UNIVERSITÄT
DES
SAARLANDES

# Motivated Learning Influences Strategic Retrieval Processing – An ERP and Behavioral Approach

Dissertation
zur Erlangung des akademischen Grades eines
Doktors der Philosophie
der Philosophischen Fakultät III
der Universität des Saarlandes

vorgelegt von
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aus Göttingen
Saarbrücken, 2012

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Tag der Disputation: 20. Juli 2012

# General Abstract

Reward anticipation during learning is known to support memory formation but its role on processes engaged at the time of retrieval is so far unclear. Retrieval orientations, as a reflection of strategic or controlled retrieval processing, are one aspect of retrieval that might be modulated by reward. These processes can be measured using event-related potentials (ERPs) elicited by retrieval cues from tasks with different retrieval requirements, such as changes in the class of targeted memory information. To determine whether retrieval orientations of this kind are modulated by reward during learning, the effect of high and low reward expectancy on ERP correlates of retrieval orientation was investigated in two separate experiments. In Experiment 1 reward manipulation at study was associated with later memory performance, whereas in Experiment 2, reward was directly linked to accuracy in a study task. In both studies, participants performed a recognition memory exclusion task 24 hours later. In addition to a previously reported material-specific effect of retrieval orientation, a frontally distributed, reward-associated retrieval orientation effect was found in both experiments. These findings were interpreted as indicating that reward motivation during learning leads to the adoption of a reward-associated retrieval orientation to support the retrieval of highly motivational information. Thus, ERP retrieval orientation effects not only reflect retrieval processes related to the sought-for materials but also relate to the reward conditions with which items were combined during encoding. In Experiments 3a-d, effects of positive (potential gain of money) and negative incentives (potential loss of money) during learning on later memory performance were behaviorally investigated in a cross-cultural context with a similar experimental design as used in Experiment 1. Independent of participants' origin (China or Germany), memory performance was better when the positive or negative incentive to memorize an item was high. However, a cross-cultural effect was found in the experiments that used negative incentives during learning. The magnitude of the differences in memory accuracy for items previously studied in apprehension of potential high loss of money compared to low loss was significantly higher in Chinese than in German participants. This effect might reflect that Chinese participants were more sensitive to the pending loss of money than German participants. The findings reported here provide new insights into how strategic retrieval processes and accurate memory judgments are affected by motivated learning and into how cross-cultural influences might act on these.

# Table of Contents

# Index of Publications

This doctoral thesis is based on three studies, of which two (Experiment 1 and Experiment 2) were submitted as an 'original article' in an international peer-reviewed journal and currently under revision. I am the first author of the article. However, other authors also contributed to the work and are listed below. The article is not exactly presented as in the submitted form, but single paragraphs of the introduction and discussion sections, figures and particularly the method and results sections were taken over.

| ***Content*** | ***has been published/submitted as*** |
|---|---|
| Chapter II, Chapter III | Halsband, T.M., Ferdinand, N.K., Bridger, E.K., & Mecklinger, A. (2012). Monetary rewards influence retrieval orientations. Cognitive, Affective, and Behavioral Neuroscience, 12, 430-445. DOI 10.3758/S13415-012-0093-Y |

# Index of Figures

# Index of Tables

# Abbreviations

| | |
|---|---|
| µV | micro-volt |
| Ag/Agcl | silver / silver chloride |
| ANOVA | analysis of variance |
| cm | centimeter |
| DC | direct current |
| dB | decibel |
| EEG | electroencephalography |
| e.g. | for example |
| EOG | electro-ocular activity |
| ERPs | event-related potentials |
| fMRI | functional magnetic resonance imaging |
| Hz | hertz |
| i.e. | that is |
| kΩ | kilo-ohm |
| ms | millisecond(s) |
| MTL | medial temporal lobe |
| NAcc | nucleus accumbens |
| PFC | prefrontal cortex |
| ROIs | regions of interest |
| RTs | reaction times |
| SD | standard deviation |
| VTA | ventral tegmental area |

# Chapter I: General Introduction

Humans are unique amongst animals in that they are able to acquire new knowledge both by the influence of direct reward as well as via the anticipation of remote (intrinsic or extrinsic) reward. Changes in neuronal activation patterns that are driven by these processes of reward-motivated learning can take place even before new knowledge has been encountered (Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006) and are an important determinant of whether an event will be recovered at a later time (Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980).

The basic neural mechanisms of brain areas supporting motivated learning have been extensively studied in animals as well as in human beings. Data from animal experiments can be very useful and also animal models of human memory are mostly indispensable, especially when the research requires invasive, intracranial methods. For instance, already in the early 1950s, Olds and Milner (1954) were able to demonstrate that rats equipped with intracranially implanted electrodes mainly in the septal area (medial olfactory area, considered as a 'pleasure zone' in animals) and the nucleus accumbens (NAcc) of the brain, continuously pressed a lever for electrical self-stimulation of these particular brains areas to obtain a (presumably) rewarding, pleasant experience. Through the decades, the ventral tegmental area (VTA) in the brain turned out to play a central role in conveying reward effects when dopaminergic neurons in the medial forebrain bundle became activated through electrical stimulation (Bozarth, 1994).

Recent brain imaging studies (Adcock et al., 2006; Wittmann, Schott, Guderian, Frey, Heinze, & Düzel, 2005) indicate that two neural systems in the human brain play a crucial role during reward-motivated learning, the mesolimbic dopamine system and the medial temporal lobe (MTL). Activation of the first system has been shown not only to redirect attention but also to interact with hippocampal memory processes in the second system, mainly by activating dopaminergic pathways in the VTA and projections to the NAcc in the ventral striatum (see Figure 1.1).

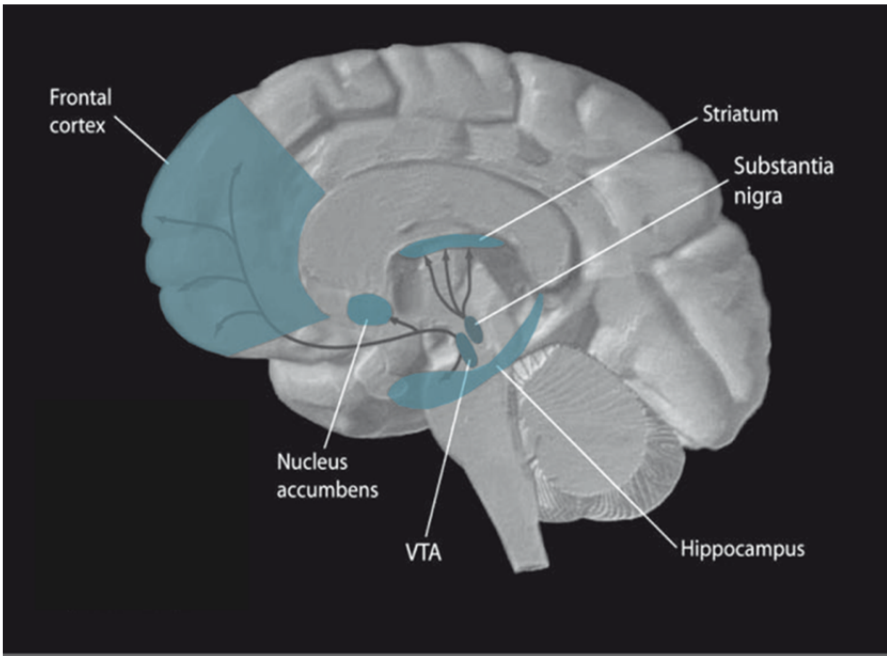



**Figure 1.1** Simplified schematic of the mesolimbic dopamine system in the human brain. Retrieved and modified from the National (US) Institute on Drug Abuse Research Report Series. Dopamine (in blue) located within the VTA is released in the NAcc and the PFC. Dopamine pathways also project to the hippocampus (as part of the MTL) and via the substantia nigra to the striatum. (http://www.nida.nih.gov/Researchreports/methamph/methamph3.html).

The findings presented above provide insights into how expectation of rewards during learning supports memory formation in humans. These processes that were engaged when new information was encoded into memory are important to be strictly investigated as they determine whether that information will be later recovered or not. However, the potentially influential role of motivated learning on processes engaged at the time of retrieval is so far unclear and was therefore the main goal of the present thesis. This was investigated in two experiments using event-related potentials (ERPs) and in one experiment using behavioral measures.

Of principal interest was to find out whether high amounts of incentives during learning might have an impact on the degree of effectiveness during controlled memory retrieval. In this, the question of whether and how monetary incentives during learning influence episodic memory retrieval processes has been foregrounded. This is necessary because in order to provide an exact account of the influence of motivated learning on retrieval, the neural and behavioral correlates of memory retrieval processes need to be taken into account.

A particularly noteworthy feature of a 'reward system' in the animal or human brain is that it not only responds to positive but also to negative events. That is, the dopamine transmitter system appears to respond to stimuli that are potentially rewarding, punishing or painful, next to novel or other salient stimuli. Positive, reinforcing events generally lead hereby to approaching behavior, negative events to avoidance behavior.

Furthermore, recent research has often focused on the impact of inter-individual differences on the neural processing of reward, hence mainly investigated clinical populations. In this way, it was revealed that learning disabilities but also neuropsychiatric diseases such as substance dependence (Bjork, Smith, & Hommer, 2008), schizophrenia (Juckel, Schlagenhauf, Koslowski, Filonov, Wüstenberg, Villringer et al., 2006), eating disorders (Harrison, O'Brian, Lopez, & Treasure, 2010) and mania (Abler, Greenhouse, Ongur, Walter, & Heckers, 2007) originated from abnormal sensitivity to reward or punishment or from dysfunctional learning with any form of rewards. Clinical results like these are of high relevance, especially for successful treatments of these diseases and impairments. However, in order to be able to make inferences about motivated learning and its influences on episodic memory retrieval processes in a general population of healthy subjects, less extreme inter-individual variations on the normal, non-pathological range should be taken into account and included in current research. Insights into cognitive processing of healthy individuals during motivated learning and memory retrieval are crucial for the understanding of dysfunctional learning and for the development of innovative, effective therapy methods. On these grounds, the work in this thesis capitalizes on this and focuses on healthy, young students in an effort to understand the factors that are associated with the improvement of learning and episodic memory to provide further input into the domain of fundamental research in experimental neuropsychology.

The next paragraphs will begin by a brief introduction of the fundamentals of the event-related potential technique to demonstrate the way ERPs can be used to test cognitive theories and describe how it was used in two of the studies presented in this thesis. This method of ERPs will be described first to enable a clearer understanding of the ERP memory studies that will be reported later. ERPs form an indispensable approach used in neuroimaging research as they provide temporally sensitive indicators of, for instance, participants' cognitive processes engaged during memory retrieval that would not be measurable via behavioral measures alone (e.g. reaction times, accuracy) or other imaging methods.

Next, a brief overview of the theoretical considerations with regard to processes of learning and strategic memory retrieval will be provided. Findings of current research will be presented that provide details about the role of fronto-temporal brain networks during the anticipation of rewards and retrieval. Selected, fundamental research studies will be presented and discussed and I will particularly concentrate on the cognitive state of retrieval orientations which are relevant for memory retrieval. Their neural correlates as revealed by ERP measures and the situations in which they are usually adopted will be outlined.

Then, at the end of the introductory Chapter I, an overview will be given of the main research questions that were intended to be investigated in the work presented in this thesis and a brief summary of the obtained results. This thesis comprises three studies which form the empirical work. The main research goal hereby was to determine whether strategic memory retrieval processes, i.e. retrieval orientations, are modulated by high and low amounts of monetary incentives during learning and whether cross-cultural influences might act on these. Each study will be individually presented and discussed in detail in Chapter II, III and IV. Finally, in the last chapter (Chapter V), the achieved findings will be discussed in the context of the role of motivated learning at the time of retrieval and in a broader framework in order to make an attempt of an integrative account of the obtained ERP and cross-cultural, behavioral results and to outline some future directions.

## 1.1 The Method of Electroencephalography and Event-Related Potentials

In the first two experiments (Experiment 1 and Experiment 2) that are presented in this thesis, electrical brain activity was measured by electroencephalogram (EEG), a device which was developed by Hans Berger (1929). This neuroimaging method in its non-invasive form can be applied in scientific as well as in clinical settings. The EEG is usually recorded from multiple electrode sites placed on the scalp. By this means, the measurement of voltage fluctuations is possible that were found to result from ionic current flows arising from neocortical pyramid cells contiguous to the locations at which they were recorded (Birbaumer, Elbert, Canavan, & Rockstroh, 1990; Niedermeyer & Da Silva, 2004). According to Coles and Rugg (1995), amplitudes of a standard EEG usually lie in the range of -100 and +100 µV with frequency ranges around 40 Hz or above. Unlike hemodynamic imaging techniques (e.g. fMRI), the millisecond-range temporal resolution that can be achieved with EEG is very impressive and can be seen as a nearly real-time index of neural activity. It allows an assessment of the time course of cognitive operations such as how retrieval-related processes evolve in relation to the timing of a retrieval cue. By contrast, the spatial resolution is much less impressive which is why care should be taken with the localization of the generating brain structures.

The majority of the experiments that form the empirical part of this thesis focus on ERP indices of controlled memory retrieval, in particular on ERP slow waves to investigate neural correlates of retrieval orientations. In general, ERPs refer to averaged EEG responses that are associated with the presentation of a particular stimulus (Coles & Rugg, 1995). Necessary to that end is an averaging process that has to be separately conducted for each electrode site in order to obtain an individual averaged ERP waveform for each combination of experimental condition and electrode site of interest. Finally, the averaged waveforms of all individual subjects of an experiment based on the same combination of stimulus type and electrode site can then be averaged together to obtain the grand averaged ERP waveforms. These grand averaged ERP waveforms have the advantage of being less influenced by between-subject variability than ERPs of single subjects. Furthermore, ERPs can either be time-locked to the stimulus presentation or to the delivery of a subject's response. ERP slow waves are characterized by a positive or a negative deflection in the averaged ERP and usually extend over several milliseconds up to several seconds. Changes in the amplitude of a waveform can be determined by contrasting waveforms of different experimental conditions. By this, it can be examined whether a difference exists in the degree to which a process was invoked in order to demonstrate the specific time courses of cognitive operations. The amplitude of an ERP waveform is seen to reflect the magnitude of an engaged cognitive process. The latency of a waveform's peak is thought to index the point at which neural activity was at its highest. By this means, ERP slow waves are a particularly useful and highly sensitive tool in order to examine processes involved during the initiation and maintenance of retrieval orientations. In sum, the measurement of ERPs is seen as a very suitable and highly sensitive method providing indices of processes engaged in service of retrieval as well as those that come about during successful retrieval. The detailed examination of the initiation and maintenance of these controlled memory retrieval processes are in the focus of the present thesis.

