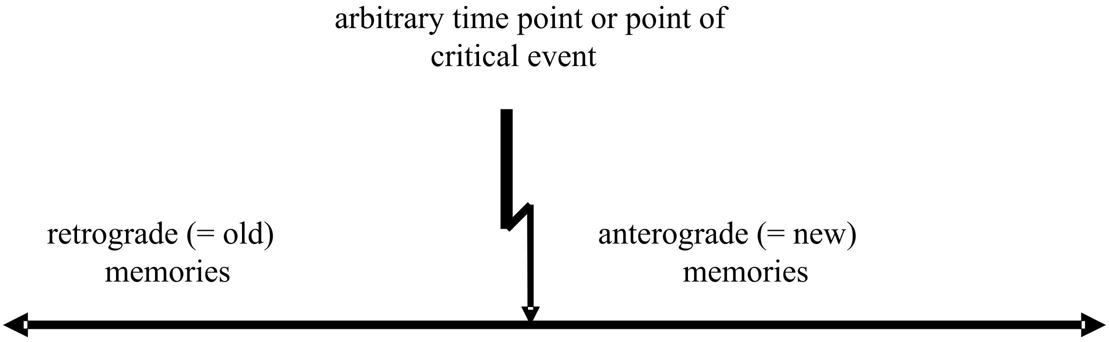


Figure 4: Classification of retrograde and anterograde memory corresponding to an arbitrary time point in life; analogous classification between retrograde and anterograde amnesia in patients caused by an organic or psychic trauma (modified from Brand & Markowitsch, 2003)

It is further shown in Figure 4 that this classification in retrograde and anterograde memory is not only used for patients but also for healthy subjects. For healthy subjects, the terms are used to distinguish between older and recent memories. An arbitrary time point in life is fixed and memories before are classified as retrograde memories and memories after as anterograde. More recently, researchers have focussed increasingly on patients suffering from psychogenic amnesia (Kopelman, 2002). Factors for a psychogenic amnesia are stress or a mental trauma. Today, a vivid discussion addresses the question to which extent amnesia caused by an organic trauma and amnesia resulting from psychogenic factors can be distinguished (Markowitsch, 2002, 2003b; Reinhold, Kuehnel, Brand, & Markowitsch, 2006).

2.1.3 Classification by content

There are two most influential theories regarding the classification of the content of memories. One was formulated by Squire (1987) differentiating between non-declarative and declarative memory. The second one, introduced by Tulving (1972), originally distinguished between four long-term memory systems: procedural memory, priming, semantic memory, and episodic memory. More recently a fifth system was integrated, the perceptual memory system (Tulving, 2005).

The classification of Squire (1987) draws an intrinsic picture of the long-term memory systems, from the simplest one, like reflexes, up to memory for facts and events. By integrating results from animal studies (e.g. Mishkin, 1982) as well as from work with patients, Squire (2004) developed a taxonomy of mammalian long-term memory. Regarding the level of consciousness during retrieval, he distinguished two main branches: the declarative (or explicit) and the non-declarative (or implicit) memory system (Fig. 5). Declarative memory can be consciously retrieved, whereas non-declarative memory works without our awareness of it.

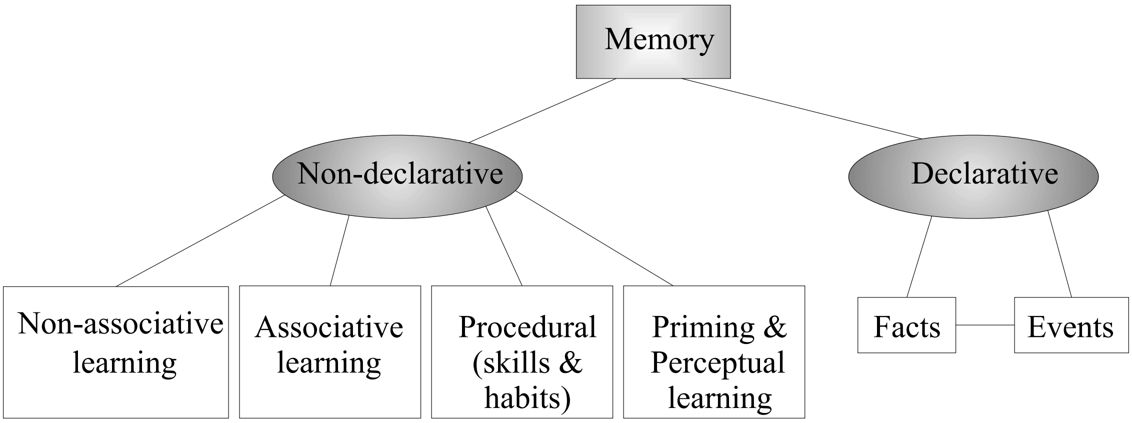


Figure 5: Squires taxonomy of long-term memory (modified from Squire, 2004)

Declarative memory contains knowledge that can be accessed consciously. It includes general knowledge (semantic memory) and memory for personal experiences (episodic memory). Squire (2004) stated: "Declarative memory is representational. It provides a way to model the external world, and as a model of the world it is either true or false. In contrast, non-declarative memory is neither true nor false." Non-declarative memory is used as an umbrella term for heterogeneous, mainly unconsciously processed memory systems. It contains non-associative learning (e.g. habituation), associative learning (e.g. simple classical conditioning), procedural learning (e.g. skill learning), priming, and perceptual learning (Squire & Zola-Morgan, 1988).

Tulving's classification mainly developed from results of observation of amnesic patients. Unlike Squire' model, it does not define two distinct subsystems (declarative and non-declarative memory) (e.g. Tulving, 1972, 1995). Tulving subdivided human long-term memory into five, hierarchically organised, interacting, but also parallel working, memory systems: procedural (e.g. skills), priming, perceptual, semantic, and episodic memory. Figure 6 presents these five memory systems together with small examples.

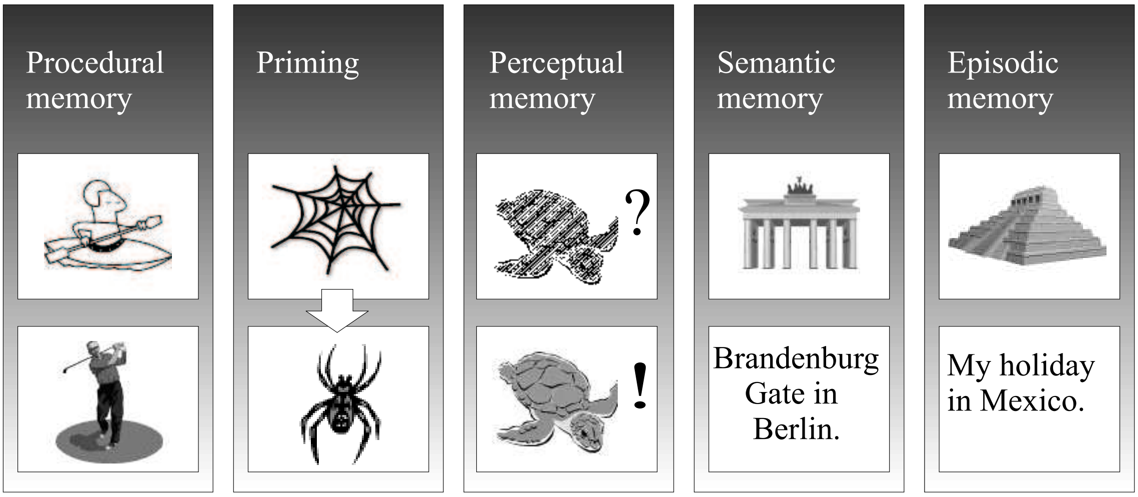


Figure 6: The five memory systems together with examples for each one (Tulving and Markowitsch, in preparation)

The most basic system is the procedural memory system that contains motor-related memories, cognitive skills, and routines. An example is the knowledge to walk or drive a car. Priming describes the ability to recognise a stimulus easier and faster because of a previous (unconscious) exposure to this stimulus or a related one. Priming can be divided into repetition (repeated exposure to the same stimulus), semantic (related words, like Mercedes, BMW, VW, which enhance the generation of 'car'), and new association priming (stands for association between unrelated stimuli by presenting them together) (Wagner & Koutstaal, 2002). The perceptual memory system refers to the recognition of stimuli because of the familiarity of them. The semantic memory describes all information for common knowledge, for which it is impossible to recall the time and event of encoding. Finally, the episodic memory system contains all information of our personal autobiography. For these memories we can recollect specific, sensory information. It is highly interrelated with the view of our self and allows us to travel mentally back in time (Tulving, 2002). A special classification has to be made for autobiographical facts, like dates of special events (e.g. birthdays, wedding). These memories are important for our own biography and therefore strongly connected to episodic memories but nevertheless, we are often unable to recall when the facts were learnt or what the exact circumstances were.

A special relationship was characterised between episodic, semantic and perceptual memory system, named the serial–parallel–independent (SPI) model (Tulving, 1995). SPI stands for *serial encoding* followed by *parallel storage* of information and a subsequent *independent retrieval*. It is assumed that information attains episodic memory through the perceptual and the semantic memory systems (Fig. 7).

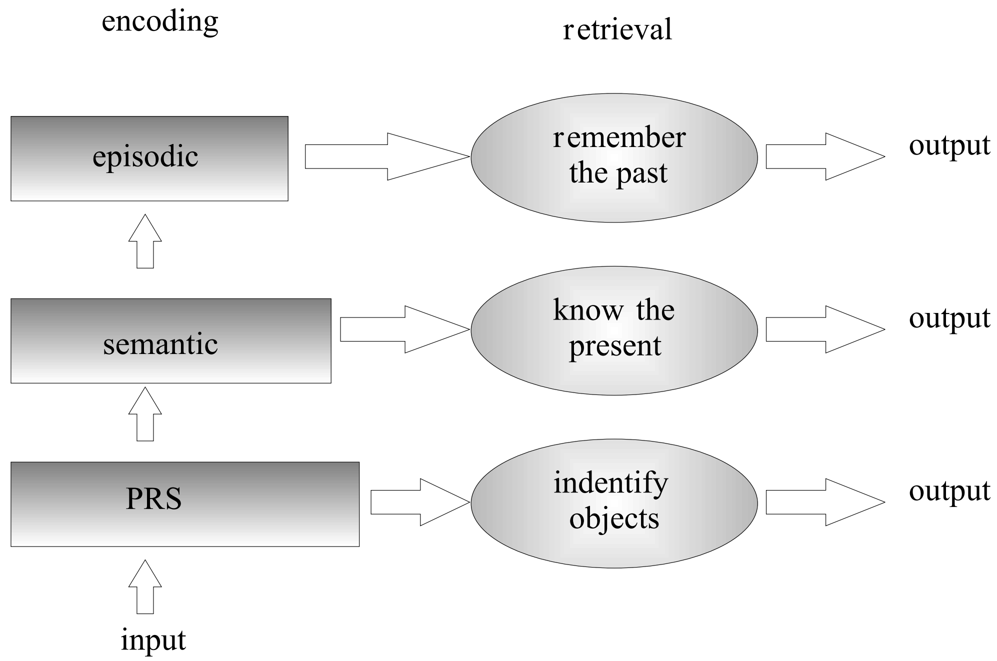


Figure 7: Representation of the serial–parallel–independent (SPI) model embodying the processes of episodic memory (modified from Tulving, 2001)

According to the SPI model, new perceptual information is first encoded, prepared, and momentarily stored in the perceptual system, which is also called perceptual representing system (PRS) (Tulving & Schacter, 1990). The next step in the serial encoding of new information is the semantic memory system. Here, general information about an event is processed and stored. Finally, in the episodic memory system, the new information is processed regarding its value for oneself and the subjective information is stored. Because the information was encoded serially, but stored in parallel, it is possible to retrieve only a part of the information relative to a given cue. For example, when we hear the first notes of a melody, which we heard during a holiday years ago, this perceptual information acts as a cue to remember parts of this special holiday. However, we are also able to retrieve the memory by recalling all the last holidays and remembering, in which year we went where. Thus, we depend strongly on the semantically stored information. When we talk with friends about events that happened in different holidays, we possibly retrieve an episode of this holiday, recalling it with all the experienced richness. For example, how warm the weather was, how relaxed we were, lying there on the beach. It is important to note, that not all perceived information has to reach the semantic and the episodic memory system. Factors like the novelty of information can influence the processing (Tulving, Kapur, Craik, Moscovitch, & Houle, 1994) as well as the 'level of processing', meaning that information can be processed in a shallow or in a deep way (Craik & Lockhart, 1972; Craik & Tulving, 1975).

2.1.4 Neural correlates

Most of the knowledge of memory and the corresponding brain structures was acquired by examination of patients who had suffered from brain damage. The development of neuroimaging techniques like electroencephalography (EEG), positron emission tomography (PET), magnetic resonance imaging (MRI), and functional magnetic resonance imaging (fMRI) allowed deeper insights into the underlying brain structures of memory in patients, but also in healthy subjects. Recently, the number of publications that deal with the results of memory studies using neuroimaging techniques has increased constantly. In the following sections, first a brief outline of changes on the neuronal level is given, followed by the description of the involvement of brain regions in short-term and working memory. The final section illustrates long-term memory processes and their associated areas in the brain.

2.1.4.1 Cellular basis of memory

Independent of the content of new information, learning requires synaptic changes (Martin & Morris, 2002). Kandel and colleagues (2001) investigated simple learning of habituation, sensitisation, and classical conditioning in the sea slug (*Aplysia*). They showed that even these simple forms of learning manifest themselves in synaptic changes. The cellular plasticity in neurons is separated into two distinct forms: long-term potentiation (LTP) and long-term depression (LTD) (cf. Hebb, 1949). Long-term potentiation was first reported by Bliss and Lømo (1973) and describes the lasting enhancement of synaptic transmission between neurons due to repetitive presynaptic activation. This results in a continuous flow of neurotransmitters and a lasting connection of pre- and postsynaptic neurons (e.g. Kushner et al., 2005; Shinoe, Matsue, Taketo, & Manabe, 2005). Long-term depression on the other hand illustrates the reverse development, when the synaptic efficiency between neurons is reduced (e.g. Teskey et al., 2006). Furthermore, long-term potentiation and long-term depression can result in evolving (exocytosis) or reducing (endocytosis) the conjunctions (receptors) between pre- and postsynaptic neurons (Pérez-Otaño & Ehlers, 2005).

2.1.4.2 Neural correlates of short-term and working memory

The posterior parietal cortex was found activated for visual short-term memory tasks (Todd & Marois, 2004). Todd and Marois (2005) also found that individual differences of the visual short-term memory capacity can be correlated with activity in the posterior parietal as well as the visual occipital cortex. Most research regarding short-term memory focussed more specifically on the components of the working memory system. In general, working memory tasks activated brain regions in the premotor and parietal cortex (Nyberg, Forkstam, Petersson, Cabeza, & Ingvar, 2002). Patients with lesions in the left temporo-parietal area showed deficits in the phonological loop but still had language abilities mainly intact (Vallar & Baddeley, 1984; Vallar, DiBetta, & Silveri, 1997). The left temporo-parietal area was confirmed as the storage component of the phonological loop (Paulesu et al., 1993). For the rehearsing process of the phonological loop Broca's area was found activated (Jonides et al., 1996). Patient studies also showed that the visuospatial sketchpad is associated with the right frontal cortex (Della Salla, Gray, Baddeley, Allamano, & Wilson, 1999; Henson, 2001). More specifically, activations were found in the right inferior parietal cortex, the right premotor cortex, the right inferior frontal cortex and the right anterior extrastriate occipital cortex. The right anterior extrastriate occipital cortex is also associated with visual imagery (Kosslyn et al., 1993). Anatomically the central executive seems not to be localised in one region only, but activates a more widespread network involving the frontal regions (Baddeley, 2003b). The long-term memory system comprises the different memory systems, therefore, the neural correlates are explained in the next section.

2.1.4.3 Neural correlates of long-term memory

Encoding

The encoding of newly acquired information of semantic and episodic memories mainly requires two brain circuits. They are located mainly within the limbic lobe (cf. Markowitsch, 2000b) and called the Papez circuit and the basolateral limbic circuit.

The Papez circuit was originally introduced by Papez (1937). He assumed that it connects the responsible brain regions for processing of emotional memories. Nowadays, the Papez circuit is proposed to be predominantly involved in the transfer of new information in general, episodic and semantic, into the long-term memory systems. In the Papez circuit, information is first processed in the hippocampal formation, which is connected via the fornix with the mammillary bodies, which are connected via the mammillothalamic tract (or tract of Vicq d'Azyr) with the anterior thalamus, which is further connected via the thalamo-cortical pedunculi with the cingulate gyrus, and this is connected via the cingulum with the hippocampal formation.

The basolateral limbic circuit is known today to be responsible for the processing of emotionally relevant information (Markowitsch, 2000a). It connects the amygdala via the ventral amygdalofugal projection with the mediodorsal nucleus of the thalamus, from there via the anterior thalamic pedunculi with the subcallosal region within the basal forebrain, and via the bandeletta diagonalis back again with the amygdala. Because of their high importance for information processing some of these structures are also named 'bottleneck structures' (Brand & Markowitsch, 2003). Damage to these structures, even to a single one, have intrinsic implications on memory functions (cf. Calabrese, Haupts, Markowitsch, & Gehlen, 1993; Markowitsch, von Cramon, & Schuri, 1993; Markowitsch et al., 1994; Kopelman, Stanhope, & Kingsley, 1999).

The importance of the medial temporal lobe for encoding processes of episodic and semantic memories was exemplified by patient H.M. After a bilateral medial temporal lobectomy, conducted because of a severe case of epilepsy, H.M. suffered from anterograde amnesia for the rest of his life. Among others, Milner (1965) showed that, even though H.M. was able to learn new skills, like mirror drawing, he was unaware of doing it. H.M had no memories of performing repeatedly this task and had no knowledge about his own improvement. This result further suggested the division of long-term memory into several separate systems (e.g. Sherry & Schacter, 1987).

The amygdala plays a special role in encoding of affective information. Together with the thalamus and the basal forebrain the amygdala allows a faster and more efficient encoding of emotional memories (LeDoux, 2000; Piefke, Weiss, Zilles, Markowitsch, & Fink, 2003). The hippocampal formation, especially the hippocampus, is known from animal studies to be involved in processing of spatial information (Morris, 1981; Holland & Bouton, 1999). In a recent review Burgess, Maguire, and O'Keefe summarised the relevance of the hippocampus for human (2002). The right hippocampus in humans is associated with encoding processes of spatial relationships in the environment. The left hippocampus is engaged in processing verbal information and context-dependent information of episodic memories. Both hippocampi are connected to the frontal lobe and are provided from there with temporal information. Thus, they create the basis for developing spatial-temporal episodic memories.

The two circuits are not only interconnected with each other through some of the structures but also connected with further regions, most prominently the prefrontal regions. The left prefrontal region was found to be activated during incidental (Demb et al., 1995; Wagner, Schacter, et al., 1998) as well as intentional encoding processes (Kapur et al., 1996; Kelley et al., 1998). These studies showed that even though these two forms of encoding are distinguishable on behavioural level (Craik & Lockhart, 1972), they still share almost equal neural correlates. Interestingly, this result was anticipated earlier by Craik and Tulving due to plain behavioural studies (1975). It was found, nevertheless, that deep encoding, which is connected to intentional encoding, activates a significantly larger region in the left prefrontal area than shallow encoding (Demb et al., 1995; Gabrieli et al., 1996). Kapur et al. (1994) found activation in the left inferior prefrontal cortex for deep encoding, though the subjects did not know during the learning phase that they would be tested later on. Shallow encoding on the other hand is associated with activation in the right prefrontal cortex (Fletcher et al., 2003). Encoding of verbal material is associated with areas in the left inferior and dorsal prefrontal regions together with the anterior cingulate and the right-lateral cerebellum (Buckner & Koutstaal, 1998; Tulving et al., 1994). Activations in the left prefrontal region are also related to face learning in younger and older adults, additionally in younger adults regions in the left medial temporal lobe are activated (Daselaar, Veltman, Rombouts, Raaijmakers, & Jonker, 2003). In addition to the importance of the prefrontal cortex and the hippocampal formation for memorisation processes, activation was found for encoding of episodic and semantic information in the anterior thalamus (von Zerssen, Mecklinger, Opitz, & von Cramon, 2001) and the cingulate gyrus (Heun et al., 2000).

Consolidation

The process of consolidation is still the most challenging one of memory formation. It is difficult to undertake studies to investigate how memories are consolidated. One of the assumed key structures is the amygdala (McGaugh, 2002), which is also one of the key structures of the basolateral thalamic circuit. The medial temporal lobe formation, containing the hippocampus, entorhinal, perirhinal, and parahippocampal cortices, was found to be involved in temporarily storing new information (Squire & Zola-Morgan, 1991). The structures of the medial temporal lobe are connected further to neocortical areas. The information, which is for a time stored in the medial temporal lobe, guides the longer lasting changes into the neocortex where the information is then permanently stored (Alvarez & Squire, 1994). Over time, information retrieval results in decreased activation in the medial temporal lobe regions but in increases in regions of the neocortex (Takashima et al., 2006). This is also consistent with findings in amnesic patients, who suffered from damage in the medial temporal lobe and were unable to encode new primarily episodic information (Vargha-Khadem et al., 1997). Even though these patients were still able to retrieve old memories.

Storage

The storage of memories depends on their modality, which further results in a wide network throughout the brain for each event. For example, the last birthday party contains semantic information (when, where, who, etc.), visual, auditory, olfactory, gustatory, and somatosensory information as well as episodic data (e.g. feelings). Combining all this information, we can describe how we experienced the night. We are able to form a rich episodic autobiographical memory. The single details are stored separately; the visual information is stored in the visual cortex (occipital lobe), the auditory information in the auditory cortex, and so on. Evidence of the different modalities of one experience comes from studies on patients who suffered from brain damage (e.g. Markowitsch, Fink, Thöne, Kessler, & Heiss, 1997).

Retrieval

As mentioned earlier in the section **Memory processes (2.1.1)**, retrieval processes can be distinguished regarding ecphory and retrieval mode (REMO).

Ecphory of old memories is assumed to be strongly related to the region of the right lateral temporo-frontal junction area, as damage to this area together, with minor damage in the left hemisphere, causes severe retrograde amnesia (Calabrese et al., 1996; Kroll, Markowitsch, Knight, & von Cramon, 1997). In a recent study, it was found that ecphory of autobiographical memories activates a broad neural network (Steinvorth et al., 2006). Beyond that of the medial temporal lobe, the following structures are associated: the temporo-parieto-occipital-junction, the dorsal prefrontal cortex, the medial frontal cortex, and the retrosplenial cortex together with surrounding areas. The right prefrontal cortex (mainly anterior frontal, orbitofrontal, and dorsolateral frontal) is involved in the retrieval mode for retrieval of episodic memories, corresponding to findings of Fletcher and Henson (2001).

In general, it can be stated that retrieval attempt and monitoring of the retrieval process is associated with frontal regions (Wagner, 2002). Whereas the restoring of information and the retrieval success engages neocortical regions and medial temporal lobe structures (Bayley, Gold, Hopkins, & Squire, 2005). Parietal together with frontal regions produce a signal that indicates that truly an old memory is retrieved and processed, and not a new information (Buckner et al., 2001). To be more specific, activations in both lateral inferior parietal cortices, often stronger in the left than in the right hemisphere, and the left anterior prefrontal region indicate retrieval success.

Stronger activation in the medial temporal lobe is assumed to be related to the retrieval of stored patterns (Nyberg, McIntosh, Houle, Nilsson, & Tulving, 1996). Using a shallow versus deep encoding task, neural differences between retrieval attempt and retrieval success were investigated (Buckner, Koutstaal, Schacter, Wagner, & Rosen, 1998). After shallow encoding, a high retrieval attempt was found to have only minor retrieval success. Here, the anterior insular regions were activated bilaterally and the left dorsal prefrontal region. On the other hand, high retrieval success, which was connected with lesser retrieval attempt, was distinguished after a deep encoding task and was found to be associated with activation in the right anterior prefrontal cortex (Buckner et al., 1998).

Overlapping structures

Further studies showed that encoding and retrieval processes of semantic and episodic memories use partly overlapping neural networks (e.g. Schacter & Wagner, 1999).

Tulving (1994) introduced one of the models, which pointed these overlaps out, calling it hemispheric encoding/retrieval asymmetry model (HERA). He illustrated that during episodic encoding and semantic retrieval the left prefrontal region was activated, whereas the right prefrontal region was associated with episodic retrieval processes (cf. Nyberg, Cabeza, & Tulving, 1996; Nyberg, 2002; Habib, Nyberg, & Tulving, 2003). This asymmetrical involvement of brain regions was also found in other studies investigating differences of brain activation for heterogeneous stimuli. Encoding of verbal material engaged the left frontal region, whereas the right frontal region was found to be more involved in processing of nonverbal material (Kelley et al., 1998; Wagner, Poldrack, et al., 1998; Golby et al., 2001). A study of Rossi et al. (2001) showed that encoding of pictures activated the left dorsolateral prefrontal region, and retrieval of this information, the right dorsolateral cortex. The left prefrontal region was further found activated during encoding of faces, whereas the right hemispheric prefrontal region was activated during recognition of the same material (Haxby et al., 1996).

The other model deals specifically with the involvement of the hippocampus in memory processes and is named HIPER (hippocampal encoding/retrieval model) (Lepage, Habib, & Tulving, 1998). Lepage and colleagues found that for visuospatial material, the anterior part of the hippocampal formation was involved in successful encoding of episodic memories, whereas the posterior part was activated during successful retrieval of semantic information. A recent study of Bernard et al. (2004), which used pictures of faces, confirmed the HIPER model. Contrary to the study of Lepage (1998), a study reported for verbal material only slightly more activations during encoding and retrieval processes within the middle and posterior part of the hippocampus than within the anterior part (Greicius et al., 2003).

Importantly, these controversial results show again the impact of the availed stimulus material. Activation in the brain shows the differences in the processing of unequal material. Even when only visual stimuli are used, it was shown that different regions activated specifically for the context of faces, locations, and objects (Polyn, Natu, Cohen, & Norman, 2005).

The overlapping of brain regions during encoding and retrieval processes can be explained by the engagement of encoding of new episodic information during the retrieval of old semantic memories. Additionally, encoding of new episodic memories can involve old semantic information to achieve a deeper encoding of the information (Cabeza & Nyberg, 2000).

2.1.4.4 Content-specific neural correlates

The medial temporal lobes as well as parts of the diencephalon are important for the declarative memory system (Squire & Zola-Morgan, 1991; McKee & Squire, 1992; Schacter & Wagner, 1999). Squire (2004) does not differentiate, like Tulving (1998), between semantic and episodic memory. However, he reports neuroanatomical differences between these two systems, for example for the frontal lobes, which were additionally found to be associated during episodic memory tasks (Shimamura & Squire, 1987).

The learning of motor skills, procedural memory, activates the basal ganglia (Lehericy et al., 2006) as well as the cerebellum. Additionally, activations were found in the motor areas of the frontal lobes, especially in the premotor and supplementary areas of the motor cortex, parts of the parietal lobes and fronto-parietal interactions (Cabeza & Nyberg, 2000).

Encoding and retrieval during priming and perceptual memory tasks activates uni- and polymodal cortical regions (Schacter & Buckner, 1998; Wagner & Koutstaal, 2002). It depends on the stimulus material and of the way it is processed, which brain regions are mainly engaged in priming (Henson, 2003). For example, visual stimulus material is related to activation in the lateral occipital complex (Grill-Spector et al., 1999). Neuroimaging studies also showed that priming processes are correlated with reduced neuronal activation (Demb et al., 1995; Wagner, Desmond, Demb, Glover, & Gabrieli, 1997).

Semantic and episodic memories acquire several brain structures during the processes of memory formation. These are mainly the prefrontal cortex (Buckner, 2000), the medial temporal lobes, and further parts of the limbic system during encoding process. The storage of semantic and episodic memories is correlated to neocortical structures (Eichenbaum, 1997; Fuster, 1997). During retrieval of semantic and episodic memories, the temporo-frontal cortex is activated (e.g. Markowitsch, 1998).

In Table 1 an overview is given of the memory processes and the relevant brain structures regarding the content of the treated information.

Table 1: Memory processes as well as contents and the relevant brain regions (modified from Pritzel et al., 2003

	procedural memory	priming	perceptual memory	semantic memory	episodic memory
encoding	basal ganglia, cerebellum, premotor areas	cerebral cortex (uni- and polymodal regions)	cerebral cortex (uni- and polymodal regions)	limbic system, prefrontal cortex	limbic system (strong), prefrontal cortex
consolidation and storage	basal ganglia, cerebellum, premotor areas	cerebral cortex (uni- and polymodal regions)	cerebral cortex (uni- and polymodal regions)	limbic structures, cerebral cortex	limbic structures, cerebral cortex
retrieval	basal ganglia, premotor areas	cerebral cortex (uni- and polymodal regions)	cerebral cortex (uni- and polymodal regions)	temporo-frontal cortex (left)	temporo-frontal cortex (right), limbic structures

In summary, these sections showed the multifaceted aspects of memory. The different neural structures were introduced and assembled regarding their affiliation to memory processes and content. The different theories and explanations showed that researchers came up with different classifications of memory depending strongly on their own area of interest. For example, the classification after Squire is widely used among biologists, whereas that of Tulving is the more common taxonomy among psychologists. The investigations of the neural correlates of memory urge researchers to be careful with the interpretation of neuroimaging results. The way memory displays itself everyday is as complex as the connections and relationships of the involved brain regions. One process can engage different structures, and one structure can be involved in several processes. In the next section, the theory of false memories is introduced. The necessity of the last section will be clarified and links between approaches regarding true and false memories will be elaborated.

2.2 False memory

"There is in general no guarantee of the correctness of our memory; and yet we yield to the compulsion to attach belief to its data far more often than is objectively justified." (Freud, 1901, p. 193)

The earlier described processes of encoding, storage, consolidation, and retrieval are complex and thus also error-prone. This can be manifested in the distortion of memories, also referred to as false memories. The term false memories endorses the phenomenon that someone remembers an event that was never experienced or was experienced in a different way (Schacter & Curran, 2000). One of the pioneers in the research of false memories was F.C. Bartlett (1932) who carried out a series of studies investigating the memory abilities of undergraduate students. The students heard a story and later attended recall tests on several proximate time points. Several changes to the story were recorded and also numerous omissions, especially with regards to those parts of the story that did not match the students own view of the world. Therefore, this study showed quite nicely that our own attitude towards life can influence our memories of prior and of recent events. In psychology, the term 'schema' or 'script' describes an established model of the world on the basis of past experiences. Schemata are very useful from the economic perspective. As the amount of stored information is reduced, one schema can be used for several occasions. On the other hand, a schema can be at odds with a new experience and, as illustrated above by Bartlett's study, can therefore create false memories.

During the 1990s several investigations were conducted into recovered memories of childhood sexual abuse (e.g. Dale & Allen, 1998; E. F. Loftus, Polonsky, & Fullilove, 1993; Porter, Yuille, & Lehman, 1999). While many of these recovered memories could be confirmed, there were also cases that seemed to be inaccurate and some of them even appeared to be entirely false (e.g. E. F. Loftus, 1996). The ensuing controversy resulted in an increase of false memory research. Recent years have witnessed the development of diverse paradigms for investigating this phenomenon under controlled circumstances. The most popular method to induce and hence investigate false memories is the word-list or Deese-Roediger-McDermott (DRM) paradigm. It was originally developed by Deese (1959) and later re-introduced and refined by Roediger and McDermott (1995). First, subjects hear several word-lists each containing 12 words. The words of each list are related to each other (e.g. butter, food, eat, sandwich, etc.) and associated with one critical word (e.g. bread). Subjects performed afterwards a recognition test, in which the studied words were randomly presented and mixed with non-studied words, so-called lures. The lures were divided into words derived from lists that were not studied earlier and critical lures like the aforementioned 'bread'. This paradigm is used widely for the investigation of the different aspects of false recognitions (e.g. Gallo, Roediger, H. L.

III, & McDermott, 2001; Marsh & Hicks, 2001; Neuschatz, Payne, Lampinen, & Toglia, 2001). In the next sections, first a characterisation is given of the three frequently used forms of false memories: confabulation, intrusion, and false recognition. Then, different theoretical explanations for the occurrence of false memory are presented. This is followed by Schacter's classification of false memories regarding their cause, namely 'The seven sins of memory'. In addition, the different research paradigms are briefly introduced alongside up-to-date knowledge about the neural nature of false memories.

2.2.1 Forms of false memories

In the literature, three forms of false memories are mostly described and investigated: confabulation, intrusion, and false recognition (Schacter, Norman, & Koutstaal, 1998). Figure 8 shows the three forms, together with a short explanation and the main area, in which they were found and studied.