## 1.2 Reward and Memory Formation

To data, there are only a few studies that have examined the relationship between influences of rewards and memory formation by the use of brain imaging techniques.

Recently, one brain imaging study was conducted by Wittmann et al. (2005) in which pictures were presented that either cued possible monetary reward or were neutral. On reward trials, participants earned money for a correct and fast response in a subsequent reaction time task whereas they lost money for an incorrect or slow response. After three weeks, an unexpected recognition memory test followed in which pictures that were previously presented had to be discriminated from new, unstudied pictures. Reward anticipation during the reaction time task was found to activate brain regions associated with the dopaminergic system (mainly substantia nigra and striatum) which in turn co-activated the hippocampus (in MTL) and led to enhanced recognition memory performance. In a related fMRI-study (Adcock et al., 2006), reward cues were incorporated into an intentional memory paradigm. Participants' task was to study pictures that were either preceded by a high or a low reward cue and to perform a visual-motor task in each trial. The cues indicated the amount of money that would be received for each correctly recognized study picture during a recognition test the next day. Memory performance was better for pictures studied with a high than a low reward cue which was linked to enhanced brain activation in areas related to the mesolimbic dopamine system (VTA and NAcc) and in the hippocampus during learning (see Figure 1.2). This enhanced activity in the high reward condition during learning predicted later memory of the picture, that is it differed as a function of later remembrance, even though it occurred before the stimulus had been presented (subsequent memory effect, further described below).

A B

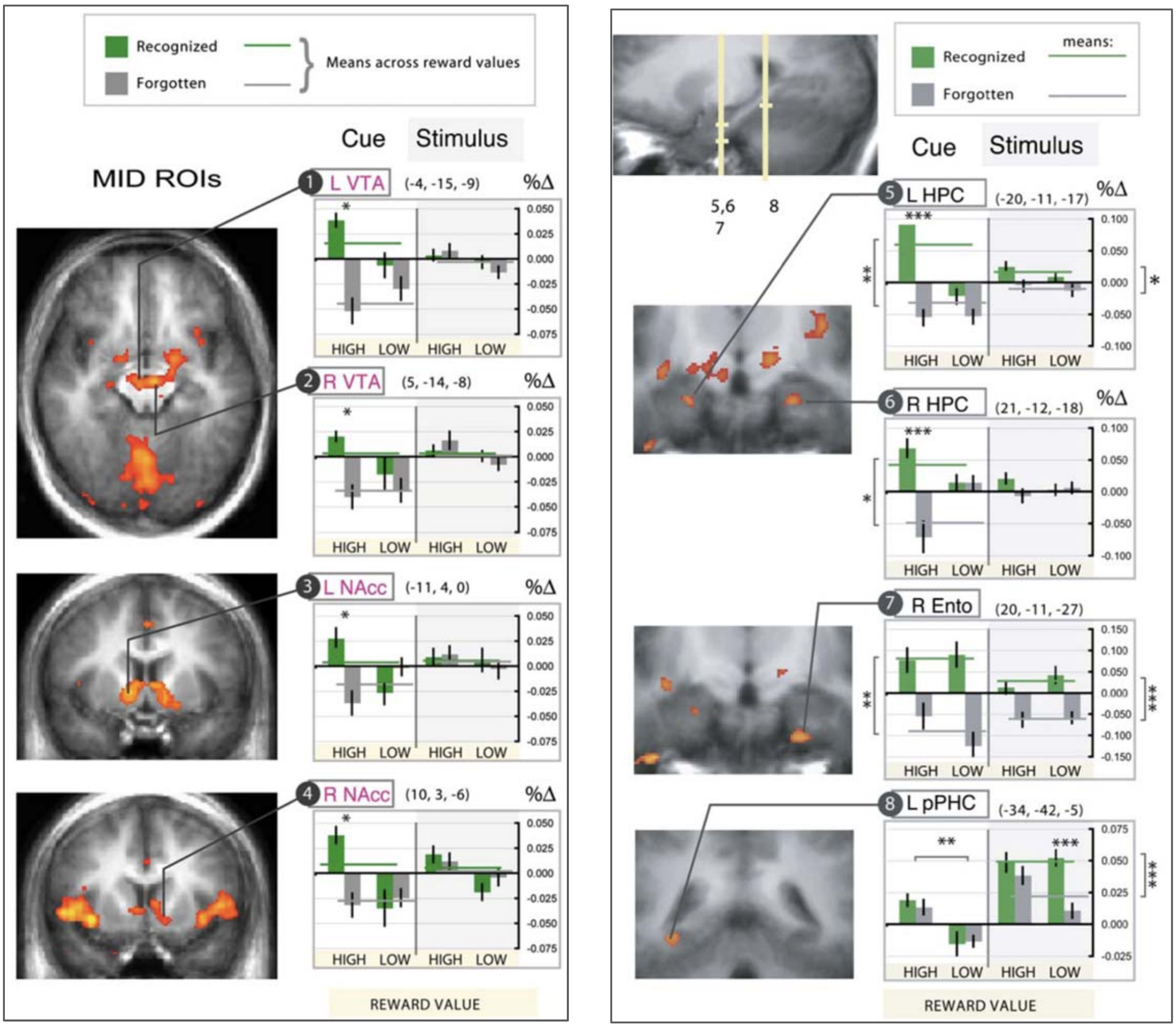



**Figure 1.2** Taken from Adcock et al., 2006. Depiction of the measured neural activity in brain areas of the mesolimbic dopamine system (VTA and NAcc) in part A (left side) and the activity of brain areas that belong to the medial temporal lobe in part B (right side). Green bars represent the amount of signal change versus baseline (in percent units) before (cue interval) and after (stimulus interval) an item was recognized, gray bars refer to subsequently forgotten items. L = left; R = right hemisphere, HPC = hippocampus; ENTO = entorhinal cortex. High reward cue = 5$; low reward cue = $0. Increased activity only for high reward cues were found in the VTA, NAcc and the hippocampus preceding only subsequently remembered instead of forgotten items (cue interval). Memory-related activation during encoding (stimulus interval) was only found in MTL regions.

Taken together, these findings support the view that in humans reward or anticipation of reward during learning modulates memory formation via direct neuronal connections between the mesolimbic reward system and the medial temporal lobe memory system. However, an important and yet unexplored issue is the role of reward during retrieval.

Common to all studies that are reported in this thesis was a 24 hours retention interval between a study and a test phase. This was based on the finding that, so far, memory enhancing effects of reward anticipation were only found with long (24 hours until 3 weeks) retention intervals. It is suggested that processes underlying memory consolidation, including the assumed dopaminergic input to the hippocampus and its memory enhancing consolidation effect in the hippocampus, need some time until consolidation is equally finished (Wittmann et al., 2005). That is, the co-activation of dopaminergic midbrain areas and the hippocampus might have a stronger impact on long-term than on immediate memory. Support for this assumption comes, for instance, from in-vitro studies demonstrating that dopaminergic neuromodulation influences the expression of long-term potentiation (LTP) by lowering the threshold for it, but only in late-LTP and not in early-LTP (Huang & Kandel, 1995; Sajikumar & Frey, 2004, but see Jay, 2003 for a review). In addition, LTP was found to be important for synaptic plasticity (Pittenger & Kandel, 2003) and together with the release of dopamine during motivated learning it might be responsible for an accuracy enhancing effect on long-term memory. In sum, it can be assumed that an increase of memory accuracy for stimuli predicting high levels of incentives might be based on a boosted consolidation for these stimuli that needs time for completion.

## 1.3 Episodic Memory

To begin and before more details about processes will be presented that are involved at the time of memory retrieval, a brief introduction to the human memory system is given. First of all, processes of learning and memory generally involve at least three stages: encoding, storage and retrieval (Melton, 1963). That is, after perception of new information, successful encoding is a necessary prerequisite for the creation of a storable memory trace (Tulving & Thomson, 1973). By this, a memory trace can be seen as the connection between processes that were active during successful encoding of an event and later retrieval environment.

The long-term memory is seen as an efficient mnemonic system that possesses the capacity to store large amounts of various types of information over long periods of time. Moreover, it is able to select only that part of information that is needed in a particular situation. As can be seen in Figure 1.3., long-term memory is assumed to be divisible into subcategories of explicit (declarative) and implicit (nondeclarative) memory (e.g. Squire, 1992; Tulving, 1972). Of principal interest in the work presented here is the episodic memory system which, next to semantic memory, is categorized as part of the explicit long-term memory. Episodic memory refers to the storage of assemblies of memory representations that consists of events embedded in their contexts of time and place. For example, the remembrance of details of the last summer holidays (e.g. location, atmosphere, food) might form an entry as an event in episodic memory. By contrast, semantic memory is defined as storage for memory representations that usually emerge due to repeated exposure of the same information in different contexts. These semantic memory representations comprise general knowledge of events, facts and the meaning of physical objects or words (e.g. in fragment completion tests) (Tulving & Markowitsch, 1998).

However, whether episodic memory can clearly be seen as a separate and independent system from the semantic one is still debatable (f.e. see Howard & Kahana (2002) for more details). For instance, anterograde amnesia due to lesions in the MTL was classified as an impairment of explicit memory in which operations of episodic and semantic memory are equally affected. But according to Tulving (1972) and Tulving and Markowitsch (1998), whose ideas have been extremely influential in this domain, retrieval of episodic memory differs from retrieval of semantic memory in many aspects. For example, wherever a reference is made to a previous event in one's own past (e.g. reference to a study phase in a recognition test), it relates to episodic memory. In other words, and to be exact in Tulving's words, episodic memory retrieval was metaphorically labeled as "mental time travel through and to one's past" (Tulving,1983; Tulving & Markowitsch, 1998) referring to the 'travel' back in time to search and select personally relevant, episodic information for conscious recollection and re-experience of the past and to 'travel' forward in order to anticipate future events. According to the currently widely held view this flexible mechanism is seen to be unique to episodic memory.

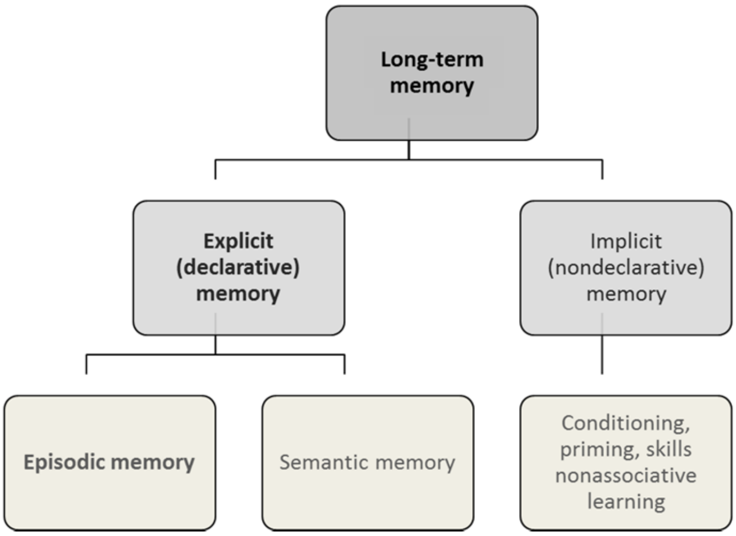



**Figure 1.3** Rough scheme of long-term memory components as proposed by Squire (1992).

Furthermore, as episodic memory is characterized by the possibility to focus attention on own, personal experiences, it is said to be associated with 'autonoetic' awareness. Autonoetic awareness enables humans to differentiate between episodic memories they themselves experienced and impersonal facts they have learned in the past (Tulving, 1983) due to explicit memory that consists of contextual associations. For instance, within the scope of the present studies, an episodic event which requires autonoetic awareness is formed by the occurrence of pictures and words in a list that participants were previously asked to remember.

Finally, in contrast to semantic memory, episodic memory was found to develop later in young children and to be sooner impaired in old age (Tulving & Markowitsch, 1998). A great role in episodic memory plays the medial temporal lobe structures, including the hippocampus which associates episodic memory with selective and unique cortical activity.

## 1.4 Memory Retrieval Processing

According to Tulving (1983), memory retrieval can occur when retrieval cues successfully interact with stored memory representations. The conducted studies of this thesis mainly comprise investigations of the relationship between ERP correlates of retrieval processes - principally, ERP new item effects - and memory performance, in order to find out whether motivation during learning might have an influence on memory retrieval and if so whether they might be detectable in the ERPs and behavioral outcomes. ERP new item effects refer to the differences between ERPs elicited by new items in a memory recognition test.

They are assumed reflect processes that are active when participants make an attempt to search for memories. These effects will be further described below.

It is assumed that strategic or controlled memory retrieval processes do not simply refer to the recovery of a previously encountered event. They rather involve whole series of control mechanisms operating before and after retrieval in order to facilitate and adapt the interaction between one or more internal or external retrieval cue and an already existing memory representation to current goals of task demands or intentions (Mecklinger, 2010). A retrieval cue is defined as a tiny part of previously encoded information which enables the access to a memory. It can be presented in whichever modality and can be either internally or externally generated. In sum, retrieval refers to the whole process that ensures task-appropriate behavior, including the progression around the time point of appearance of a retrieval cue until the reproduction of the targeted memory representation.

This critical process of the successful interaction of a retrieval cue with a memory trace was originally termed ecphory by Semon (1921, p. 12) and described as "[…] the influences which awaken the mnemic trace […] out of its latent state into one of manifest activity […]". Ecphory was then interpreted and reworded by Schacter, Eich and Tulving (1978) as the transmission of a hidden memory trace into usable information in order to activate and re-experience the stored details. However, for successful retrieval cue-memory interactions, supportive automatic and strategic binding mechanisms are indispensable (Moscovitch, 1989; 1992; Moscovitch & Melo, 1997; Zimmer, Mecklinger, & Lindenberger, 2006). These are needed in order to link several events or single features into coherent episodes and to form associative connections in response to a retrieval cue such that the episode can then be retrieved all in one. By this, same memory contents can be retrieved by means of different retrieval cues.