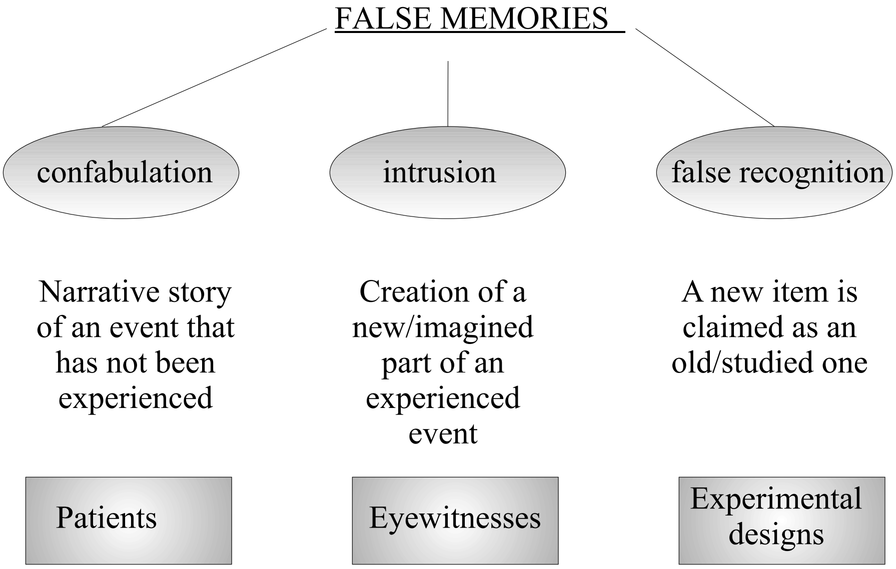


Figure 8: Taxonomy of the three forms of false memories with examples for the main research areas

When someone invents a completely new and therefore not experienced event, often with a narrative character, it is called a confabulation. A person claims, for example, that he was abducted by aliens. Probably he describes the event in-depth, how it happened, what he saw and felt. Confabulations are a form of false memories that can often be detected in stories of patients, like people who are suffering from Korsakoff's syndrome (Dalla Barba, Cipolotti, & Denes, 1990). Confabulations of patients often include possible personal events, like a detailed description of a birthday party several years ago that could have occurred in that way. Only a conversation with relatives or friends can show if this event was truly experienced or not.

Intrusions refer to a part of an event that was not experienced, but was inserted into a truly experienced event. Intrusions can be found, for example, in a report from a witness of a crime. An eyewitness describes the progression of an event and unconsciously intrudes details, which possibly have not been witnessed at all (Lindsay, Allen, Chan, & Dahl, 2004). Apart from such serious situations, intrusions can also occur in everyday life, by agitating a real event with something only imagined.

False recognitions describe instances when a new item (e.g. word, picture) is incorrectly classified during a recognition test as a known one from an earlier studied list. A prominent example for such a paradigm is the aforementioned Deese-Roediger-McDermott (DRM) paradigm or word-list paradigm (Deese, 1959; Roediger, H. L. III & McDermott, 1995). With this paradigm it was possible to induce an astonishingly high value of falsely recognised lures as previously studied words. These word-lists can also be used to provoke false recall of critical lures (Melo, Winocur, & Moscovitch, 1999; McDermott & Watson, 2001). Despite the fact that these three forms of false memories are the best investigated ones, there are more varieties of false memories. Quite often it depends on the used paradigm and also on the scientific area of the experimenter, what kind of false memories are explored. An accurate discrimination between true and false memories is in many cases difficult, as can be seen in the following sections.

2.2.2 Theoretical approaches to false memories

Different theories were developed to explain the occurrence of false memories. All theories for false memories are strongly connected to findings and theories considering true memories. Early explanations include constructivism, schema theory, and source-monitoring framework. More recent theories realign themselves to the dual-process explanation, which was developed primarily as an explanation for true memories. According to two-process accounts of recognition memory, a familiarity-based process is followed by a slower, more accurate, recollection process. Three different theories based on this dual-process explanation are: fuzzy-trace theory, activation/monitoring theory, and distinctiveness heuristic theory.

Constructivism describes the creation of an idea for the overall meaning of one or more presented stimuli, which contain more information than the original stimulus/stimuli. Constructivism is based on work from Bransford and Franks (1971). They created sets of short sentences, which were studied by subjects. Afterwards, the subjects attended a surprised recognition test containing studied sentences (targets), meaning-

Table 2: Example sentences for each of the four levels of the semantic-integration method (Bransford & Franks, 1971).

propositions	sentences	type
level 1	The ants were in the kitchen.	target, untested
	The jelly was on the table.	target, untested
	The jelly was sweet.	distractor 1
	The ants ate the jelly.	distractor 1
level 2	The ants in the kitchen ate the jelly.	target, untested
	The ants ate the sweet jelly.	target, tested
	The sweet jelly was on the table.	distractor 1
	The ants ate the jelly which was on the table.	distractor 1
level 3	The ants ate the sweet jelly which was on the table.	target, untested
	The ants in the kitchen ate the jelly which was on the table.	target, untested
	The ants in the kitchen ate the sweet jelly.	distractor 1
level 4	The ants in the kitchen ate the sweet jelly which was in the table.	distractor 1

preserving new sentences (distractor 1), and meaning-violating new sentences (distractor 2). Table 2 shows examples for one set containing four possible propositions (levels): eat, ants, jelly, past; sweet, jelly; on, jelly, table, past; in, ants, kitchen, past. Examples for meaning-violating sentences (distractor 2) are not presented in the table. These are sentences that combine information from different presented sets. One example sentence for a meaning-violating sentence would be “The ants ate the jelly beside the woods.”.

It was found that subjects were able to discriminate accurately between target sentences and meaning-violating sentences, but they had problems to correctly differentiate between targets and meaning-preserving sentences. The interpretation from Bransford and Franks was that subjects formed an interpretation (overall meaning) of the studied propositions and integrated them into semantic structures (Bransford & Franks, 1971). From this it follows that during the recognition task subjects mainly decided by relying on the integrated interpretations and not on the original content (surface form) of the studied sentences. Notably is further that Bransford and Franks thought that the surface form is only stored in the short-term memory and vanishes after the integration process. Following studies showed, however, that the surface form can be stored for a longer period of time (e.g. Hintzman, Block, & Inskeep, 1973; Kintsch, Welsch, Schmalhofer, & Zimny, 1990), but is then harder to access than the overall meaning of the sentences (Murphy & Shapiro, 1994).

Routine sequences exemplify a similar acting in comparable situation with reference to a previously developed schema. A schema represents a learnt concept or action in a common situation (Minsky, 1975; W. F. Brewer & Treyens, 1981). The schema theory went back to the early work of Bartlett (1932). It separates four key principles: selection, abstraction, interpretation, and integration. Selection means that only a part of the available information of an event is encoded (Brown, Smiley, Day, Townsend, & Lawton, 1977). After the selection, objects are encoded in an abstract way. For example, a red cup with white points is encoded simply as the schema ‘cup’. Like the surface form proposed in constructivism, which vanishes after a short time, the abstraction principle describes the situation where only the meaning of an item is encoded, and not the exact content. The third principle, interpretation, is also the one during which memories are most likely to be distorted. The simplified encoded information is compared with existing memories, thus the new information is enhanced. In the example of the cup it could mean that even though the handle of it is broken, someone later remembers holding the cup at the handle because this would be the common procedure. As long as the attention is not explicitly drawn to the fact that the cup is incomplete, the memory can be changed in cause of the general schema of this object. During integration, the stored information is consolidated and thus connected with similar memories to one consistent schema. At this point, true and false memories can be connected to one holistic memory. Based on the schema theory, paradigms were developed that clearly showed that subjects are vulnerable to schema-induced memory distortions (e.g. Graesser, Woll, Kowalski, & Smith, 1979; Lampinen, Farias, Neuschatz, & Toglia, 2000).

Any information that is encoded contains a source. This source, for example, can be a place where an event happened, a person, a television programme, a book, or a conversation. During the encoding process, the source of an event has to be encoded together with the content of it. It can happen that the true source of a memory is confused with another source (e.g. thinking you have seen something on TV, when you actually read it in a paper). When a person makes such an error, it is called a source-monitoring error, which is defined in the source-monitoring framework by Johnson and colleagues (M. K. Johnson, Hashtroudi, & Lindsay, 1993; Lindsay & Johnson, 2000). The ulterior motive of the framework is the fact that even memories of a single event are complex and contain different information like facts, feelings, and sensory perceptions. Reasons for confusions are manifold, for example, vivid imaginations of an event that come into conflict with the true event (‘Have I switched off the cooker or have I only imagined it?’). The degree of attention during an experience can increase or decrease the possibility for source-monitoring errors. Subjects can use a source-monitoring criterion to distinguish more accurate, which source is the true one (Martell & Evans, 2005). This can be supported, for example, by giving explicit instructions to a subject to focus consciously on a source and thus develop the criterion. There are two reasons why a source-monitoring failure can occur. One is when a subject has built a source-monitoring criterion during encoding but still fails to distinguish the true from the false source. The second one is when a subject is unsuccessful to create a criterion in the first place (Gordon, Franklin, & Beck, 2005).

The fuzzy-trace theory was introduced by Brainerd and Reyna (1990a, 1990b) originally as a model for reasoning and decision making later refined to explain the formation of false memories (Brainerd & Reyna, 2001). The fuzzy-trace theory depends on the five principles presented in Figure 9.

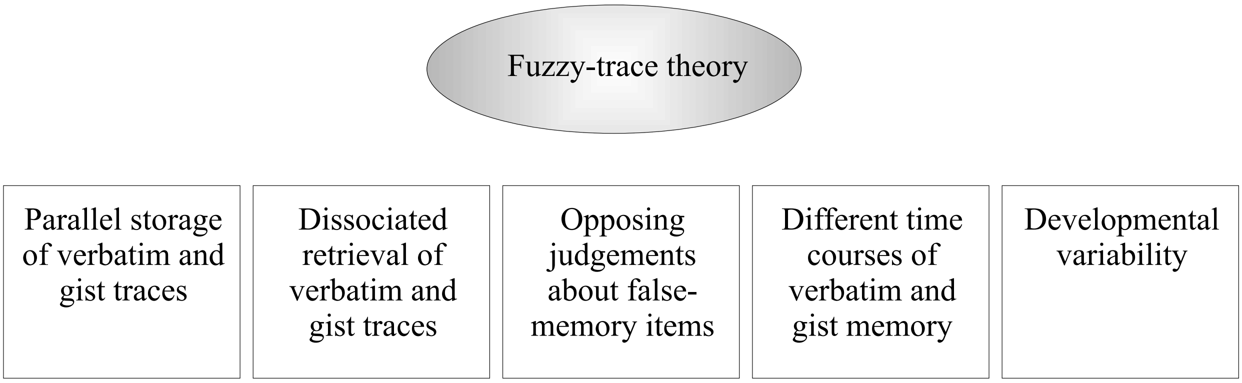


Figure 9: The five core principles of the fuzzy-trace theory developed by Brainerd and Reyna (2001)

The first principle says that verbatim and gist traces are stored in parallel (Reyna & Brainerd, 1992). Studies showed that the gist traces are processed and stored like the verbatim traces within the first second after the presented stimulus (Seamon, Luo, & Gallo, 1998; Abrams & Greenwald, 2002). Verbatim traces are integrations of various surface features, which were combined during the retrieval. Here, the whole surface form is remembered and creates a similar mental re-enactment of the encoded event. If the verbatim traces vanish, a disintegration of the features takes place (Reyna & Titcomb, 1997). Gist traces on the other hand represent the interpretation of the content, their meaning, relation, and pattern. Regarding false memories this means that subjects maybe are unable to remember the detailed verbatim trace (e.g. studied word-list contained cat, bee, lion, pig, pigeon, cheetah, etc.) but are still able to name the gist information of the stimuli (e.g. animals, house animals, African animals). From one event many gist traces can be processed and stored together with one verbatim trace. The gist traces can vary in their specificity, like being of a global (animals) or of a specific type (African animals).

Though the verbatim and gist traces are stored in parallel the retrieval of them seemed to be more or less independent from each other. This is stated in the second principle, which says that verbatim and gist traces are dissociated retrieved. By varying cue items and instructions, subjects can be influenced to retrieve verbatim or gist traces. When target probes are used as retrieval cues, subjects rely mainly on their verbatim traces. The same was found for hits during recognition tasks and target recalls during recall tasks (Reyna, Holliday, & Marche, 2002). By using semantically related items as cue items, it can be ensured that subjects use predominantly their gist traces. These are also related to the production of false alarms during recognition tasks and intrusions during recall tasks (Reyna, 1998).

The third principle, opposing judgements about false-memory items, explains the different nature of verbatim and gist traces during the processes of true memories and false memories. During the former, verbatim and gist traces work together to form a true memory. Verbatim traces are used for the recollection of a memory. First an identity judgement between the retrieved information and a ‘to-be recognised’ or ‘to-be recalled’ item is made. Then, a direct access of the memory is endorsed. The second part of the dual-process theory, familiarity, is initiated by the gist traces. The retrieval of the gist traces implies a similarity judgement of a ‘to-be recognised’ or ‘to-be recalled’ item and if this is verified, a reconstruction of it. However, in the case of false memories, these two processes are assumed to work in opposition to one another. Verbatim traces suppress the production of false memories, whereas gist traces support them (Brainerd & Reyna, 2005). For example, a subject studies a word-list of several animal species. The verbatim traces would support the true recognition of the studied words, whereas the gist information could interfere with it by retrieving names of species that were related but not learnt.

Different time courses of verbatim and gist memory is the fourth principle. Several studies showed that verbatim traces decline faster over time than gist traces (e.g. Murphy & Shapiro, 1994). This implies that over the time the rate to produce false memories increases and they are also be strengthen by time.

The fifth and last principle mentioned, developmental variability, illustrates the different susceptibility to false memories of younger and older adults. The difference results from the temporally shifted development of verbatim and gist memory. Children of the age five to eight years perform highly in a recognition task showing different cats, whereas older children and adults do poorly (Fisher & Sloutsky, 2005). The ability to store verbatim traces seemed to be developed earlier in life than the one for gist traces. That older children and adults performed more poorly than the younger children indicates that the younger have not established a category for cats yet, but have truly learnt the various distinct forms. A further result of the study of Fisher and Sloutsky (2005) confirms this interpretation. In a second experiment they showed pictures of imaginary animals; in this case, younger and older subjects performed alike. Younger children only have better verbatim memory when the gist of the material is in general graspable for them (Reyna, Mills, Estrada, & Brainerd, 2005). In conclusion, fuzzy-trace theory explains false memories with the two processes verbatim and gist memory that act in concert to support true memories but generate false memories when they act in a dissociated way.

Another dual-process explanation for false memories depends on results of the word-list or DRM-paradigm and was named activation/monitoring framework (McDermott & Watson, 2001). It describes the concept that memories are semantically linked. For example, the word canary also activates the information bird, yellow, sings; activation of one piece of information can result in a spreading activation of the network (Collins & Loftus, 1975). This process operates fast after a trigger was perceived and is compulsory and intangible by our consciousness (Posner & Snyder, 1975). The spreading activation facilitates the accessibility of semantically related words, considering the DRM-paradigm, and this may result in false recall and false recognition (Roediger, H. L. III, Balota, & Watson, 2001). During encoding processes, monitoring controls the attention toward the environment as well as the thoughts towards the external information. During retrieval processes, the activated information is compared with the earlier encoded one. When subjects are instructed about the false recall/recognition effect before the encoding phase they are able to decrease this effect significantly (Gallo, Roberts, & Seamon, 1997).

The distinctiveness heuristic theory (Schacter, Israel, & Racine, 1999) relies, like the activation/monitoring framework, mostly on results of the DRM-paradigm. In the study of Schacter et al. subjects studied word-lists, in which each word was followed by an adequate picture. The false memory rate sunk drastically in the following recognition task. Schacter et al. interpreted their findings, concluding that the subjects encoded distinct feature details from the pictures and used this information during the recognition task. Similar findings were observed in a recent study where subjects studied black words either with a picture, the same word in red font, or with both (Gallo, Weiss, & Schacter, 2004). Again the best results were accomplished for the picture condition. The distinctiveness heuristic was also verified by the results of another study, in which during the study phase subjects spoke the words aloud, which also decreased the false memory rate supposedly because of the encoded distinct information during speaking the words (Dodson & Schacter, 2001). The distinctiveness heuristic is therefore a theory that explains how false memories can be reduced in general by dismissing all items for which no supplementary distinct memory is available.

2.2.3 Schacter's seven sins of memory

Daniel Schacter suggested that memory failures can be differentiated regarding their cause into seven sins of memory: transience, absent-mindedness, blocking, misattribution, suggestibility, bias, and persistence (Schacter, 1999, 2001). The first three sins describe different variations of loosing information/memories, the second three endorse deformation of memories, whereas the last one stands for memories, which sometimes want to be forgotten but which are stuck. Schacter connected these seven types of false memories with known research results of studies throughout the broad field of false memories.

The sin 'transience' combines short-term and long-term forgetting and includes the roles of encoding and retrieval failures, respectively. A well-known example for transience is the forgetting of the name of someone. It is very awkward to meet someone, an assumed stranger, who smiles and starts a conversation by using the first name of the other person. One of the first studies considering this phenomenon was made by Ebbinghaus (1913). He learnt lists with nonsense syllables and tested himself at six different times ranging between one hour and one month after the study phase. During the first tests he recorded a swift drop-off, after nine hours he had forgotten nearly 60 percent of the list. However, this rate of forgetting slowed down during the later tests and after a month the rate was by 75 percent. Presumably, Ebbinghaus has re-encoded the nonsense syllables during each retrieval task. This would explain the smaller forgetting rate after the first nine hours. This is also consistent with the assumption that forgetting is closely connected to the usage of a memory. If information is not used over time by retrieving and rehearsing it, it seemed to diminish more and more (Koutstaal, Schacter, Johnson, Angell, & Gross, 1998).

The sin of 'absent-mindedness' depends highly on the level of attention during the encoding process, as well as during an attempted retrieval of information (Reason & Mycielska, 1982). The level of encoding, shallow or deep, influences the likelihood of the subject being aware of the encoded information or not. A famous example for this is the phenomenon of 'changed blindness' (e.g. Levin & Simons, 1997; Levin, Drivdahl, Momen, & Beck, 2002). Levin's studies demonstrated that even huge changes went unrecognised because the attention of the subjects was drawn to a specific task. For example, students received the task to watch a film, in which some people played ball and they had to count how often the ball was thrown from one to another. In the middle of the film a person dressed as a gorilla walked through and was not noticed by most of the students. Simons and Levin (1997) explained this phenomenon thus: information is normally encoded at a shallow level, because only the general features of a scene are needed to behave appropriately. It is not important in everyday life to deeply encode, for example, the features of a bus driver in the morning. Normally, we do not need this information at any subsequent time. This effect even grows when we go to work every day by bus. Then, we have an image (or schema, see schema theory) of bus drivers in general and the knowledge how to behave in such situations and that is all we need to reach our goal. When absent-mindedness occurs during retrieval it is also interrelated with some kind of forgetting what was supposed to be done. In this context the term of prospective memory is often used. Failure in the prospective memory is, for example, when we forget to tell a colleague about an article at the next meeting (event-based failure). A more serious example is when patients forget to take their medicine regularly (time-based failure).

The sin of 'blocking' can occur even when the information was deeply encoded. The information is not forever lost but cannot be reached in that moment. The tip-of-the-tongue (TOT) state (Schwartz, 1999) is the most common example for an information block and can occur for semantic as well as episodic information. Interestingly, it was found that alternating words did not induce the tip-of-the-tongue state, which was assumed earlier (Cross & Burke, 2004). Instead Cross and Burke found that answering questions of famous person's names and naming actors who played these famous persons reduce incorrect answers but did not affect the tip-of-the-tongue state. They concluded that alternate words emerge as a consequence of the tip-of-the-tongue state and were not caused by it. In most cases, the memory comes back after some hours. Often, when we are engaged with something completely different.

The sin of 'misattribution' envelops falsely connected memories. One type of misattribution was explained earlier when a false source is attributed to an event, 'source monitoring framework' (M. K. Johnson, 1988; M. K. Johnson et al., 1993). Another form of misattribution is also interrelated with source confusion but results in different implications. Cryptomnesia, also known as unintentional plagiarism, occurs when a subject claims an idea as self-made and forgets that the information was perceived from an external source (Marsh & Bower, 1993; Bredart, Lampinen, & Defeldre, 2003). In a recognition study using a list of famous and non-famous names it could be demonstrated that subjects sometimes adopt the fame of a famous person (like Ronald Reagan) to a completely unpopular person ('false fame effect') (Jacoby, Kelly, Brown, & Jaeschko, 1989). The aforementioned word-list or DRM-paradigm (Deese, 1959; Roediger, H. L. III & McDermott, 1995) demonstrated remarkably high levels of the third kind of misattributions, false recognitions. By using this paradigm it was shown that even unintentional learning can produce robust false recognitions (Dodd & MacLeod, 2004). A reduction of false recognitions was found by changing the structure of the DRM-paradigm and encouraging the subjects to use strategies during the study phase (Libby & Neisser, 2001). An abutting paradigm is the picture paradigm developed by Miller and Gazzaniga (1998).

The picture paradigm turned out to be nearly as effective in inducing false recognitions as the word-list paradigm. It had the further advantage that only a few learning pictures were needed to obtain a large sample of recognition pictures. A cause for the high rate of false recognitions in these paradigms is that subjects relied mainly on general features (or gist) of the studied stimuli (Brainerd, Payne, Wright, & Reyna, 2003; Brainerd & Reyna, 2005; Schacter et al., 1998). Misattributions are supported by the illusory-truth effect (Begg, Anas, & Farinacci, 1992; Begg, Robertson, Gruppuso, Anas, & Needham, 1996). Begg reasoned that true recognitions based on correct source memory and familiarity statement, while false recognitions have no source and thus base only on the familiarity statement. They described two behavioural results, which confirm this effect. One was that the mere exposure of information, even false one, leads to an increase of its truth value. The second result was the tendency of the subjects to misjudge false stimuli as true.

The sin of ‘suggestibility’ describes the influence of misleading information that can alter the recollection of an event (E. F. Loftus, Miller, & Burns, 1978; E. F. Loftus & Pickrell, 1995). This can happen by asking suggestive questions during an interrogation or during a talk between two persons. Suggestibility is closely related to misattribution but different in so far that misattribution can occur without any interference from an external source (e.g. police). The best known work considering suggestibility was done by Loftus and colleagues. They performed several studies on memory distortions initiated by suggestive questions (E. F. Loftus, 1979; E. F. Loftus & Fathi, 1985; E. F. Loftus & Pickrell, 1995). From their work, Loftus introduced the phrase ‘misinformation effect’. Misinformation occurs when, for example, people who witnessed an incident (e.g. accident, robbery) listen to the report of another witness. Here, the different perception of the incident from the second witness can be adopted by the first witness. Thus, the first witness unconsciously changes his/her own memory of the event. Several researchers refer to this important point, that interviewers of eyewitnesses have to keep the misinformation effect in mind while they perform an interrogation (E. F. Loftus, 2002; Ihlebæk, Løve, Eilertsen, & Magnussen, 2003; Lindsay et al., 2004). They further emphasise that it is not important if the interview takes place directly after an incident, or later during a hearing. That misinformation from outside sources can interfere with original memories was investigated by several studies, but research considering internally produced misinformation is rare. Pickel (2004) performed a study where subjects watched a videotape of a robbery. One group was interviewed afterwards. After a week all subject had to describe the robbery. Subjects who were not interviewed after the presentation of the videotape and subjects who mixed details up during the initial interview, created more incorrect details than the subjects who performed well during the first interview. The reason for internally fabricated misinformation could be that during encoding or retrieval, not only the actual information is manipulated. Prior memories may also be biased by the new information and these two get connected by content or emotion (Buckner et al., 2001).

The sin of 'bias' is well-known since the influencing work of Bartlett (1932), which was introduced at the beginning of this section. Older memories, beliefs, and prejudices influence the encoding, as well as the retrieval, of memories. In this context, another concept from social psychology, 'cognitive dissonance' (Festinger, 1957), shall be introduced as an explanation of the development of bias. Cognitive dissonance describes the urge to minimise the discrepancy between attitudes and actions. A good example is the dilemma, with which a smoker lives. He or she knows that his or her habit is bad for their health and that it could and probably will shorten his or her lifespan. The logical consequence of this knowledge would be to stop smoking. Instead he or she devises arguments to defend his or her habit before him- or herself and others. The mental mechanisms that are used to balance our attitudes with our actions are very effective (Griffin, 1997). One mechanism is to avoid information which could increase the dissonance (e.g. information about negative consequence of smoking). Another one is to seek the confirmation of our environment that the decision is correct. Processes of cognitive dissonance are likely to be involved in the production of false memories. To reassure ourselves of doing the right thing by changing memories and perhaps creating false memories is an easy and ensuring way to live with conflicting information (Ross, Buehler, & Karr, 1998). The sin of bias is differentiated into five major types (Schacter, 2001): consistency, change, hindsight, egocentric, and stereotypical biases. Consistency and change biases are influencing the view of our own past regarding the present situation, e.g. rating levels of pain (Gedney & Logan, 2006) or long-term relationships (Karney & Coombs, 2000). These two forms of bias are also the ones that help to reduce cognitive dissonance. Hindsight bias describes the often heard statement 'I told you so', which demonstrates the speaker's feeling of knowing all along what will happen. Hindsight bias is a very strong mechanism of self-protection that can be found in several contexts, for example jurors in a courtroom (A. C. Smith & Greene, 2005). Egocentric biases show how strong our view of ourselves can influence past memories and current events, respectively. It changes effectively our estimation of ourselves in the past (Ross & Wilson, 1999), for example, if we see ourselves as narrow-minded in the past we can appear more open-minded today. An example for stereotypical bias is when we act on the basis of prejudices. During our development we learn the ways of our environment, e.g. how people look like, how they act in common situations. We are culturally imprinted. Stereotypical bias leads to a wrong sight of other people that can lead further to an inappropriate reaction, e.g. do not employ someone because of the race or sex without acknowledging this reason (Uhlmann & Cohen, 2005).

The sin of 'persistence' describes the inability to forget certain events. A benign case is a song, heard on the radio in the morning, which unintentionally repeats itself in the mind. This experience can be very annoying but has no severe consequences. The persistence of memories depends strongly on the emotional state during the encoding. That emotions have a powerful effect on the memorisation process was supported by several studies (Rapaport, 1961; LeDoux, 1996; Cahill & McGaugh, 1998; Ochsner & Schacter, 2000). Depressed people and patients suffering of post-traumatic stress disorder (PTSD) were found to be most susceptible to negative persistent memories. These people can be literally stuck in their past (Holman & Silver, 1998). The sin of persistence forces us to confront ourselves with stressful events. When we do this, we eventually are able to integrate the event into our past. Thus we can learn to live with the memories without suffering from them.

2.2.4 False memory paradigms

As the research of false memories increased, the methods for investigating them also improved. In their recent book 'The science of false memories' Brainerd and Reyna (2005) merged together the most common paradigms. Some of the paradigms, like the semantic intrusions in list recall and semantic false alarms in list recognition, are only used in the laboratory, often using the DRM-paradigm. It is important to study false memories in controlled situations, but at the same time it has the disadvantage of testing a more artificial form of our memory abilities. The occurrence of false memories in eyewitnesses is very important, because the consequences are often serious. The different paradigms also demonstrate the broad range of false memory occurrences. As most of the paradigms were explained in detail earlier within this section only short definitions are given here.

- *Semantic intrusions in list recall*:

Subjects hear or see several word-lists. Some lists contain words that are semantically related to each other whereas other lists consist of unrelated words. Afterwards subjects recall as many words from the lists as they can remember.

- *Semantic false alarms in list recognition*:

Similar to the previous paradigm, only that subjects shall recognise studied words, which are presented together with new and/or related words.

- *False memory in semantic inferences*:

Subjects learn sentences with different meanings of the same content and with differential length. During a recognition task they often falsely recognise sentences that sum up information from several studied sentences, but which were nevertheless not learnt (see also constructivism, section **2.2.2**; Bransford & Franks, 1971).

- *Suggestibility of eyewitness memory*:

The memory of an eyewitness can be distorted during a questionnaire by the police, or other authorities. Knowingly or unconsciously the inquirer can lead the answers of the witness toward the desired direction and outcome.

- *False identification of criminal suspects*:

Investigated were line-ups (witnesses see four – six persons and shall identify the culprit), show-ups (witnesses view a single person or a single picture and have to say if this was the culprit or not), and photo spreads (witnesses see pictures of four – six persons and have to identify the culprit).

- *False memory for schema-consistent events*:

The memory of subjects is tested for familiar events. Events for which it is assumed that the subjects have developed a schema at an earlier time, e.g. going into a restaurant, visiting the dentist. In both cases, subjects will have expectations (schemata) about how the locality will look like and what will happen there.

- *False memory in reality monitoring*:

People can make failures when they remember something and have to decide which part of a memory was truly experienced and which part was internally fabricated. This can be tested, for example, when subjects hear or read stories. Later, they perform a memory test examining their memory for the narrative contents. Reality monitoring paradigms are often closely related to source-monitoring theory.

- *False memory from reasoning*:

Reasoning about an event, a topic, or any other matter, to decide how to deal with it (Shavir, Simonson, & Tversky, 1993) can lead to false memories because of reasoning errors. Conjunction problems and decision framing problems are two examples for reasoning errors (Tversky & Kahneman, 1981, 1983).

- *Autobiographical false memory*:

One study investigated this paradigm by instructing subjects to write a daily diary for five months with one true event, one true thought, and either an altered event and a false thought or a false event and an altered thought (Conway, Collins, Gathercole, & Anderson, 1996). The highest correct recognition rate was found for true events and thoughts; false memories were found for thoughts, rather than for events.

2.2.5 Neural correlates

The last sections showed the complex nature of false memories and the difficulties to classify them. The presented overview was knowingly extensively construed to show these difficulties as well as to clarify that false memories and true memories origin to the same root. In both cases people remember events of their past, which truly happened for them. The previous sections addressed false memories from the behavioural point of view. To look more closely into the brain might be a more thoroughly solution to discriminate between true and false memories. During the last decades researchers investigated the neural correlates of false memories. They used three different approaches for this: neuropsychology, electrophysiology, and neuroimaging. The findings are sorted regarding encoding and retrieval processes.

Encoding

One of the key structures to identify neural differences in activity during encoding processes, which results later in false memories, is the left prefrontal cortex. Higher activation during encoding processes in the parahippocampal region, the posterior temporal lobe, and the left inferior frontal gyrus indicated which stimuli (e.g. words) were later remembered (Wagner, Schacter, et al., 1998). Other studies showed that a lower level of neural activity in the left parahippocampal gyrus and the left inferior prefrontal cortex for semantic stimuli during encoding was associated with a higher likeliness of absent-minded encoding processes (Demb et al., 1995; Gabrieli et al., 1996; Wagner et al., 1997). The underlying process seems to be repetition priming, which results in a decrease of activation in the left inferior prefrontal cortex. A study of Mitchell et al. investigated which brain regions are involved in the successful avoidance of misattributions (Mitchell, Dodson, & Schacter, 2005). They found an increase in neural activity in the hippocampus and the ventrolateral prefrontal cortex. Okado and Stark (2005) explored the misinformation effect during encoding processes of pictorial and misinformation material. Their results revealed that activation in the left hippocampus tail and the left perirhinal cortex indicate successful encoding, independent of the information was studied during the original event phase or the misinformation phase.

Retrieval

Cabeza et al. (2001) reported similar activation of the hippocampal region during true and false recognitions while the parahippocampal region was differentially activated during true but not false recognitions. The conclusion was that part of the hippocampal region is involved in the recovery process of semantic information, which was equal for true and false stimuli. The part of the parahippocampal region on the other hand was associated with the recovery of sensory information. The latter refers to the sensory reactivation hypothesis (Wheeler, Peterson, & Buckner, 2000; Okada et al., 2003). Wheeler et al. (2000) refers to findings that during retrieval process of visual or auditory information a subset of the same sensory regions are reactivated, which were activated during perception. A similar finding was reported regarding early and late visual processing areas (Slotnick & Schacter, 2004). These regions, namely middle occipital gyrus and fusiform/inferior temporal gyrus in both hemispheres, were similarly activated during correct and false recognitions.

A decreased activation in several left medial temporal regions is also assumed to be responsible for the inability to retrieve specific semantic information (like names of animals) at a certain time, meaning that this information is temporally blocked. This conclusion can be drawn from studies investigating correct retrieval of names that resulted in greater activation in the temporal pole (Grabowski et al., 2001). Source monitoring failures are associated with information binding processes in the brain and damage in medial temporal regions (mainly hippocampal formation), diencephalic regions or the basal forebrain can result in a higher rate of these errors (Squire, 1995). Damage in frontal regions can have a similar effect because the region is correlated with initiating retrieval, monitoring processes, and inhibiting inappropriate memories as well as temporal and source evaluations (e.g. Shallice & Evans, 1978; Shimamura, 1995). By using a reality monitoring paradigm containing pictures of concrete objects, Okado and Stark (2003) reported three main findings. The first was that activation in the left parietal cortex and the left frontal regions did not differ between true and false retrieval. However, a correlation was found between the activity of the left parietal cortex and the subjects' belief that the stimulus was studied regardless of the validity of it. The second finding was that activity in occipital regions and the posterior right parahippocampal region was greater for true than false memories. They assumed that these regions processes perceived and imagined stimuli in a systematic fashion. The perceived stimuli contain richer sensory details that result in the greater activation of the occipital region. Similar results were reported by Slotnick and Schacter (2004), who found that the early visual processing regions (lingual/fusiform gyri) are stronger activated for true compared with false recognitions. True and false recognitions activated regions in the early and late visual processing regions (middle occipital/inferior temporal gyri). These activations are also assumed to be involved in giving a 'known' or 'old' response regardless of the correctness of it. The third finding of Okado and Stark's study was that greater activity in the right anterior cingulate gyrus was associated with false recognitions, rather than true recognitions. They suggested therefore that this region is strongly associated with retrieval effort. The anterior cingulate cortex was further described in several studies to be involved wit conflict monitoring processes (see Botvinick, Cohen, & Carter, 2004, for a recent update).

In summary, the general finding of several studies was that true and false memories are associated with similar brain regions. These are explicitly regions that are involved in episodic retrieval tasks, like dorsolateral/anterior prefrontal, medial parietal, and medial temporal areas. If differences were reported they showed that greater activations are associated with true than false recognitions.

In summary, this section introduced the three common forms of false memories and theoretical explanations of their appearances, respectively. Schacter's seven sins illustrated not only the complex nature of false memories but also the relationships between several research areas. It showed the difficulties to define the causes of false memories in general and how important it is to imply findings of 'normal' memory in false memory research. Furthermore, the included paradigms brought the aforementioned points in a few words together. They demonstrated the closeness between research area and which specific cause and form of false memories is investigated. This was further mirrored in the results of the neuroimaging studies. Especially the latter point revealed that the knowledge of false memories and their neural correlates is still incomplete. In the next section (**3**), questions and hypotheses are given, which arose of the introduced information about false memories.

3 Questions and hypotheses

The aim of this study was the investigation of false memories, more specifically false recognitions with regard to mistakes made by eyewitnesses.

- One of the starting questions was what kind of paradigm can be used to investigate reasons of failures in eyewitness reports?
- How should a learning stimulus be created to investigate specifically the visual sense but, nevertheless, still be close to our everyday life?
- Can false recognitions be divided regarding common situations?
- How can it be investigated if something is truly remembered or only imagined?
- In what way are response times effected, if a studied stimulus is truly accepted or falsely rejected, and if an unstudied stimulus is correct rejected or falsely accepted, respectively?
- Can neural correlates be distinguished for correct as well as false recognitions that are caused by a complex visual stimulus?

In the following, the hypotheses that were developed out of these questions are introduced.

Hypothesis I

A mute film, mirroring real life, provokes false recognitions reliable.

The most popular method to induce false recognitions is the word-list paradigm developed by Deese (1959), later re-introduced and refined by Roediger and McDermott (1995) (see also section **2.2**). Though this paradigm is widely used to study different aspects of false recognitions (e.g. Gallo et al., 1997; Marsh & Hicks, 2001; Neuschatz et al., 2001), it has several disadvantages. A critical point of the word-list paradigm is that the used word-lists are artificial stimuli. Except for learning of vocabularies, it is not common to study word-lists in everyday life. Therefore, results have to be applied carefully to false recognitions observed in real life incidents, for example, when an eyewitness identifies a culprit (e.g. E. F. Loftus, 2003). Only one study is known, in which the word-list paradigm was compared with a picture paradigm (M. B. Miller & Gazzaniga, 1998). By using the picture paradigm the experimenters aimed to avoid two limitations of the word-list paradigm: the particular small number of lures and the higher likelihood of source confusion. They demonstrated that the picture paradigm was nearly as effective in inducing false recognitions as the word-list paradigm. A positive side-effect of the picture paradigm was that only a few pictures were needed as learning stimuli to create a large sample of lures for the adjacent auditory recognition test. In this, Miller and Gazzaniga followed the original word-list paradigm, in which subjects saw the words during the learning phase and attended an auditory recognition test afterwards. More recently further picture paradigms were developed to investigate false memories (e.g. Wade, Garry, Read, & Lindsay, 2002), and their neural basis (e.g. Okado & Stark, 2003; Slotnick & Schacter, 2004). The attempt of this study was to take one further step to examine the memory abilities of healthy subjects and their proneness to failure, by using a newly developed film paradigm. The paradigm should be close to everyday experiences, without strong emotional values, testing explicitly the visual sense, and still be adaptable to neuroimaging techniques.

The film should present several activities as they can occur every day, like getting up in the morning or shopping. Earlier studies showed that the emotional value of the used stimulus has a high impact on the memorisation processes (cf. Siebert, Markowitsch, & Bartel, 2003; Kensinger & Schacter, 2005). Hence, the film should contain ordinary everyday scenes, without strong affective material, like accidents or weddings. A further requirement of the film paradigm was that the memory for visual information should be explicitly investigated. The reason for this was that during interviews of eyewitnesses, a lot of the revealed information is gained from what was actually seen. This fact is not only mirrored in the term eyewitness but also in the amount of papers investigating the accuracy of visual recognition methods (for recent studies see among others Pryke, Lindsay, Dysart, & Dupuis, 2004; Haw & Fisher, 2004; MacLin, Meissner, & Zimmermann, 2005).

Furthermore, one study examined memory for staged crimes, either witnessed live or on video (Ihlebæk et al., 2003). It showed that the subjects witnessing a crime on video had better and more accurate memory for it than the ones who witnessed it in person. With this study the advantage of a film for investigating memory abilities of witnesses under controlled conditions was confirmed. Thus, it was decided to investigate the effect of an unemotional, mute, complex visual stimulus, and its capacity to induce false memories in healthy subjects.

Hypothesis II

False recognitions are caused by two different reasons.

When subjects identify an unstudied stimulus, for example a word or a picture, falsely as a known one, they have made a false recognition (Schacter et al., 1998). Thinking about witnessing an incident, two different forms of occurring memory failures can be assumed. One is that the description of the appearance of an object or a suspect is changed. The other one is that a described action was not truly witnessed.

An example for the first kind of memory failures was reported during the sniper attacks that killed ten people in the area of Washington DC, 2002 (E. F. Loftus, 2003). It was reported that after the attacks, a white van or truck was seen fleeing the crime scene. However, the sniper subjects drove a blue car when they were caught. This memory distortion was supposedly effected by the media, which incorporated the information of the colour from one of the first attacks and repeated the information constantly. Later witnesses probably knew this information even before they witnessed an attack for themselves and integrated the false information into their own experience.

The second assumed reason that results in false recognitions is defined by the process when someone fills in gaps of a truly witnessed event. For example, if someone hears a tale and is preoccupied with a phone-call for a couple of minutes, then rejoins the tale, the person is mostly able to generate the missing parts of the story to understand its content completely. Another example is, when someone observes a person walking to a car. Because of a tree or a moment of inattention it is impossible to actually see how this person opens the car and gets into it. What is witnessed is that this person drives away with the car. Naturally, it can be assumed that the person has opened and entered the car, but it is not possible to have a true visual memory of this exact action. Interestingly, it seems that people often unconsciously connect those sequences to one consistent event. The gap in memory is filled via imagination, which is assisted by the knowledge how a certain action proceeds. The existing knowledge is often based on scripts or schemas, which were introduced in the 'schema theory' (see section **2.2.2**; Bartlett, 1932).

These two kinds of false recognitions should be caused by the recognition stimuli of the film paradigm.

Hypothesis III

Longer response times indicate false recognitions, while shorter response times indicate correct recognitions.

The response time is a valuable indicator of the response behaviour of subjects. Differences between response times for varying stimulus sets point out to a different handling of them. Most of the studies investigating false memories also measured the response time, which the subjects needed for correct and false responses. A common result was that subjects responded faster when they made a correct response to a previously experienced stimulus, than when they reject an unstudied, related stimulus (cf. von Zerssen et al., 2001; Conway, Pleydell-Pearce, Whitecross, & Sharpe, 2003; Garoff-Eaton, Slotnick, & Schacter, 2005). Interestingly, it was also found that when an imagined stimulus was falsely accepted, the response time was even longer than for an imagined stimulus that were correctly rejected (Okado & Stark, 2003). The response times illustrate that different processes underlie the decision processes for studied and unstudied stimuli.

For the present film paradigm it is assumed that comparable response times will be revealed. The fastest responses are expected for correct accepted studied stimuli, and the longest response times for false accepted unstudied ones. Possible differences in the response times of the two above described unstudied stimulus sets should show if one of them is more difficultly to process for the subjects.

Hypothesis IV

There are distinguishable neural patterns for correct and false recognitions.

By using functional neuroimaging technique a more sophisticated view of the neural processes of correct and false recognitions induced by the film paradigm are expected. Several studies showed that true recognitions elicited a larger neural network than false ones (e.g. Okado & Stark, 2003). In a recent review, Schacter and Slotnick (2004) concluded that regions within the medial temporal lobe are associated with the generation of false recognitions. Furthermore, monitoring processes, which are necessary during recognition tasks, are related to regions within the prefrontal cortex. The film paradigm tests explicitly visual memory. Thus, further activations in regions that are engaged in the processing of visual material, namely the occipital lobe, should be found. Similar to the previous hypotheses, the processing of studied and unstudied stimuli is expected to differ not only at the behavioural level but also at the neural one. Previous studies showed that, for example, *hits* (correct recognition of studied stimuli) are associated with increased neural activity within early visual processing areas (Brodmann area (BA) 17, BA 18) for abstract shapes (Slotnick & Schacter, 2004). While, true and false recognitions of these stimuli activated the early and the late visual processing areas (BA 19, BA

37). These results showed that false recognitions activated a subset of the brain regions involved with correct recognitions.

Thus, distinguishable neural patterns are expected between correct and false recognitions in general. Stronger and larger neural networks are anticipated for correct recognitions of studied stimuli. Further differences are expected between the two unstudied sets regarding correct and false recognitions because of the hypothesised different underlying causes of them. The neuroimaging technique is assumed to provide the results that will possibly show if the different sets truly induce false recognitions because of different reasons.

4 Method

For this study 'normal', healthy subjects were tested with a newly developed film paradigm to investigate failures in eyewitness reports in the context of false memories. The recognition stimuli consisted of pictures, which were taken out of the film. The film paradigm was first tested with a group of 25 subjects (pilot study). Then, twelve subjects were examined during the recognition task with event-related functional magnetic resonance imaging (fMRI).

In the following section the development of the film paradigm is presented, the demographical data of the subjects are introduced, and a description of the conducted procedure of the pilot study and the fMRI study, respectively, is given. Furthermore, a short overview of the used fMRI-technique and the statistical method 'signal detection theory' is included.

4.1 Film paradigm

4.1.1 Development of the film material

The film material was produced by using a 'Digital Video Camera DCR-PC9E, Sony' and was edited with Adobe Premiere 6.5' (Rockford, Adobe System, Inc.). The film was developed with a close touch to everyday experiences. Half of the scenes were produced with a man as main character and the other half with a woman. This was done to prevent a possible gender specific memorisation effect of the material. The outcome was a film containing scenes of common everyday activities without emotive actions. The second scene of the film, for example, shows the woman walking into a perfumery, looking around, walking to a shelf, and picking up a bottle. She opens the bottle and sprays some perfume on her right wrist, sniffs the scent, puts the bottle back, and leaves the store. The next scene shows the man, getting up in the morning, pulling up the roller blind, and stretching his arms while standing. The final film lasts 19:44 minutes and consists of 42 scenes, whereby each scene represents a self-contained activity. The scenes were presented alternately, meaning that a scene with the man was followed by one with the woman, followed by the next with the man, and so on. These alternations were made to obtain an equal probability of memorisation for both films. The perpetuation of the two stories was still preserved. The two characters did not meet in any of the scenes and also no locations were used for both. The film was presented without sound to ensure that only the visual memory ability was tested and thus no auditory information interfered with the memorisation process.

4.1.2 Development of the recognition material

The recognition material consists of three picture sets. Each set includes 42 pictures, where each picture contains to one of the 42 scenes. Figure 10 exemplifies for each set two pictures.

Figure 10: Examples for the three sets of recognition stimuli: left *originals*, middle *similars* and right *outtakes* (see **Appendix A** for all used stimuli)

The pictures of one set show a part of each scene that was originally presented in the film. For the scene, which was described above (cf. **4.1.1**), the original picture shows the woman sniffing on her right wrist, that is the action presented in the film. In the following sections pictures of this set are referred to as *originals*. The second set comprises pictures that show similar activities to the ones of the first set; however, one significant part is changed. Again, for the sequence in the perfumery, the similar picture shows the woman sniffing on her left wrist instead of her right one. In the following sections pictures of this set are referred to as *similars*. It is important to state that only details that were supposed to be in the focus of the observer whilst watching the film were changed. For example, in the perfumery scene, the woman handles the bottle and shakes her hand before sniffing the scent on the wrist. Therefore, it can be assumed that subjects had a good chance to memorise which hand she uses and recognise it later. The third set includes pictures that show a fragment of each scene that was not presented in the film. These fragments belong to significant parts of each scene that were removed from the film. Therefore, the pictures show an activity, which could not be observed during the film, but must have taken place for the completeness of the action of the scene. In the case of the perfumery scene, the woman can be observed while she takes the bottle from the shelf, opening it, sniffing at the bottle and then at her wrist. The part where she sprayed the perfume on her wrist was removed, but for the consistency of the content of the scene she must have done this. In the following sections pictures of this set are referred to as *outtakes*.

Altogether the recognition material includes 126 pictures from three different sets. The pictures of the first and the last scene were presented as test stimuli at the beginning of the recognition task. Thus, at the end 120 pictures, forty of each set, entered the statistical analysis. The procedure of the recognition task will be explained later in this section (**4.3**).

4.2 Subjects

4.2.1 Pilot study

A group of 25 students (15 male, 10 female) was tested for a first investigation of the developed film paradigm. The subjects ranged in age from 24 to 36 years (M = 28.96, SD = 2.793). All had completed 13 years of education. Two of the subjects were left-handed, the rest were right-handed. The subjects were informed that they could terminate the experiment any time. No psychiatric or neurological history was known for any of the subjects. After the experiment, each subject was given information with regards to why the study was conducted as well as information about the theoretical background of the recognition task. If requested, they also got an informal verbal feedback concerning their own performance in the recognition task. As far as possible, it was avoided that after their participation the subjects communicated with each other about the experiment.

4.2.2 fMRI study

Twelve male, right-handed, native German speakers participated in this part of the study. The subjects varied in age from 34 to 54 years (M = 42.75 years, SD = 6.21). Duration of education varied from 9 to 13 years (M = 11.67 years, SD = 1.7). Subjects had no known psychiatric or neurological history. At the beginning of the test procedure the subjects were informed about participating in a memory study. The true nature of the study was not mentioned at this time. Furthermore, they were informed about their right to terminate the study at any time. All twelve subjects signed a letter of agreement for their participation and gave consent that their data could be used later for publication. After the fMRI study, subjects were rewarded for their participation with 40 Euro for the inconvenience caused. The subjects were not given the possibility to talk with each other about the test.

4.3 Procedure of the film paradigm

First, the procedure for the film paradigm of the pilot study is introduced, followed by the one of the fMRI study. Many parts of the procedure were identically preformed in both studies. Thus, only the differences in the procedure during the fMRI study are described in the second section. Afterwards, the details of the fMRI study are given with regard to the hardware equipment and the image analysis.

4.3.1 Pilot study

The test procedure of the film paradigm consisted of two phases. First, the film was presented during the learning phase. Then followed the recognition task, in which the subjects had to categorise the stimuli pictures as ‘known’ or ‘unknown’. Before the test started, the subjects were informed that they were going to watch a mute film of an approximately duration of twenty minutes. Additionally, they were told that afterwards they had to undertake a recognition task that is closely related to the film. Therefore, the subjects were asked to pay close attention to the film. The film was presented on a computer screen. The subjects saw the film on the same computer, on which the recognition task was afterwards presented. When the film was finished the subjects were given instructions for the recognition task. They were informed that they would see several different pictures. They had to decide whether they had seen the pictures in the film or not. A two-button mouse was used for responding in the pilot study. Subjects were told to press the left button with the left thumb for a ‘known’ picture and the right button with the right thumb for an ‘unknown’ picture. For this task, the subjects hold the mouse in both hands and placed their thumbs on the respective buttons.

Furthermore, the subjects were informed that a picture was shown to them for a maximum of 3 seconds before it vanished. If they made their decision during the presentation time by pressing a button the picture vanishes instantaneously (response connected). Between each picture the screen went black for 6 seconds. Without this delay their was a risk that the response for one picture would be unwillingly shifted to the next presented one when a response was not fast enough.

The pictures consisted of the recognition material described above (i.e. *originals*, *similars*, and *outtakes*) as well as 42 reference pictures. The reference pictures showed a train or a plane. The head of the train/plane points either to the left or the right. For these pictures, the subjects were given the instruction to indicate the direction of the head of the vehicle by pressing the respective button (e.g. front of the train points to the left, press the left button). The subjects were informed that at the beginning of the recognition task they would see three slides with instructions reminding them of which button to press for which decision. Then, they would see six recognition pictures and two reference pictures to familiarise them with the task procedure. The six recognition pictures were taken from the first and the last scene of the film. The instructions were repeated before the beginning of the main recognition task. For every subject the order of the pictures was randomized to avoid possible recency or position effects. The program 'Presentation Version 081 Build 04.28.04' (Neurobehavioral Systems) was used to present the film and the recognition material as well.

4.3.2 fMRI study

The subjects of the fMRI study watched the film on a computer screen like the ones of the pilot study. The difference was that the film was presented in a separate, shaded room. This was necessary because the study took place in a hospital and it was important that the subjects watched the film in a quiet atmosphere. Thus the results are better comparable to the ones of the pilot study. Afterwards, the subjects attended the fMRI study, which comprised of two parts. The first part was an anatomical scan of each subject, which is explained later in section **4.4**. For the second part, subjects were given two response boxes, one for each hand. During the recognition task, they were instructed to place their left thumb on the previously determined button on the left response box, and their right thumb on the respective button on the right response box. Subjects were additionally informed that the scanner was very loud during the scanning, and that they should try to move their head as less as possible. Similar to the pilot study, further instructions were given regarding the duration of the pictures. Subjects were told that the intermediate pauses between each picture and the next are fixed. The main reason for this was that during the fMRI study this duration was needed to keep two events apart, here two pictures, regarding the subsequent analysis of the fMRI-data. The reference pictures (train and plane) served an additional purpose in the fMRI study. They were used as a control for the proper functioning of the response boxes during the scanning.

4.4 fMRI procedure

4.4.1 Hardware equipment

Whole brain, event-related fMRI was conducted on a 1.5 T scanner (Siemens Magnetom Symphony, Erlangen, Germany), which was equipped with a standard head coil and was capable of echoplanar imaging. First, to position the axial T2*-weighted images along the anterior-posterior commissure (AC-PC), line scout and sagittal T1-weighted images were acquired from each subject. To ensure anatomical reference data and to exclude brain anomalies, structural brain images were obtained from each subject using a T1-weighted 3DMP-RAGE pulse sequence (TR = 11.1 ms, TE = 4.3 ms, slice thickness = 1.5 mm, field of view (FOV) 201x230 mm, matrix 224x256). A mirror was installed at the head coil, over which the subjects could see a screen. On this screen the stimuli were presented. Every third second a volume scan was done using a standard EPI sequence (TR = 3000 ms, TE = 50 ms, flip angle 90°, FOV 192 mm, matrix 64x64). Each volume scan covered the whole brain and consisted of 16 axial T2*-weighted MR-slices with a slice thickness of 7 mm. The stimuli were presented using the program 'Presentation Version 081 Build 04.28.04' ('Neurobehavioral Systems') over a beamer on the screen.

4.4.2 Image analysis

All data analysis was done using MATLAB (The Mathworks Inc., Natick, MA, USA) and SPM 99 (Statistical Parametric Mapping software, SPM99; Wellcome Department of Cognitive Neurology, London, UK; http://www.fil.ion.ucl.ac.uk). For each session, the first two images were discarded to facilitate the T1 saturation during the first scans. To compensate for head movements, images were realigned using the SPM99 default algorithm. In order to achieve spatial smoothing and group comparisons of the images, anatomical differences were compensated by spatial normalisation and resclicing using the SPM99 default settings and the standard stereotactic space, which is known as the Montreal Neurological Institute (MNI) brain.

With a Gaussian kernel of 10 mm full-width at half-maximum (FWHM) the spatial smoothing was performed, which allows for signal increase and anatomical conformity across the subjects. A fixed-effects statistical analysis was done on a voxel-by-voxel basis using the General Linear Model (GLM). For the final analysis of the data, maps of t-statistics were corrected for multiple comparisons at $p < .05$. Furthermore, a restriction was made with a minimum size of the displayed cluster beginning with 10 voxels. As a last step of the image analysis, the MNI-coordinates were transformed into the Talairach and Tournoux (1988) space using a correction procedure developed by Brett (1999) and finally fed into the Talairach Daemon (Lancaster et al., 2000) to obtain anatomical projections of maximum activation cluster.

4.5 Signal detection theory

The interpretation of data gathered during a paradigm that allows only two possible responses (e.g. yes - no) forces subjects to make a decision. Responses given under pressure involve some uncertainty of the subjects during the process of their decision making. The signal detection theory was developed by Green and Swets (1966) to calculate this uncertainty during the decision process. In each experiment, where two possible stimuli have to be discriminated, subjects have also to discriminate between a 'signal' and a 'noise'. The signal stands for a previously studied and therefore known word or picture, whereas the noise represents a new and therefore unknown word or picture. Noise and signal distribution can be estimated as a Gaussian distribution (Fig. 11), and depending on the subject's responses, the graphs are separated or overlap.

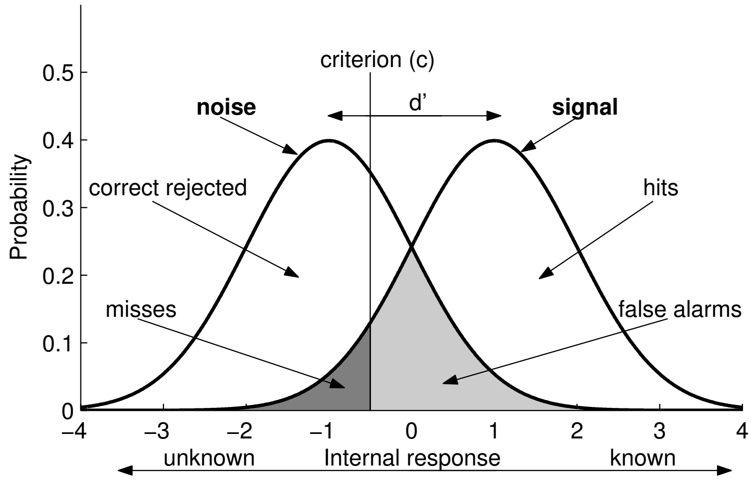


Figure 11: Signal and noise distributions generating variables d' and c, and the constituted intersections for hits, false alarms, misses, and correct rejected

Two variables are shown in Figure 11. One is the discriminability index, d', and the other is the response bias, c. The response bias describes the criterion, on which a response decision is made by a subject. The criterion is located on the internal response axis of a subject. The response bias indicates that when the internal response is above the criterion the subject responds with a verifying response that is a 'known' one. When it is lower than the criterion, the subject reacts with a refusing response that is an 'unknown' one. The discriminability index is defined by the separation and spread between signal and noise curves.

The discriminability index and the response bias have to be interpreted in conjunction with each other and not separately. Both variables are highly dependent on each other during the calculation. If the discriminability index of signal and noise produces a positive value, it represents that the maxima of the two graphs are separated. This further indicates that the subjects can discriminate between signal and noise (q.v. the two graphs in Fig. 11). However, when the value of the discriminability index is negative, the two graphs strongly overlap, which indicates that signal and noise are handled identically. Considering the response bias, a negative value indicates that the material induced a high false alarms rate, whereas a positive value demonstrates a high misses with a small false alarms rate.

In the case of the film paradigm, the *originals* constitute the signal, as these pictures belonged to the scenes presented in the film. The *outtakes* and *similars* represent the noise, as they were related to the studied material but differed from them. That means that positive (‘known’) responses to *originals* lead to *hits*. However, for unstudied stimuli of the sets *similars* and *outtakes* ‘known’ responses result in *false alarms*. Negative (‘unknown’) responses to *originals*, however, constitute *misses*, whereas for *similars* and *outtakes* these responses result in *correct rejections*. In Figure 12 these relations between the stimuli and the response modi are presented with the resulting sets.

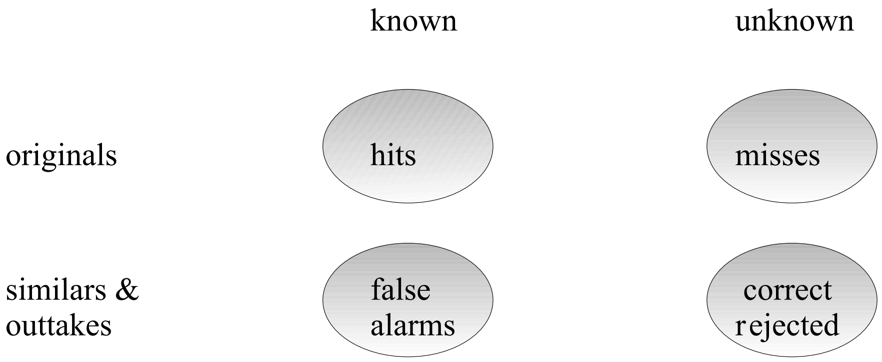


Figure 12: Classification of possible responses to the different stimuli categories following signal detection theory

For this study the group of *originals*, presenting the signal, consisted of 40 pictures. The group of the *similars* and *outtakes* (noise) comprised 80 pictures. Taken together, 120 pictures were analysed for this study. If the film paradigm provoked the expected false recognitions, most of the responses for the unstudied stimuli are expected to be ‘known’ ones. Because the unstudied stimuli represent the noise and they comprise twice as many stimuli as the signal, the estimated result should lie within the left Gaussian distribution.

5 Results

In the following chapter, first the behavioural data are reported separately for the pilot and for the fMRI study. Afterwards the results of the neuroimaging are presented. All statistical analyses were performed with the program SPSS ('Statistical Package for the Social Sciences', Version 12.0 for Windows).

Before the results of the recognition task are presented, it is necessary to clarify the used terms below. During the recognition task subjects responded either with a 'known' or an 'unknown' response. It depended on the set affiliation of the picture, which response was correct or false. Known response for *originals* were correct and produced *originals-correct*, equal to *hits*. Unknown responses resulted in *originals-false*, equal to *misses*. A contrary correlation resulted of these response possibilities for the unstudied stimulus sets *similars* and *outtakes*. Here, an unknown response was the correct rejection of these unstudied stimuli and resulted in *similars-correct* and *outtakes-correct*, respectively. A known response was a false recognition. Hence, *similars-false* and *outtakes-false* are the corresponding terms. Combining these two groups, the group *false alarms* is generated.

5.1 Behavioural data

5.1.1 Pilot study

The data of 25 subjects were analysed within the pilot study. The demographical data are described in section **4.2.1**. The recognition data and the response times are normally distributed across the group.

5.1.1.1 Recognition rate

Descriptive analysis revealed that, independent of their affiliation to one of the three sets, subjects falsely responded, on average, to 49.9 pictures (SD = 8.2, minimum = 32, maximum = 64) or 41.6% of the 120 presented pictures. An integration of *similars-false* and *outtakes-false* to *false alarms* showed that, on average, 42 out of 80 unstudied pictures (SD = 7.8, minimum = 23, maximum = 57) or 52.5% were falsely recognised. The results of the descriptive analysis for each set regarding the recognition mode are listed in Table 3.

Table 3: Descriptive statistic of correct and false recognition rates of the three stimulus sets (40 pictures per set) across the 25 subjects

	mean	SD	range
originals-correct	32.1	4.43	17 – 39
originals-false	7.9	4.42	1 – 23
similars-correct	21.5	4.88	11 – 34
similars-false	18.5	4.88	6 – 29
outtakes-correct	16.4	4.44	8 – 26
outtakes-false	23.5	4.46	14 – 32

Especially the pictures of the set *outtakes* were falsely recognised with a percentage of 19.6%, followed by the set *similars* with 15.4%. The least failures were found for the set *originals* with 6.6%.

The results were further investigated regarding the signal detection theory. Thus, the response bias, c, and the discriminability index, d', were evaluated. The response bias revealed for *hits* and *false alarms* a negative mean value of -0.42 (SD = 0.22). The discriminability index resulted in a positive value (mean = 0.98, SD = 0.51) for *hits* and *false alarms*.

5.1.1.2 Two unstudied stimulus sets

A multivariate analysis of variance (MANOVA) with repeated measures with sets-false (i.e. *originals-false*, *similars-false*, and *outtakes-false*) as within-subjects factor was used to explore if subjects handled the three sets equally. Figure 13 shows the mean false recognition rates of the three sets.

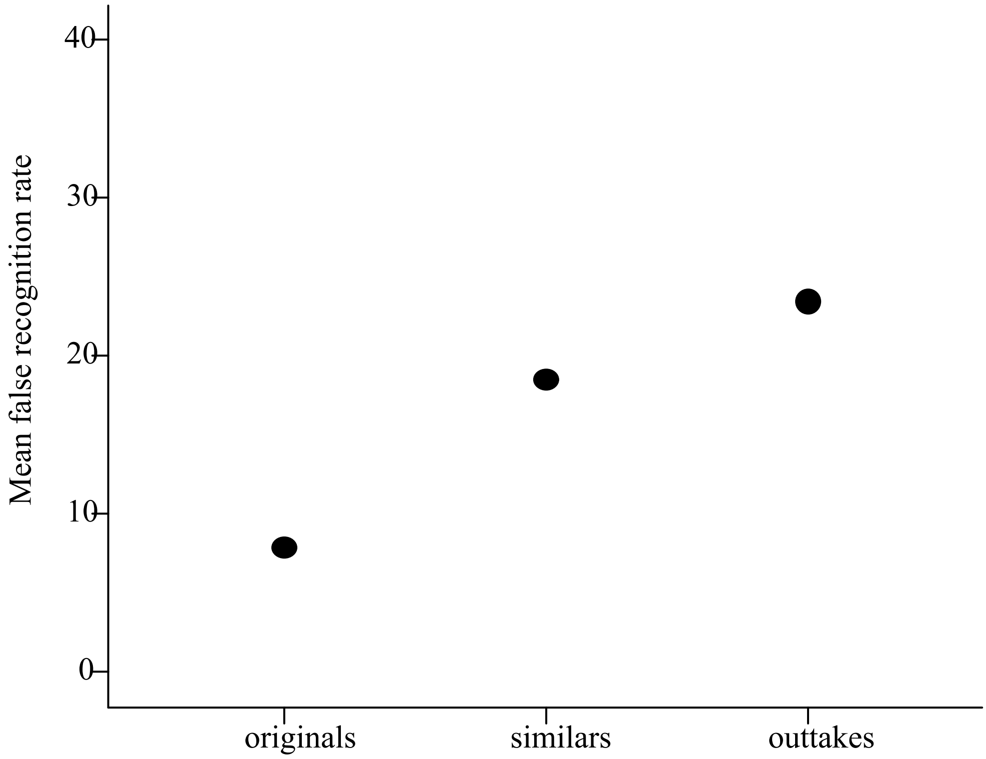


Figure 13: Mean false recognition rates for the three stimuli sets. Maximum recognition rate for each set was 40

The main effect of sets-false was highly significant (F = 77.66, df = 2, p < .001). Single comparisons between the sets were corrected after Bonferroni and revealed further significant differences between the three pairs:

originals-false – similars-false: mean difference = 10.6, standard failure = 1.36, p < .001,
originals-false – outtakes-false: mean difference = 15.7, standard failure = 1.40, p < .001,
similars-false – outtakes-false: mean difference = 5.12, standard failure = 1.02, p < .001.

The results of sets-false showed that the three sets were differentiated on a behavioural level by the subjects.