In order to measure activity in brain regions during successful retrieval (e.g. regions in the MTL), several studies have been conducted in which either functional magnetic resonance imaging (fMRI) (Gabrieli, Brewer, Desmond, & Glover, 1997; Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000; Cabeza, Rao, Wagner, Mayer, & Schacter, 2001), depth electrode recordings (Paller & McCarthy, 2002), or magnetic source imaging (Papanicolaou, Simos, Castillo, Breier, Katz, & Wright, 2002) was used. However, it was often relatively difficult to measure activity associated with retrieval success in the MTL, as it was revealed that this region of the brain is also active during encoding, even during incidental encoding (Stark & Okado, 2003). That is, because a standard recognition memory test typically consists of previously studied items, together with new, unstudied items, those new items will be simultaneously encoded, resulting in increased activity mainly of the MTL (Stark & Okado, 2003). And, in order to determine retrieval success, the contrast between correctly identified old items and new items is taken, the results are often blurred or obscured by this increased activity for both item types (retrieval of old item information and incidental encoding of new item information). In other words, activity in the MTL not only predicts subsequent memory performance during an intentional memory test but also predicts subsequent remembrance for new items that were shown only during memory testing (Stark & Okado, 2003). These findings might be the underlying reason for the fact that incidental encoding-related activity in memory tests has often obscured results of retrieval success (e.g. Schacter & Wagner, 1999).

In sum, controlled memory retrieval processes are very flexible as memory representations can be retrieved from a variety of cues in highly diverse environments and even in different states of minds of the person who attempts to remember as long as enough attention is paid to the cues.

Since many years, it is known that episodic memory retrieval is not an all-in-one process but that retrieval can rather be subdivided into more or less clearly dissociable subprocesses. Most of them that are of interest here are thought to occur prior to actual retrieval by having an impact on which memory contents are recovered. Other retrieval processes, so-called post-retrieval processes affect how recovered memory content is processed later.

### *1.4.1 Retrieval Mode*

One of these processes that occur prior to retrieval is retrieval mode. It refers to a cognitive state that has to be adopted in order to ensure that environmental stimuli are treated as episodic retrieval cues and consequently to enable autonoetic awareness (Lepage, Ghaffar, Nyberg, & Tulving, 2000; Tulving, 1983; Wheeler, Stuss, & Tulving, 1997).

### *1.4.2 Retrieval Orientation*

Furthermore, the recovery of previously studied information has to be accompanied by a specifically adopted retrieval orientation. Retrieval orientations are a class of retrieval processes that are related to the concept of retrieval mode (Mecklinger, 2010; Rugg & Wilding, 2000). The adoption of a particular retrieval orientation is assumed to enable the very high degree of selectivity which is needed when only one discrete event at a given moment is aimed to be retrieved. It was suggested that retrieval orientations provide a more constrained and task-specific form of retrieval processing than retrieval mode as it supports the recovery of specific kinds of studied information (Rugg & Wilding, 2000). Furthermore, Rugg and Wilding (2000) proposed that whereas a specific retrieval mode remains stable across different episodic retrieval tasks, retrieval orientations alter between specific task demands. That is, retrieval orientations are flexible cognitive states adopted to strategically initiate processes according to particular retrieval demands in response to retrieval cues. Being or not being in a specific retrieval mode together with an adopted retrieval orientation determines whether or not a retrieval cue in one situation may be effective with regard to successful memory retrieval.

Processes underlying the adoption of retrieval orientations have been investigated in recognition memory tests in which neural activity elicited by correctly rejected new items has been compared between test conditions that differ with respect to the type of information encoded at study or the type of study task (Dzulkifli & Wilding, 2005; Herron & Rugg, 2003; Hornberger, Morcom, & Rugg, 2004; Hornberger, Rugg, & Henson, 2006; Robb & Rugg, 2002). Across studies of this kind, ERP analyses have been limited to new items because this ensures that any differences in these contrasts can be attributed to changes in retrieval cue processing, whilst confounding changes in retrieval success are removed (Donaldson, Wilding, & Allan, 2003).

Furthermore, in some reports, the adoption of specific retrieval orientations has been found to relate to memory performance (Bridger, Herron, Elward, & Wilding, 2009; Herron & Rugg, 2003; Herron & Wilding, 2004). For example, in one recent report by Rosburg, Mecklinger and Johansson (2011), words were presented at study that were either followed by a picture depicting the object of the word (perceived condition) or by a white rectangle which meant that participants had to create a mental image of the object word themselves (imagined condition). In subsequent test blocks, these old items were represented intermixed with new items. In one test, participants were asked to respond on one key to previously imagined items (targets) and on a second key to seen items (non-targets) as well as to new words. The designation of items to target and non-target/new responses in this way is typical of the retrieval demands employed during recognition memory exclusion tasks (Jacoby, 1991). To enable a comparison of ERPs to new items exposed to different retrieval demands (a change in retrieval orientation), the target/non-target designation was switched in a second retrieval block. ERP deflections for new words were more positive when items from the imagined condition were targets than when perceived items were targets. Memory performance was lower in the imagined target condition, and frontal ERP retrieval orientation effects were larger for those participants who showed a greater memory performance difference between the imagined and the perceived target condition. This pattern comprises an important link between the adoption of specific retrieval orientations and recognition memory performance (see Bridger et al., 2009 for a comparable relationship) and highlights the influential role of the engagement of certain retrieval orientations on memory performance. Influential processes of this kind may also be sensitive to reward manipulations and may thus provide one locus by which reward modulates memory performance. Retrieval orientations, as a sensitive and influential index of retrieval processes, therefore provide a suitable starting point for assessing the impact of reward-motivated learning on episodic memory retrieval.

Herron and Rugg (2003) have previously reported the outcomes of contrasts between new item ERPs from a comparable task but in which only the type of information encoded at study differed. In this case, the study history of the different items remained the same. Participants were presented with a series of pictures and words at study. At test, words which either corresponded to the studied pictures or had previously been studied as words were presented intermixed with new words, and again a binary discrimination was required for these three types of test items. In one test block, participants were then asked to respond on one key to studied words (targets) and on a second key to studied pictures (non-targets) as well as to new words.

As can be seen from Figure 1.4, ERPs elicited by new words were more negative-going in blocks in which studied pictures served as targets compared to blocks in which studied words were targets. This effect was most pronounced between 300 and 1000 ms post-stimulus and was broadly distributed over the scalp. The effect is thought to reflect retrieval cue processes that maximize the likelihood of retrieving targeted memory representations in each test phase, in line with the notion that participants can in principle perform the exclusion task on the basis of recovering target items alone (Herron & Rugg, 2003; Bridger et al., 2009).

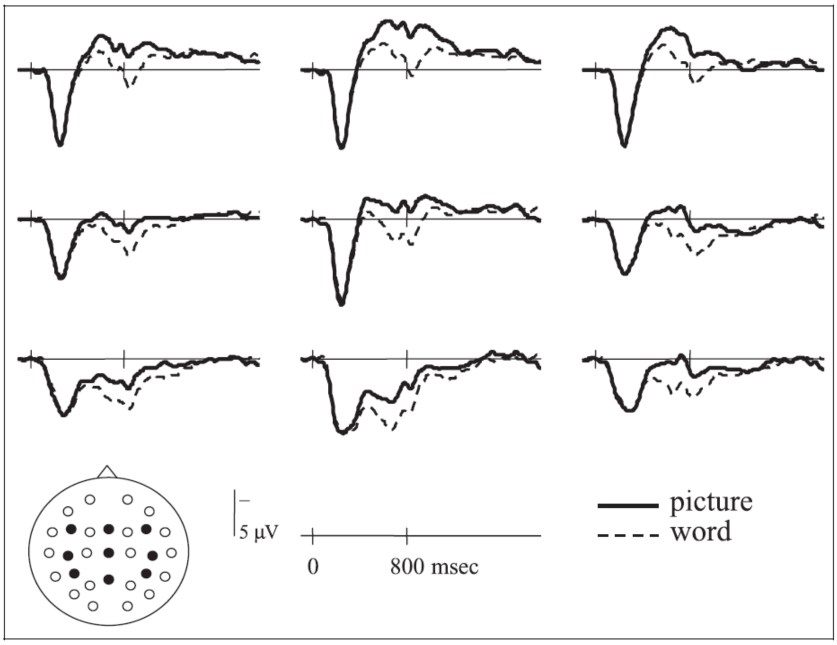



**Figure 1.4** Adapted from Herron and Rugg, 2003. Grand average ERPs elicited by correctly classified new items in the target-picture and in the target-word blocks. Data are shown for 9 electrode locations at left, midline and right hemisphere sites at frontal, central and, posterior scalp sites. The waveforms were inverted such that negative polarity is up.

Support for this comes from experiments which have reported characteristically similar retrieval orientation effects in item recognition tests in which all old items in a test phase either did or did not match their studied format (Hornberger et al., 2004; Hornberger et al., 2006). As can be seen from Figure 1.5, when retrieval cues at test were presented as words, ERP waveforms were more negative-going when studied pictures served as targets. By contrast, the effect reversed when the retrieval cue format had changed. That is, when memory was cued by pictures and when studied words served as targets, the ERP waveforms were more negative-going.

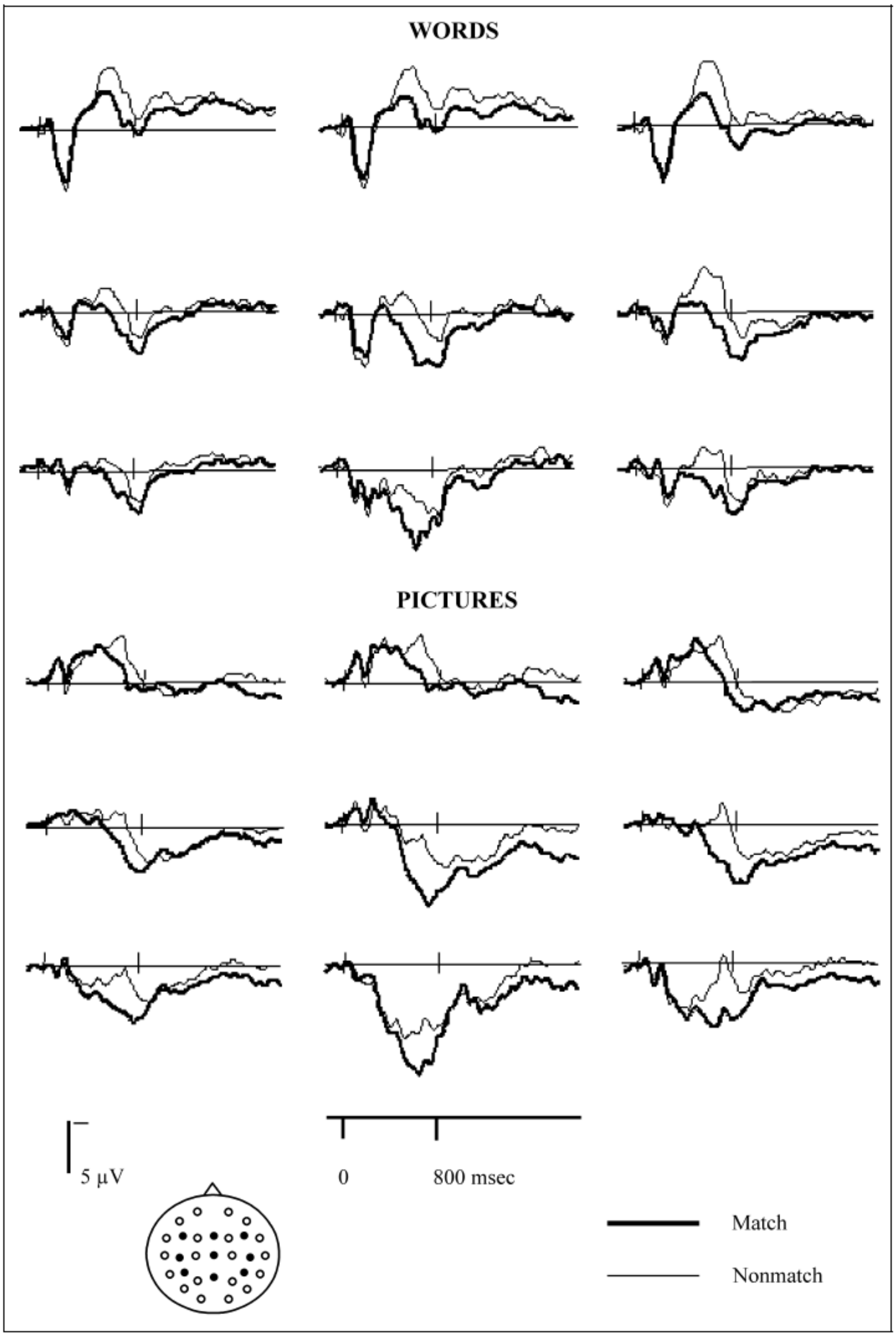



**Figure 1.5** Taken from Hornberger et al., 2004. Grand average ERPs elicited by correctly classified new items when either word or pictures were used as retrieval cues under the condition that study items (pictures versus words) were matching or nonmatching with the cue material. Data are shown for 9 electrode locations at left, midline and right hemisphere sites at frontal, central and, posterior scalp sites. The waveforms were inverted such that negative polarity is up.

ERP correlates of retrieval orientations in these paradigms are thus assumed to reflect strategic retrieval processes that optimize the resemblance between a cue and memory representation in order to facilitate the retrieval of targeted information. Thus, especially based on the results of Hornberger et al. (2004), it can be assumed that ERP retrieval orientation effects are not simply a consequence of the attempt to retrieve pictures versus words (a material effect), that is they appear to be independent of the particular type of material that was presented at study or test. ERP retrieval orientation effects rather arise under conditions in which retrieval cues differ in the degree of similarity to the targeted type of information (a cue similarity effect). In those kinds of modality-mismatch conditions, in which the retrieval cue format and the items format at study differed from each other, the ERP waveforms were typically found to be characterized by a greater negativity than in matching conditions. This relative ERP-negativity is thought to reflect the process of conceptually constraining retrieval cue representations in the direction of a more similar representation level of the sought-for memory representation (Hornberger et al., 2004).

Additionally, similar retrieval orientation effects were even found under conditions when retrieval cues did not physically overlap in material with either class of study item (e.g. pictures and visual words as study items and auditory word as retrieval cues) (Hornberger et al., 2004).

Important in this context is also that ERP retrieval orientation effects were found to be independent of differences in task difficulty or task performance at test (Robb & Rugg, 2002) and of the use of different study tasks (e.g. indoor/outdoor judgment task for words versus size judgment task for pictures, as used by Hornberger et al., 2004).

### *1.4.3 Retrieval Effort*

Retrieval effort can be defined as the amount of resources needed during the whole process of memory retrieval, especially in service of a retrieval attempt (Rugg & Wilding, 2000). The mobilization of these processing resources usually depends on the difficulty for example of a previous study task or a recognition task. When new information is only superficially encoded, e.g. during a categorical study task, much more effort during retrieval is assumed to be needed than when information was more deeply encoded (e.g. a semantic study task). Therefore, neural correlates of retrieval effort can usually be found by comparing ERPs to new items of two recognition tests that differ in difficulty (e.g. long versus short study list, as used in in the study of Robb & Rugg, 2002) and not in which the associated study material differed (as used to investigate neural correlates of retrieval orientations) .

### *1.4.4 ERP Old/New Effects*

ERP-Old/New effects are indices of successful memory retrieval in EEG-research. These effects come about when ERPs to correctly identified old items in a recognition memory test are typically more positive as compared to ERPs to correctly classified new items. Whereas processes as retrieval mode, retrieval orientation and retrieval effort usually refer to processes operating just before a finally successful retrieval (i.e. pre-retrieval processes), there are also processes that can be categorized as post-retrieval processes. These are those that operate according to specific task goals and intentions. For this purpose, post-retrieval processes facilitate the allocation of attention towards particular details of retrieved information or the capture of information in working memory until the intended retrieval goal was attained.

Neural correlates of post-retrieval processes that are of interest in the context of this work are the so-called late posterior negativity (LPN) and the right frontal old/new effect. The analysis of post-retrieval processes can shed some light on retrieval ‘contents’. Commonly, post-retrieval processes begin around the time at which a subject makes a response and lasts for several hundred milliseconds. A commonly agreed operational definition of the analysis of these correlates is to contrast ERPs to correctly classified ‘old’ items with those to correctly classified new items of an item recognition task.

The LPN is a well-investigated component (for a review see Johansson and Mecklinger, 2003) which is, as its name already implies, characterized by a relatively late onsetting, bilateral posterior negativity and is currently functionally interpreted in various ways. For instance, this effect is proposed to index successful retrieval of source information (Senkfor & Van Petten, 1998; Van Petten, Senkfor, & Newberg, 2000), response processing (Wilding & Rugg, 1997, Kuo & Van Petten, 2006), memory search processing for detailed sensory information (Cycowitz, Friedman, & Snodgrass, 2001; Cycowicz & Friedman, 2003), retrieval and evaluation of attribute conjunctions (Johansson & Mecklinger, 2003), or in fact, a conglomeration of parts all of these listed processes (Herron, 2007).

For instance, in a recent study conducted by Mecklinger, Johansson, Parra and Hanslmayr (2007) it was examined whether the LPN would alter its size as a function of varying extents of source retrieval requirements in a recognition memory test. Participants’ task at test was to either recover how they had interacted with the item when it was studied or to retrieve the study location of the item. The results indicated that the LPN was greater for the condition in which participants retrieved semantic operations as compared to judging the study location. Accordingly, this effect was interpreted as an index of the search for task-relevant, source-specifying attributes in order to reconstruct previous episodes.

The right/frontal old/new effect is defined as a temporally widespread effect with a relative positivity for old items. This effect is predominant at right frontal electrode sites (Wilding & Rugg, 1996) and interpreted as a reflection of the evaluation of post-decisional aspects during retrieval and is therefore seen as an effect which is independent of the correctness of a response judgment. This is based on the finding that the right frontal old/new effect was also elicited irrespective of whether old items were judged as old on the basis of retrieved episodic or semantic information (Hayama, Johnson, & Rugg, 2008). Hayama and colleagues (2008) therefore assumed that the effect reflects monitoring processes that operate on retrieved information independent of the type of retrieved contents from episodic memory.

## 1.5 The Cortical Reinstatement Hypothesis

As already mentioned above, for finally successful memory retrieval information has to undergo some processes which imply encoding and storage. Processing of this kind was found to be highly context-dependent which refers to the basic principles of ‘transfer-appropriate processing’ or ‘encoding specificity’ (Tulving, 1983).

Craik and Lockhart (1972) stated in their levels of processing theory that the depth at which information is processed during encoding (seen as a continuous process) influences later memory performance. According to the authors, deeper encoding, e.g. through the form of semantic processing, implies a greater level of cognitive analysis and elaboration of new material which consequently results in an often durable memory trace. Conversely, more shallow encoding, e.g. through the form of processing based on orthographic or phonemic components of the new information was assumed to lead to rather short-lasting and weaker memory traces (Craik & Lockhart, 1972). Furthermore, these authors, together with Tulving and Thomson (1973) were one of the first who postulated that encoding processes and subsequent retrieval operations interact with each other. The extent to which a retrieval cue is finally effective, that is successfully comes together with a memory representation, depends on how much the learning context is reinstated by the retrieval situation. Tulving and Thomson (1973) used the label ‘encoding specificity principle’ in order to describe the extent to which memory representations depend on how information was previously perceived and encoded, as this in turn determines what aspects of information would be finally retrieved.

However, in the same decade, Morris, Bransford and Franks (1977) brought some opposing wind to the idea that deeper, semantic levels of encoding mostly result in better memory performance than encoding at shallower levels (Craik & Lockhart, 1972). They conducted several behavioral experiments in which participants incidentally studied words either via deep, semantic levels of processing (does the word fit in the context of the sentence?) or via shallow, phonetic encoding (does the word rhymes with this second word?), followed either by a standard yes/no-recognition test or by a recognition test in which the targets were rhymes of the items presented at study. With this between-subjects design in which not only the processing levels during encoding but also during test were taken into account, it was revealed that encoding efficiency depended on the later form of testing. Semantic ('deep') processing during encoding was superior to rhyme ('shallow') processing when participants were given a standard yes/no-recognition test. However, rhyme processing during encoding outperformed semantic encoding when the rhyme item characteristics that have been relevant during study were the sought-for information at test again, that is when a rhyme recognition test was given. This pattern of effects appeared to be persistent as they were not only found when recognition tests immediately followed the study phase but also after a 24-hour retention delay between study and test. Based on these findings, Morris and colleagues (1977) claimed that not only the level of processing as such determines the later strength of a memory trace but that testing situations are often biased in favor of semantic processing. By this, the authors agreed with the 'encoding specificity principle' framework of Tulving and Thomson (1973) by arguing again that what matters most with regard to the later memory performance is the appropriate similarity between how memory traces are acquired during study and how they are later tested. The greater the similarity of processes involved during study and test, the greater the probability of successful retrieval. This brought them to the alternate concept of 'transfer appropriate processing' referring to the idea that different levels of processing (varying between deep and shallow) during encoding are useful in order to acquire different types of relevant information and consequently these different levels of processing are similarly potent for a strong and durable memory trace in appropriate testing situations.

Rugg, Johnson, Park, & Uncapher (2008) integrated those frameworks in his cortical reinstatement theory. He argued that encoding and retrieval processes should be seen as closely interconnected processes. He could demonstrate that neural correlates of successful encoding depended on the way retrieval took place and how it was cued and that on the other site neural correlates of successful retrieval were influenced by the manner items were processed during encoding. In sum, the framework of cortical reinstatement (Rugg et al, 2008) refers to the idea that retrieval is successful when processes prevalent during the encoding of an event are reactivated at the time of attempted retrieval.

Common to the principles of transfer appropriate processing and the cortical reinstatement hypothesis (Morris et al., 1977; Rugg et al., 2008; Tulving & Thomson, 1973) is a double assumption. On the one hand, it is assumed that the reactivation of processes that were engaged at encoding is beneficial for memory retrieval and on the other hand that successful encoding depends on the way retrieval is subsequently cued. This is why it is important in memory research to take encoding as well as retrieval processes into account even though the aim of one's research might primarily be to investigate only one of these processes.

However, by no means, the frameworks described here suggest that once new information was encoded, the resulting memory trace remains stable until retrieval processes would be set into operation. By contrast, recoding processes (Tulving & Thomson, 1973) and many other factors can result in slight modifications of stored information that influences its subsequent retrievability in various retrieval environments. They can be caused by different occasions before explicit retrieval was fulfilled and can, for instance, influence the interpretation or emotional context of memories by new experiences that were acquired in the meantime (e.g. Schacter, Norman, & Koutstaal, 1998). Thus, the final content at the moment of memory retrieval is not only influenced by the information that was originally encoded but also by factors such as recoding, personal life experiences that happened in the intervening time or the relevance of a specific memory representation in a particular situation. The last point refers to the supposition that not all details of an encoded event can be equally likely retrieved on any given retrieval attempt (Rugg et al., 2008). By contrast, if no highly differential information about an encoded event is needed it won't consequently be retrieved.

Furthermore, the degree of study-test similarity does not have to be equally high in all situations, which means that processes activated via a retrieval cue can be efficient even though they only partially overlap with processes that were active during encoding (Rugg et al, 2008). This was based on the finding that the hippocampus was found to be fairly tolerant towards similarity of pattern activation at encoding and its later re-activation at retrieval (Wallenstein, Hasselmo, & Eichenbaum, 1998). However, what remains true is again that the greater the similarity of pattern activity during study and test, the greater the probability of successful memory retrieval.

In the context of the goal of this thesis and with the cortical reinstatement hypothesis in mind, it can be assumed that reward-motivated learning is a form of deep encoding, even though the study task of the to-be-presented experiment was not at a very deep level. Items that are preceded by high reward or high punishment cues respectively would presumably undergo a more elaborative, deeper perceptual processing compared to items of a low reward or low punishment condition and finally would, as a logical consequence, improve memory performance.

In paragraph 1.2, some details were presented about how different forms of reward or punishment can serve as motivational factors influencing learning and presumably also retrieval processes. However, there are many more conditions that might facilitate memory retrieval and consequently increase memory performance. One of these conditions is the so-called "copy cue condition" (Herron & Rugg, 2003; Hornberger et al., 2004) or "cue-congruency effect" (Park & Rugg, 2008). A copy cue exists when both, study and test materials are presented in identical format (e.g., word - word). That is, the retrieval cue would be congruent with the study item format. In this case, memory performance was found to be higher than when formats were non-identical or incongruent (e.g., word-picture). For example, in a recently conducted fMRI-study conducted by Park and Rugg (2008) study items consisted of words and pictures that were subsequently tested either with a congruent (e.g. picture-picture) or an incongruent retrieval cue (e.g. word-picture). Interestingly, results revealed congruency effects. These were identified by enhanced activity in brain areas that overlapped with activity elicited by study activity during encoding of the items with identical format compared to incongruent cue-study item conditions. Thus, memory was found to be generally better for test materials that resemble the study material.

## 1.6 Subsequent Memory Effects

It is possible to analyze retrieval processes separately from processes involved at encoding. This is very useful as it enables a closer look to each of these processes, although it is important to keep in mind that all processes between the time of perception and retrieval of information are not independent from one another. According to Tulving and Thomson (1973) successful retrieval of episodic memory does not reflect a mere re-activation of arousal or learned associations of a memory trace by a certain retrieval cue. The whole process of remembering rather reflects a kind of interplay between certain properties of the encoded information and of the retrieval environment. Therefore, it is important to take also those processes into account that were active during encoding. This serves the purpose of examining what and how information was studied and whether there were any similarities with what and how it was subsequently retrieved.

To investigate whether encoding of items might differ as a function of later remembrance or oblivion, the behavioral accuracy of a memory test can be used to label items during the study phase depending on whether they were subsequently remembered or forgotten. The fMRI- or EEG-data from the study phase can then be analyzed to search for subsequent memory effects (Friedman & Johnson, 2000; Paller, Kutas & Mayes, 1987). ERP-effects of subsequent memory arise from contrasts between ERPs elicited by study items that were subsequently remembered ("hits") with ERPs to study items that were forgotten ("misses"). Typically, waveforms elicited by later remembered items are more positive-going than those to later forgotten items. Usually, these waveforms start to differ at approximately 400 ms post-stimulus onset until approximately 900 ms, depending on the task instructions at study and on the stimulus material. Several studies further revealed that contrasts of subsequent memory particularly activated the frontal lobes in the posterior parts of the parahippocampal gyrus (Brewer, Zhao, Desmond, Glover, & Gabrieli, 1998; Wagner, Desmond, Glover, & Gabrieli, 1998) and also areas in the MTL, especially the hippocampal region (Davachi & Wagner, 2002; Otten, & Rugg, 2001). In sum, subsequent memory effects are assumed to reflect processes that determine whether an item will be later remembered or not and are therefore very useful for the investigation of individual neural differences in encoding operations.

Evidence that reward-related processing prior to a stimulus predicts whether a stimulus will be remembered later, comes from an event-related potential (ERP) study by Gruber and Otten (2010). Using a study phase similar to Adcock et al. (2006), it was demonstrated that ERP activity elicited by a high monetary reward cue before stimulus onset predicted whether the stimulus was later remembered. ERPs elicited by high reward cues preceding later remembered stimuli (a given remember of confident old judgment) were more positive-going than ERPs to reward cues preceding forgotten stimuli (incorrectly judged as new) from around 300 ms after cue onset until the end of the cue-stimulus interval (2000 ms) (see Figure 1.6). This subsequent memory effect, which was only obtained for trials in which the incentive to memorize a word was high, supports the view that activity preceding a study event can be strategically influenced by a high level of learning motivation and, by this, is under voluntary control.

In addition, a second effect in the cue-interval, reflected by a relative positivity to ERPs associated with high reward cues was also found. In contrast to the subsequent memory effect, this reward-related effect was not modulated by later memory performance and was maximal over posterior scalp sites in a shorter time window, between 300 and 600 ms after cue onset (see Figure 1.7).