Since it was possible, that either the set of the *similars* or of the *outtakes* had a bigger impact within the *false alarms*, the discriminability index and the response bias were evaluated separately for *hits* and *similars-false*, and *hits* and *outtakes-false.* These calculations resulted for both pairs in a positive value for the discriminability index. The response bias, on the other hand, revealed for both pairs negative values. Table 4 presents these results together with the previous results of the discriminability index and the response bias of the pair *hits* and *false alarms*.

Table 4: Descriptive statistic of the discriminability indices, d', and the response biases, c, of the pairs *hits* – *false alarms*, *hits* – *similars-false*, and *hits* – *outtakes-false*

	mean	SD	range
d' (*hits* & *false alarms*)	0.98	0.51	-0.12 – 2.02
d' (*hits* & *similars-false*)	0.81	0.53	-0.28 – 1.77
d' (*hits* & *outtakes-false*)	1.15	0.56	0.01 – 2.28
c (*hits* & *false alarms*)	-0.42	0.22	-0.95 – 0.13
c (*hits* & *similars-false*)	-0.51	0.25	-1.07 – 0.06
c (*hits* & *outtakes-false*)	-0.34	0.21	-0.82 – 0.19

A paired t-test revealed highly significant differences between the discriminability indices of *hits* and *false alarms* with *hits* and *similars-false* (t(24) = 4.852, p < .001) as well as *hits* and *outtakes-false* (t(24) = -4.780, p < .001). This demonstrated that the subjects were able to discriminate not only between studied and unstudied stimuli but also between the two unstudied sets. The negative response bias showed that the unstudied stimulus sets provoked false recognitions.

5.1.1.3 Response time

The response time (RT) was investigated for each set regarding correct and false recognitions. The descriptive statistic for each set is given in Table 5.

Table 5: Descriptive statistic of the response times (RT) of correct and false recognitions of the three sets

	mean	SD	range
RT *originals-correct*	2.200 s	0.632 s	1.32 s – 4.38 s
RT *originals-false*	2.882 s	0.602 s	1.91 s – 4.28 s
RT *similars-correct*	2.443 s	0.551 s	1.68 s – 4.13 s
RT *similars-false*	2.408 s	0.676 s	1.40 s – 4.36 s
RT *outtakes-correct*	2.821 s	0.598 s	1.94 s – 4.04 s
RT *outtakes-false*	2.501 s	0.672 s	1.59 s – 4.38 s

The results of the descriptive analysis in Table 5 indicated that the subjects reacted faster when they made a correct response than when they made a false one. A paired t-test showed that RT for correct and false recognitions of the set *originals* differed to a highly significant degree (t(24) = -6.12, p < .001), opposite to the set *similars* (t(24) = 0.5, p = .62). For the set *outtakes*, a paired t-test again showed significant difference between correct and false recognitions (t(24) = 3.32, p < .05).

A MANOVA with repeated measures was calculated with RT of sets-correct and sets-false, respectively, as within-subjects factor. It revealed highly significant main effects of response times of sets-correct (F = 35.01, df = 2, p < .001) as well as of sets-false (F = 17.9, df = 2, p < .001).

Single comparisons between response times of each set were corrected after Bonferroni:

RT *originals-correct* – RT *similars-correct*: mean difference = .243, standard failure = 0.05, p < .001,
RT *originals-correct* – RT *outtakes-correct*: mean difference = .62, standard failure = 0.09, p < .001,
RT *similars-correct* – RT *outtakes-correct*: mean difference = .38, standard failure = 0.08, p < .001,
RT *originals-false* – RT *similars-false*: mean difference = .47, standard failure = 0.09, p < .001,

RT *originals-false* – RT *outtakes-false*: mean difference = .38, standard failure = 0.1, $p < .002$,
RT *similars-false* – RT *outtakes-false*: mean difference = .09, standard failure = 0.05, $p < .22$.

Only the comparison of the RTs of the sets *similars-correct* with *outtakes-correct* differed not significantly. All other pairs revealed highly significant differences. Figure 14 summarises these results. It presents not only the RTs together for correct and false recognitions (a), only for false recognitions (b), and only for correct recognitions (c), but also the calculated significant differences.

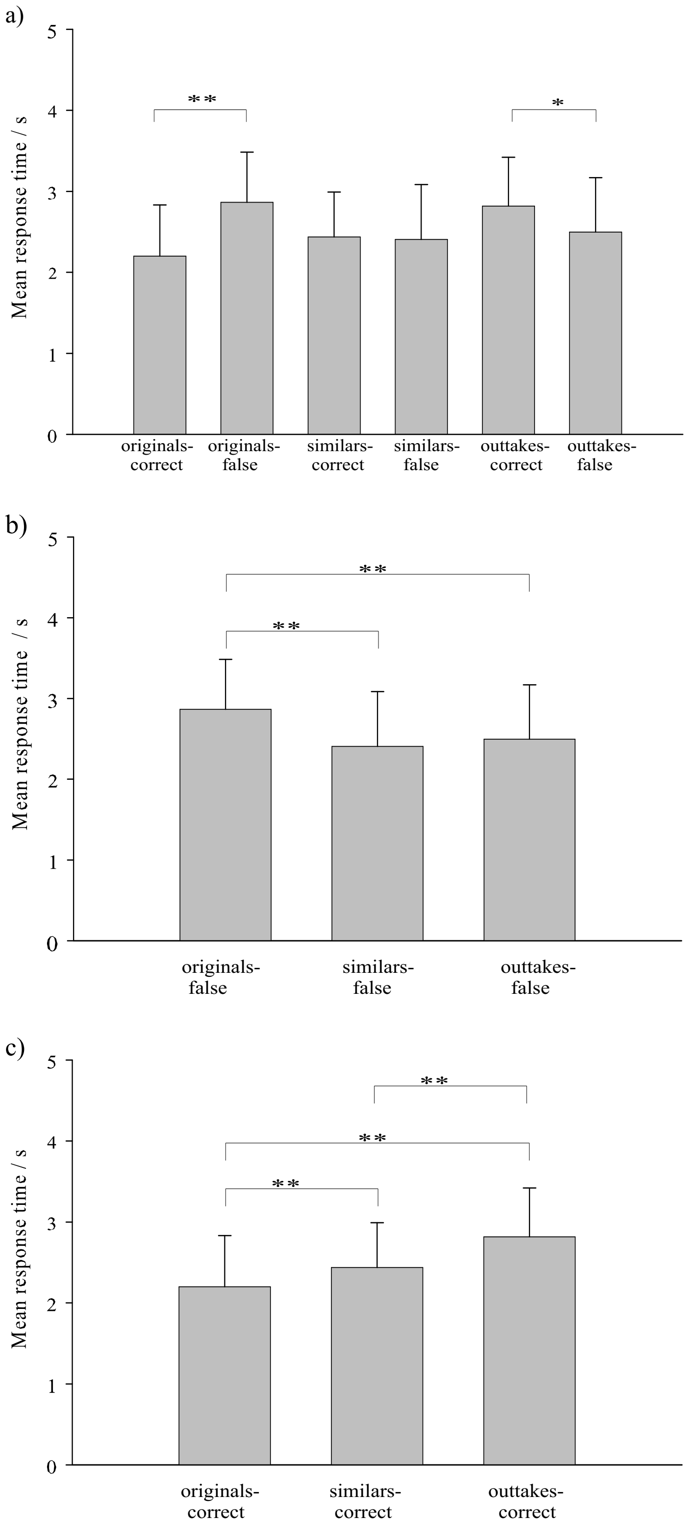


Figure 14: Mean response times with the standard deviations for the three sets across all 25 subjects. a) correct and false recognitions for all sets, b) only the false recognitions, and c) only the correct recognitions for the three sets. Located significant differences highlighted with asterisks (** = p < .001, * = p < .05)

In the next step, the response times were examined regarding the duration of the recognition task. This was done in order to see if subjects increased or decreased their decision process along the task. Thus, three parts of the presented 120 stimuli were generated. The response times of the first forty, the second forty, and the last forty pictures were calculated together, respectively. Table 6 presents the descriptive statistic for each part of the recognition task, regarding correct and false recognitions.

Table 6: Descriptive statistic of the response times of the three parts – each containing 40 pictures – of the recognition task

	mean	SD	range
1. third-correct	2.398 s	0.577 s	1.71 s – 4.28 s
1. third-false	2.515 s	0.598 s	1.57 s – 3.94 s
2. third-correct	2.378 s	0.568 s	1.61 s – 4.19 s
2. third-false	2.463 s	0.697 s	1.38 s – 4.16 s
3. third-correct	2.433 s	0.626 s	1.59 s – 4.09 s
3. third-false	2.583 s	0.766 s	1.53 s – 4.58 s

A MANOVA with repeated measures was calculated with response times of the thirds-correct and thirds-false, respectively, as within-subjects factor. The analysis revealed neither for correct recognitions (F = .229, df = 1, p = .637) nor for false recognitions (F = .490, df = 1, p = .491) any influence of the duration of the task on the decision behaviour of the subjects.

5.1.2 fMRI study

The behavioural data of the fMRI study were analysed in the same way as the results of the pilot study regarding the formulated hypotheses. The demographical data of the twelve subjects, who participated in this study, were described in section **4.2.2**.

5.1.2.1 Recognition rate

The false recognition rate revealed, on average, a mean of 53 pictures (44.2%, SD = 7.7, range = 47 – 73) of the presented 120 stimuli across all 12 subjects. This rate is independent of the affiliations of the stimuli to one of the three sets. Combining the false recognitions of *outtakes* and *similars* to *false alarms*, a mean of 47 pictures (58.8%, SD = 9.7, range: 38 – 73) was calculated. These two sets together consisted of 80 presented unstudied stimuli. In Table 7 an overview of the descriptive analysis is given for each set.

Table 7: Descriptive statistic of correct and false recognition rates of the three stimulus sets (40 pictures per set) across the 12 subjects

	mean	SD	range
originals-correct	33.8	3.79	26 – 40
originals-false	6.1	3.78	0 – 14
similars-correct	18.2	6.29	2 – 24
similars-false	21.8	6.25	16 – 38
outtakes-correct	14.5	5.13	5 – 22
outtakes-false	25.3	5.42	16 – 35

Table 7 shows that one subject has made a ‘known’ response to most of the presented pictures. Thus, he has correctly accepted all pictures of the set *originals*, but has only rejected a few of the unstudied stimuli correctly. Taken together, the subject responded to 113 pictures with a ‘known’ response. After the recognition task he was questioned, how he estimated his own performance. He answered that he memorised the stories of the film and that nearly all pictures were part of them. His data remained, nevertheless, in the analysis because the underlying processes of his decisions did not differ from the other subjects. For each picture he decided if he had seen it during the learning phase or not. The same decision process was made by all the other subjects, and therefore his data were considered comparable.

Most of the false responses were made for the pictures of the set *outtakes* with a percentage of 21.1%, followed by the set *similars* with 18.2%, and *originals* with 5.1%. The *false alarms* rate showed a mean value of 47.1 (SD = 9.70, minimum = 38, maximum = 73) or 58.9% of overall 80 unstudied pictures.

Likewise to the results of the pilot study, the discriminability index, d', revealed for *hits* and *false alarms* a positive value (mean = 1.41, SD = 0.87). The response bias, c, showed a negative value across the group of -0.45 (SD = 0.19). That is also comparable to the negative value calculated with the data of the pilot study.

5.1.2.2 Two unstudied stimulus sets

A MANOVA with repeated measures with sets-false (i.e. *originals-false*, *similars-false*, and *outtakes-false*) as within-subjects factor was used to evaluate if the three sets were handled equally by the subjects or not. Figure 15 presents the mean false recognition rates of the three sets. The recognition rates of this group did not significantly differ to the ones of the pilot study (see **Appendix B**).

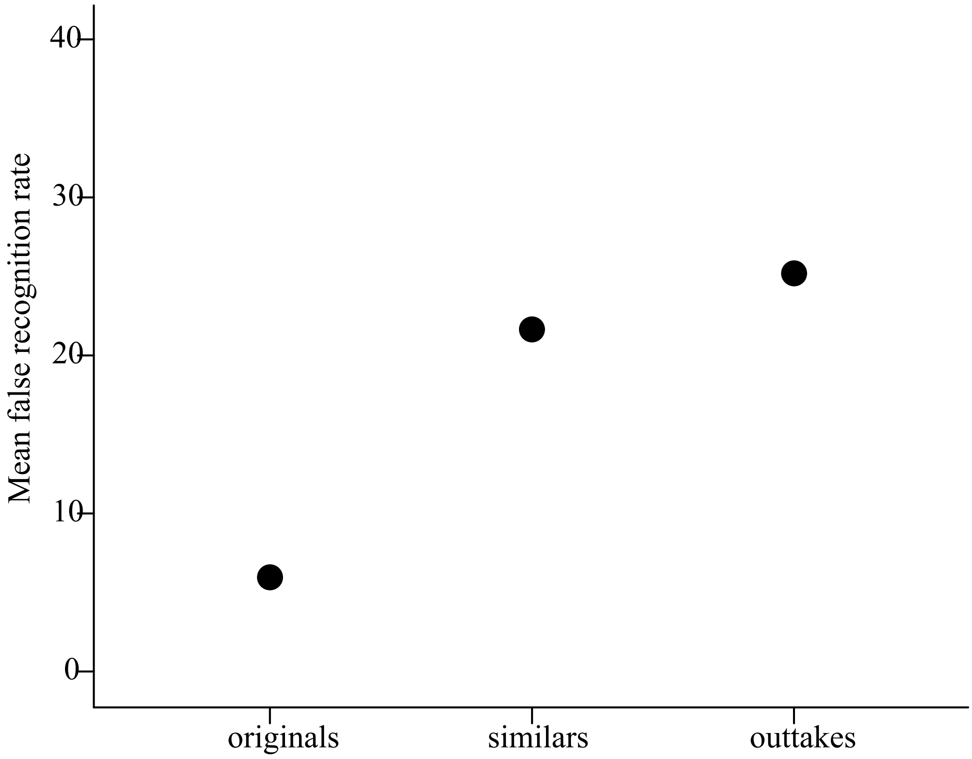


Figure 15: Mean false recognition rates the three stimuli sets. Maximum recognition rate for each set was 40

The main effect of sets-false was highly significant (F = 39.83, df = 2, $p < .001$). Single comparisons between the sets were corrected after Bonferroni and revealed significant differences between two pairs:

originals-false – similars-false: mean difference = -15.7, standard failure = 2.51, $p < .001$,

originals-false – outtakes-false: mean difference = -19.3, standard failure = 2.42, $p < .001$.

The comparison between *similars-false* and *outtakes-false* resulted in no significant difference (mean difference = -3.6, standard failure = 1.9, $p < .258$).

These results showed that the subjects handled the items of the set *originals* differently from the ones of the unstudied sets, *similars* and *outtakes*. However, the stimuli of the two unstudied sets were handled alike.

Nevertheless, the discriminability index, d', and the response bias, c, were evaluated across the 12 subjects. Similar to the pilot study, the pairs *hits – similars-false*, and *hits – outtakes-false*, respectively, were calculated. Table 8 presents the results including the ones of the pair *hits* and *false alarms*, calculated regarding the first hypothesis.

Table 8: Descriptive statistic for the discriminability indices, d', and the response biases, c, of the pairs *hits – false alarms*, *hits – similars-false*, and *hits – outtakes-false*.

	mean	SD	range
d' (*hits* & *false alarms*)	1.41	0.87	0.32 – 3.68
d' (*hits* & *similars-false*)	1.31	0.96	0.26 – 3.97
d' (*hits* & *outtakes-false*)	1.52	0.88	0.39 – 3.48
c (*hits* & *false alarms*)	-0.45	0.19	-0.89 – -0.22
c (*hits* & *similars-false*)	-0.50	0.24	-0.95 – -0.21
c (*hits* & *outtakes-false*)	-0.39	0.20	-0.82 – -0.17

The analysis revealed for the three pairs positive values of the discriminability index. The descriptive statistic of the discriminability indices showed higher values than the one calculated for the pilot study. However, besides of the comparison between the indices of *hits* and *similars-false*, no significant differences were found (see **Appendix B**). The response bias showed for all comparisons negative values, which did not significantly differ to the ones of the pilot study (see **Appendix B**). A paired t-test showed no significant differences between the discriminability indices ((*hits* & *false alarms*) – (*hits* & *similars-false*): t(11) = 1.460, p = .172; (*hits* & *false alarms*) – (*hits* & *outtakes-false*): t(11) = -1.690, p = .119). This is contrary to the revealed significant differences of the pilot study.

5.1.2.3 Response time

The final calculation of the behavioural data for the fMRI-group was the investigation of the response time (RT), likewise to the pilot study. The descriptive statistic for each set is given in Table 9. Comparisons between response times of the pilot and the fMRI study revealed no significant differences (see **Appendix B**).

Table 9: Descriptive statistic for the response times (RT) of correct and false recognitions of the three sets

	mean	SD	range
RT *originals-correct*	1.896 s	0.410 s	1.19 s – 3.64 s
RT *originals-false*	2.286 s	0.626 s	1.10 s – 3.22 s
RT *similars-correct*	2.123 s	0.448 s	1.23 s – 2.67 s
RT *similars-false*	2.075 s	0.509 s	1.04 s – 2.77 s
RT *outtakes-correct*	2.493 s	0.483 s	1.56 s – 4.18 s
RT *outtakes-false*	2.102 s	0.469 s	1.18 s – 2.69 s

Paired t-tests revealed only significant difference between correct and false recognitions of the set *outtakes*: t(10) = 3.289, p < .008. For the other two sets, *originals* and *similars*, no significant differences were detected with paired t-tests (*originals*: t(9) = -1.831, p = .100; *similars*: t(10) = 847, p = .417.

A MANOVA with repeated measures was calculated with RTs of sets-correct and sets-false, respectively, as within-subjects factor. It revealed a highly significant main effect of the response times of sets-correct (F = 15.570, df = 2, p < .001) but not of sets-false (F = .375, df = 2, p = .692).

Single comparisons between RTs of each set were corrected after Bonferroni and revealed significant differences between the six pairs:

RT *originals-correct* – RT *similars-correct*: mean difference = .239, standard failure = 0.077, p = .033,
RT *originals-correct* – RT *outtakes-correct*: mean difference = .624, standard failure = 0.117, p = .001,
RT *similars-correct* – RT *outtakes-correct*: mean difference = .385, standard failure = 0.136, p = .054,

The comparisons showed that only the one between *similars-correct* and *outtakes-correct* revealed no significant difference. Figure 16 summarises the mean response times of each set regarding correct and false recognitions. Additionally, the significant differences are plotted.

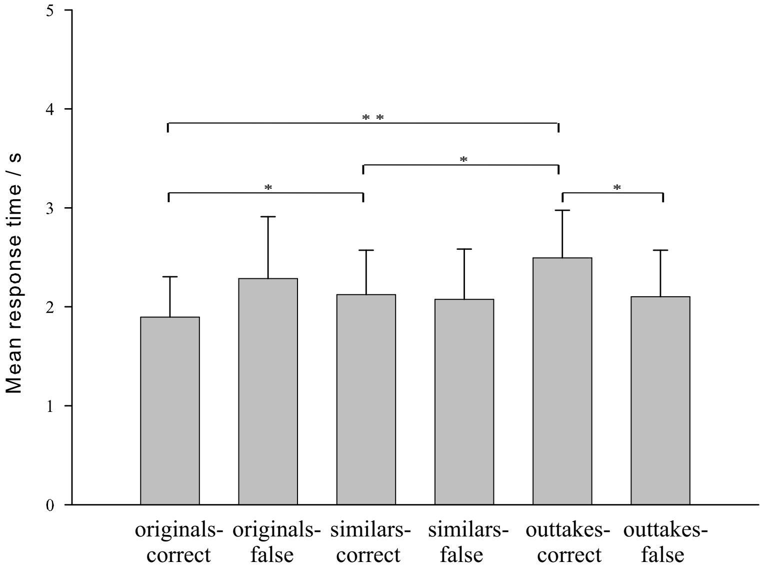


Figure 16: Mean response time for the 12 subjects of the fMRI study in seconds for correct and false recognitions across the three sets. Located significant differences highlighted with asterisks (** = p < .001, * = p < .05)

Similar to the calculation of the results of the pilot study, an investigation was conducted considering the recognition data along the time of the recognition task. Therefore, three parts were generated of the 120 presented pictures, each including 40 pictures. Thus, it was possible to investigate if the response behaviour of the subjects changed over the time of the recognition task. Table 10 presents the descriptive statistic for each of the generated three parts of the recognition task, regarding correct and false recognitions.

Table 10: Descriptive statistic of the response times of the three parts – each containing 40 pictures – of the recognition task

	mean	SD	range
1. third-correct	2.078 s	0.389 s	1.46 s – 2.57 s
1. third-false	2.135 s	0.595 s	1.12 s – 3.22 s
2. third-correct	2.089 s	0.456 s	1.24 s – 2.72 s
2. third-false	2.236 s	0.593 s	1.13 s – 3.06 s
3. third-correct	2.171 s	0.487 s	1.35 s – 2.83 s
3. third-false	2.265 s	0.629 s	1.07 s – 3.15 s

A MANOVA with repeated measures analysed with the response times of thirds-correct and thirds-false, respectively, as within-subjects factor. The analysis revealed neither for correct recognitions (F = 1.171, df = 1, p = .302) nor for false recognitions (F = .828, df = 1, p = .382) a significant difference. These results did not differ from the ones of the pilot study (see **Appendix B**). These results demonstrated that the subjects did not change in their response behaviour over the time.

5.2 Neuroimaging data

The functional magnetic resonance imaging data were analysed across all 12 subjects. Only statistically significant increases in neural activity with a cluster-size above 10 voxels entered the analysis.

5.2.1 Neural correlates

The neuroimaging results were analysed in four steps. First, all correct and all false recognitions across the three sets were analysed versus baseline. Then, all correct recognitions were compared with all false recognitions, and vice versa, to detect differences of the involved neural correlates. In the second step, studied and unstudied stimuli were contrasted against each other. In the third analysis step were single sets contrasted against each other, and at last each set was contrasted with baseline with respect to correct and false recognitions.

In the following sections these contrasts are presented successively. Tables show the coordinates, cluster-size, Z-scores, Brodmann areas (BA), and the regions. The x-, y-, and z-coordinates are standardised Talairach coordinates. They refer to the local maxima within an area of activation. In addition, these maxima are indicated by the highest Z-score of each cluster. Some of the revealed areas of activation are very big and cover several regions. Therefore, the voxels of each cluster are included in the tables.

For all contrasts the so-called “glass brains” are presented. These are projections of significant activations onto representations of the standard stereotaxic space, which was defined by Talairach and Tournoux (1988). Additionally, for the first two analysis steps images were included that show 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.

5.2.1.1 Correct/false recognitions across all sets

The contrasts all correct recognitions and all false recognitions, respectively, versus baseline revealed significant increases in neural activity with a p-value corrected for multiple comparisons (p < .001). The activated regions are presented in Table 11.

Table 11: Activated regions and the significant local maxima of all correct recognitions and all false recognitions versus baseline. First sorted by pattern, then by level of significance (Z-score)

Side	Region	BA	Voxels in cluster	Z	x	y	z
	all correct recognitions						
L	middle temporal gyrus	19	4818	Inf.	-36	-81	21
L	middle frontal gyrus	9	375	7.22	-48	8	36
L	anterior cingulate gyrus	32/6	453	7.06	-6	25	35
L	inferior frontal gyrus	47	81	6.53	-33	23	-1
R	inferior frontal gyrus	45/46	288	6.84	56	27	18
R	inferior frontal gyrus	47	91	6.80	36	26	-6
R	brainstem, pons		121	5.20	0	-24	-19
	all false recognitions						
L	middle occipital gyrus	19	773	7.30	-36	-81	18
L	posterior cingulate gyrus	31	86	6.40	-18	-60	22
L	middle frontal gyrus	9	17	5.22	-45	7	33
R	middle temporal gyrus	19	457	7.67	45	-78	12
R	fusiform gyrus	37	100	6.92	42	-50	-15
R	inferior frontal gyrus	45/46	83	6.19	54	27	21
R	posterior cingulate gyrus	23/30	128	6.11	15	-52	14

Threshold: T = 4.53, $p_{corrected} < .001$. 'Side' defines the hemisphere, in which the activation was found, L = left, R = right. BA is the respective Brodmann area of each activated cluster.

The contrast all correct recognitions versus baseline revealed local maxima in the left hemisphere in the middle temporal gyrus, the middle frontal gyrus, the anterior cingulate gyrus, and the inferior frontal gyrus. In the right hemisphere two local maxima are found within the inferior frontal gyrus, and one within the pons (Fig. 17).

An interesting finding is the big cluster in the occipital lobe found for the contrast all correct recognitions versus baseline. Its local maxima lies within the left middle temporal gyrus. However, as it is pictured in Figure 17, the cluster itself also covers big parts of the right hemispheric middle occipital gyrus, and presumably parts of the left and right posterior cingulate gyri.

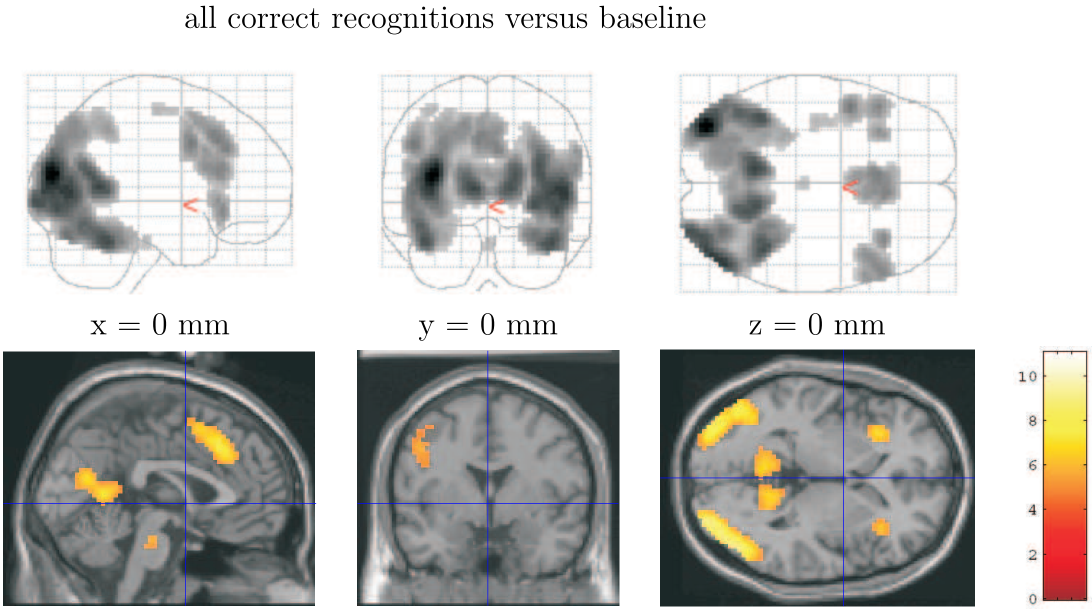


Figure 17: Relative increases in neural activity associated with all correct false recognitions across all sets analysed versus baseline. Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space (“glass brains”) as defined by Talairach and Tournoux (1988). Statistically significant increases ($p < .05$, corrected for multiple comparisons) in neural activity are superimposed in terms of colour on MRI sections. The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 11.

The order of the brain images in Figure 17 is exemplary for all following images. At the left is the sagittal slice (posterior = left, anterior = right), in the middle is the coronal one (left = left hemisphere, right = right hemisphere), and at the right is the horizontal slice (top = left hemisphere, bottom = right hemisphere).

All false recognitions contrasted versus baseline revealed local maxima within the left middle occipital gyrus, the left posterior cingulate gyrus, and the middle frontal gyrus. Within the right hemisphere local maxima of cluster are found in the middle temporal gyrus, the fusiform gyrus, the inferior frontal gyrus, and the posterior cingulate gyrus (Fig. 18).

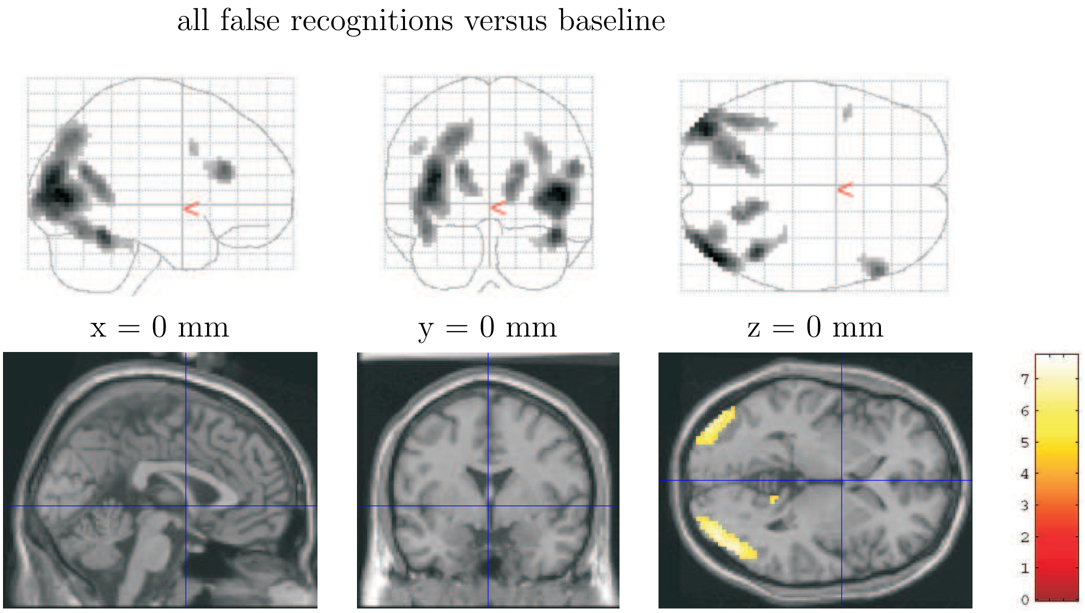

all false recognitions versus baseline

Figure 18: Relative increases in neural activity associated with all false recognitions across all sets analysed versus baseline. Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space ("glass brains") as defined by Talairach and Tournoux (1988). Statistically significant increases ($p < .05$, corrected for multiple comparisons) in neural activity are superimposed in terms of colour on MRI sections. The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 11.

The contrast between all correct recognitions versus all false recognitions showed mainly neural activations in the left hemisphere, while the reverse contrast only revealed one activation in the right hemisphere (Tab. 12).

Table 12: Local maxima of significantly activated regions associated with all correct versus all false recognitions and vice versa across the three sets. First sorted by pattern, then by level of significance (Z-score)

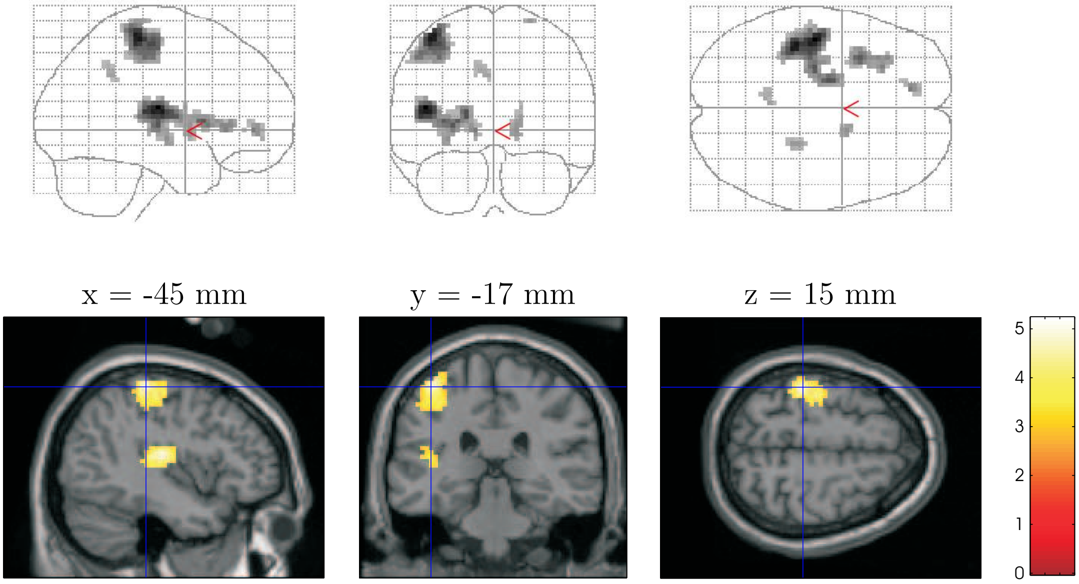
Side	**Region**	**BA**	Voxels in cluster	**Z**	**x**	**y**	**z**
	all correct recognitions > all false recognitions						
L	insula		291	5.19	-45	-17	15
L	postcentral gyrus	3	291	4.86	-42	-26	57
L	insula/claustrum		89	4.13	-33	12	5
L	anterior cingulate gyrus	10/32	22	3.77	-12	44	-2
L	posterior cingulate gyrus	31	20	3.35	-3	-45	35
R	lateral/medial globus pallidus		33	3.55	15	3	0
	all false recognitions > all correct recognitions						
R	precentral gyrus	4	116	3.61	36	-18	48

Threshold: T = 3.09, $p_{uncorrected} < .001$. 'Side' defines the hemisphere, in which the activation was found, L = left, R = right. BA is the respective Brodmann area of each activated cluster.

Comparison between all correct versus all false recognitions showed significant left hemispheric activations in the insula, the postcentral gyrus, the medial frontal gyrus, the anterior cingulate, the posterior cingulate gyrus, and the precuneus. Additionally, one cluster within the right hemispheric lateral globus pallidus was detected (Fig. 19a). The left hemispheric activations in the insula and the medial frontal/anterior cingulate gyrus are also presented with coloured brain images in Figure 19a.

The reverse comparison, all false versus all correct recognitions, revealed significant activation in the right precentral gyrus (Fig. 19b).

(a) all correct recognitions versus all false recognitions



(b) all false recognitions versus all correct recognitions

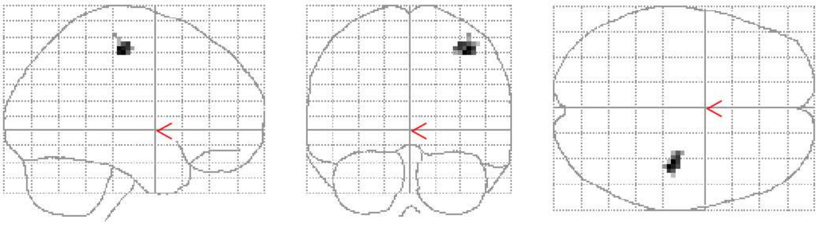


Figure 19: Relative increases in neural activity associated with the comparison all correct versus all false recognitions (a) and all false versus all correct recognitions (b) across the three sets. Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space ("glass brains") as defined by Talairach and Tournoux (1988). Statistically significant increases ($p < .05$, corrected for multiple comparisons) in neural activity are superimposed in terms of colour on MRI sections. The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 12.

5.2.1.2 Contrasts between studied and unstudied sets

For this analysis *originals-correct* are redefined to *hits* and *originals-false* to *misses*. The data of the falsely recognised pictures of *similars* and *outtakes* are combined to *false alarms* and the correct recognised ones to *correct rejected*. Thus, the following pairs are analysed: *hits – false alarms*, *misses – false alarms*, *correct rejected – misses*, and *correct rejected – hits*. Table 13 summarises the results of these contrasts.

Table 13: Local maxima of significantly activated regions associated with comparisons between (*hits*, *false alarms*, *misses*, and *correct rejected*). First sorted by pattern, then by level of significance (Z-score)

Side	**Region**	**BA**	Voxels in cluster	**Z**	**x**	**y**	**z**
	hits > false alarms						
L	anterior cingulate gyrus	24/32	207	4.83	0	38	1
L	claustrum		36	4.09	-30	3	8
L	superior temporal gyrus	22	34	3.78	-42	-20	9
	false alarms > hits						
L	middle occipital gyrus	19/18	1525	5.65	-36	-84	13
L	middle frontal gyrus	46	192	4.12	-39	30	18
R	middle occipital gyrus	19	947	5.52	42	-78	12
R	retrosplenial cortex	30	244	4.99	15	-52	14
R	inferior frontal gyrus	45/46	125	4.44	53	27	21
R	nucleus ruber		86	4.20	6	-21	-4
R	superior frontal gyrus	8	106	4.02	6	20	49
R	middle frontal gyrus	6	59	3.75	39	0	55
	misses > correct rejected						
R	middle temporal gyrus	21	10	3.72	53	-27	-11
	correct rejected > misses						
L	restrosplenial cortex	29	1822	5.04	-6	-52	11
L	insula		236	4.33	-33	23	2
L	thalamus/lateral globus pallidus		139	4.23	-18	-11	9
L	inferior frontal gyrus	9	70	4.00	-42	-2	22
L	insula		38	4.00	-45	-17	15
L	postcentral gyrus	2	97	3.88	-42	-29	54
L	posterior cingulate gyrus	31	33	3.60	-12	-45	41
R	middle occipital gyrus	19	995	5.18	36	-84	18
R	anterior cingulate gyrus	32	402	4.35	6	28	29
R	precentral gyrus	3/4	21	3.78	24	-26	67
R	lateral globus pallidus		28	3.44	15	0	3
	hits > correct rejected						
R	precentral gyrus	4	246	5.61	36	-18	51

Continued on next page

Table 13 – continued from previous page

Side	Region	BA	Voxels in cluster	Z	x	y	z
	correct rejected > hits						
L	precentral gyrus	4	1214	Inf.	-39	-15	53
L	middle occipital gyrus	19	2313	7.17	-36	-84	18
L	inferior frontal gyrus	47	138	5.11	-33	23	-1
L	midbrain/subthalamic nucleus		93	4.02	-12	-15	-4
L	insula		21	3.64	-45	-17	15
R	middle occipital gyrus	18	1517	6.67	27	-90	5
R	anterior cingulate gyrus	32	1132	5.79	6	31	29
R	inferior frontal gyrus	47	627	5.75	39	23	-6
R	brainstem, pons		98	5.21	3	-22	-24
R	subcallosal gyrus	47	29	4.62	15	11	-11
R	lingual gyrus	18	13	3.38	6	-78	4
	misses > false alarms						
L	precentral gyrus	4	161	4.51	-39	-15	56
	false alarms > misses						
L	middle frontal gyrus	46	148	4.88	-36	30	18
L	cerebellum, posterior lobe		393	4.04	-30	-65	-14
L	superior parietal lobule	7	91	3.88	-30	-65	47
L	lateral parietal gyrus	39	56	3.67	-39	-66	28
L	middle frontal gyrus	6	13	3.63	-30	14	46
R	inferior temporal gyrus	37	123	4.48	56	-59	-7
R	middle frontal gyrus	6	233	4.42	33	-6	61
R	retrosplenial cortex	30	292	4.00	9	-49	14
R	middle occipital gyrus	19	30	3.96	36	-84	18
R	anterior cingulate gyrus	32/24	10	3.72	18	5	41

Threshold for uncorrected: T = 3.09, $p_{uncorrected} < .001$. ‘Side’ defines the hemisphere, in which the activation was found, L = left, R = right. BA is the respective Brodmann area of each activated cluster.

The comparison *hits* versus *false alarms* is associated with three smaller left hemispheric activations in the anterior cingulate gyrus, the claustrum, and the superior temporal gyrus (Fig. 20).

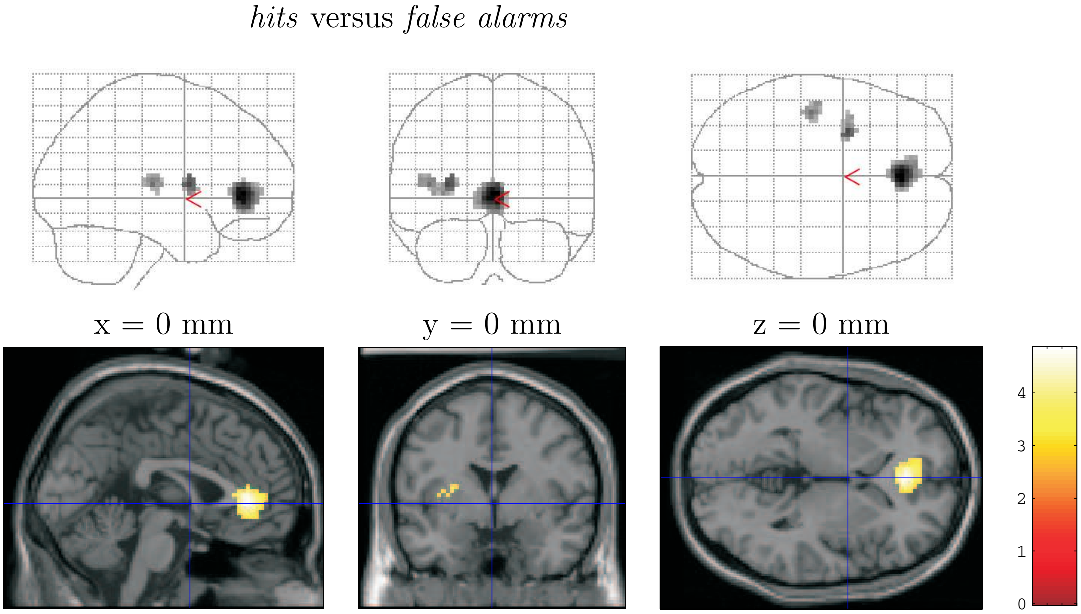


Figure 20: Relative increases in neural activity associated with *hits* versus *false alarms*. Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space ("glass brains") as defined by Talairach and Tournoux (1988). Statistically significant increases ($p < .05$, corrected for multiple comparisons) in neural activity are superimposed in terms of colour on MRI sections. The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 13.

The reverse comparison *false alarms* versus *hits* revealed activations mainly in the left but also in the right middle occipital gyrus. Furthermore, a cluster in the left middle frontal gyrus was exposed. However, increases in neural activity are predominately revealed in the right hemisphere within the posterior cingulate gyrus, the inferior and the middle frontal gyrus, and the nucleus ruber (Fig. 21).

false alarms versus *hits*

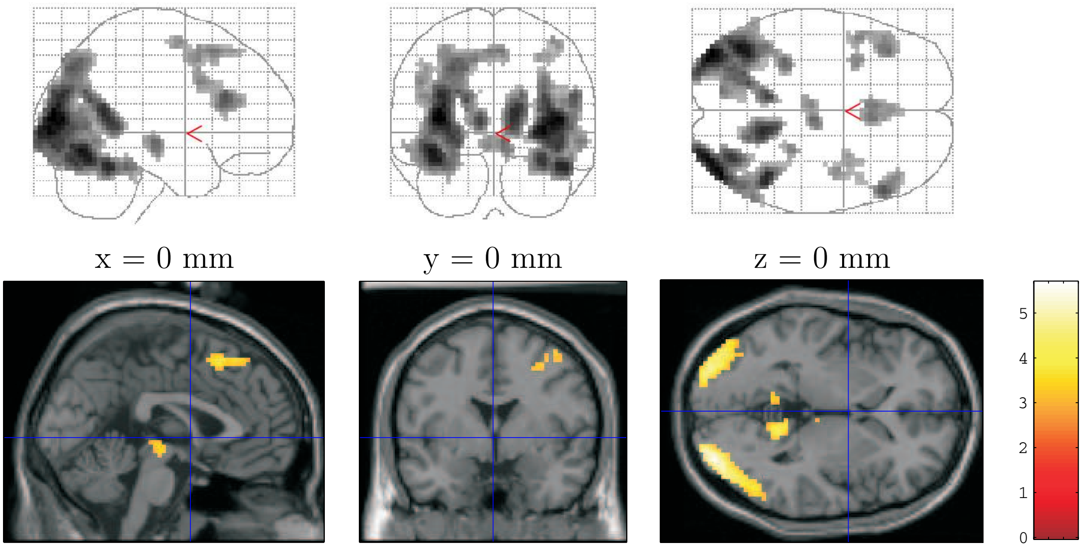


Figure 21: Relative increases in neural activity associated with *false alarms* versus *hits*. Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space ("glass brains") as defined by Talairach and Tournoux (1988). Statistically significant increases ($p < .05$, corrected for multiple comparisons) in neural activity are superimposed in terms of colour on MRI sections. The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 13.

The contrast between *misses* versus *correct rejected* revealed one activation in the right middle temporal gyrus (Fig. 22).

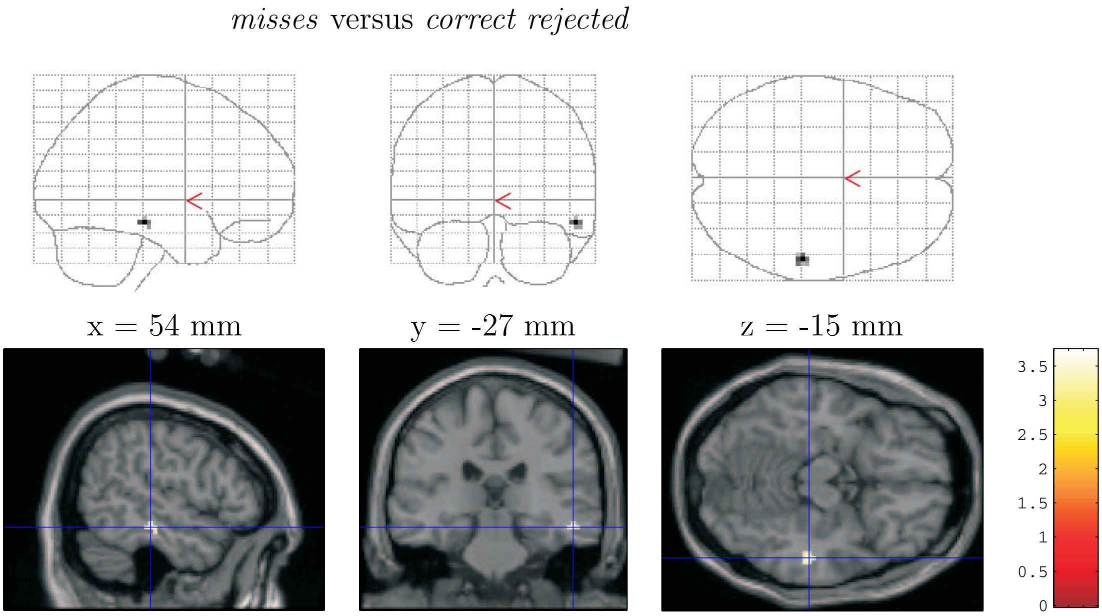


Figure 22: Relative increases in neural activity associated with *misses* versus *correct rejected*. Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space (“glass brains”) as defined by Talairach and Tournoux (1988). Statistically significant increases (p < .05, corrected for multiple comparisons) in neural activity are superimposed in terms of colour on MRI sections. The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 13.

The reverse comparison *correct rejected* versus *misses* showed a preferentially left hemispheric activity within the retrosplenial cortex, the insula, the thalamus, the inferior frontal gyrus, the postcentral gyrus, and the posterior cingulate gyrus. Furthermore, two activations are found in the right hemisphere within the middle occipital gyrus, and the anterior cingulate gyrus (Fig. 23).

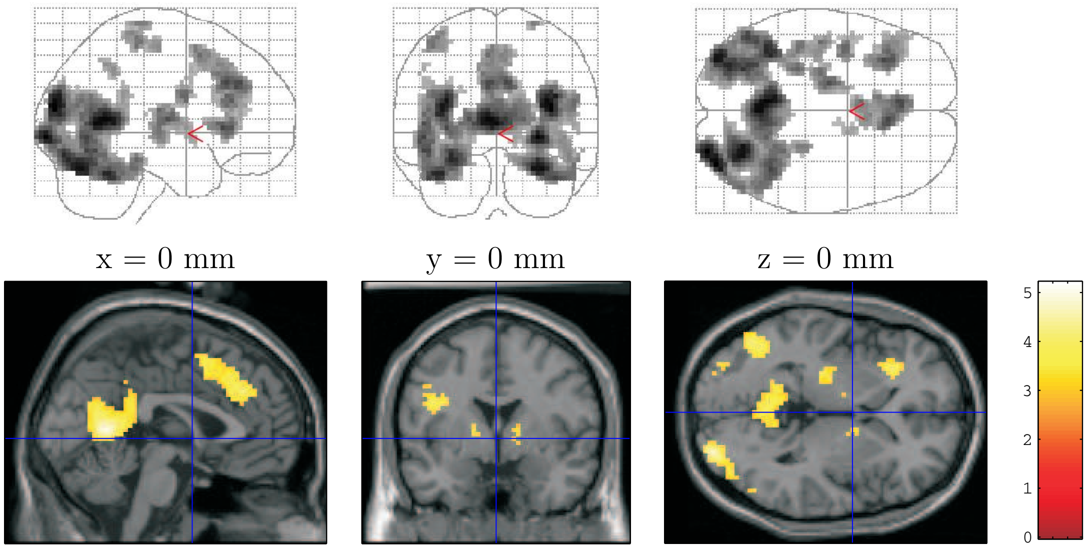

correct rejected versus *misses*

Figure 23: Relative increases in neural activity associated with *correct rejected* versus *misses*. Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space ("glass brains") as defined by Talairach and Tournoux (1988). Statistically significant increases ($p < .05$, corrected for multiple comparisons) in neural activity are superimposed in terms of colour on MRI sections. The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 13.

The comparison between *hits* and *correct rejected* revealed one cluster in the right precentral gyrus (Fig. 24).

hits versus *correct rejected*

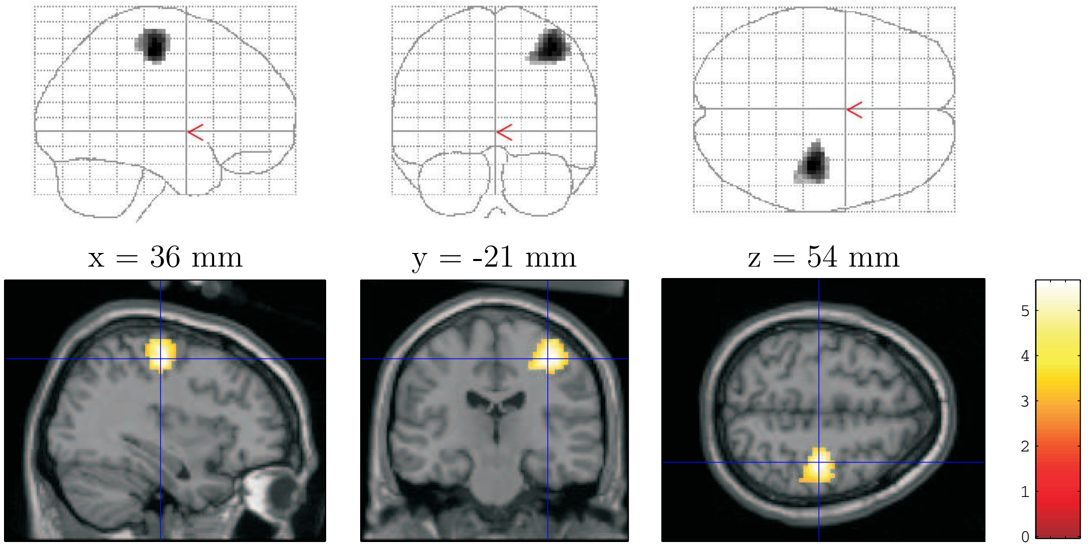


Figure 24: Relative increases in neural activity associated with *hits* versus *correct rejected*. Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space ("glass brains") as defined by Talairach and Tournoux (1988). Statistically significant increases ($p < .05$, corrected for multiple comparisons) in neural activity are superimposed in terms of colour on MRI sections. The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 13.

For the reverse contrast significant increases in neural activity are revealed within the left precentral gyrus, bilateral in the occipital gyri, and the right anterior cingulate gyrus. Furthermore, activations in the right hemispheric inferior frontal gyrus, the pons, the subcallosal gyrus, the lingual gyrus, and in the left hemispheric inferior frontal gyrus, the subthalamic nucleus, and the insula are associated with this comparison (Fig. 25).

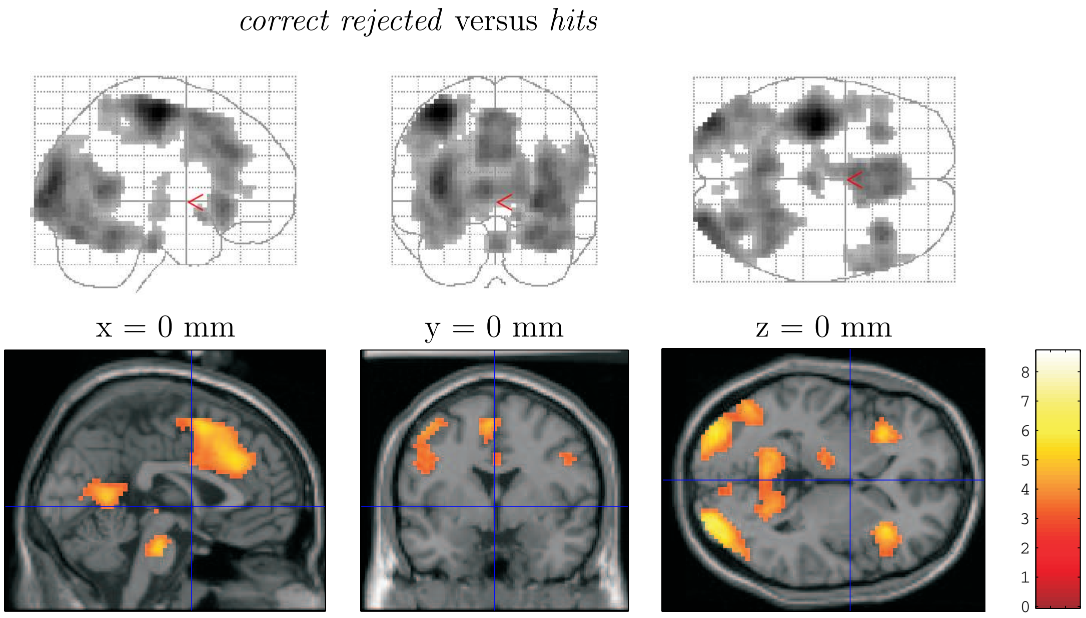


Figure 25: Relative increases in neural activity associated with *correct rejected* versus *hits*. Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space (“glass brains”) as defined by Talairach and Tournoux (1988). Statistically significant increases ($p < .05$, corrected for multiple comparisons) in neural activity are superimposed in terms of colour on MRI sections. The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 13.

The comparison *misses* versus *false alarms* showed one significant activation within the left precentral gyrus (Fig. 26).

misses versus *false alarms*

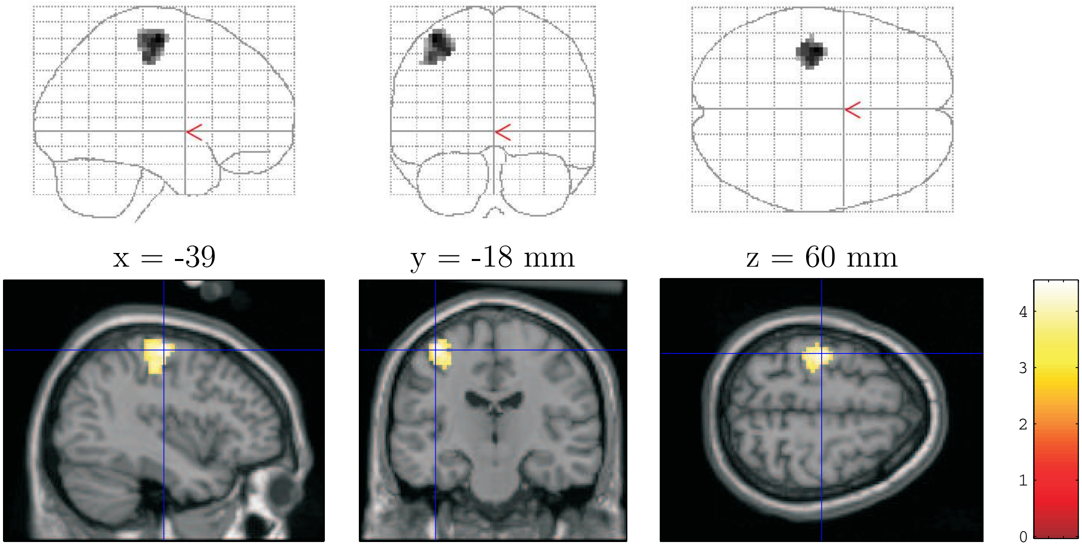
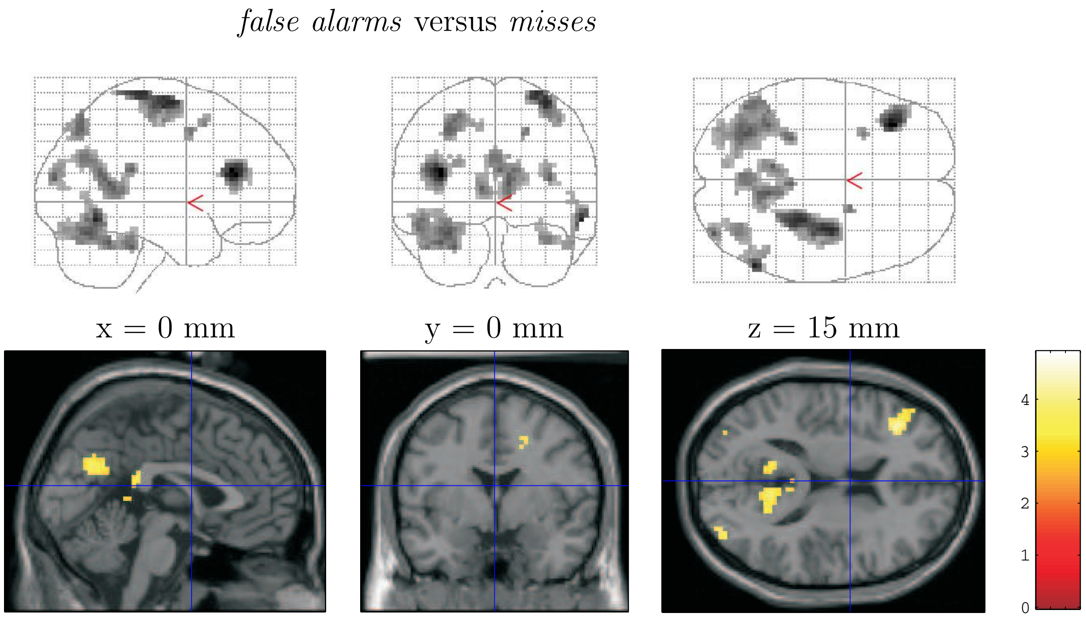


Figure 26: Relative increases in neural activity associated with *misses* versus *false alarms*. Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space ("glass brains") as defined by Talairach and Tournoux (1988). Statistically significant increases ($p < .05$, corrected for multiple comparisons) in neural activity are superimposed in terms of colour on MRI sections. The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 13.

The reverse contrast *false alarms* versus *misses* showed increase in neural activity in the left hemisphere within the middle frontal gyrus, the cerebellum, the superior parietal lobule, the lateral parietal gyrus, and middle frontal gyrus. Furthermore, activations are revealed in the right hemisphere within the inferior temporal gyrus, the middle frontal gyrus, the retrosplenial cortex, the middle occipital gyrus, and the anterior cingulate gyrus (Fig. 27).



false alarms versus *misses*

x = 0 mm y = 0 mm z = 15 mm

Figure 27: Relative increases in neural activity associated with *false alarms* versus *misses*. Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space (“glass brains”) as defined by Talairach and Tournoux (1988). Statistically significant increases ($p < .05$, corrected for multiple comparisons) in neural activity are superimposed in terms of colour on MRI sections. The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 13.

5.2.1.3 Contrasts between the sets

Following pairs of the sets are analysed: *originals-correct – similars-correct*, *originals-correct – outtakes-correct*, *similars-correct – outtakes-correct*, *originals-false – similars-false*, *originals-false – outtakes-false*, *similars-false – outtakes-false.* The results of these contrasts are presented in Table 14.

Table 14: Local maxima of significantly activated regions associated with the comparisons of the three sets with respect to recognition mode. First sorted by pattern, then by level of significance (Z-score)

Side	Region	BA	Voxels in cluster	Z	x	y	z
	originals-correct > similars-correct						
R	precentral gyrus	4	238	5.02	36	-18	56
	similars-correct > originals-correct						
L	precentral gyrus	4	563	6.63	-36	-18	56
L	putamen, claustrum		208	4.56	-33	-12	1
L	middle occipital gyrus	18/19	12	3.62	-36	-87	10
L	lingual gyrus	18	10	3.57	-21	-93	-3
L	inferior frontal gyrus	47	22	3.56	-30	20	-4
L	anterior cingulate gyrus	32	27	3.51	-6	33	26
L	anterior cingulate gyrus	24	12	3.42	-9	-13	39
L	superior frontal gyrus	6	10	3.37	-9	11	49
L	inferior frontal gyrus	47	21	3.34	-56	15	-1
R	inferior frontal gyrus	47	100	4.18	39	23	-6
R	superior frontal gyrus	8	27	3.66	12	23	49
R	middle occipital gyrus	18	13	3.52	27	-90	2
	originals-correct > outtakes-correct						
L	anterior cingulate gyrus	24	21	3.56	-6	32	-2
R	precentral gyrus	4	139	4.67	36	-15	51
	outtakes-correct > originals-correct						
L	precentral gyrus	4	597	7.84	-33	15	53
L	anterior cingulate gyrus	32	274	4.45	-9	24	26
L	superior frontal gyrus	9	71	4.39	-33	37	31
L	anterior cingulate gyrus	24	162	4.35	-6	-4	47
L	middle occipital gyrus	19	177	4.21	-36	-87	15
L	retrosplenial cortex	30	135	3.88	-6	-55	8
L	brainstem, pons		17	3.76	0	-23	-24
L	postcentral gyrus	3	12	3.43	-15	-38	63

Continued on next page

Table 14 – continued from previous page

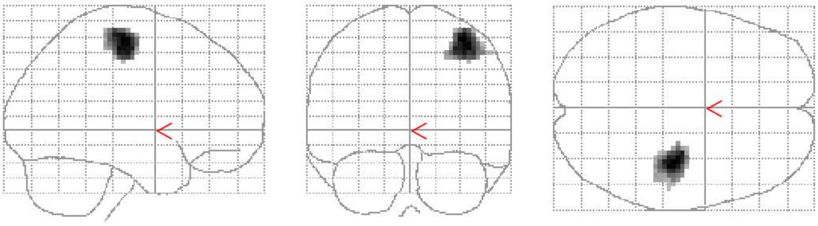
Side	Region	BA	Voxels in cluster	Z	x	y	z
R	middle occipital gyrus	18/19	186	4.12	27	-90	7
R	cerebellum		96	4.10	24	-47	-15
R	superior frontal gyrus	10	83	3.97	27	54	22
R	inferior frontal gyrus	45/46	35	3.90	56	24	18
R	parahippocampal gyrus		32	3.84	21	-52	5
	similars-correct > outtakes-correct						
L	insula		55	4.09	-36	-8	6
	outtakes-correct > similars-correct						
	no suprathreshold clusters						
	originals-false > similars-false						
L	precentral gyrus	4	51	4.07	-36	-12	56
	similars-false > originals-false						
L	middle frontal gyrus	46	43	4.01	-36	33	15
R	postcentral gyrus	3	99	4.61	27	-29	67
	originals-false > outtakes-false						
L	precentral gyrus	4	14	3.65	-39	-12	56
	outtakes-false > originals-false						
L	middle frontal gyrus	46	34	3.89	-36	30	18
L	medial frontal gyrus	10	21	3.67	-9	49	-5
R	postcentral gyrus	3	152	4.58	27	-29	68
R	retrosplenial cortex	29	23	3.82	3	-34	21
R	posterior cingulate gyrus	31	67	3.63	3	-54	28
R	superior frontal gyrus	10	11	3.43	27	58	0
	similars-false > outtakes-false						
	no suprathreshold clusters						
	outtakes-false > similars-false						
L	anterior cingulate gyrus	32	132	4.14	-6	22	27
R	posterior cingulate gyrus	31	13	3.37	9	-36	38

Threshold for uncorrected: T = 3.09, $p_{uncorrected} < .001$. ‘Side’ defines the hemisphere, in which the activation was found, L = left, R = right. BA is the respective Brodmann area of each activated cluster.

The comparison between *originals-correct* and *similars-correct* revealed one significant increase in neural activity in the right precentral gyrus (Fig. 28a).

The reverse comparison showed a wider network of neural activations comprising in the left hemisphere the precentral gyrus, the claustrum, the middle occipital gyrus, the lingual gyrus, the inferior frontal gyrus, the anterior cingulate gyrus, the super and inferior frontal gyri. In the right hemisphere the inferior and superior frontal gyri, the dentate nucleus, and middle occipital gyrus are associated with this contrast (Fig. 28b).