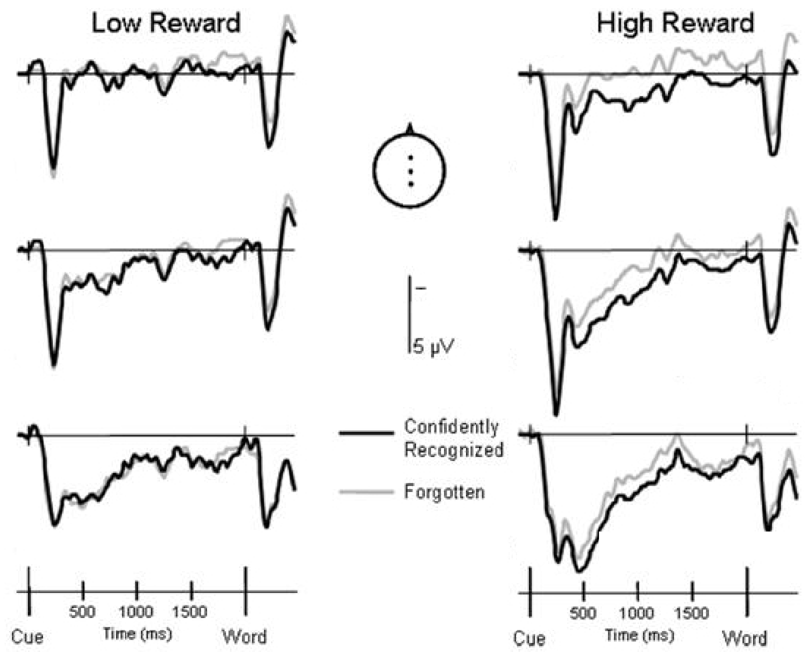



**Figure 1.6** Taken from Gruber and Otten, 2010. Depiction of encoding-related neural activity at representative midline electrode sites (Fz, Cz and Pz) in which ERP waveforms during study were elicited by low (left side) and high reward cues (right side), separated as a function of subsequent memory performance to the following item. The waveforms were inverted such that negative polarity is up.

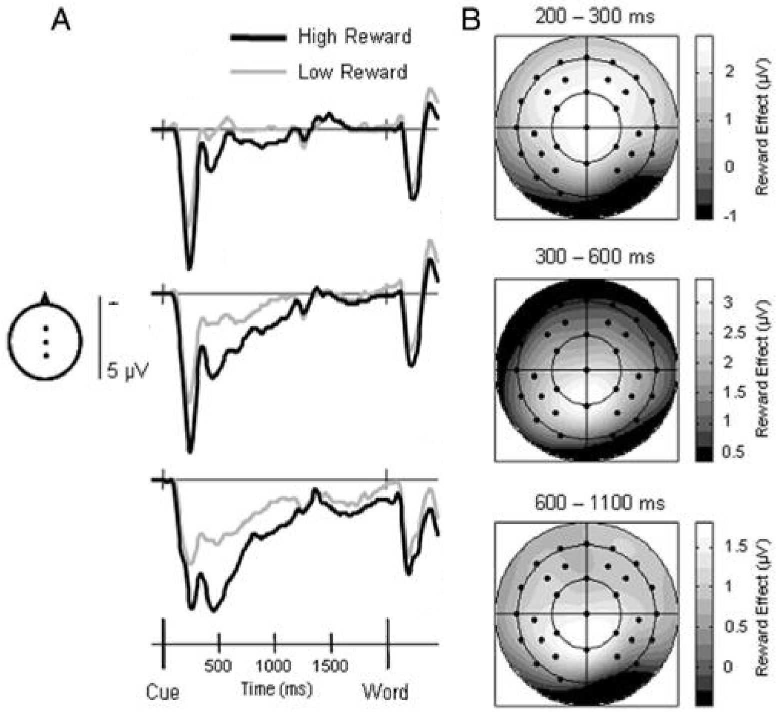



**Figure 1.7** Taken from Gruber and Otten, 2010. Depiction of reward-related neural activity at representative midline electrode sites (Fz, Cz and Pz) in which ERP waveforms during study were elicited by high and low reward cues in A (left side). Subsequent memory performance was not taken into account. Topographic, range scaled difference maps showing the scalp distribution of the differences between neural activity elicited by high and low reward cues in the time windows from 200 - 300, 300 - 600, and 600 - 1100 ms after reward cue onset in B (right side). The waveforms were inverted such that negative polarity is up and low-pass filtered at 15.5 Hz for visual presentation.

## 1.7 Effects of Incidental versus Intentional Testing on Memory Performance

Encoding of new events can take place in several occasions and in various ways. One of it is that encoding can be intentional, that is in a goal-directed, strategic manner, mostly combined with the knowledge of a following memory test or, in a more practical every day situation, combined with the knowledge of a subsequent need to use that information again in the future. Often subjects adopt deliberate encoding strategies during intentional encoding in order to prepare themselves for the later retrieval, for example during a memory test. It has to be mentioned however that in an experimental setup the precise nature of a subsequent memory test is mostly unknown to the participant, that is, participants were often left in the dark about whether for instance a yes/no-recognition test, cued recall or a memory exclusion test would constitute the form of testing. If participants would be informed about the precise nature of testing, they may tend to emphasize the particular encoding of information they believe to be most appropriate for the test. This is often attempted to be prevented in memory studies because otherwise individual encoding strategies would play a predominant role instead of natural forms of encoding and later retrieval processes.

Successful encoding can also happen incidentally, which means that a person does not have the explicit intention to encode new information of the environment. This means that new knowledge can also be acquired already by the mere perception of new events which eventually remain in memory for later successful retrieval. Therefore, the emergence of a memory trace might be rather seen as a byproduct of the perceptual analysis of new information than as a product that only develops by the intention to encode.

An advantage of incidental over intentional learning experiments is that the experimenter has more direct control over the kind of encoding operations participants apply to the presented items in a study phase. During intentional learning, when participants were instructed to learn, they might use individually different encoding strategies which are difficult to control for.

It is extremely difficult if not impossible to determine which kind of encoding operations a participant used during encoding as it can only be done by experimental manipulation such as instructions and the like. Therefore, incidental encoding is often preferred compared to intentional encoding.

## 1.8 Cross-Cultural Variability in Motivated Learning

Training of East Asian professional teams of imported Western sports, e.g. baseball or football, is found to be often influenced by culture-specific factors that might increase achievement motivation (e.g. Heine, Kitayama, Lehman, Takata, Ide, Leung, & Matsumoto, 2001; Whiting, 2006). For instance, submergence of the ego or the coordination of one's mind, heart and body to the ideal forms of tackling and battling might play a more predominant, motivation increasing role in Asian than in Western countries even though this 'Asianization' of Western sports was not found to necessarily lead to better performance.

Without negating that in all societies across the world, individuals differ to a great extent due to within-culture variability and show much cross-cultural overlap with respect to personality characteristics, it is worth looking at potential cross-cultural differences, too. Culture is thought to affect the development of individual's cognitive and motivational processes, such as the manner individuals respond to customs and ideals, keep themselves motivated in order to pursue goals or intentions and to persist in actions or by contrast to change behavior.

Findings of Heine et al. (2001) suggest that motivational systems prevalent in distinct cultures might not be universal, but divergent. More specifically, the authors investigated by means of an intrinsic motivation paradigm whether self-improving and self-enhancing motivations might differ between a Canadian and a Japanese sample. More specifically, the authors measured the persistence in an achievement task in time. The results indicate that Canadian participants became more motivated by success as they persisted longer in the task after positive than after negative feedback. By contrast, for Japanese participants failure served as a motivating force to the extent that they persisted longer in the task after negative feedback. Whereas the former sample used strategies of self-enhancing motivation with the focus on positive outcomes, the latter one was more motivated by situations that enabled self-improvement with a focus on negative aspects. These finding indicate that self-motivation for achieving a goal can be realized in different ways, either by positive, self-enhancing beliefs in oneself as did the North American participants or by a negative, self-critical view, as was used by the Japanese participants.

A cross-cultural background for these findings is additionally supplied by the assumption that personality is assumed to be shaped by culture and by this might affect personality (Lin & Church, 2004). For example, Western countries (e.g. North America, Germany etc.) compared with East-Asian countries (e.g. Japan, China etc.) are seen as highly individualistic cultures. By contrast, East-Asian countries are seen as more collectivistic (Gabrenya & Hwang, 1996; Ho, 1998; Hofstede, 2001).

More specifically, a person of the Western culture is seen as an autonomous, individualistic entity with an individual set of qualities and attributes that are related to individual behavior. As these attributes are defined as relatively immutable and stable entities across different situations and over time, it might be seen as a logical and useful consequence for individuals to accept these attributes as positive (Markus & Kitayama, 1991). Therefore, a cultural assumption is that Westerners might often develop habitual psychological tendencies to identify the self with positive, self-confirming and -enhancing attributes (self-enhancing orientation, Heine et al, 2001) while the attempt to improve the self would not be very rewarding for Westerners as the self is assumed to be largely immutable. Thus, it is supposed that individuals of Western countries selectively focus on positive aspects of themselves and feel motivated to work hard on tasks in which they are good at in order to increase the positivity of the self (Bandura, 1999).

By contrast, a person of the East-Asian culture is generally seen as a more collectivistic individual that has to adjust itself to norms and role obligations of the group to which they belong (Markus & Kitayama, 1991; Su, Chiu, Hong, Leung, Peng, & Morris, 1999). Whereas the standard determining roles are thought to be relatively stable, the self, if necessary, can or has to be adjusted for role perfection. That is, the self is rather seen as a dependent entity with varying as well as adaptable attributes. Thus, it might be reasonable that individuals in East Asian cultural contexts are assumed to focus particularly to negative instead of positive aspects of their selves in order to improve the self by motivated hard work (Heine et al., 2001).

In the light of the above and particularly in the context of the research goals of the work presented in this thesis, it is therefore considered that in more collectivistic countries (e.g. East Asia) the focus lies on a bias toward negative information and events that led to the development of avoidance based coping strategies (Eaton & Dembo, 1997) in order to avoid negative, punishing experiences and to counteract the fear of failure. By contrast, in individualistic countries (e.g. North America or Western Europe) a bias towards positive information is emphasized in order to boost oneself on the move toward a rewarding outcome.

Taken together, these different cultural perspectives in which the focus lies primarily on the comparison between individuals of Western and Asian countries are assumed to promote distinct motivate dispositions. Whereas individualistic cultures (operationalized in terms of a cultural attribute) are assumed to promote more approach orientation, collectivistic cultures are thought to promote more avoidance orientation.

## 1.9 Within-Culture Variability in Motivated Learning

Recent studies showed that neural reward processing also varies in healthy participants of similar cultural background. These findings indicate that inter-individual differences in personality affect learning through reward anticipation and punishment avoidance (e.g. Simon, Walther, Fiebach, Friederich, Stippich, Weisbrod, & Kaiser, 2010). Therefore it is important to combine sophisticated experimental procedures with the study of individual personality aspects or trait, e.g. the tendency to approach versus avoid reward- or punishment-related situations, because they can account for a large portion of variance in behavior. The dependence of memory performance on the type of motivated learning might be modulated by the individual personality style of learners. For instance, neural reward processing was found to be modulated by individual varieties of impulsivity and extraversion (Cohen, Young, Baek, Kessler, & Ranganath, 2005; Martin and Potts, 2004), as well as by academic motivation and risk aversion (e.g. Tobler, O'Doherty, Dolan, & Schultz, 2007).

An outstanding, biologically based personality model in this context is the Reinforcement Sensitivity Theory proposed by Jeffrey Gray (1970, 1972, 2000). He employed an animal model of rat learning to propose a neuropsychological basis of anxiety which revised Hans Eyseneck's theory of introversion-extraversion and neuroticism. Gray argued that individuals differ in their sensitivity to cues for reward with a behavioral activation system (BAS) and the sensitivity to cues for punishment with a behavioral inhibition system (BIS). In line with his ideas, the personality trait impulsivity is associated with the BAS, anxiety with the BIS. However, evidence for this hypothesis is mixed (z.B. Zinbarg and Revelle, 1989, Nugent and Revelle, 1991).

The behavioral activation system (BAS) is considered as a motivational system that mainly responds to rewarding and generally non-punishing stimuli (Corr, 2004). It is associated with enthusiastic feelings and reward-seeking behavior even in case of personal risks. By contrast, the behavioral inhibition system (BIS) is conceptualized as an attentional system that is associated with the reaction to punishing and generally non-rewarding stimuli. It is associated with the promotion of inhibition of approaching responses and an increase of arousal to relevant cues (Gray & McNaughton, 2000). That is, persons scoring high on the high behavioral approach scale appear to be sensitive mainly to positive outcomes and to a lesser extent to the omissions of rewards, whereas subjects with low behavioral approach as well as those with a high inhibition tendency display a blunted response to rewards (Simon et al., 2010).

## 1.10 Learning via Rewarding as well as Punishing Events

In general, human learning is known to be influenceable by highly diverse, motivating factors. Two of these factors that are relatively well investigated are the anticipation of monetary reward and the avoidance of loss of money during learning. Learning through negative, punishing events, refers to the fact that animals or humans learn to perform an action or intent to learn a stimulus in order to avoid obtaining an aversive outcome. This is a well-known phenomenon and shows that motivated learning not only takes place by the anticipation of positive rewards (sweets, gain of money, a good grade etc.) but also by the avoidance of negative events (e.g. pain, loss of money, a bad grade).

For instance, as described in more detail in paragraph 1.2, anticipation of monetary reward was found to facilitate learning and to increase later memory for items that were either preceded by reward cues or that were rewarding by itself (Wittmann et al., 2005; Adcock et al, 2006; Gruber & Otten, 2010).

By contrast, motivated learning in humans was also found to take place through avoidance of punishment, e.g. deduction of money (e.g. Kim, Shimojo, & O'Doherty, 2006). When it comes to learning that is motivated by the avoidance of punishment, an interesting question is whether on a cognitive level successful avoidance of negative, punishing events would be similarly rewarding compared to the attainment of positive, rewarding events and whether the two conditions are similarly processed. According to this idea, successful avoidance of an aversive outcome might be perceived as an "intrinsic" reward, with similar positively motivating characteristics as a real "extrinsic" reward (Kim et al., 2006). This would fit with ideas of the opponent process theory (Solomon & Corbit, 1974), in which it is argued that the offset of an affective process activated by an either positive or negative incentive leads to the onset of a complimentary affective response of the opposite valence. So, in this context, a negative affective state due to the anticipation of a potential loss of money would, in opponent process terms, be subsequently converted in an opposing positively valenced hedonic response when potential punishment can be successfully prevented (Kim et al., 2006). In this case, it might be assumed that similar brain areas would become activated during learning through positive as well as negative incentives. If not, other brain areas might be engaged or even another neuromodulatory neurotransmitter such as serotonin may be involved (Daw, Kakade, & Dayan, 2002).