(a) *originals-correct* versus *similars-correct*



(b) *similars-correct* versus *originals-correct*

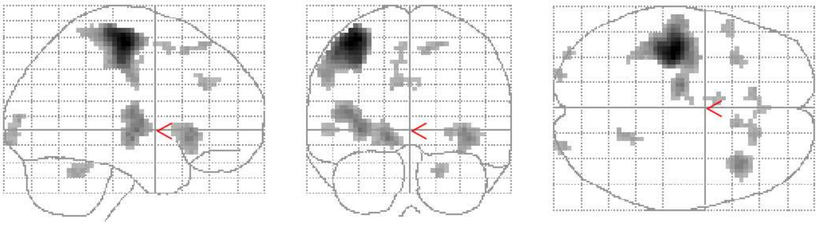
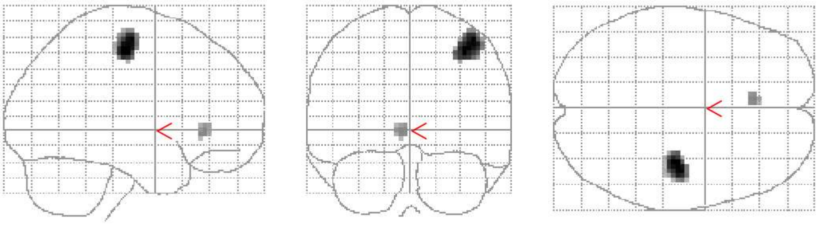


Figure 28: Relative increases in neural activity associated with *originals-correct* versus *similars-correct* (a) and vice versa (b). Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space ("glass brains") as defined by Talairach and Tournoux (1988). The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 14.

The comparison between *originals-correct* versus *outtakes-correct* revealed two significant activations, one in the right precentral gyrus and one in the left anterior cingulate gyrus (Fig. 29a).

The contrariwise comparison between *outtakes-correct* and *originals-correct* is associated with activations in the left hemisphere in the precentral gyrus, the anterior cingulate gyrus, the retrosplenial cortex, the pons, and the postcentral gyrus. In the right hemisphere increase in neural activity was revealed in the cerebellum, the inferior frontal gyrus, and the parahippocampal gyrus. Further bilateral activations are found in the superior frontal gyrus, and the middle occipital gyrus (Fig. 29b).

(a) *originals-correct* versus *outtakes-correct*



(b) *outtakes-correct* versus *originals-correct*

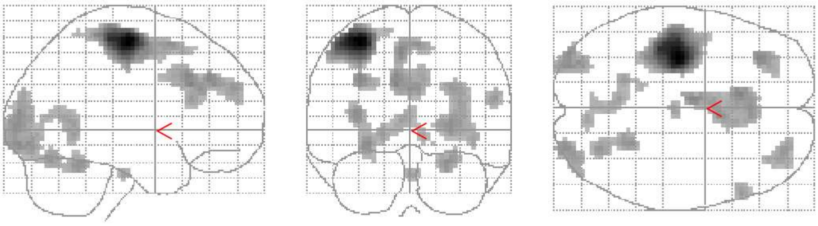


Figure 29: Relative increases in neural activity associated with *originals-correct* versus *outtakes-correct* (a) and vice versa (b). Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space (“glass brains”) as defined by Talairach and Tournoux (1988). The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 14.

The comparisons between the correct rejected pictures of the set *similars* versus the ones of the set *outtakes* revealed only one cluster in the left insula (Fig. 30).

The reverse comparison resulted in no suprathreshold clusters.

similars-correct versus *outtakes-correct*

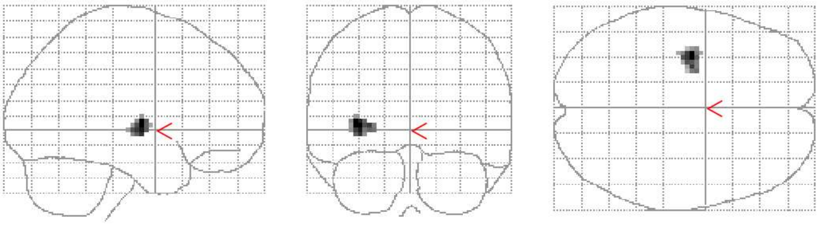
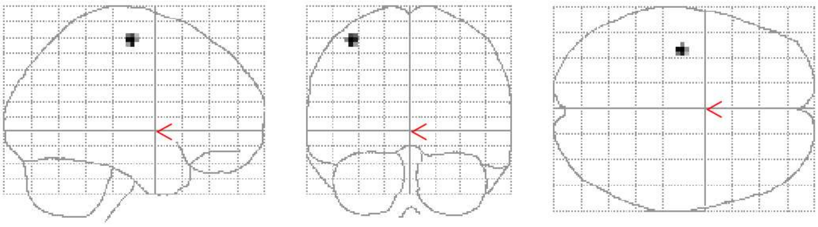


Figure 30: Relative increases in neural activity associated with *outtakes-correct* versus *similars-correct*. Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space ("glass brains") as defined by Talairach and Tournoux (1988). The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 14.

The contrast *originals-false* versus *similars-false* revealed one cluster in the left precentral gyrus (Fig. 31a).

The inverse comparison showed one significant increase in neural activity in the right postcentral gyrus, and in the left middle frontal gyrus (Fig. 31b).

(a) *originals-false* versus *similars-false*



(b) *similars-false* versus *originals-false*

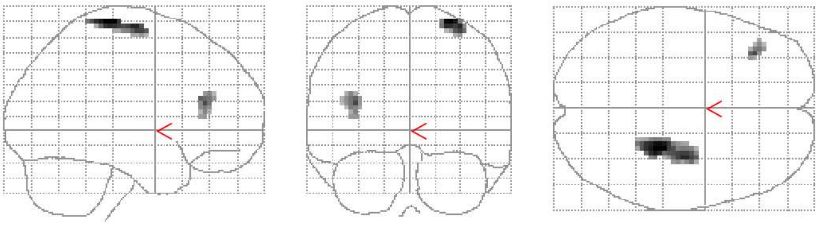
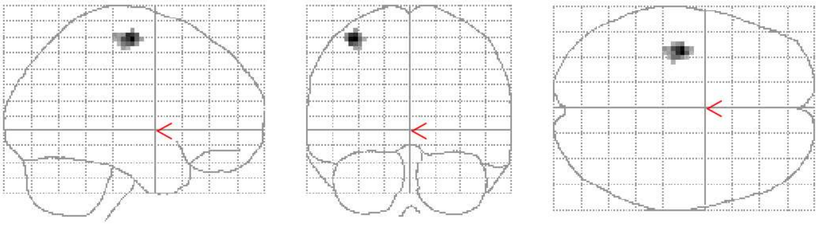


Figure 31: Relative increases in neural activity associated with *originals-false* versus *similars-false* (a) and vice versa (b). Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space ("glass brains") as defined by Talairach and Tournoux (1988). The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 14.

One cluster in the left precentral gyrus is associated with the contrast *originals-false* versus *outtakes-false* (Fig. 32a).

The reverse comparison showed significant activations in the right hemisphere within the postcentral gyrus, the retrosplenial cortex, the posterior cingulate gyrus, and the superior frontal gyrus. In the left hemisphere increase in neural activity are revealed within the middle and medial frontal gyri (Fig. 32b).

(a) *originals-false* versus *outtakes-false*



(b) *outtakes-false* versus *originals-false*

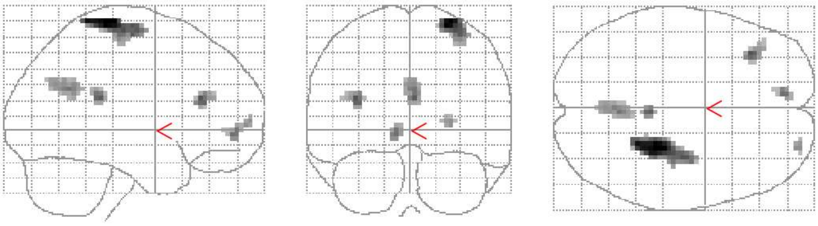


Figure 32: Relative increases in neural activity associated with *originals-false* versus *outtakes-false* (a) and vice versa (b). Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space ("glass brains") as defined by Talairach and Tournoux (1988). The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 14.

Comparison between *similars-false* versus *outtakes-false* showed no suprathreshold activation (Tab. 14).

The contrariwise comparison revealed one significant activation in the left anterior cingulate gyrus, and one in the right posterior cingulate gyrus (Fig. 33).

outtakes-false versus *similars-false*

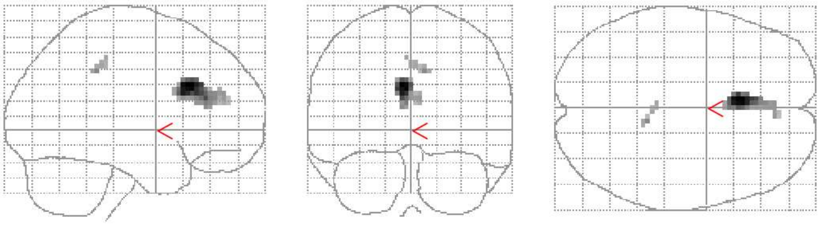


Figure 33: Relative increases in neural activity associated with *outtakes-false* versus *similars-false*. Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space ("glass brains") as defined by Talairach and Tournoux (1988). The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 14.

In general, the comparisons between the falsely recognised stimulus sets revealed activations with smaller cluster-sizes and lesser Z-values than the ones containing the correct recognised stimuli. While, on the other hand the biggest activation was revealed for *outtakes-false*, followed by *outtakes-correct*, and *similars-correct* (Tab. 14).

5.2.1.4 Contrasts sets versus baseline

The activations of each set, *originals*, *similars*, and *outtakes* versus baseline are associated with significant increase in neural activity with an uncorrected p-value ($p < .001$). The results are summarised in Table 15.

Table 15: Local maxima of significantly activated regions associated with comparisons between the three sets with respect to the recognition mode. First sorted by pattern, then by level of significance (Z-score)

Side	Region	BA	Voxels in cluster	Z	x	y	z
	originals correct						
L	middle frontal gyrus	9	241	4.45	-48	8	36
L	middle frontal gyrus	6	29	3.80	-30	11	46
R	middle occipital gyrus	19	4701	7.35	50	-69	9
R	inferior frontal gyrus	45/46	159	5.19	42	16	19
R	precentral gyrus	4	43	3.92	36	-12	48
R	medial frontal gyrus	6	35	3.59	3	28	37
	originals false						
L	middle occipital gyrus	19	24	3.89	-39	-87	7
L	precentral gyrus	6	10	3.60	-39	-6	56
R	middle frontal gyrus	46	13	3.40	56	30	18
R	middle occipital gyrus	19	16	3.33	48	-73	6
	similars correct						
L	middle temporal gyrus	19	4122	6.86	-36	-81	21
L	inferior frontal gyrus	47	204	5.43	-33	23	-1
L	middle frontal gyrus	9	408	5.18	-48	8	36
L	subthalamic nucleus		81	3.84	-12	-15	-4
R	inferior frontal gyrus	47	346	5.77	36	26	-4
R	middle frontal gyrus	9	490	4.96	6	31	32
R	middle frontal gyrus	9	39	4.60	59	16	30
R	brainstem, pons		63	4.28	0	-24	-19
	similars false						
L	middle temporal gyrus	19	1956	6.76	-36	-78	20
L	middle frontal gyrus	6	359	5.13	-30	11	46
R	middle occipital gyrus	19	978	6.04	45	-78	12
R	posterior cingulate gyrus	29	245	5.43	15	-46	11
R	inferior frontal gyrus	45/46	173	4.65	54	24	15
R	middle inferior frontal gyrus	6	78	3.95	36	5	47
	outtakes correct						
L	middle occipital gyrus	19	5421	Inf.	-36	-84	18
L	precentral gyrus	4	879	6.34	-36	-12	53

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Table 15 – continued from previous page

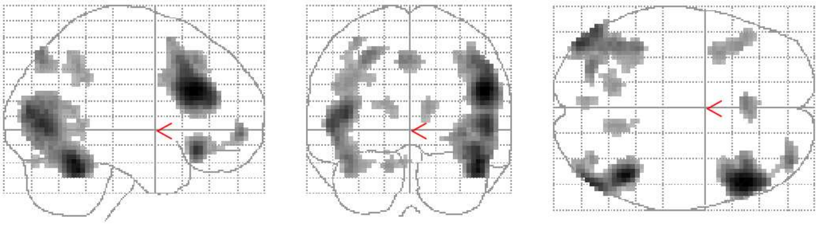
Side	**Region**	**BA**	Voxels in cluster	**Z**	**x**	**y**	**z**
L	anterior cingulate gyrus	32	932	5.89	-9	22	32
L	inferior frontal gyrus	46	83	4.16	-45	24	15
L	insula		57	4.11	-30	21	5
L	precuneus	7	18	3.40	0	-49	61
R	inferior frontal gyrus	45/46	431	6.66	56	24	18
R	brainstem, pons		52	4.48	0	-21	-22
R	inferior frontal gyrus	47	62	4.30	33	23	-4
R	middle frontal gyrus	6	29	4.01	42	2	47
R	inferior parietal gyrus	40	12	3.58	33	-47	47
	outtakes false						
L	medial frontal gyrus	8	341	5.57	-3	23	46
L	middle frontal gyrus	46/45	459	5.49	-42	24	15
L	superior frontal gyrus	10	25	4.09	-27	62	11
L	hypothalamus		34	3.66	-9	-3	-7
R	middle occipital gyrus	19	6665	Inf.	45	-78	9
R	inferior frontal gyrus	45/46	336	5.44	54	24	21
R	precentral gyrus	6	355	4.95	33	-15	56
R	midbrain		24	4.05	9	-21	-12
R	middle frontal gyrus	8/6	15	3.69	33	17	43
R	posterior cingulate gyrus	31	15	3.68	12	-39	38
R	inferior parietal gyrus	40	17	3.66	36	-44	44

Threshold: T = 3.09, $p_{uncorrected} < .001$. 'Side' defines the hemisphere, in which the activation was found, L = left, R = right. BA is the respective Brodmann area of each activated cluster.

Correct recognition of *originals* versus baseline revealed significant increases bilaterally in the middle frontal gyrus. Only in the right hemisphere activations are found in the middle occipital gyrus, the inferior frontal gyrus, the medial frontal gyrus, and the precentral gyrus (Fig. 34a).

False recognitions of *originals* versus baseline are associated with activations in the left and right middle occipital gyrus, left precentral gyrus, and right middle frontal gyrus (Fig. 34b).

(a) *originals-correct* versus baseline



(b) *originals-false* versus baseline

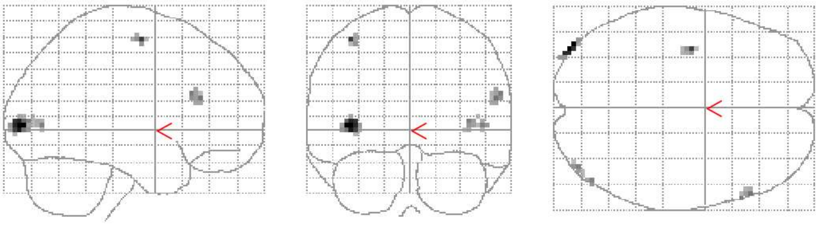
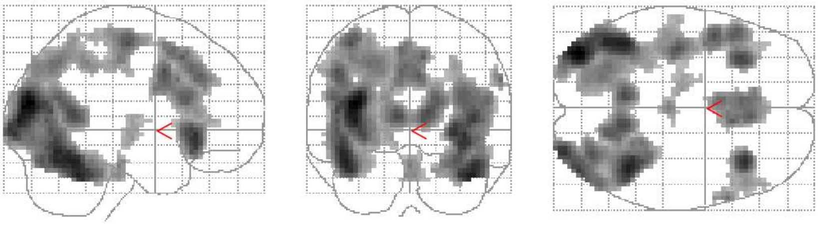


Figure 34: Relative increases in neural activity associated with correct as well as false recognitions for *originals* versus baseline. Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space ("glass brains") as defined by Talairach and Tournoux (1988). The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 15.

Correct rejection of *similars* versus baseline showed significant activations in the left hemisphere in the middle temporal/occipital gyrus, the inferior and the middle frontal gyrus, and the subthalamic nucleus. In the right hemisphere clusters in the inferior and the middle frontal gyrus, and in the pons are also associated with correct rejection of this set (Fig. 35a).

The false recognised *similars* are associated with activations mainly in the left but also in the right occipital/temporal gyri. In the left hemisphere additionally the middle frontal gyrus was activated, in the right hemisphere further activations are revealed within the middle frontal gyrus, the inferior frontal gyrus, and the posterior cingulate gyrus (Fig. 35b).

(a) *similars-correct* versus baseline



(b) *similars-false* versus baseline

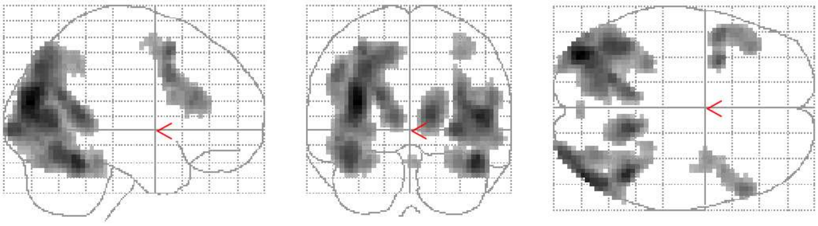
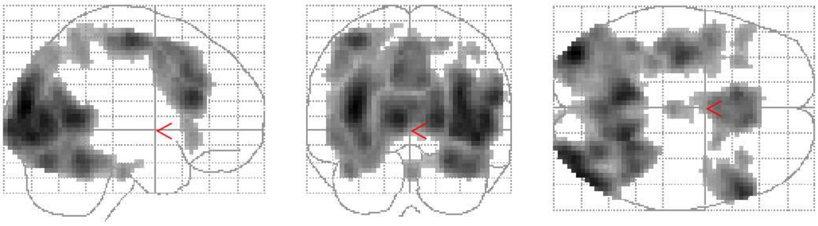


Figure 35: Relative increases in neural activity associated with correct as well as false recognitions for *similars* versus baseline. Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space ("glass brains") as defined by Talairach and Tournoux (1988). The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 15.

Correct rejection of *outtakes* showed significant activation in the left middle occipital gyrus and bilaterally in the inferior frontal gyrus. Additionally, in the left hemisphere the precentral gyrus, the anterior cingulate gyrus, the insula, the precuneus, and in the right hemisphere the middle frontal gyrus, the inferior parietal gyrus, and the pons are activated (Fig 36a).

The biggest cluster within this analysis was found for falsely accepted *outtakes* within the right middle occipital gyrus. Beside of that, further significant increases of neural activity are revealed in left hemisphere within the medial, middle, and superior frontal gyri, and in the hypothalamus. Right hemispheric are the inferior, and middle frontal gyri, the precentral gyrus, the posterior cingulate gyrus, the inferior parietal gyrus, and the midbrain associated with *outtakes-false* (Fig. 36b).

(a) *outtakes-correct* versus baseline



(b) *outtakes-false* versus baseline

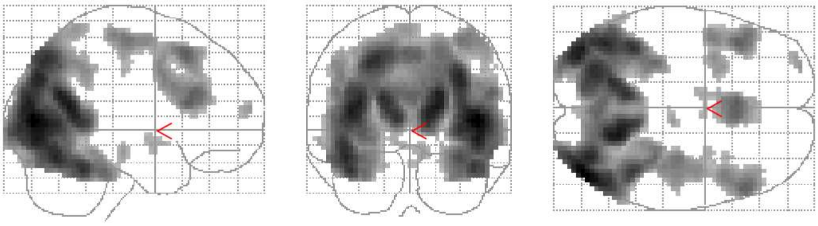


Figure 36: Relative increases in neural activity associated with correct as well as false recognitions for *outtakes* versus baseline. Areas of significant relative increase in neural activity are shown as through-projection onto representations of standard stereotaxic space ("glass brains") as defined by Talairach and Tournoux (1988). The Talairach coordinates of the significant maximum for each activated cluster are presented in Table 15.

6 Discussion

In this chapter, the results of the study are discussed in the context of previous research carried out on false memories. For the first three hypotheses the behavioural data of the pilot and the fMRI study is interpreted together. The neuroimaging results of the fMRI study are presented in the last section.

6.1 Recognition rate

The first question raised in this study asked whether a new developed film paradigm can induce efficiently false recognitions. The behavioural data of the pilot study, and the later fMRI study, demonstrated that the film paradigm provoked false recognitions. The high rates of false recognitions, which were revealed for this study, are comparable to results of previous investigations that used word-lists and pictures (M. B. Miller & Gazzaniga, 1998) and abstract shapes (Slotnick & Schacter, 2004) as stimulus material. To evaluate the accuracy and the false memory rates of the subjects, overall discriminability indices were calculated. For both studies, the pilot and the fMRI study, the discriminability indices revealed a positive value. This result proved that the subjects responded not by chance, but rather that they made their decisions deliberately. Furthermore, the response bias was calculated to control if the film paradigm induced false recognitions of the unstudied stimuli as it should do. This resulted in a negative value for both studies, which confirmed that the film paradigm provoked reliable false recognitions of unstudied stimuli. The calculation according to signal detection theory verified that the film paradigm is a suitable method to investigate false recognitions. Even though the presented film was not emotionally laden (see Holmes, Brewin, & Hennessy, 2004, for possible effects in memory abilities of traumatic films), it caused reliable false recognitions.

At first glance, the film paradigm of this study appears similar to test designs examining the phenomenon of change blindness with a film (Levin & Simons, 1997). Changed blindness is not a form of false recognitions but is defined as a result of being absent-minded (see Schacter's seven sins, section **2.2.3**). One of the differences between the procedure of the film paradigm of this study and of the films investigating changed blindness is that for the latter the attention of the subjects was actively focussed by specific instructions. For example, subjects were told to count how often a ball was thrown between several people. Thus engaged, subjects missed that one person, costumed like a gorilla, walked through the group (D. J. Simons & Chabris, 1999). Change blindness research expanded over the last years (D. J. Simons & Rensink, 2005) showing that it is a common phenomenon. It was not only found in experimental but also in real-life settings (Levin, Simons, Angelone, & Chabris, 2002). A comparison between change blindness paradigms and the film paradigm shows important differences. The film paradigm was not developed to investigate change detection abilities like change blindness paradigms. This becomes apparent when the procedure of this study is compared with another one which investigated changed blindness (Mäntylä & Sundström, 2004). The subjects of Mäntylä's and Sundström's study watched a naturalistic film, presenting realistic scenes like being in an office and answering the phone. After a movie cut, the colour of the phone was changed and was again used by the actor. In the following recall questionnaire, subjects often did not recall change in colour of the phone. Thus, they made mistakes in change detection. The difference between their study and this one is that neither objects nor persons were changed in the film. Even though several movie cuts were made in the film, the aim was not to examine the subjects' ability to detect changes whilst watching the film. The close comparability of the two stimuli made it necessary to expose the differences between them and emphasised again that the film paradigm truly provoked false recognitions. One further study shows the difference between change blindness and the film paradigm. Varakin and Levin (2006) found that even when the ability to detect changes is poor, the recognition abilities are above that of mere chance. This suggests that when the film paradigm is comparable to change blindness paradigms the recognition rate should be above that of chance as well. The data showed that this was not the case. To sum up, the film paradigm has some superficial parallels to change blindness paradigms, but the main focus of this study was the investigation of recognition abilities and not of change detection.

There are further relevant differences between the film paradigm and previous false memories paradigms. Subjects of this study were not urged to focus at a specific part or action of the film. During the recognition task the subjects were neither influenced nor distracted in any way. This was important because other studies showed that the memory of subjects can be easily changed, for example by suggestive questions during an interview (E. F. Loftus, 2000, 2004; Bernstein, Laney, Morris, & Loftus, 2005). The aim of the film paradigm was to investigate false recognitions without any additional external influence. The subjects were only told to watch the entire film closely because of a subsequent memory task. It was not explained to them what kind of memory task they would participate in or what the main focus of the study was.

One of the new aspects of this study was that a naturalistic, not emotive, film was used. Furthermore, one studied and two different unstudied stimulus sets were tested. In addition and of utmost importance, the subjects were never influenced during the whole procedure. The recognition results clearly demonstrate that the combination of these factors in the film paradigm was successful and that false recognitions can be caused and investigated with this paradigm.

6.2 Two unstudied stimulus sets

Two unstudied stimulus sets which should cause false recognitions were investigated in this study: *similars* and *outtakes*. The assumption was that significant differences can be found between false recognitions of changed studied scenes and false recognitions of parts of events which were not perceived. The pilot study and the fMRI study showed that the subjects were able to discriminate between the three sets. The response bias demonstrated that both unstudied stimulus sets provoked reliable false recognitions. The hypothesis that two different reasons might cause false recognitions was supported by the results. It was also demonstrated that *similars* and *outtakes* were handled differently by the subjects, indicating that they provoke false recognitions in different ways.

The stimulus set *similars* tested the ability of the subjects to retrieve details of a witnessed event. Considering normal everyday situations, it seems unimportant to remember correctly whether a tea cup was red or yellow. However, these details can be very important if it comes to eyewitnesses. When a witness reports that the car of a bank robber is blue, it can be assumed that the police will only look for a blue car. If the description of the witness was wrong, the tracing might be based on this false information. In a recent study, Silvia et al. (2006) investigated the importance of attention for schema-consistent and schema-inconsistent objects in everyday scenes. Their results showed that it mostly depends on the instruction, whether details of objects (schema-consistent as well as schema-inconsistent) are correctly recognised or not. In this study, the set *similars* presented schema-consistent objects or actions, because they pictured perceived scenes with changes. Schema-consistent objects are memorised regarding their gist information, irrespective of the attentional focus. This suggests that most parts of the film were only memorised with respect to their general content, which further resulted in confusion during the recognition task when *originals* and *similars* were presented. Considering the fuzzy-trace theory, gist and verbatim information are stored in parallel but retrieved separately from each other (see section **2.2.2**, Brainerd & Reyna, 2001). Only about half of the presented stimuli of the set *similars* were correctly rejected by the subjects. This suggests that the *similars* induced the retrieval of the gist of the film scenes, rather than the detailed verbatim information. A way to further examine this particular point would be to show subjects *originals* and *similars* in parallel during the recognition task. The assumption is that the false recognition rate for *similars* would drop significantly, because seeing these two stimuli in parallel, gist and verbatim traces should be reactivated. This reactivation would result in correct decisions for *originals* as well as *similars*. This outlines the problem of the form of false recognition stimuli, which are depicted in this study by the *similars*. When subjects need to focus their attention on specific objects or actions in order to fully recognise them later, behavioural data alone is not enough to analyse this phenomenon.

The stimulus set *outtakes* was designed to provoke false recognitions from scene parts that were not presented in the film. The results revealed that subjects felt confident that they had actually seen more than half of the parts that were not presented. The mechanisms of 'cognitive dissonance' (introduced in section **2.2.3**) may provide an explanation for the underlying processes of this finding (Festinger, 1957). Cognitive dissonance describes the urge to avoid conflicts between knowledge and behaviour. In the experimental setting of the film paradigm, it can be assumed that the subjects responded under the pressure to perform as well as possible. This might conflict with what one is actually capable of memorising. One way to solve this discrepancy is to fill in the gaps unconsciously, and thus create a consistent course of events. This process was also described by Schacter (1999; 2001) as the sin of bias, which is one of the seven sins of memory (see also section **2.2.3**). He explained that consistency and change biases, two of the major types of biases, may help to reduce cognitive dissonance (Schacter, 2001). The fragmented film scenes of this study, which resulted from the creation of the stimuli *outtakes*, disrupted the consistency of the perceived content of the film. Moreover, a study of Lyle and Johnson (2006) revealed that perceived information can be imported into false memories. The imported, truly perceived, information can be used to fill in the gaps, achieve the consistency of the events, and avoid cognitive dissonance. The process of 'filling the gaps' is only possible via the imagination. If something is repeatedly imagined, it can result in a powerful false recollection, which can lead to the belief that an imagined event was actually experienced (Goff & Roediger, H. L. III, 1998). Other studies came to the conclusion that scene perception and imaginations activate similar mental images or schematic representations (Intraub, Gottesman, & Bills, 1998). The visual perception of an event is not continuous. The most obvious indicator for this is the necessary blinking of the eye. Among others, Hochberg (1986) proposed that instead of a multitude of single detailed images, abstract mental schemata of visual scenes are memorised. Schemata can evolve for every common situation, i.e. like going to the cinema (see section **2.2.2**, schema theory). It is reasonable and economically sensible that the mind connects perceived with imagined information to receive a complete representation of an event. When perceived information is embedded in the imagined parts, the end results will be consistent. These processes are very expedient in normal life, but not when a crime is witnessed. It can be very important to recognise the face of a culprit or to report the details of the crime correctly. False recollection and false recognition in this scenario are the results of source monitoring error (see also section **2.2.2**, Lindsay & Johnson, 2000). Thus, false recognitions of *outtakes* are not the same as false recognitions in the original meaning, which describe a false positive response to an unknown stimulus, but rather a product of unconsciously used schemata followed by a source monitoring error during the recognition task. Nevertheless, they are still false recognitions because the subjects have to recognise the stimuli. Therefore, they have to synchronise the previously studied material (i.e. film, pictures, word-lists) with the presented recognition stimuli (i.e. pictures, words).

In conclusion, it was satisfactorily shown that two different causes, represented by the unstudied stimulus sets *similars* and *outtakes*, resulted in false recognitions. Moreover, the data suggests that both forms of false recognitions might commonly occur in everyday life.

6.3 Response time

The hypothesis concerning the response time as a valid measure to differentiate between correct and false recognitions was partially confirmed by the results. Subjects of both studies responded to the stimulus set *originals* as predicted. Fast responses are associated with correct recognitions of these stimuli, whereas falsely rejected ones are connected to longer response times. Results of the two unstudied sets revealed a different picture. For both studies, and both sets, correct rejections of the stimuli are associated with longer response times, while faster decisions are found for false recognitions. Though the response behaviour of the subjects for these two unstudied stimulus sets seemed to be comparable, there is one difference. The response times of *outtakes-correct* and *outtakes-false* showed a bigger difference between them than the results of the set *similars* for correct and false recognitions. After the separate discussions of the three stimulus sets and the revealed response times, conclusions are drawn for the response times regarding the hypothesis.

The results of the set *originals* comprise the fastest response times for correct recognitions in both studies. This is in line with previous studies, which showed that correct responses of studied stimuli are associated with the fastest responses (e.g. Nessler, Mecklinger, & Penney, 2001; Okado & Stark, 2003). The results for the set *originals* confirm the intuitive expectation of how someone should respond regarding studied material. It seems plausible that a studied stimulus can be correctly recognised within a shorter time, and that longer time to make a decision leads to a false response. The longer we think about something, the more information can interfere with our first intuitive thought. Thus, reasoning can lead to false recognitions (Shavir et al., 1993) of studied stimuli.

Following the dual-process model, which refers to two components (familiarity and recollection) during the retrieval process (Yonelinas & Jacoby, 1994), the response times of the unstudied stimuli revealed the expected result. The general assumption of the dual-process model is that the familiarity process is an automatic, fast process, followed by a slower and more accurate recollection process (Atkinson & Juola, 1974; Mandler, 1980; Yonelinas & Jacoby, 1994). Several studies investigated this with the speed-accuracy trade-off (SAT) paradigm, developed by Dosher (1984a, 1984b). Here, subjects receive a response signal at variable times after the stimulus is presented. They are forced to respond more quickly with less accuracy. Results revealed an inverted-U relation between response time and false recognition rate (Rotello & Heit, 2000). Thus, initial increase in response times is associated with increases in false recognition rates, but subsequent increase in response times leads to reductions of false response rates. Importantly, the inverted-U relation is between the response times and false recognitions of meaning-preserving new stimuli (see section **2.2.2**). Considering the picture sets used in this study, only the set *outtakes* follows this assumption. These stimuli did not violate the presented content of the film scenes by changing it, they completed the events of the film by representing the parts that were not presented. Compared with the results of the *similars*, the set *outtakes* caused response times for correct and false recognitions that differed significantly. The data for this set is in line with the dual-process model.

The pictures of the set *similars* can be classified as meaning-violating new stimuli, because they represent changed scenes. For example, in one scene of the film the man takes a small white letter out of a mail box. The picture of the set *similars* shows the man taking a big brown letter out of the mail box. Only a small object was changed in this scene but the content is, nevertheless, different. The work of Bransford (1971) showed that subjects were good at correctly classifying meaning-violating new stimuli. This is also mirrored in the recognition rates of both unstudied sets, which showed that subjects performed better for the set *similars* than for *outtakes*. The response times of correct and false recognitions of *similars* are very close to each other, even though correct responses were associated with slightly longer response times.

In summary, the hypothesis was only supported by the results of the set *originals*. The set *outtakes* showed a contrary course of the response times as it was described in previous studies regarding related but unstudied stimuli. The results for the set *similars* differed only slightly between correct and false recognitions. Nevertheless, the response times for this set showed a similar development to the set *outtakes*. The results of the unstudied stimulus sets suggest that for correct recognitions of these stimuli more time is needed, probably reflecting an accurate processing of these stimuli which leads to correct rejections. This interpretation challenges the assumption of the hypothesis that fast, intuitive responses lead to correct responses in general. The data showed that it might be very difficulty to distinguish between correct and false recognitions in real life situations. In those cases, it might not be known whether a spontaneous response is correct or not. The results of this study indicate that fast decisions lead to correct responses for studied material, but to false responses for unstudied material. Hence, the response time can be used as an additional measure to distinguish between correct and false recognitions, but it should not be used as a single or main factor for this kind of recognition task.