Consistent with this possibility, Kim and colleagues (2006) let participants perform an instrumental choice task while they were lying in an fMRI-scanner. It was found that responses that successfully prevented loss of money as well responses that resulted in gain of money similarly exhibited increases in neural activity of the medial orbitofrontal cortex. Neural activity of the medial orbitofrontal cortex was already previously found to be implicated during the encoding of rewarding stimuli. But these results further extended previous findings as they suggested that avoidance of an aversive outcome becomes a positive hedonic experience which acts as a reward similar to when one indeed receives a reward. Interesting in this context would be to investigate whether failing to not receive positive outcome would have similar neural bases in processing compared to failing to avoid aversive outcome.

However, to date empirical evidence with regard to the involvement of dopaminergic neurons during aversive learning is mixed. No evidence for that was found in single-unit studies (Schultz, Tremblay, & Hollerman, 1998; Ungless, Magill, & Bolam, 2004) but when dopamine release in the striatum in rats was measured, increased dopamine levels appeared to be involved during aversive as well as appetitive conditioning (Pezze & Feldon, 2004). Furthermore, by means of fMRI data it was demonstrated that prediction error signals in the human brain do also emerge during aversive and not only during appetitive learning (Pessiglione, Seymour, Flandin, Dolan, & Frith, 2006). Generally, dopamine-dependent or "reward" prediction errors are understood as theoretical learning signals that refer to the mismatch between a predicted and an actual outcome (see Schultz & Dickinon, 2000 for a review) and are assumed to be useful for humans (and primates) in order to guide their behavioral choices, such as approach or consummation.

## 1.11 Main Research Questions, General Experiment Procedures and Materials

In the following, I will describe in more detail the main research questions that were addressed in this thesis. As was shown in the preceding theoretical parts, reward anticipation during learning supports memory formation, whereas its role on retrieval processes remains unclear so far. Therefore, the present thesis will focus on four main questions. The first important question deals with the influence of monetary reward during intentional learning and its impact on later episodic memory retrieval, particularly on the adoption of specific retrieval orientations. This issue was particularly addressed in Experiment 1 (Chapter II). The second study (Experiment 2) described in Chapter III, aims to extend the first research question and focuses on the influence of reward-motivated learning on the adoption of retrieval orientations in an entirely incidental study-test setting. The third question refers to the impact of anticipated rewards versus punishment avoidance during learning on later memory performance while the fourth finally brings these two different types of motivated learning into a broader cross-cultural context by comparing memory performances of German and Chinese participants in the same experimental paradigm with each other (both addressed in Experiments 3a-d, Chapter IV).

For the purpose of pursuing these questions, neural correlates mainly of episodic retrieval but also of encoding were examined in healthy humans with functional neuroimaging methods, notably the method of EEG and ERPs, and with behavioral methods, including the measurement of reaction times and accuracy. By this means, the questions have been subjected to appropriate experimental test in two EEG-studies and a series of four behavioral studies.

The basic paradigm of the present studies was as follows: Participants in each experiment studied randomly intermixed series of visually presented pictures and words that were either preceded by a high or a low positive or negative monetary incentive cue. They were asked to judge whether the referent of each study item would be bigger or smaller than the computer screen. In a test phase 24 hours later, memory for the study items was tested using a memory exclusion task (Jacoby, 1991). Participants were presented with words which were either new or had been previously presented as words or previously presented as pictures, and which of these classes of old information were designated as targets was manipulated across test phases. In line with the logic of retrieval orientation contrasts (Rugg & Wilding, 2000) all retrieval cues were words, in order to keep retrieval cues physically constant and to vary only the type of memory representation that was sought for. This permitted a previously studied word to be congruently cued because the retrieval cue was also a word and therefore exactly identical ('copy cue'). By contrast, it permitted formerly studied pictures to be incongruently cued as the retrieval cues were always in word format. Importantly, nested within the factor of target material in the test phase (formerly studied pictures/formerly studied words) was an incentive factor (high/low) such that always four test blocks were formed.

In Experiment 1 the experimental paradigm (as described above) was used in an intentional setting and only with high and low positive reward cues. That is, participants were instructed to learn the presented words and pictures at study as they would be only rewarded, either with a high or low monetary reward cue, if they would correctly recognize the items in a later memory test.

In Experiment 2, the design was slightly modified such that payout of high and low monetary reward cues directly depended on the study task performance instead of performance at test. By this means, it was possible to let participants incidentally study the pictures and words. That is, they were kept uninformed about the following memory recognition test on the next day.

Finally, in the series of behavioral experiments (Experiments 3a-d) that were similarly conducted in Germany and in China, the identical experimental paradigm as in Experiment 1 was used, but with a fewer amount of trials and in Experiment 3c and 3d high and low negative instead of positive incentives were used. Hence, in these two last behavioral experiments participants were encouraged to keep as much money as possible of their initially received start-up capital by avoiding the high, respectively low loss of money.

The stimulus material that was used in all experiments in the context of the present thesis was taken with permission from the “International Picture Naming Project” (Bates et al., 2003; Szekely et al., 2004). This enormous validation study for norming large sets of pictures was conducted at the Center for Research in Language which is housed by the University of California, San Diego. It provides norms for cross-cultural, timed picture naming of 520 black-and-white drawings of common, nameable objects tested and normed in children and adult populations. The database currently consists of data that was collected in seven different languages (American English, German, Mexican Spanish, Italian, Bulgarian, Hungarian, and Mandarin Chinese spoken in Taiwan) and aims to be extended across more languages in the future (e.g. timed picture naming norms in Belgian Dutch by Severens, Lommel, Ratinckx and Hartsuiker (2005) or in Mandarin Chinese spoken in Mainland China by Liu, Hao, Li and Shu (2011). It is important that norming studies for pictorial stimuli are carried out in different languages since cultural differences in picture naming might exist.

The international database has the advantage of providing standardized tools in order to enable the comparison of different studies addressing different theoretical questions. Those tools included among others variables such as name and image agreement, naming latency, visual complexity, word length and frequency, and age of acquisition in order to attempt to determine factors that might influence naming difficulty of the presented pictures.

However, as norms for the variant of Mandarin Chinese spoken in Mainland China were lacking at the time of data collection in Beijing, China (in 2010), picture names were obtained by using the same pictures as for the experiments conducted in Germany and letting two native Chinese speakers from Beijing independently translating and retranslating object names of Mandarin Chinese spoken in Taiwan into Mandarin Chinese spoken in Mainland China and back into English. Items which differed in naming were not included into the used stimulus material, neither as a picture nor as word. This was possible as fewer items were needed for this series of behavioral, cross-cultural experiments (Experiments 3a-d) than in the two EEG-studies (Experiment 1 and 2) that were only conducted in Germany.

In the studies presented in this thesis, name agreement was one the variables that was prioritized over others because especially with regard of the aimed cross-cultural background and the use of pictures together with corresponding names, it was crucial to use only pictures that were consistently given the same name. That is, name agreement was defined as the degree to which similarity exists between the mental image generated by a participant to the effectively given picture’s name and the actually presented picture. Beside this variable, care was taken to use pictures from the database that satisfied the criteria of a relatively low visual complexity and words that were of relatively low mean frequency usage and not too high in number of characters (especially in German language).

# Chapter II: Experiment 1

# Influences of intentional, reward-motivated learning on strategic retrieval processes: an ERP study

## 2.1 Introduction

The main goal of the first experiment was to examine whether and, if so, how the ERP correlates of retrieval orientations are modulated by reward expectancy. The focus was on retrieval orientations as they are assumed to reflect strategic retrieval processes that optimize the resemblance between a cue and a memory representation in order to facilitate the retrieval of targeted information (e.g. Bridger et al., 2009; Herron & Rugg, 2003; Hornberger et al., 2004; Hornberger et al., 2006).

Other points of focus, next to the investigation of reward-modulating effects on neural correlates of retrieval orientations, lay in the investigation of processes involved during and after successful memory retrieval. This was done with the intent to corroborate a functional interpretation of retrieval orientation effects by the additional investigation of corresponding neural correlates of retrieval success (ERP old/new effects, see Chapter I). Previous findings have shown that the explicit instruction to retrieve pictures or words in a memory exclusion task with only words as retrieval cues had an influence on the degree of specificity with which test words were used to search for the targeted memory representation (Herron & Rugg, 2003). More specifically, the authors discovered that, when formerly studied pictures formed the target condition, a less specific retrieval orientation was adopted than when words formed the targets. This was reflected by the finding that in the target-picture condition, correct responses to test items corresponding to non-targets (e.g. studied words) as well as to target-pictures elicited reliable, positive-going old/new effects, whereas in the target-word condition, old/new effects were found for correctly classified targets only. This finding was interpreted as evidence that when participants were required to retrieve formerly studied pictures as targets, their adopted "target-picture specific" retrieval orientation was also effective in retrieving memory representations that corresponded to non-target memory representations. Conversely, an adopted "target-word specific" retrieval orientation was more specific such that retrieval cues corresponding to non-target memory information (i.e. formerly studied pictures) were ineffective in eliciting signs of successful retrieval (i.e. old/new effects). According to the author, a possible reason for this differing pattern of effects might be based on the fact that targets in the target-word condition were perceptually identical at test from their studied format (copy cues) and were therefore easier to detect than in the target-picture condition in which the discrimination between targets and non-targets required additional processing to evaluate retrieved content information (Herron & Rugg, 2003). In general, old/new effects were mostly obtained in recognition memory tests around 300 ms after a stimulus was presented and usually characterized by more positive-going ERPs to correctly classified old items compared to ERPs elicited by new items (review: Friedman & Johnson, 2000; Rugg, Allan, & Birch, 2000).

The task that was used in the present study was as follows. At study, subjects encoded a mixed list of pictures and words that were preceded by high or low monetary reward cues. Participants' memory for these items was tested one day after study, via a series of recognition memory tests with exclusion task response requirements (Jacoby, 1991). At these tests, participants were presented with words that were either new (i.e. unstudied) or had been previously presented as words or previously presented as pictures, and which of these classes of old information were designated as targets was manipulated across test phases. A binary response was required and a correct target response was rewarded with the amount of money indicated in the study phase. The class of targeted material (pictures/words) and reward conditions (high/ low incentive, cf. Figure 2.1) were orthogonally manipulated across these tests. ERPs were recorded for all study and test items, but of main interest in this study were ERP waveforms to new test items.

## 2.2 Hypotheses

As there is mounting evidence to support the assumption that participants often prioritize the recovery of target items in the memory exclusion task (e.g., Herron & Rugg, 2003; Bridger et al., 2009) and because of the assumption that retrieval orientations facilitate the recovery of targeted information, it was predicted that ERPs elicited by new words would differ between the target-word and the target-picture conditions. These differences are likely to be similar to those previously reported in experiments with comparable contrasts (e.g. Herron & Rugg, 2003; Hornberger et al., 2004) in which ERPs elicited by new items were more negative-going when the sought-for material was dissimilar to the retrieval cues. The sensitivity of these effects to the sought-for material leads me to refer to these as material-specific retrieval orientation effects.

Moreover, in light of the fact that both reward and the adoption of a specific retrieval orientation have separately been shown to influence later memory performance, the possibility was considered that reward might affect retrieval processing via retrieval orientation. It was expected that reward would either enhance the material-specific orientation effect (by eliciting a larger material-specific ERP effect for pictures and words encoded with high than with low reward expectancy) or that reward would elicit a reward-associated retrieval orientation effect (an ERP difference between high and low reward trials, irrespective of target material).

Based on the findings of Herron and Rugg (2003, outline above) and in line with the purpose of this first experiment, it was hypothesized that correctly classified targets would elicit old/new effects in both target-material conditions as an indication of successful memory retrieval, with additional old/new effects selectively for the non-targets in the target-picture condition mainly due to copy cue facilitation in this target designation. Moreover, additional old/new effects separately for the high and low reward condition were expected. The possibility to detect neural correlates of strategic memory retrieval separately for the reward conditions was taken into consideration as memory testing was intentional and reward delivery was linked to performance at retrieval. In case of prevalent old/new effects for the high and the low reward condition, it was further hypothesized that only in the low reward condition old/new effects for non-targets would also be found, that is it was expected that ERPs to non-targets would statistically differ from those to the new items. This would then be interpreted in terms of an indication of less specific retrieval cue processing for material that was studied in anticipation of a lower monetary incentive, similarly to the findings of the distinct material-specific old/new-effects for targets and non-targets reported in the study of Herron and Rugg (2003).

On the behavioral level, higher memory accuracy was expected for stimuli that were preceded by high reward cues compared to those preceded by low reward cues. Finally, to investigate whether ERP differences related to reward were also present at encoding, it was additionally explored whether ERP activity elicited by a cue preceding the stimulus presentation differed between high and low reward conditions and whether it is related to the subsequent memory for that stimulus (Gruber & Otten, 2010).

## 2.3 Experimental Procedure

### *2.3.1 Participants*

Twenty-four students (12 men) were recruited from Saarland University, Saarbrücken, Germany. Participants were all right-handed (as assessed by the Edinburgh Handedness Inventory; Oldfield, 1971) and had normal or corrected-to-normal vision. All participants gave written informed consent before participating in the study (which was approved by an Institutional Ethics committee) and were paid between 25 and 45 € (including the earned reward). Five participants' data were discarded because of excessive eye movement artifacts (2), fewer than 16 artifact-free trials in one of the critical conditions (1), or because behavioral test performance was below chance level (2). Data are reported and analyzed for nineteen participants (10 men; 24 years, range 18 – 31 years).

### *2.3.2 Stimuli and Procedure*

480 black- and white line drawings of common, nameable objects and the corresponding words were used in this experiment. All stimuli were taken with permission from the database of the International Picture Naming Project (Szekely et al., 2004). In both experimental sessions, the stimuli were presented in the center of a white background of a computer monitor. The pictures had a mean name agreement of 89% (min. > 30%), relatively low visual complexity and were shown with maximum vertical and horizontal visual angles of 4.5 ° each. The words were of low mean frequency usage (mean = 2 per million, CELEX-corpus) (Szekely et al., 2004), word length did not exceed 16 characters (mean = 7) and they were displayed in black letters and subtended a vertical visual angle of 0.4 ° and a maximum horizontal angle of 4.5°.

Two 170-item study lists were formed for each participant by randomly intermixing 85 pictures and 85 (non-corresponding) words. The test list consisted of 480 items and was divided into four blocks of 120 items each. Each test block was composed of 50 target words, 35 non-target words and 35 new words. In two of these blocks, subjects were to respond "old" to words that had formerly been studied as pictures (termed as targets) and to respond "new" to words that had formerly been studied as words (termed as non-targets) and to completely new words. In the other two blocks, target/non-target designation changed such that targets were the studied words and non-targets were words that had formerly been studied as pictures. Four test blocks allowed target material (pictures/words) and reward conditions (high/ low incentive) to be manipulated orthogonally: one of each of the target condition blocks contained items that had been accompanied by high reward cues in the study phase while the other block contained items that had been accompanied by low reward cues.