6.4 Neural correlates

The intention of the analysis of the neuroimaging data was to reveal brain regions that are associated with correct and false recognitions. The results given in section **5.2** are now discussed. Firstly, the neural activity findings regarding all correct and all false recognitions are interpreted (results of section **5.2.1.1**). All correct recognitions included correct responses ('known') to *originals* and correct rejections ('unknown') to *similars* and *outtakes*. All false recognitions on the other hand included false 'unknown' responses to *originals* and 'known' ones to *similars* and *outtakes*. However, the analysis of this data should reveal brain regions, which are involved in correct and false recognitions, independent of the content of the stimuli and the given response ('known/unknown'). In the next analysis steps, studied and unstudied stimuli were contrasted against each other as well as against baseline. The large amount of activations revealed for these contrasts are not interpreted with regard to single contrasts but to their anatomical affiliation. Thus, the activations displayed in the sections **5.2.1.2**, **5.1.2.3** and **5.1.2.4** are discussed regarding the frontal cortex, parietal cortex, temporal cortex, occipital cortex, subcortical nuclei, cerebellum, and pons.

As supplementary material, a map of the human Brodmann areas (BA) is included in **Appendix C**. The classification of the revealed activations of this study within the frontal cortex was made as follows: inferior and superior frontal gyrus (BA 47/10) equal orbitofrontal cortex; superior, middle, and inferior frontal gyrus (BA 8/9/46) equal dorsolateral frontal cortex; inferior frontal gyrus (BA 45) equal ventrolateral frontal cortex; middle frontal gyrus (BA 6) equal supplementary motor area (cf. Fletcher & Henson, 2001; Kringelbach & Rolls, 2004).

6.4.1 Correct/false recognitions across all sets

The first contrasts were made to see if specific brain regions are activated regarding correct recognitions as well as false recognitions. As expected the increase in neural activity was larger for all correct recognitions than for all false recognitions.

The contrast all correct recognitions against baseline displayed significant activations within the frontal lobes, specifically the bilateral orbitofrontal cortex (BA 47), the right ventrolateral/dorsolateral frontal cortex (BA 45/46), the left dorsolateral cortex (BA 9), and the left anterior cingulate cortex/supplementary motor area (BA 32/6). Furthermore, an increase in neural activity was revealed in the left middle temporal gyrus (BA 19) and the right pons. The findings demonstrated that bilateral orbitofrontal cortex activations are more involved in the processing of false (new related) and old stimuli than in new (not related) stimuli, which suggests that this region reflects verification processes at retrieval (Cabeza et al., 2001). For this study, these verification processes should be very important, especially regarding unstudied stimuli. Contrary to studied stimuli, which present truly perceived information from the film, unstudied stimuli might induce a familiar feeling, but without truly perceived information. Although verification processes are needed to correctly discriminate between the truly perceived information of the film and information, which is only associated with a familiar feeling. This interpretation is further supported by results of studies examining patients with lesions in the orbitofrontal cortex, or connected areas, who spontaneously confabulate (Schnider, von Daniken, & Gutbrod, 1996; Schnider & Ptak, 1999). These patients showed higher false response rates for unstudied stimuli together with constant hit rates. This was interpreted as an inability to suppress unimportant stimuli. Further studies showed that lesions in the orbitofrontal cortex cause deficits during retrieval processes because of the patient's inability to inhibit irrelevant information (Schnider, Treyer, & Buck, 2000). This might result in discrimination deficits to distinguish between old and new stimuli (Curran, Schacter, Norman, & Galluccio, 1997). A study on primates further supported the function of the orbitofrontal cortex to discriminate between truly perceived information and new information (Rolls, Browning, Inoue, & Hernadi, 2005), which showed that neurons in this area specifically respond to novel visual stimuli. Thus, the involvement of the bilateral orbitofrontal cortex in this study, for correct recognitions in general, demonstrates its function as a mediator between memories and current demand. Bilateral activation of the dorsolateral frontal cortex is thought to be more involved in performance monitoring processes than the ventrolateral frontal cortex (Stern et al., 2000). The recognition task of this study demanded high monitoring effort because the viewed film had to be evaluated together with the recognition pictures, and the resultant response was also monitored. Thus, activations in these regions (BA 9/46) supposedly mirror the initiation of retrieving old visual information from the film, as well as performance monitoring processes (cf. Nieuwenhuis, Yeung, Holroyd, Schurger, & Cohen, 2004; Grady, McIntosh, & Craik, 2005). This interpretation is supported by findings that the right ventrolateral/dorsolateral frontal cortex seems to be specifically associated with active retrieval processes of the visual studied material (Petrides, Alivisatos, & Evans, 1995; E. E. Smith, Jonides, & Koeppe, 1996; Henson, 2001; Owen, 2000; Stern et al., 2000). This indicates that in this study the right ventrolateral frontal cortex performs the initiation of retrieving the visual information of the film, whereas the dorsolateral frontal cortex is more involved in monitoring processes of this operation. Moreover, the anterior cingulate cortex is assumed, along with an increase in neural activity in the orbitofrontal cortex, to be associated with response conflict and inhibition of inadequate responses (cf. Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003; Aron, Monsell, Sahakian, & Robbins, 2004; Kemmotsu, Villalobos, Gaffrey, Courchesne, & Muller, 2005). The engagement of this region in conflicts at the level of response decisions, is anatomically supported by its connection with structures, which control the actual motor response (Hazeltine, Poldrack, & Gabrieli, 2000). These are premotor, supplementary motor, and primary motor areas. For the contrast, all correct recognitions versus baseline, the activation of the left hemispheric anterior cingulate cortex lies in the border region to the supplementary motor cortex (BA 6). This area is supposedly engaged in the preparation of required motor responses (Cavina-Pratesi et al., 2006). Thus, the left anterior cingulate cortex can be considered across all correct recognitions to be associated with response conflict and the initiation of motor responses. The latter one further indicates a stronger influence of the sets *similars* and *outtakes* within the group of all correct recognitions. Correct responses to these unstudied stimuli were made with the right hand, which was initiated by the left motor cortex. The strongest and largest activation of this contrast was found in the occipital lobes. The maximum increase of neural activity lies in the left middle temporal gyrus (BA 19), but the cluster extends from the left into the right hemisphere (see also Fig. 17, **5.2.1.1**). In this study, the occipital region is assumed to play a key role not only in the perception but also in the. evaluation of visual information (Grill-Spector, 2003). The 'Sensory Reactivation Hypothesis' postulates that during the retrieval of information sensory imprints of the encoded stimuli are reactivated (K. A. Norman & Schacter, 1997). In order to make a 'known' or an 'unknown' decision, the perceived information of the film has to be reactivated, so that it can be evaluated together with the recognition stimuli. The large and strong activation revealed for this contrast within the occipital lobe presumably mirrors the effort to retrieve the old visual information from the film as well as the processing of the perceived recognition stimuli. The activation in the right pons might reflect activation of the sixth cranial nerve (Nervus abducens), which is responsible for eye movements (cf. Komisaruk et al., 2002). Lesion of this nerve results in paralysis of conjugate lateral eye movements (Pierrot-Deseilligny, 2004). Thus, the activation in the pons can be interpreted in this study as being associated with an increase of eye movements during the watching of the recognition pictures. The more intensive a picture is scanned the better the resolution (Underwood, Crundall, & Hodson, 2005). It can be assumed that when a recognition stimulus is more precisely watched, the details of it are better perceived and processed. Thus, the increase in eye movements enhances that the subjects correctly discriminate the stimulus as a studied or an unstudied one.

All false recognitions versus baseline displayed smaller clusters than all correct recognitions versus baseline. In the frontal lobe left hemispheric activation was revealed in the dorsolateral frontal cortex (BA 9) and right hemispheric activation in the ventrolateral/dorsolateral frontal cortex (BA 45/46). Parietal activations are displayed in the left posterior cingulate cortex (BA 31) and in the right posterior cingulate cortex/retrosplenial cortex (BA 23/30). Additionally, the right fusiform gyrus (BA 37) is activated as well as bilaterally the middle occipital-temporal gyri (BA 19). The activations within the left dorsolateral frontal cortex (BA 9) and the right ventrolateral/dorsolateral frontal cortex (BA 45/46) are similar to the ones discussed above. Thus, it can be assumed that these frontal regions are involved in performance monitoring processes in general. Contrary to the earlier assumption, this suggests that they are not specifically associated with correct or false responses or with the processing of studied or unstudied stimuli. The assumption that the bilateral middle occipital-temporal region is related to the processing of the stimuli and reactivation of the information of the film can also be assumed for this contrast. The posterior cingulate cortex (left BA 31) is assumed in this study to demonstrate a general monitoring of the recognition stimuli and their current relevance. This area is reported to be part of a "default mode" network, which is active till attention is focussed (Raichle et al., 2001). This indicates that one reason for false recognitions might be a shallow or superficial processing of the stimuli. A further explanation would be that because of the closeness of this activation to the left motor cortex (BA 4), it is related to the movement of the right hand, which corresponds to false responses to *originals*. The right hemispheric activation of the posterior cingulate cortex (BA 23/30) is surprising because this region is often reported to be associated with correct responses and successful retrieval (von Zerssen et al., 2001; Herron, Henson, & Rugg, 2004; Ranganath, Heller, Cohen, Brozinsky, & Rissman, 2005). Other studies have described how this region is involved in ecphory processes of affective autobiographical memories (Fink et al., 1996), and familiarity checking of faces and voices (Shah et al., 2001). For the purpose of this study, it can be assumed that this region is associated with monitoring and evaluation of familiarity caused by the recognition stimuli. In particular, the sets *similars* and *outtakes* might induce a familiar feeling, which results in false recognitions. Additionally, the activation might reflect a positive internally feedback to support the decision made, even if it turned out to be false. Activation of the right fusiform gyrus (BA 37) is associated with the perception of visual information, as well as the processing of specific information about the form of presented objects (J. S. Simons, Koutstaal, Prince, Wagner, & Schacter, 2003; Garoff-Eaton et al., 2005). In this study, a possible explanation for this activation is that during the processing of the recognition stimuli, the fusiform gyrus might discriminate details of the presented scenes. This further indicates that even though an unstudied picture is recognised as unknown, subjects are oblivious to this realisation. Other factors, like familiarity, might outweigh the perceived difference and result in false recognitions. Importantly, this interpretation might be true for the processing of the unstudied stimuli but not for the studied ones, which represent presented film scenes. Thus, the studied stimuli should be associated with a familiar feeling that further should result in correct recognitions.

The contrast all correct versus all false recognitions displayed a mainly left hemispherical neural network in the insula, the postcentral gyrus (BA 3), the orbitofrontal cortex/anterior cingulate cortex (BA 10/32), and the posterior cingulate cortex (BA 31). In the right hemisphere the lateral globus pallidus was activated. There were two activations in the left insula, one at the boundary to the postcentral gyrus (BA 3) and one near the claustrum. The left insula and the medial posterior cingulate cortex (BA 31) are presumably involved in self-monitoring processes emerging from willed action and predictability of the recognition stimuli (Blakemore, Rees, & Frith, 1998). Predictability of sensory stimuli implies the detection of their spatial-temporal patterns. Thus, stimulus predictability is easily estimated for self-generated actions because for them the spatial-temporal pattern is known. It seems that these two regions reflect the successful evaluation of the recognition stimuli and the resulting self-generated response performance (cf. Konishi, Wheeler, Donaldson, & Buckner, 2000). Additionally, together with the claustrum, the insula is assumed to be associated with the integration of sensory, motivational, emotional, and mnemonic information via reciprocal claustro-neocortical and its claustro-limbic connections (Guldin & Markowitsch, 1983, 1984; Markowitsch, Irle, Bang-Olsen, & Flindt-Egebak, 1984). Thus, the activation in the insula supposedly mirrors the processing and integration of the recognition stimuli and the perceived information of the film. Thus, the stimuli became better predictable that further resulted in correct responses of studied as well as unstudied stimuli. The small cluster activated within the left orbitofrontal cortex/anterior cingulate cortex (BA 10/32) possibly demonstrates a positive feedback for giving the correct response. The orbitofrontal cortex was reported to be involved in the representation of abstract reward situations (O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2002). Even though activation in the anterior cingulate cortex was found during false responses it is also associated with correct responses, which were made under conditions of increased response competition (Carter et al., 1998). These results indicate for this study that the orbitofrontal cortex/anterior cingulate cortex activation demonstrates successful monitoring during difficult decision processes (cf. Ullsperger & von Cramon, 2004). An interesting finding is the cluster within the left postcentral gyrus (BA 3). The left postcentral gyrus receives somatosensory information from the right side of the body. This indicates that in the group, all correct recognitions, the necessary mental processes to handle unstudied stimuli outweigh the ones for the studied ones, because to give a correct response to an unstudied picture, subjects had to press the right button with their right thumb. The left activation in the postcentral gyrus might demonstrate the sensorimotor process of their decision to reject unstudied stimuli. The only activation within the right hemisphere lies in the lateral globus pallidus, a structure, which is involved in initiating a selected motor program and inhibiting other competing programs (cf. 'cortico-subthalamo-pallidal 'hyperdirect' pathway', Nambu, Tokuno, & Takada, 2002; Nambu, 2004). Thus, there are two possible explanations for this activation. One is that it is related to correct recognitions of *originals*, which were given with the left hand. The other one indicates that this region is mainly associated with the suppression of moving the left hand. This would indicate that the revealed activation in the right lateral globus pallidus for all correct versus all false recognitions are predominantly related to the correct response of *similars* and *outtakes* ('unknown' – left hand, suppressing 'known' – right hand). In conclusion, the neural network, which was revealed to be activated for all correct recognitions, displayed regions that were mainly associated with successful recognition processes, self-monitoring processes of self-generated actions, and the execution of the respective motor responses.

The contrast between all false and all correct recognitions revealed activation within the right precentral gyrus (BA 4). This result supports the interpretation for the above described left postcentral gyrus activation. For studied stimuli, false recognitions mirror 'unknown' responses, which were given with the right hand, and correspond to the activation within the left hemisphere. For unstudied stimuli, false recognitions are associated with activation within the right motor cortex, which initiates the movement of the left hand for 'known' responses. It seems that the responses for *similars* and *outtakes* are related to stronger activation in the respective brain region, which outweighed the ones for *originals*.

The above discussed contrasts mostly displayed similar neural activities regarding correct and false recognitions across all sets. Thus, more interesting are the regions that are distinctively involved in giving correct and false responses. For correct recognitions these are the anterior cingulate cortex and the insula. The posterior cingulate cortex (BA 23/30) might be of specific relevance regarding false recognitions, as well as the fusiform cortex. Furthermore, the contrasts showed the expected results, stronger and larger activations for correct than for false recognitions.

The following results will not be discussed on the basis of the individual contrasts but on the basis of the anatomical affiliation of the revealed activations. The reason for that was that each contrast displayed several activations, from which some were displayed for several contrasts. This would entail repetitive interpretations of some regions. To avoid this it was decided to discuss the activations with regard to their affiliation. First, activations within the frontal cortex will be interpreted, followed by the ones within the parietal cortex, the temporal cortex, the occipital cortex, subcortical nuclei, cerebellum, and pons.

6.4.2 Frontal cortex

Activation within the frontal cortex was revealed in the orbitofrontal cortex (BA 10/47, inferior frontal gyrus, superior frontal gyrus), the dorsolateral frontal cortex (BA 8/9/47, medial frontal gyrus, middle frontal gyrus, inferior frontal gyrus), ventrolateral frontal cortex (BA 45, inferior frontal gyrus), insula, anterior cingulate cortex (BA 32/24), supplementary motor area (BA 6, medial frontal gyrus), and the precentral gyrus (BA 4).

In this study, the activations displayed in the orbitofrontal cortex were located in two areas, one was in the frontopolar area 10 and dorsal to that the other was found in the orbital area 47.

The frontopolar area 10 was activated in the right hemisphere for *outtakes-correct* versus *originals-correct*, bilaterally for *outtakes-false* versus *originals-false*, and left hemispherical for *outtakes-false* versus baseline.

The activation in the frontopolar area demonstrates that the decision making for *outtakes* might be harder than for the other sets (Cohen, Heller, & Ranganath, 2005). This region was associated with high-risk versus low-risk decisions (Rolls, 2004) and therefore its involvement in correct and false responses for *outtakes* might mainly indicate the degree of complexity of this set.

Similar to the first discussed contrast (all correct recognitions versus baseline) the orbital area 47 was bilaterally activated for three contrasts *correct rejected* versus *hits*, *similars-correct* versus *originals-correct*, and *similars-correct* versus baseline. For the contrast *outtakes-correct* versus baseline only the right orbital area 47 was displayed.

The previous interpretation that the orbitofrontal cortex is associated with verification processes of the recognition stimuli is supported by these findings. The activation in this region mirrors the successful distinction between perceived and not perceived information (Rolls et al., 2005), which is essential for decision making (Harrington et al., 2004). Furthermore, the orbital area 47 is exclusively activated for correct rejected unstudied stimuli. Thus, it can be assumed that this area mirrors the successful discrimination of *similars* and *outtakes*.

The dorsolateral frontal cortex (BA 8/9/46) is associated with several contrasts. Bilateral activations were found for *false alarms* versus *hits*, *outtakes-correct* versus *originals-correct*, *originals-correct* versus baseline, *similars-correct* versus baseline, *outtakes-correct* versus baseline, and *outtakes-false* versus baseline. Only the left hemispheric region was revealed for *correct rejected* versus *misses*, *false alarms* versus *misses*, *similars-false* versus *originals-false*, and *outtakes-false* versus *originals-false*. Activation only in the right hemisphere was displayed for *similars-correct* versus *originals-correct*, *originals-false* versus baseline, and *similars-false* versus baseline.

The dorsolateral frontal cortex mirrors the effort to evaluate the recognition stimuli appropriately (Rahm et al., 2006). This includes that active information of the recognition stimuli and of the film is selected, manipulated and the performance is monitored (Fletcher & Henson, 2001). Especially during complex recognition operations, which in this study were needed for the unstudied stimulus sets *similars* and *outtakes*, activation in the dorsolateral frontal cortex might reflect monitoring of the present stimulus together with information of the studied film, previous seen stimuli, and previous decisions (cf. Owen, 2000). The recognition stimuli in this study were presented randomly. Thus, subjects needed to monitor if they have seen of one specific scene, for example, first the stimulus of the set *originals* or of the set *similars* and what their response for it was. That the dorsolateral frontal cortex is mainly associated bilaterally with correct responses, except for the set *outtakes*, suggests that higher processing effort is needed to successfully evaluate the recognition stimuli and to respond correctly. Additionally, hemispherical differences of this region were reported, which suggests that the right dorsolateral frontal cortex is mainly associated with task planning and the corresponding left region with executive functions (cf. Newman, Carpenter, Varma, & Just, 2003). It can be assumed that for correct responses of the recognition stimuli of this study the dorsolateral frontal cortex has to be activated bilaterally so that both processes, task planning and their execution, can be executed. This interpretation is further supported by patients with lesions in the dorsolateral frontal cortex, three in right and three in left hemisphere, who showed higher false alarms rates Budson et al., 2005. Furthermore, the set *outtakes* was the only one, for which this region was found bilaterally activated for false recognitions. This might demonstrate that this set was more difficult to be correctly discriminated as unstudied. Thus, it is assumed that the stimulus set *outtakes* is more prone to false recognitions than stimuli of the sets *similars* and *originals*.

Activation in the ventrolateral frontal cortex (BA 45) was revealed only for some of the contrasts. Right hemispherical activation was found for the comparison *false alarms* versus *hits*, *outtakes-correct* versus *originals-correct*, *originals-correct* versus baseline, *similars-false* versus baseline, *outtakes-correct* versus baseline, and bilaterally for *outtakes-false* versus baseline.

The ventrolateral frontal cortex supposedly mirrors the mental comparison of the recognition stimuli with the information from the film by detecting elements in the pictures, which equal the film (cf. Rahm et al., 2006). This would mean that it strongly depends on the focus of the subjects' attention if a picture is correctly recognised or not. Supported is this interpretation by a study that investigated a verbal working memory task and related the left ventrolateral frontal cortex to decision interferences when conflicting attributes of a stimulus have to be correlated to the currently important situation

(Nelson, Reuter-Lorenz, Sylvester, Jonides, & Smith, 2003). That Nelson et al. (2003) referred to the left ventrolateral frontal cortex whereas in this study the right hemispheric one was activated might be explained with the different stimulus material. In this study visual stimulus material was investigated and not a verbal working memory task. Furthermore, other studies showed a bilateral involvement of this region for verbal as well as visual spatial tasks (e.g. Owen, 2000). Thus, the involvement of the ventrolateral frontal cortex presumably accentuates the complexity of the recognition stimuli.

Across all analysed contrasts the insula was displayed within the left hemisphere for *correct rejected* versus *misses*, *correct rejected* versus *hits*, *similars-correct* versus *outtakes-correct*, and *outtakes-correct* versus baseline.

The activation revealed in the left insula is similar to the one found for the contrast all correct versus all false recognitions. The previous assumption that the left insula is strongly involved in monitoring processes, which result from the predictability of the stimulus and the required willed action, is still acceptable. It was claimed that the predictability of a stimulus contains the detection of the specific spatial-temporal pattern of it (Blakemore et al., 1998). The spatial-temporal pattern of a stimulus can be equated with the source of it. This indicates that stronger activation in the insula reflects higher monitoring processes whilst the pattern of the unstudied stimuli is compared with the information of the film. This operation results then in the correct rejection of the unstudied stimuli.

The left anterior cingulate cortex (BA 32/24) was associated with the contrasts *hits* versus *false alarms*, *similars-correct* versus *originals-correct*, *outtakes-correct* versus *originals-correct*, *outtakes-false* versus *similars-false*, and *outtakes-correct* versus baseline. Activation in the right anterior cingulate cortex was found for *correct rejected* versus *misses*, *correct rejected* versus *hits*, and *false alarms* versus *misses*.

Except for the involvement of the left anterior cingulate cortex with *hits* versus *false alarms* this region can be mainly associated with the processing of unstudied stimuli. The activation in the left dorsal anterior cingulate cortex is similar to the one discussed for all correct recognitions versus baseline. The involvement of the anterior cingulate cortex might be mainly associated with the detection of situations, in which response conflict, and furthermore errors, might occur (Magno, Foxe, Molholm, Robertson, & Garavan, 2006). One assumed function of the anterior cingulate cortex is the monitoring of information processing and if necessary the initiation of adequate changes in cognitive control processes (Botvinick et al., 2004). This function is also described in the conflict monitoring hypothesis (Carter et al., 1998; Botvinick, Braver, Barch, Carter, & Cohen, 2001). This hypothesis further assumes that activation in the anterior cingulate cortex reflects error sensitivity and response inhibition (Braver, Barch, Gray, Molfese, & Snyder, 2001). Thus, it is not surprising that anterior cingulate cortex activation was further reported for correct responses that were associated with response conflict (Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003). This indicates that for this study the anterior cingulate cortex can be related to the effort to distinguish the recognition pictures. Furthermore, it can be assumed that the pictures of the set *outtakes* were often related to a strong familiar feeling. The false recognitions of this set are the only ones, which are associated with activation in the anterior cingulate cortex. Maybe this activation also demonstrates a positive feedback that the decision was correct, even though it was not necessarily true for *outtakes*. Thus, the internal conflict between information of the film and willed action would be minimised (cf. cognitive dissonance theory, **2.2.3**).

The supplementary motor area (BA 6) and the precentral gyrus (BA 4) are assumed to be involved in the motor responses. Thus, they are discussed together in this section.

Activation of the supplementary motor area (BA 6) was revealed in the left hemisphere for *false alarms* versus *misses*, *originals-correct* versus baseline, *originals-false* versus baseline, *similars-false* versus baseline, and in the right hemisphere for *false alarms* versus *hits*, *false alarms* versus *misses*, *originals-correct* versus baseline, *similars-false* versus baseline, *outtakes-correct* versus baseline, and *outtakes-false* versus baseline. The left precentral gyrus (BA 4) was activated for *correct rejected* versus *hits*, *misses* versus *false alarms*, *similars-correct* versus *originals-correct*, *outtakes-correct* versus *originals-correct*, *originals-false* versus *similars-false*, and *originals-false* versus *outtakes-false*. The right precentral gyrus (BA 4) was found for the contrasts *correct rejected* versus *misses*, *hits* versus *correct rejected*, *originals-correct* versus *similars-correct*, and *originals-correct* versus *outtakes-correct*.

A ‘known’ response was given with the left hand and though it was expected that correct responses to *originals* and false responses to *similars* and *outtakes* are associated with activations in the right supplementary motor area and precentral gyrus. Regarding to ‘unknown’ responses activation in the respective left regions was estimated. For this study, the left insula and the adjacent supplementary motor cortex was earlier assumed to be responsible for the active preparation of the motor response. In a recent study, subjects were instructed to respond with the index or middle finger of their right hand and activation in the left supplementary motor area was revealed (Cavina-Pratesi et al., 2006). In this study subjects used response-dependent their left or right thumb to respond. Though it is traceable that when a ‘known’ response is given with the right hand the left supplementary motor area is activated and the respective right area is activated for an ‘unknown’ response. Unexpected were the bilateral activations of these regions for some of the contrasts. These results suggest that, for example, a left hemispherical activation, which is not related to the active motor response for an 'unknown' decision (left hand), can be associated with the active inhibition of the right hand. The actual motor response is initiated in the precentral gyrus. 'Known' responses given with the left hand are associated with activation in the right precentral gyrus. For 'unknown' responses the right hand was used and was associated with the left precentral gyrus. Most of the results represent this expected activation aside from the right precentral gyrus activation revealed for the contrast *correct rejected* versus *misses*. The activated cluster for this contrast is small and lies adjacent to the postcentral gyrus (BA 3). Thus, this activation might also be related to the willed inhibition to move the left hand. Other studies also found activations in both hemispheres of the motor cortex, though the one contralateral to the used hand was stronger, but they did not discuss these findings (cf. Habib, McIntosh, Wheeler, & Tulving, 2003; Ruff, Knauff, Fangmeier, & Spreer, 2003; Christensen, Ramsoy, Lund, Madsen, & Rowe, 2006).

Besides of the dorsolateral frontal cortex, the frontal regions were mainly involved in processing *outtakes* and *similars*. The frontopolar area 10, which was interpreted to be associated with high risk decisions, was specifically related to *outtakes*. A frontal network was revealed, including primarily the orbital area 47, the left insula, but also the ventrolateral frontal cortex, the dorsolateral frontal cortex, and the anterior cingulate cortex that seemed to be correlated to difficult decision processes, which mostly resulted in correct responses. Outstanding were the orbital area 47 and the left insula, which were explicitly associated with correct rejections of unstudied stimuli, supposedly mirroring successful source discrimination.

6.4.3 Parietal cortex

In the parietal cortex was mainly the posterior cingulate cortex (BA 31) and the retrosplenial cortex (BA 30/29) activated. Furthermore, the postcentral gyrus (BA 3), the inferior parietal gyrus (BA 40), the superior parietal lobule (BA 7), and the precuneus were revealed.

The left posterior cingulate cortex (BA 31) was displayed for the contrast *correct rejected* versus *misses*, whereas the right hemispheric region was activated for the contrasts *outtakes-false* versus *originals-false*, *outtakes-false* versus *similars-false*, and *outtakes-false* versus baseline.

The posterior cingulate cortex might reflect focussed attention to detect similarities and differences between seen film scenes and recognition stimuli. The right posterior cingulate cortex, which is associated with attentional control during target detection, seems to act as an mediator between motivational bias and attention (cf. Small et al., 2003).

Furthermore, the medial posterior cingulate cortex was reported together with the left insula to be involved in the estimation of the predictability of stimuli (Blakemore et al., 1998). It seems that this area is one of the key regions, with which correct and false recognitions can be distinguished, presumably especially of the unstudied stimulus set *outtakes*. The left hemispheric posterior cingulate cortex is suggested for this study, together with the left insula activation, to be associated with successful detection of the unstudied stimuli. The right posterior cingulate cortex might demonstrate the unintentional integration of the *outtakes* in the context of the film. The activation of this region is assumed to mirror the false recognitions of these pictures as a result of the internal motivation to memorise and handle the film as a complete whole. Therefore, the missing parts of the film are presumably internally produced, and the respective recognition stimuli, *outtakes*, caused false recognitions.

The retrosplenial cortex was displayed either in the right or in the left hemisphere and was across all contrasts associated with processing of unstudied stimuli. The right retrosplenial cortex (BA 29/30) was found in this study to be associated with *false alarms* contrasted with *hits*, *false alarms* versus *misses*, and *outtakes-false* versus *originals-false*. Activation in the left retrosplenial cortex was revealed for the contrasts *correct rejected* versus *misses* and *outtakes-correct* versus *originals-correct*.

The right retrosplenial cortex was described to be involved with the retrieval of recent and autobiographical memories (Piefke et al., 2003; Bernard et al., 2004; Steinvorth et al., 2006). A recent study also associated the retrosplenial cortex with self-referential decision processes (S. C. Johnson et al., 2005). Furthermore, it is one of the structures involved in integration processes of self-referential stimuli in the context of oneself (Northoff & Bermpohl, 2004). This suggests for this study that the subjects integrated the unstudied stimuli, or at least parts of them, in their memory of the film. This interpretation is supported by strong interconnections between the retrosplenial cortex with brain regions, which are involved in encoding or/and retrieval processes (mainly the medial temporal lobe (in particular the hippocampus), the posterior cingulate cortex, and the (anterior) thalamus nuclei) (cf. Ranganath et al., 2005). Additionally, it was reported that patients suffering from prodomal Alzheimer's disease demonstrate hypometabolism in the retrosplenial cortex (BA 29/30) (Nestor, Fryer, Ikeda, & Hodges, 2003) and that amnesia can follow from damage in this region (e.g Yasuda, Watanabe, Tanaka, Tadashi, & Akiguchi, 1997). These studies indicate that the retrosplenial cortex is an important relay station between new and old visual information. The integration processes might result in familiarity for unstudied stimuli that further induces false responses during the recognition task. This would explain the high false alarms rate (cf. section **6.1**). The activations within the left retrosplenial cortex for *correct rejected* and correct responses to *outtakes* are larger and stronger than the ones revealed in the right hemisphere for false recognitions. This indicates that higher processing effort is needed to correctly reject the unstudied pictures. Furthermore, that the left retrosplenial cortex is associated only with correct recognitions of *outtakes* and the right retrosplenial cortex with false recognitions of the same set indicates that the set *outtakes* might prevail in the group of unstudied stimuli. Thus, the retrosplenial cortex is assumed to be an indicator for correct and false recognitions specifically for the stimuli of the set *outtakes.*

The postcentral gyrus (BA 2/3) was revealed in the right hemisphere for the contrast between *similars-false* and *originals-false* and in the left hemisphere for the contrast *correct rejected* versus *misses.*

The activation is related to the neural network that is responsible for the motor responses. False recognitions of *similars* were given with the left hand ('known' response) that was initiated by the right motor cortex. Correct rejections ('unknown' responses) to unstudied stimuli were made with the right hand that was initiated by the left motor cortex. Thus, similar to the activation in the precentral gyrus, which is mainly associated with initiating the motor response, the postcentral gyrus is supposedly receiving somatosensory information of the moving hand.

Activation in the left lateral parietal gyrus (BA 39) and the left superior parietal lobule (BA 7) was revealed for the contrast *false alarms* versus *misses.*

These activations indicate that the subjects thought that they truly made correct responses to the unstudied stimuli of the sets *similars* and *outtakes.* The left parietal cortex was reported to reflect the generation of giving a 'known' response to studied and unstudied stimuli (Okado & Stark, 2003; Wheeler & Buckner, 2003). Furthermore, the left parietal cortex was found to be activated for retrieval success (Henson, Rugg, Shallice, Josephs, & Dolan, 1999; Konishi et al., 2000). Though, these activations in this study might demonstrate the support of a 'known' response to unstudied pictures. Additionally, the left superior parietal lobule was revealed to be involved in processing of mental images (Ishai, Ungerleider, & Haxby, 2000), which supports the assumption that the not presented film parts were imagined and integrated in the memory of the film. This further resulted in false recognitions of unstudied stimuli of the set *outtakes.*

Activation in the right inferior parietal gyrus (BA 40) was displayed for the contrasts *outtakes-correct* versus baseline and *outtakes-false* versus baseline. Additionally, activation in the left precuneus was only revealed for the contrast *outtakes-correct* versus baseline.

These activations are suggested to demonstrate in this study that for the set *outtakes* visual imagination have taken place. Both regions are associated with strong visual imagination, which represent similar perceptual complexity as memories for experienced events (Ishai et al., 2000; Suchan et al., 2002; Gonzalez, Dana, Koshino, & Just, 2005). That means for this study that the missed parts of the film induced strong imaginations, which were represented in the recognition task by the stimuli of the set *outtakes*. Furthermore, it showed that the right inferior parietal gyrus and the precuneus might be involved in imagining these missed parts, but they did not explicitly differentiate between them and truly perceived information from the film.

In summary, the most interesting activations in the parietal cortex were found in the posterior cingulate cortex and the retrosplenial cortex. Both regions seem to be explicitly involved in processing the pictures of the set *outtakes*. Thus, they demonstrate that this set demanded higher processing effort than *originals* and *similars*. Additionally, it can be concluded that the left brain regions were associated with correct rejections, whereas the right hemispheric regions were related to false recognitions of *outtakes*.

6.4.4 Temporal cortex

In the temporal cortex the superior temporal gyrus (BA 22), the middle temporal gyrus (BA 21), the inferior temporal gyrus (BA 37), and the parahippocampal gyrus were revealed. The posterior activation in the middle temporal gyrus (BA 19) is discussed in the next section (**6.4.5**) together with the middle occipital gyrus (BA 19).

The left superior temporal gyrus, activated for the contrast *hits* versus *correct rejected*, is suggested to be involved in integration processes of form, colour, and motion information (Beauchamp, Lee, Haxby, & Martin, 2003). The activated cluster found here lies at the direct border to the posterior insula, which was interpreted earlier to be involved in performance monitoring processes. Thus, it can be assumed that the left superior temporal gyrus activation is associated with the integration of old and new visual information and decision processes regarding studied stimuli. This evaluation of *originals* might further confirm their affiliation to the studied film and results in correct responses.

The right middle temporal gyrus (BA 21) was displayed with a small cluster for the contrast *misses* versus *correct rejected*. This region was found to be associated with negative, rather than positive memories (Piefke et al., 2003). Accurate recognitions of negative facial expressions are also related to activation in the right middle temporal gyrus (Rosen et al., 2006). The interpretation in this study for the activation in the right middle temporal gyrus is that false responses to *originals* induced a negative feedback.

Then, the right middle temporal gyrus would not only reflect negative emotions, but also negative feedback for false rejections of studied stimuli.

The right inferior temporal gyrus (BA 37) belongs to the neural network that was reported to be activated regarding interaction processes of predictability of stimuli and willed actions (see discussion of left insula (**6.4.1**, **6.4.2**, and of posterior cingulate cortex **6.4.1**, **6.4.3**, Blakemore et al., 1998). This right hemispheric activation in the inferior temporal gyrus was found for the contrast *false alarms* versus *misses*. This further supports the previous interpretation that the false recognitions of the unstudied stimuli are at least in part caused by failures of the estimated spatial-temporal pattern.

The maximum of neural increase in the right parahippocampal gyrus for the contrast *outtakes-correct* versus *originals-correct* was found adjacent to the lingual gyrus (BA 18). The bilateral parahippocampal gyrus is associated with processing of visual stimuli (J. B. Brewer, Zhao, Desmond, Glover, & Gabrieli, 1998; Bar & Aminoff, 2003). Furthermore, Okado and Stark (2003) found the parahippocampal gyrus to be stronger activated for true than for false memories. It was assumed that the parahippocampal gyrus is specifically related to sensory details, which allows this region to discriminate between truly perceived and mentally imagined information (Cabeza et al., 2001). Thus, the involvement of this region can be suggested to reflect the processing of more detailed information of the *outtakes* that further leads to correct rejections of them.

In summary, activation within the temporal cortex was displayed sporadic for some of the contrasts. This indicates that these regions are mainly engaged in retrieval processes in general across all three sets.

6.4.5 Occipital cortex

The middle occipital gyrus (BA 18/19) was revealed for most of the contrasts, for correct and false recognitions and for studied as well as unstudied stimuli. Nearly all of these contrasts displayed bilateral activation in the middle occipital-temporal region. It is important not only to look at the tables but also at the "glass brains" of the contrasts. As it was noted for the first discussed contrast, all correct recognitions versus baseline, some of the clusters only displayed a maximum in the left or the right hemisphere. However, the "glass brains" showed that the activation covered the middle occipital-temporal region of both hemispheres. Furthermore, the large and strong results of *similars* and *outtakes* versus baseline suggest that this area is more involved in recognition processes of unstudied than of studied stimuli.

The results of this study did not confirm the ones of the study of Slotnick and

Schacter (2004) who found that late visual processing areas (BA 19/37) are associated with 'old/known' responses in general. In this study, the middle occipital-temporal region was involved in 'known' as well as in 'unknown' responses. The previous interpretation of these activations for the contrasts all correct and all false recognitions versus baseline was that it demonstrates the reactivation of the perceived visual information of the film as well as processing of the recognition stimuli. It is noticeable, that *originals-false* versus baseline is only associated with small bilateral clusters in this region. This indicates that these pictures were not closely examined and thus falsely rejected. Following this train of thoughts the large activation of *similars-correct* and *outtakes-correct* demonstrates that when these pictures are closely examined the differences between them and the originally perceived film became clear. These unstudied stimuli were then correctly rejected. This interpretation is also supported by the large activation found for *originals-correct* and the smaller one for *similars-false*, even though the latter one is still larger than the one for *originals-false*. The large cluster, which was revealed for *outtakes-false*, suggests that a further process might be reflected in the middle occipital-temporal region beyond reactivation and perception. Earlier, it was assumed that the higher failure rate for the set *outtakes* is due to imaginations for the parts of the film, which were not presented. These gaps seemed to be filled by imagining what might be happened. In the recognition task subjects saw pictures representing these not perceived but probably imagined parts of the scenes and falsely recognised more than half of them. Lesion in bilateral medial occipital lobe can result in visual object agnosia and prosopagnosia, which can further elicit the inability to imagine visual scenarios (Ogden, 1993). The patient, described in the study by Ogden (1993), was incapable to describe a experienced event with the witnessed visual richness or to retrieve the episode at all. A related result was reported from a study investigating visual perception and imagery. Ganis et al. (2004) demonstrated that these two processes are associated with overlapping brain areas, even though activation was larger for perception than for imagery. The activation in the middle occipital-temporal region might demonstrate the effort to process the unstudied stimuli with regards to reactivated old information of the film and imagined parts, respectively. This would explain why this region is more involved with *outtakes-false* than with the other two sets.

In conclusion, in this study it can be assumed that the occipital-temporal activation is mainly related to processing of perceived recognition stimuli, reactivation of visual information of the film, and to a smaller amount to imaginations, which completed the film by filling in the gaps.

6.4.6 Subcortical nuclei

The activations of subcortical nuclei, including nucleus ruber, lateral globus pallidus, thalamus, subthalamic nucleus, claustrum, and hypothalamus, are mainly associated with unstudied stimuli. Most of these nuclei are involved with initiating or inhibition of the motor response.

The nucleus ruber (contrast *false alarms* versus *hits*) is important for willed actions of limbs (Pritzel et al., 2003). Thus, the activation in the right hemisphere can be assumed to be involved, together with the right supplementary motor area (BA 6) and the precentral gyrus (BA 4), in processing of the actual motor response.

The right hemispheric activation in the lateral globus pallidus was revealed together with activation in the left thalamus, more specifically in the ventral/lateral nucleus of the thalamus (contrast *correct rejected* versus *misses*). The complex globus pallidus/thalamus is associated with voluntary limb movements whereas other possible actions are actively suppressed (cf. Nambu et al., 2002; Nambu, 2004).

The activation in the left subthalamic nucleus was displayed for the contrast *correct rejected* versus *hits*. This activation was revealed adjacent to the substantia nigra, which indicates control of the movement of the right hand that made the 'unknown' responses. The subthalamic nucleus is part of the basal ganglia, to which also belong the globus pallidus, the substantia nigra, the caudate nuclei, and the putamen. The basal ganglia circuit is associated to different motor activities (cf. Lehericy et al., 2006) and is closely controlled by the frontal lobes (cf. Cavedini, Gorini, & Bellodi, 2006). Within this circuit the subthalamic nucleus plays a key role at coordinating motor behaviour (Yasoshima et al., 2005; Aron & Poldrack, 2006). Thus, the involvement of the subthalamic nucleus in this contrast and the activation of the globus pallidus points out the greater demand of response control for unstudied stimuli.

The interpretation above for the basal ganglia is also assumed for the cluster revealed between hypothalamus and putamen for the contrast *outtakes-false* versus baseline. Even though the maximum of this cluster lies nearer to the hypothalamus, this activation is suggested to be more related to the putamen and thus be involved in response control processes.

The claustrum was displayed in the left hemisphere for *hits* versus *false alarms*. This region was earlier discussed together with activation in the left insula and is suggested to be involved in integration processes of old and new visual information. It might be that the claustrum is more associated with the successful comparison of old information of the film with *originals* because it was specifically revealed for this set.

6.4.7 Cerebellum

Activation in the cerebellum was revealed in the left hemisphere for the contrast *false alarms* versus *misses* and in the right hemisphere for *outtakes-correct* versus *originals-correct*.

The cerebellum is strongly associated with integration processes of sensory perceived information and motor output. Furthermore, it was reported to be involved in visual perception and in visual imagery processes (Ganis et al., 2004). Lesion in the left cerebellum results in deficits in visuospatial functions (Hokkanen, Kauranen, Roine, Salonen, & Kotila, 2006). This indicates an involvement of the cerebellum in processing the unstudied stimuli, presumably specifically *outtakes*, perhaps with reference to the perceived information of the film.

6.4.8 Pons

In the right hemisphere the pons was activated for the contrasts *correct rejected* versus *hits* and *similars-correct* versus baseline.

This activation presumably reflects increase in activity in the Nervus abducens (sixth brain nerve). A similar activation was discussed earlier for the contrast all correct recognitions versus baseline (**6.4.1**). That this cluster seems to be associated with the set *similars* supports the previous explanation that it mirrors the increase in eye movement during scanning unstudied pictures. The enhanced scanning of these stimuli might lead to an exacting resolution of them that further supports the detection of differences between them and the perceived scenes of the film. Thus, the pictures of the unstudied stimulus set *similars*, which were more precisely examined, were correctly rejected.

6.4.9 Summary neural correlates

In summary, the neuroimaging results revealed different neural activations for correct and false recognitions. It was hypothesised that correct recognitions of studied stimuli would be associated with stronger and larger neural networks. The first discussed results, all correct and all false recognitions across all sets, seemed to support this hypothesis. However, the results of the following contrasts did not verify the assumption. On the contrary, correct responses to *originals* appear to engage smaller neural network than the unstudied stimulus sets *similars* and *outtakes*. In general, unstudied stimuli are associated with stronger and larger activations than studied ones. This indicates that the processing and evaluation of *similars* and *outtakes* requires wider neural resources. This was supported by the revealed frontal activations, which are mainly involved in monitoring and response conflict processes of unstudied stimuli. It was demonstrated that the dorsolateral frontal cortex is more involved in monitoring processes during recognition processes and might be associated with correct recognitions when it is bilateral activated. The involvement of the ventrolateral frontal cortex and the frontopolar area 10 presumably mirrors the complexity of the recognition stimuli. A key region might be the orbital area 47, which is assumed to verify correct recognitions especially of unstudied stimuli. Furthermore, the left insula and claustrum are supposedly involved in identifying the source of a stimulus and thus support correct recognitions of studied and of unstudied stimuli.

The involvement of the occipital region is not entirely clear because this region is associated with processing of perceived and reactivated visual information as well as imaginations. Presumably, it is engaged in all three of these processes. The increase in activity in the occipital-temporal region seems to depend on initiation and monitoring processes of the frontal regions that support activations in the occipital region. The more and stronger frontal regions are activated the larger and stronger is supposedly the occipital region involved.

It seems that correct recognitions of *originals* and *similars* are mainly depending on careful processing of the recognition stimuli. False responses to *originals* are associated only with small activations, which are involved in visual perception, motor response, and task planning. A possible key region that discriminates between correct and false recognitions of studied stimuli was not revealed. The results for correct responses of *similars* showed that apparently increase in eye movements are responsible for higher resolution of the pictures and thus for correct rejections of them.

The set *outtakes* seems to engage an exceptional position. This set is associated with the strongest and largest activations across all sets. It confirms the assumption that subjects imagined parts of the film, which they had not perceived. Especially the parietal cortex, and here explicitly the retrosplenial and posterior cingulate cortex, might be engaged in processing of the unstudied stimuli of the set *outtakes*. Left hemispheric activations are revealed for correct rejections and right hemispheric ones for false recognitions.

Finally, the neuroimaging data showed similar results like the earlier discussed behavioural ones. The film paradigm induced false recognitions and the stimulus sets engaged different neural networks. Especially, the differences in the neural activations of the *similars* and the *outtakes* supposedly resulted from the different causes of false recognitions that they represent.

7 Conclusion

The phenomenon of false memories is an active area of research, which has seen increased interest lately. False recognitions are a form of false memories that can be investigated under controlled laboratory conditions. The main aim of this study was to investigate false recognitions on the basis of a complex visual stimulus. The newly developed film paradigm was shown to be useful in causing false recognitions.

Furthermore, it was able to distinguish between two different causes of false recognitions. These two causes were represented by the stimuli of the sets: *similars* and *outtakes*. It was shown that the set *outtakes* is associated with the highest false recognition rate, followed by the set *similars* and then the set *originals*. These results verified the assumption that false recognitions are not only provoked by stimuli, which are similar to the original studied film material but also by stimuli showing parts of the film that were not presented. These results demonstrated clearly that events are memorised as a complete whole, rather than in bits and pieces. As such, events are remembered without truly perceiving each and every part.

In order to distinguish between these two different causes of false recognitions, further studies should produce two separate films. The stimulus material for the set *similars* should be extracted from one film, and the stimulus material of the set *outtakes* should be extracted from the other film. Both films and their recognition material might be tested with two different groups of subjects. For the third set, new pictures should be used, which should be independent of the films. The results of these recognition tasks should clarify how similar or different these two causes provoke false recognitions. Furthermore, a known/remember paradigm or a rating on how certain the subjects may be with their responses, would further help to deepen the knowledge of these two causes of false recognitions.

Moreover, it was shown that the response time analysis should only be used as an additional tool to examine false recognitions. The results showed that longer response times were related to correct responses of unstudied stimuli and to false responses of studied ones. It was shown that these results were generally in line with previous studies. Additionally, the assumption that the two unstudied stimulus sets were handled differently from the *originals* was supported by the response times, but the data did not demonstrate a difference between the unstudied stimulus sets *similars* and *outtakes*. Nevertheless, response times should always be integrated in an investigation with a false recognition paradigm, because it was shown that the long duration of the recognition task did not influence the response behaviour of the subjects as it might be assumed.

Of special interest were the results of the neuroimaging investigation, which revealed different neural activation for the three sets. Further studies with the presented film paradigm should explicitly look for activations within the frontal and parietal cortex. These regions showed specific involvement in the recognition process of the stimuli. Additionally, the paradigm described above, which assumes two separate films to create the unstudied stimulus sets *similars* and *outtakes*, could be used to discriminate between the associated neural networks.

As far as it is known, no previous study investigated a comparable recognition set like the set *outtakes*. This set had specific parietal activations, and induced larger and stronger activations than the other two sets. It seems that the pictures in this set mirror a cognitive process, which had not been sufficiently investigated in previous research projects. In this study, the subjects did not confuse details of an event or associate some related information with a perceived event. The *outtakes* presumably represent a mainly unconscious process of imagining these parts of an event that were not perceived. It would be interesting to investigate if different circumstances are distinguishable for the set *outtakes*. For example, if emotive material reduces the false recognitions effect, or, if films showing specific topics (e.g. documentation, movie, animated film) reduce or increase the false recognitions effect. Moreover, further work could look at whether the same brain regions are activated by this new material, or whether the increase in neural activity only depends on the used stimulus material.

Altogether, there are several interesting differences between the discussed neuroimaging results and previous studies (e.g. Cabeza et al., 2001; Okado & Stark, 2003; Slotnick & Schacter, 2004). The latter ones often described specific activation in the medial temporal lobe (specifically the parahippocampal gyrus) for correct recognitions and further showed that the correct recognitions of previous studied material were associated with larger and stronger activations. In this study, activation in the parahippocampal gyrus was only found for correct recognitions of *outtakes* and this set was related to the largest and strongest activations. Future research should be carried out in order to investigate these differences, which could help to gain a deeper insight in the neural processes underlying false recognitions.

Finally, further work should address the film paradigm in combination with picture- or word-list paradigms as well as real-world episodes in order to demonstrate more clearly differences and similarities between these paradigms and the investigated phenomenon of false recognitions.

However, it is reasonable to conclude that the here revealed results can be applied, at least in part, to memory abilities in general. Memories can deviate from perceived reality without our knowledge. Even with respect to recent experiences, the results of this study show that memories can be changed and thus modify perceived information. This study also questions, once again, the reliability of eyewitness reports and suggests that these reports should be handled very carefully.

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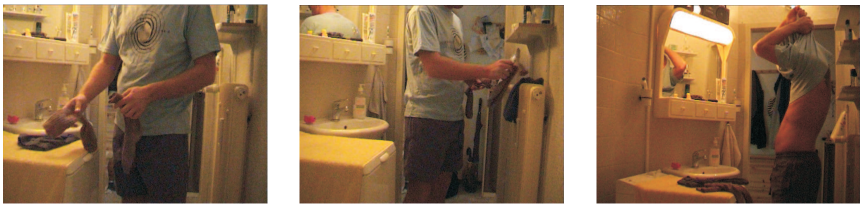
Appendix A

Pictures of the recognition task

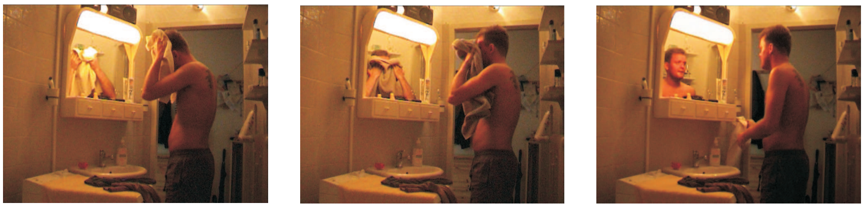
originals *similars* *outtakes*

scene 8



scene 9

scene 10



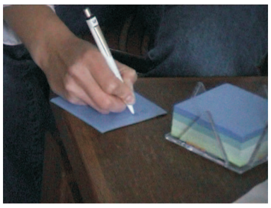
scene 11

scene 12

scene 13

scene 14

scene 15

	originals	*similars*	*outtakes*
scene 16			
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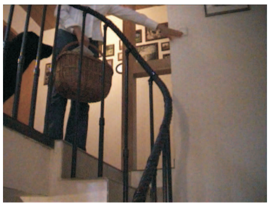
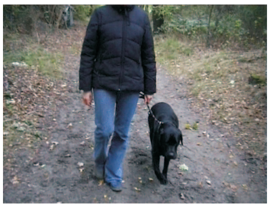
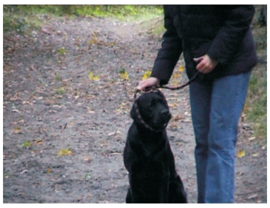
scene 18			
scene 19			
scene 20			
scene 21			
scene 22			
scene 23			

	originals	*similars*	*outtakes*
scene 24			
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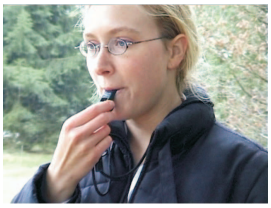
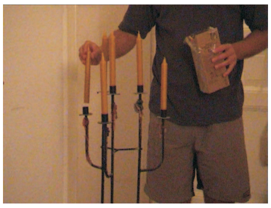
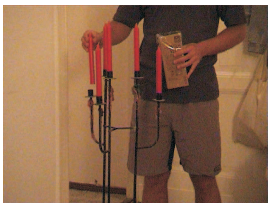
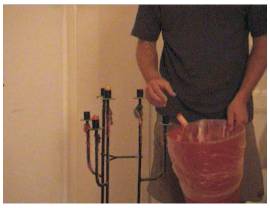
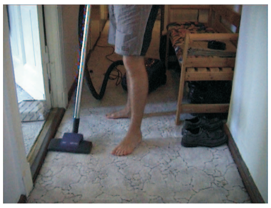
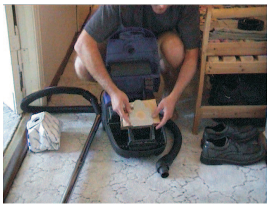
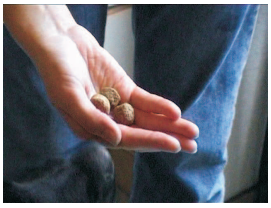
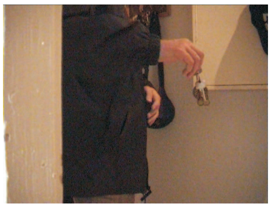
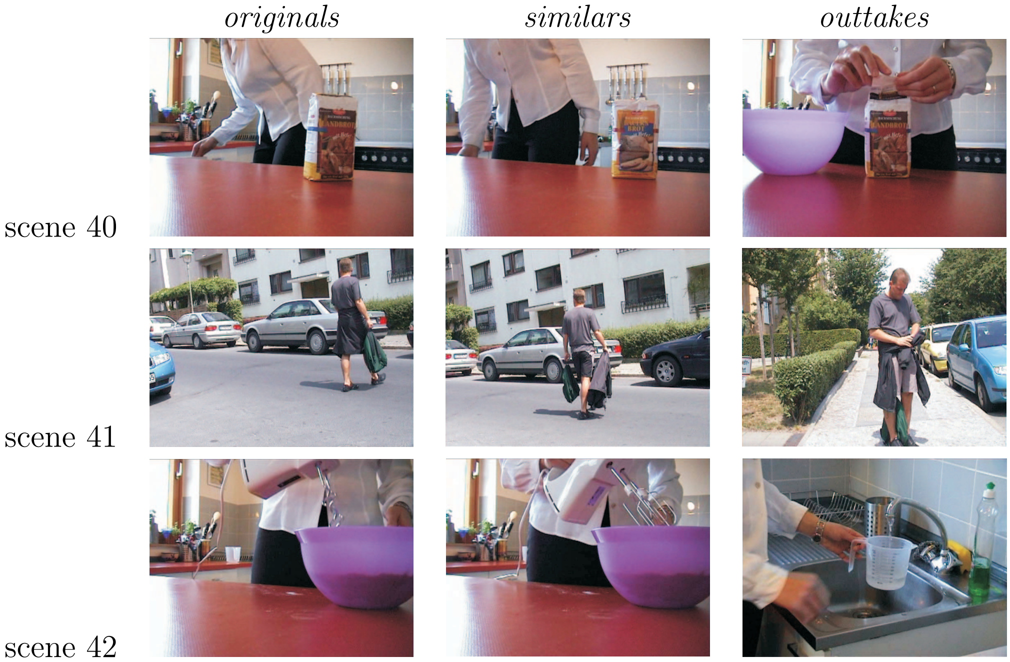
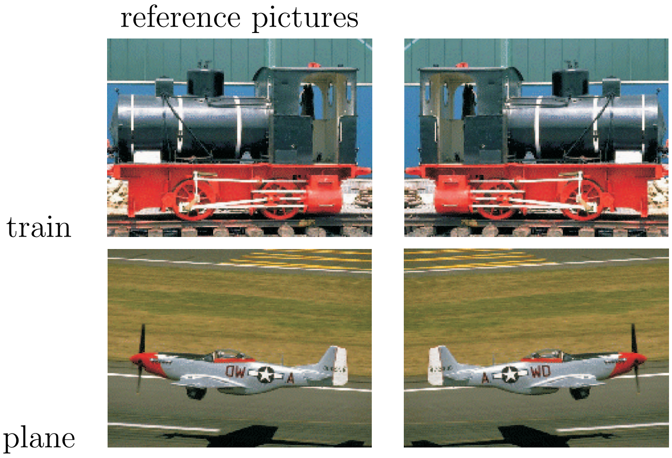
scene 26			
scene 27			
scene 28			
scene 29			
scene 30			
scene 31			

	originals	*similars*	*outtakes*
scene 32			
scene 33			
scene 34			
scene 35			
scene 36			
scene 37			
scene 38			
scene 39			


originals
similars
outtakes
scene 40
scene 41
scene 42


reference pictures
train
plane

Appendix B

Additional statistic: Comparison pilot and fMRI study

Comparison of recognition rates

A t-test for independent samples revealed neither for all correct (F = .302, p = .586) nor for all false (F = .321, p= .574) recognition rates significant differences between the two studies. Although, single comparisons are calculated with a oneway ANOVA.

originals-correct: F = 1.386, df = 1, p = .247
similars-correct: F = 3.091, df = 1, p = .087
outtakes-correct: F = 1.287, df = 1, p = .264

originals-false: F = 1.464, df = 1, p = .234
similars-false: F = 2.953, df = 1, p = .095
outtakes-false: F = 1.168, df = 1, p = .287

Comparison of discriminability indices and response biases

T-tests for independent samples revealed no significant differences between discriminability indices, d', and response biases, c, between *hits* and *false alarms*. Single comparisons showed only for the comparison between the indices of *hits* and *similars-false* significant difference.

d' (*hits* & *false alarms*): F = 2.325, df = 35, p = .067
d' (*hits* & *similars-false*): F = 2.139, df = 35, p = .049
d' (*hits* & *outtakes-false*): F = 1.747, df = 35, p = .119

c (*hits* & *false alarms*): F = 0.519, df = 35, p = .722
c (*hits* & *similars-false*): F = 0.395, df = 35, p = .920
c (*hits* & *outtakes-false*): F = 0.001, df = 35, p = .470

Comparison of response times (RT)

Single comparisons are calculated with a oneway ANOVA. The comparison of *originals-false* significantly differed. The mean values showed that the response time of the subjects of the pilot study was longer than the respective one of the fMRI study.

RT *originals-correct*: F = 2.128, df = 1, p = .154
RT *similars-correct*: F = 3.079, df = 1, p = .088
RT *outtakes-correct*: F = 2.739, df = 1, p = .107

RT *originals-false*: F = 2.719, df = 1, p = .011
RT *similars-false*: F = 0.848, df = 1, p = .154
RT *outtakes-false*: F = 1.211, df = 1, p = .084

T-tests for independent samples revealed no significant differences between the response times of first, second, and third part of the recognition task.

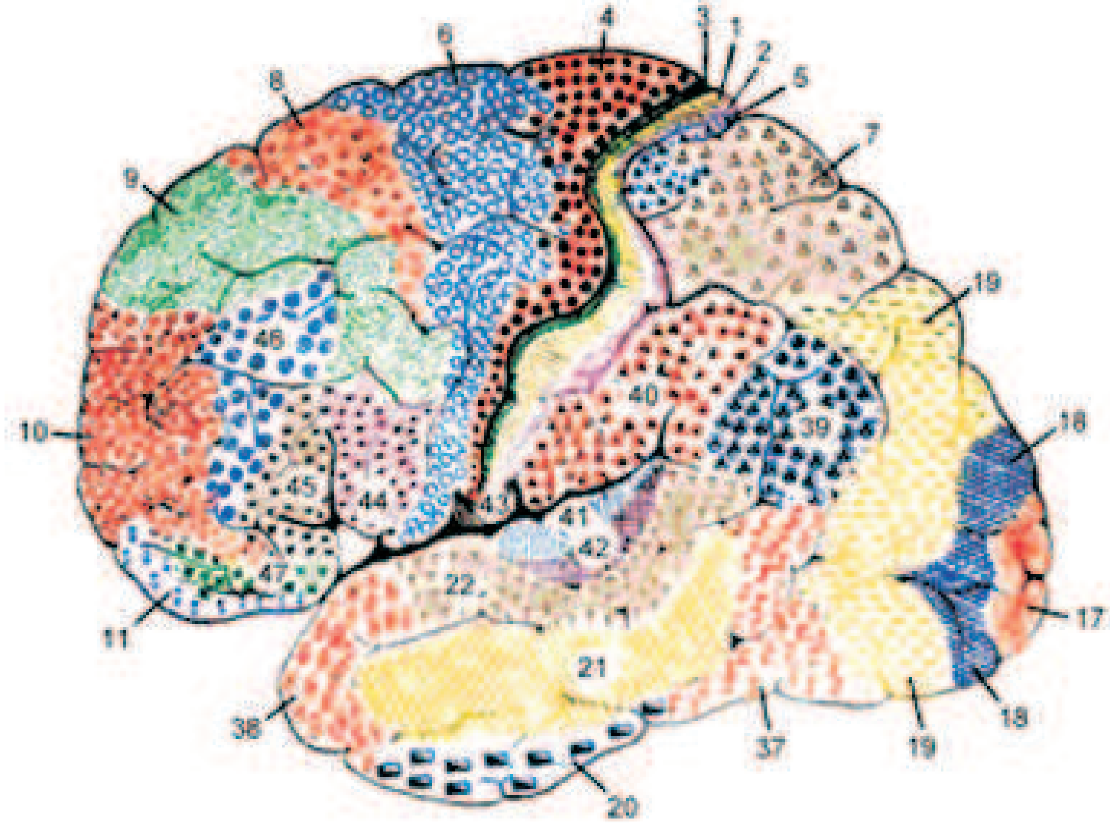
1. third-correct: F = ,0.031, df = 35, p = .236
1. third-false: F = 0.042, df = 35, p = .231

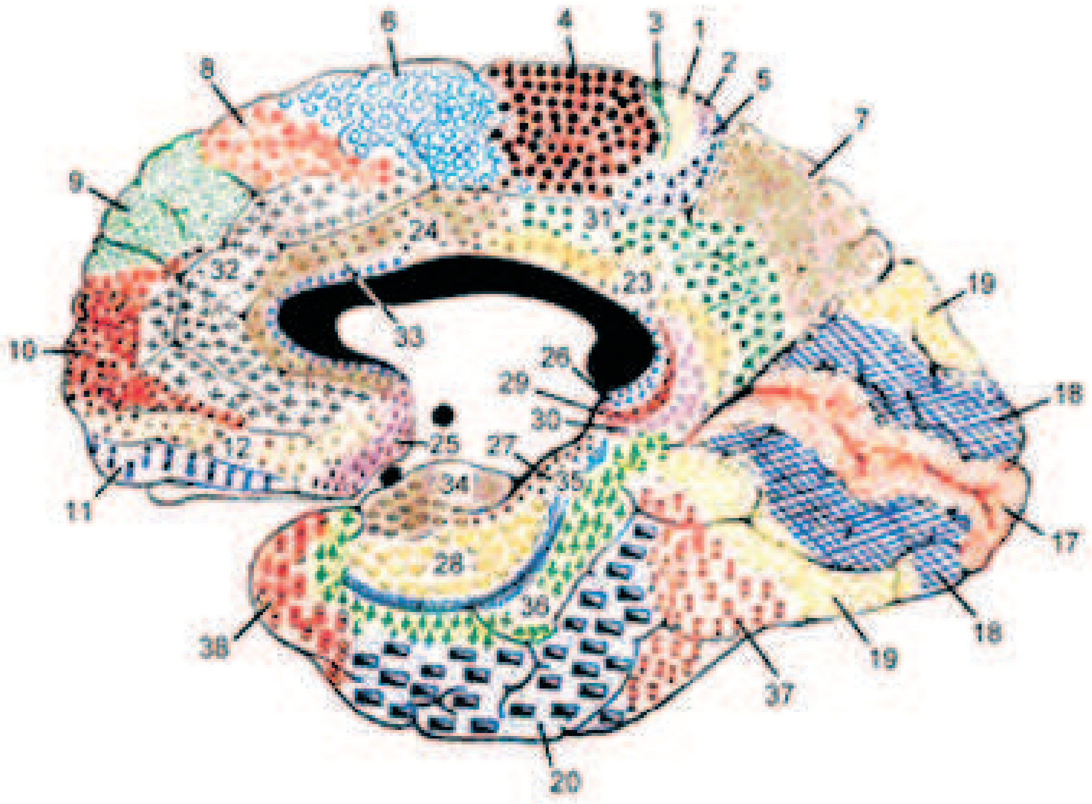
2. third-correct: F = 1.251, df = 35, p = .437
2. third-false: F = 0.927, df = 35, p = .485

3. third-correct: F = 0.091, df = 35, p = .482
3. third-false: F = 0.113, df = 35, p = .496

Appendix C

Brodmann areas





Declaration

I declare that the work presented in this thesis entitled

False memories
A study of false recognition caused by a stimulus film using functional magnetic resonance imaging (fMRI)

is my own work. None but the cited methods and materials were used. This work has not been submitted in this or another form at any other university or faculty.

________________ ________________________-

Date Signature