Response buttons were counterbalanced across participants and items were rotated across study and test lists such that they were equally often presented as studied pictures, studied words and new items across reward conditions. The test blocks were administered to participants in a counterbalanced fashion to ensure that blocks started equally often with target-pictures or target-words that were studied with a high or low reward cue. Additionally, two consecutive blocks always consisted of the same target material in order to make sure that participants needed to switch retrieval task only once.

Participants took part in two sessions, a study phase on the first day and a test phase on the following day (range: 23 - 25 hours after study). Before each phase of the experiment, participants were fitted with an electrode cap (see section 2.3.3 and 2.3.4 for more details). Prior to the study and test phase, each participant completed a short practice run to become familiar with the experimental task. Items presented in the practice run were not used during the experimental sessions.

Study trials consisted of the presentation of a fixation character (“+”) for 500 ms which was followed by either a low (“€” = 0.05€) or a high reward cue (“€€€” = 0.50€) for 300 ms. The remaining cue-interval was filled with a fixation character for 500 ms. Then, either a picture or a word appeared on the screen for 1000 ms, followed by a fixation character (“+”) for 500 ms. After that, the word “size?” was presented for 2000 ms during which time interval the participant responded. Next, the screen was blanked for 500 ms before the next trial began. Whenever the question “size?” appeared on the screen, participants had to decide whether the real life size of the shown object (depicted as a picture or a word) would be larger (e.g. tree) or smaller (e.g. mouse) than the size of the monitor and to press one of the two response keys as quickly as possible without sacrificing accuracy. This task was used to minimize the use of mnemonic strategies. Participants were told that the reward cue preceding an item indicated the money they would gain in case of correctly recognizing the item in the later memory test. Therefore, they were additionally instructed to pay attention to both the reward cues (in order to be aware of the reward status) and the pictures/words. The high and low reward cues were equiprobable and followed a pseudo-randomized order to prevent more than three consecutive pictures or words being preceded by the same reward cue. In between the two study lists, the Edinburgh Handedness Inventory (Oldfield, 1971) and a questionnaire on demographic information was filled in and participants were given a short rest.

Test trials began with the presentation of a fixation character (“+”) for 500 ms, after which a test word was presented for 400 ms. This interval was followed by the presentation of a fixation character (“+”) for 1200 ms and the trial ended with a feedback cue presented for 300 ms (red, frowning ‘smiley’ for incorrect or too slow response; green, smiling ‘smiley’ for correct response). The participant’s task was to respond with one key to words from the respective target material condition (targets) and to press another key to new, unstudied words as well as to those words studied in the other material condition (non-targets). Instructions were to respond as quickly as possible without sacrificing accuracy. Of importance is that participants were informed about the target designation (studied pictures or studied words) prior to each test block, but they were not informed about the blocked nature of the reward condition. This was done to ensure that possible influences of reward at retrieval were driven by reward processes during encoding and not confounded by additional reward instructions at test. Participants were also told that they would be rewarded for each correct recognition of a target (0.50 € or 0.05 €) and penalized for false alarms. A penalty of -0.275 € for false alarms was included to prevent participants from providing “old” responses for all items. After each of the four test blocks, general performance (in %) was shown and a brief rest interval was provided. At the end of the test, the cumulative total of the gained amount of money was presented on the screen (in €).

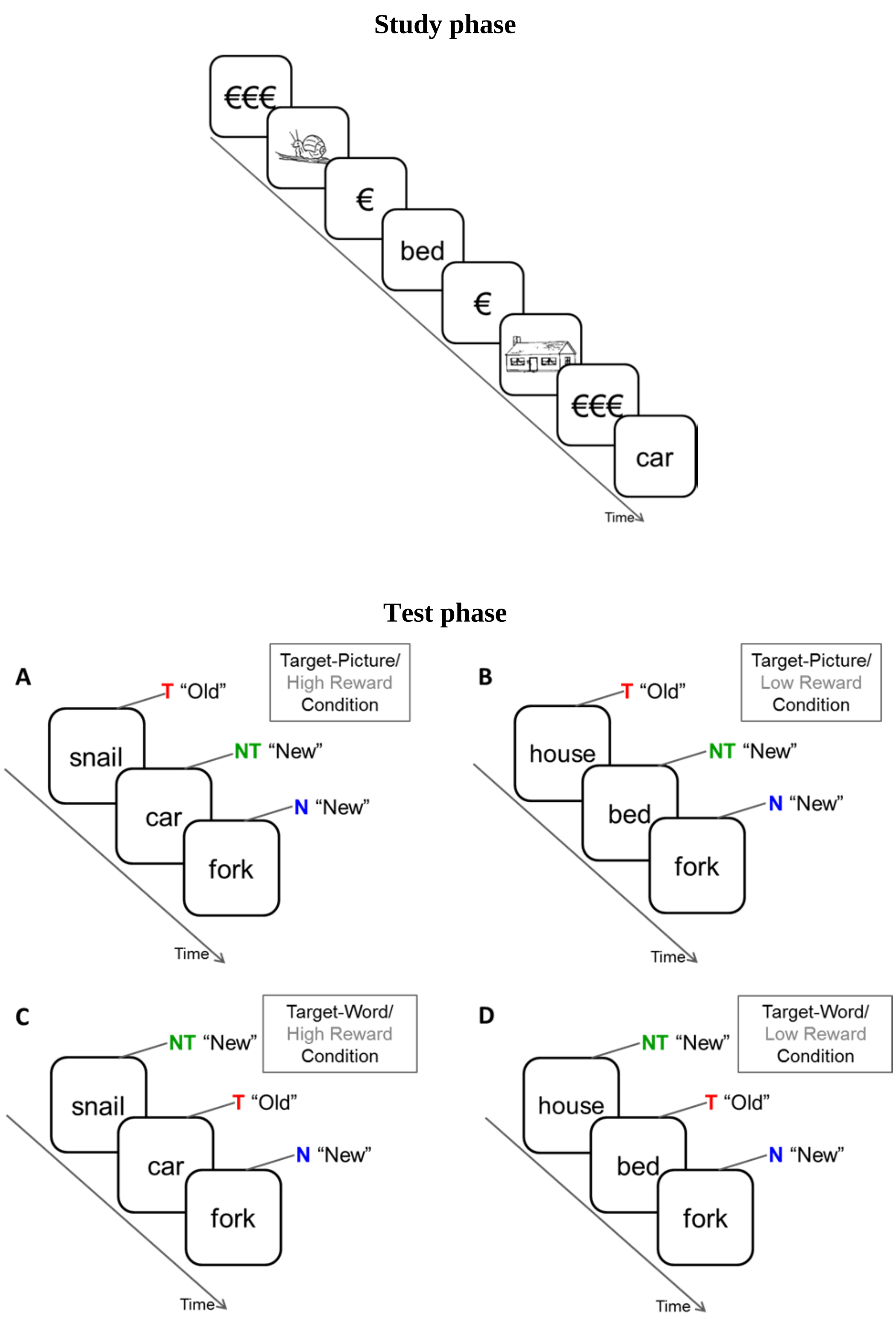



**Figure 2.1** Schematic illustration of sample items per condition of study (above) and test phase (below). At study, reward cues (high, low) and study items (pictures, words) were randomly intermixed with each other. At test, four test blocks were used and reward conditions were nested within target condition. One of the blocks in each target-picture or target-word condition contained items that had been accompanied by high reward cues in the study phase (here example block A and C) while the other block contained items that had been accompanied by low reward cues (example block B and D). In the target-picture condition, a response with one key was required for words that were formerly studied as pictures and a response with a second key for words that were studied as words as well as to new words. In the target-word condition, a response with one key was required for words that were studied as words and a response with a second key for words that were formerly studied as pictures, as well as to new words. **T** = target item; **NT** = non-target item; **N** = new item.

### 2.3.3 EEG Recording

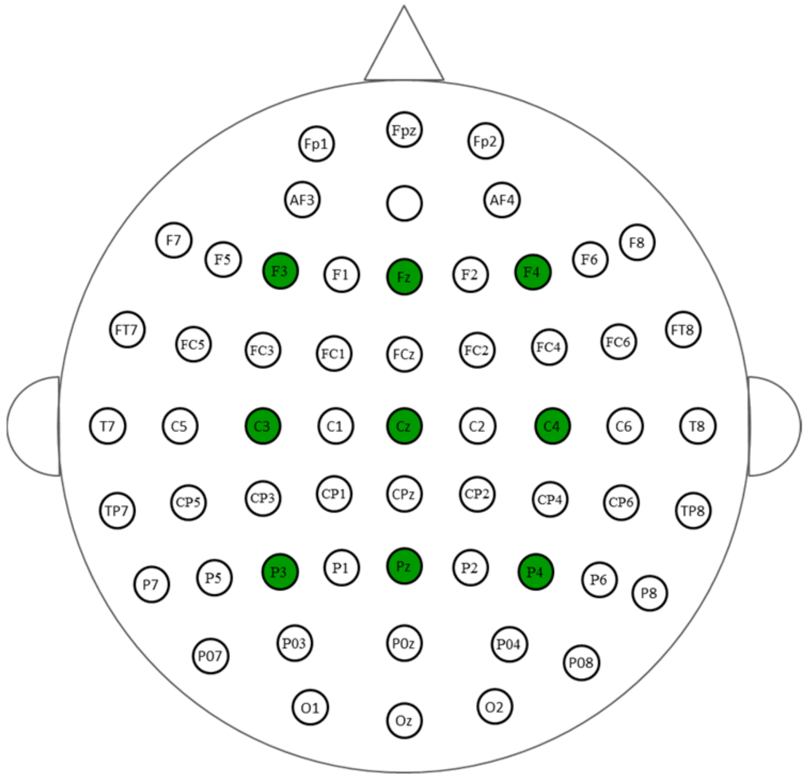



**Figure 2.2** Illustration of the electrode setting used to record scalp data based upon the extended 10-20 System of the International Federation (Jasper, 1958). Marked sites represent those electrodes employed in the standard statistical analysis setting.

EEG was recorded with Brain Vision Recorder V1.02 (Brain Products) from 58 Ag/AgCl electrodes embedded in an elastic cap which size depended on the approximate individual head circumference of each participant. Recording locations included midline (Fpz, Fz, FCz, Cz, CPz, Pz, POz, Oz) and left/right hemisphere sites (F1/F2, FC1/FC2, C1/C2, CP1/CP2, P1/P2, FP1/FP2, AF3/AF4, F3/F4, FC3/FC4, C3/C4, CP3/CP4, P3/P4, PO3/PO4, O1/O2, F5/F6, FC5/FC6, C5/C6, CP5/CP6, P5/P6, F7/F8, FT7/FT8, T7/T8, TP7/TP8, P7/P8, PO7/PO8) which were based on the extended International 10 - 20 System (Jasper, 1958). Figure 2.2 shows the position of the employed electrodes. EEG from all sites was recorded with a reference at the left mastoid electrode and re-referenced off line to the average of the left and right mastoids. Electro-ocular activity (EOG) was recorded from above and below the right eye (vertical EOG) and from the outer canthi (horizontal EOG) to control for vertical and horizontal eye movements. Electrode impedance was kept below 5 kΩ and EEG and EOG were recorded continuously with a band pass from DC (direct current) to 70 Hz with a sampling rate of 500 Hz. Offline data processing was performed with EEProbe (ANT

Software). The data were band-pass filtered off line (0.03 – 30 Hz, 3 dB points). Prior to averaging, trials containing large EOG or muscle artifacts and trials containing A/D (analogue to digital) saturation were rejected from further analysis using a pre-set criterion (threshold: standard deviation > 30 μV for EOG, standard deviation > 20 μV for electrode Cz within a sliding window of 200 ms). EOG blink artifacts were corrected using a modified linear regression technique (Gratton, Coles, & Donchin, 1983).

### *2.3.4 Data analysis*

ERPs of the test and study phase were computed separately for all electrodes, conditions and participants. For ERP analysis, selection of time windows was based on visual inspection of the grand average waveforms and on previous research. The majority of statistical analyses of the ERP data was restricted to scalp electrodes similar to those that have been used in other ERP studies on retrieval orientation (cf. Dzulkifli & Wilding, 2005) and employed electrodes F3, Fz, F4, C3, Cz, C4, P3, Pz and P4. In addition to the experimental factors of interest, the topographical factors Location (frontal, central, and parietal electrodes), Laterality (left, middle, and right electrodes) were used. For the analysis of late posterior ERP old/new effects the additional parietal electrodes (PO3, POz, PO4) and occipital electrodes (O1, Oz, O2) were employed.

For the test phase, the factor Time Window was additionally included in the analysis, ERPs were computed time-locked to the test words with epochs of 1600 ms duration and a 100 ms pre-stimulus baseline and mean trial numbers (range in brackets) for correctly rejected new items were 41 (32-51) and 41 (32-52) for the target-picture and target-word condition and 41 (32-57) and 41 (32-52) for the high and low reward condition, respectively.

For the supplemental analysis of old/new effects at test, ERPs were separately formed for correctly classified target and non-target words according to whether pictures or words were the target material and according to whether the items belonged to the high or low reward condition. The mean number of trials comprising the ERPs in the picture condition were 46 (27-67) for targets, and 37 (21-56) for non-targets; trial numbers in the word condition were 50 (27-81), and 36 (22-50), respectively. In the high reward condition trial numbers were 47 (29-87) for targets, and 37 (23-55) for non-targets and in the low reward condition they were 46 (29-59) and 35 (20-50), respectively.

In the study phase, ERPs were time-locked to the reward cues with epochs of 800 ms duration and a 100 ms pre-stimulus baseline. Mean trial numbers for ERPs elicited by high- and low-reward cues at study were 123 (84-155) and 122 (78-152), respectively.

Analysis of performance in the memory exclusion task performance was operationalized with the discrimination index *Pr* (*p*[target hit] – *p*[non-target false alarm]; derived from Snodgrass & Corwin, 1988). The reasoning behind the use of these corrected scores was driven by the intent to take response biases of individual participants into account that were in the direction of more positive or negative response tendencies regardless of a target designation. This was realized by the subtraction of false positive responses ('false alarms') from correct target responses ('hits') per condition, resulting in corrected scores which are presented as proportions.

Data were analyzed using repeated measures analyses of variance (ANOVAs) with a significance level set to .05. Greenhouse-Geisser correction for non-sphericity (Keselman & Rogan, 1980) was applied when necessary and epsilon-corrected *p*-values are reported together with uncorrected degrees of freedom and Greenhouse-Geisser epsilon values. *P*-values for follow-up analyses were adjusted applying Holm's sequential Bonferroni correction (Holm, 1979). All analyses were limited to correct responses and follow-up analyses were restricted to specific time windows, target material and reward conditions. Main effects and interactions are reported only if they include the factors of interest. Moreover, effects are only reported in the absence of higher order interactions.

## 2.4 Results

### *2.4.1 Behavioral Data*

**Study phase.** The mean likelihood of correct responses in the size judgment task was .87 (standard deviation (*SD*) ± 0.05) and the mean latency of responding was 505 ms (*SD* ± 156 ms). An ANOVA with factors of Material (picture vs. word) and Reward (high vs. low) revealed no main effects or interactions.

**Test phase.** Table 2.1 shows mean reaction times for and probabilities of correct responses to targets, new (unstudied) words and non-targets in the four test blocks. *Pr*-values were .25 (pictures-high reward), .15 (pictures-low reward), .19 (words-high reward) and .21 (words-low reward). An ANOVA with factors Target Material (picture, word) and Reward (high, low) gave rise to a marginally significant interaction between target material and reward, $F(1,18) = 4.05$, $p = .06$. Pairwise t-tests revealed that in the target-picture blocks, *Pr*-values were higher for pictures studied with high than with low reward ($t(18) = 2.72$, $p < .05$, two-tailed). No reward-related differences were found for the *Pr*-values in target-word blocks ($p = .68$). This reward effect in the target-picture blocks was primarily due to a lower false alarm rate for non-targets in the high reward condition (.31) compared to non-targets in the low reward condition (.40) in these blocks ($t(18) = 2.94$, $p < .05$, two-tailed). This reward-related difference between false alarms of the non-targets was not found in the target-word blocks ($p = .67$).

An ANOVA for the accuracy data with the factors Target Material (picture, word), Item Type (target, non-target, new) and Reward Condition (high, low) revealed only a significant effect for Item Type, $F(2,36) = 15.99$, $p < .001$). Follow-up t-tests revealed that accuracy to new words was higher than to non-targets ($t(18) = 5.25$, $p < .001$, two-tailed) and to targets ($t(18) = 4.78$, $p < .001$, two-tailed). An ANOVA of the RT data with factors of Target Material (picture, word), Item Type (target, non-target, new), and Reward Condition (high, low) did not reveal any significant differences (all *p*-values > .12).

In sum, the behavioral results from the test phase indicate that the high and low reward manipulation during study had an effect at retrieval when pictures, but not words, were the targets. In addition, performance was better for new items than for non-targets or targets, but did not differ as a function of the target material.

**Table 2.1** Mean proportions of correct responses (*p*(correct) and reaction times (RTs in ms) to targets, new items and non-targets separated according to target material and reward condition (N = 19). Standard deviations in parentheses.

| | | Item Type | | |
|---|---|---|---|---|
| Test Block | | Target | Non-target | New |
| Pictures – High Reward | *P*(correct) | .56 (.12) | .69 (.14) | .75 (.13) |
| | RT | 928 (115) | 950 (116) | 932 (124) |
| Pictures – Low Reward | *P*(correct) | .54 (.12) | .60 (.12) | .76 (.10) |
| | RT | 962 (117) | 964 (131) | 967 (124) |
| Words – High Reward | *P*(correct) | .58 (.11) | .61 (.11) | .71 (.15) |
| | RT | 923 (157) | 942 (157) | 932 (152) |
| Words – Low Reward | *P*(correct) | .59 (.12) | .62 (.14) | .69 (.13) |
| | RT | 932 (160) | 936 (159) | 910 (155) |

### *2.4.2 ERP data – New items only*

As the primary focus of this experiment is on retrieval orientations, the ERPs elicited by correctly classified new words in the test phase are described first. These are followed by analyses of ERPs elicited by correctly identified targets and non-targets (old/new-effects) and analyses of cue-locked ERPs during encoding.

Grand average waveforms elicited by correct rejections of new test words in the two material conditions, separated for the high and low reward conditions, are illustrated in Figure 2.3a. ERPs in both reward conditions are relatively more negative-going in the target-picture condition than in the target-word condition. These effects start at around 400 ms, extend for about 300 ms and show a broad topographical distribution, which is more anteriorly distributed in the high reward condition (also see Figure 2.4). Figure 2.3b shows the grand average waveforms elicited by correctly rejected new words in the two reward conditions, separated for the target-picture and target-word material conditions. In both target material conditions, ERPs elicited by high reward items show a relative positivity over frontal sites from approximately 400 ms. Although this effect appears to remain until the end of the recording epoch for the target-word condition, the effect in both target material conditions is most robust between 400 and 1000 ms post-stimulus and thus this is the time window over which the principal analyses were focused.

The observations outlined above suggest a difference in timing between the two contrasts in the critical 400 - 1000 ms epoch; a shorter-lived ERP difference related to material type from 400 - 700 ms and a more temporally protracted ERP effect associated with level of reward. To test this, mean amplitude measures were subjected to a five-way repeated measures ANOVA with factors of Target Material (picture, word), Reward (high, low), Location (frontal, central, parietal electrodes), Laterality (left, middle, right electrodes) and Time Window (400 - 700, 700 - 1000). This revealed an interaction between Target Material and Time Window ($F(1,18) = 4.21$, $p < .05$), licensing separate ANOVAs in each of the two time windows. In the early time window there was a main effect of Target Material ($F(1,18) = 5.49$, $p < .05$), interactions between Reward and Location ($F(2,36) = 12.33$, $p < .01$, $\varepsilon = .61$) and between Target Material, Reward and Location ($F(2,36) = 6.92$, $p < .05$, $\varepsilon = .66$). In the late time window there was an interaction between Reward and Location ($F(2,36) = 8.89$, $p < .01$, $\varepsilon = .73$). No effects involving the Target Material factor were obtained in the late time interval. Thus, effects including this factor were limited to the early time window, whereas effects including the factor Reward were found across both time windows. To determine the precise pattern of the effects, these interactions were then broken down separately for the two time windows.

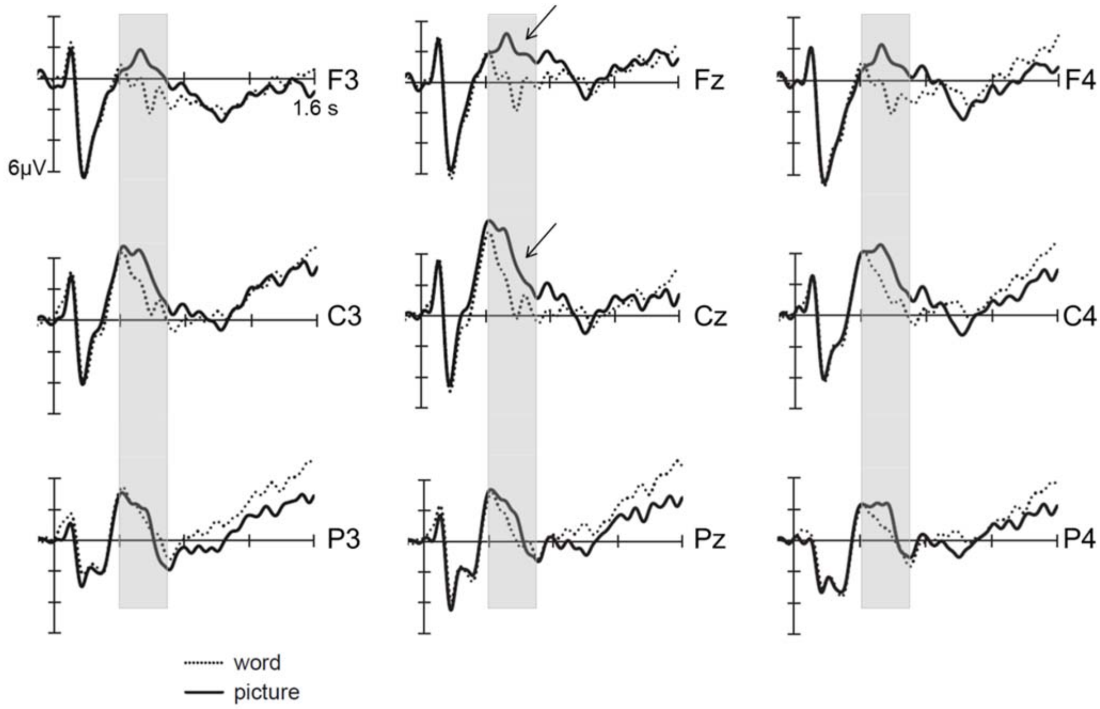
**Early time window (400 – 700 ms).** The three-way interaction between Target Material, Reward and Location in the early time window was deconstructed by examining material effects at each level of the Reward and Location factors. ANOVAs in the high reward condition ERPs yielded significant effects of Target Material at frontal ($F(1,18) = 9.29$, $p < .01$) and central sites ($F(1,18) = 8.37$, $p < .05$). ANOVAs for the low reward condition ERPs yielded significant effects of Target Material at central ($F(1,18) = 5.58$, $p < .05$) and parietal sites ($F(1,18) = 4.60$, $p < .05$). This pattern indicates that the material-specific retrieval orientation effect was most pronounced at frontal and central sites in the high reward condition whereas it was more posteriorly distributed in the low reward condition. The results confirm that, in both reward conditions, ERPs were relatively more negative-going in the target-picture condition than in the target-word condition. Whilst there was some indication of a topographical difference between the high and low reward conditions, the material-specific ERP effects were of similar magnitudes and had similar temporal characteristics in both reward conditions.

The three-way interaction in the early time window was further deconstructed by examining reward effects at each level of the Target Material and Location factors. The ANOVAs for the target-picture condition revealed a main effect of Reward ($F(1,18) = 4.37$, $p<.05$), whereas for the target-word condition there was a significant interaction between Reward and Location ($F(2,36) = 15.95$, $p < .001$, $\varepsilon = .66$), indicating reliable effects of Reward at frontal ($F(1,18) = 10.39$, $p < .01$) and central sites ($F(1,18) = 9.72$, $p < .01$) but not at parietal sites ($p = .27$). These effects confirm that in both material conditions, high reward items elicited more positive-going ERP waveforms than low reward ones in the early time window, albeit the effect was more frontally distributed in the target-word condition.

**Late time window (700 – 1000 ms).** To deconstruct the two-way interaction between Reward and Location in the late time window, reward effects were again examined at each level of the Location factor. The ANOVA yielded a significant effect of Reward at frontal sites ($F(1,18) = 6.85$, $p < .05$), but not at central or parietal sites (both $p$-values > .32), indicating that the reward-related ERP effect in this later time window was most pronounced at anterior electrode sites and did not differ between the two material conditions.

Figure 2.3b also indicates that ERPs to correctly rejected new words in the high and low reward conditions continue to diverge from one another in the 1000 - 1600 ms interval. To test this observation, reward effects were examined in two additional time windows (1000 - 1300 ms, 1300 - 1600 ms). A five-way repeated measures ANOVA with the same factors as in the initial analysis but with an additional factor of Time Window (1000 - 1300 ms, 1300 - 1600 ms) revealed a two-way interaction between Reward and Location ($F(2,36) = 4.23$, $p < .05$, $\varepsilon = .71$). Deconstruction of the interaction with further ANOVAs yielded a marginally significant effect of Reward at frontal ($F(1,18) = 4.2$, $p = .055$) but not at central or parietal sites (all $p$-values > .22). This analysis confirms that the reward-related ERP effect continued from 1000 ms onwards and that it was most pronounced at frontal electrodes as was the case in the preceding time windows. Although these analyses were only marginally significant, they indicate a temporally protracted frontal reward-related effect.

**High Reward Condition**




**Low Reward Condition**

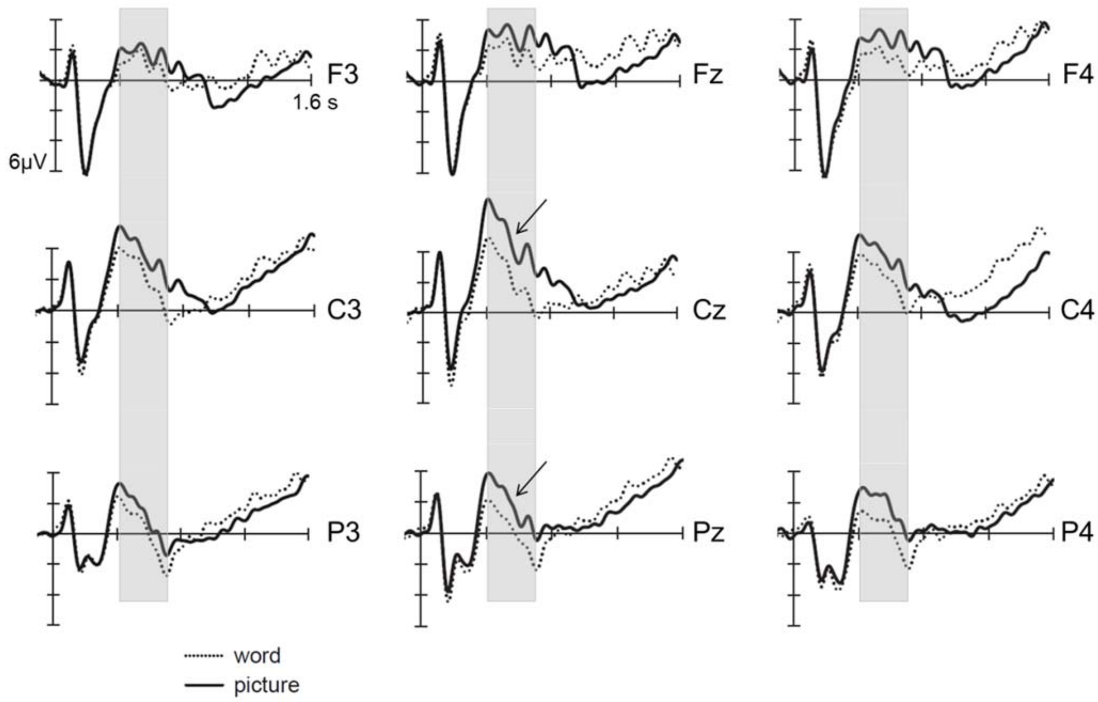
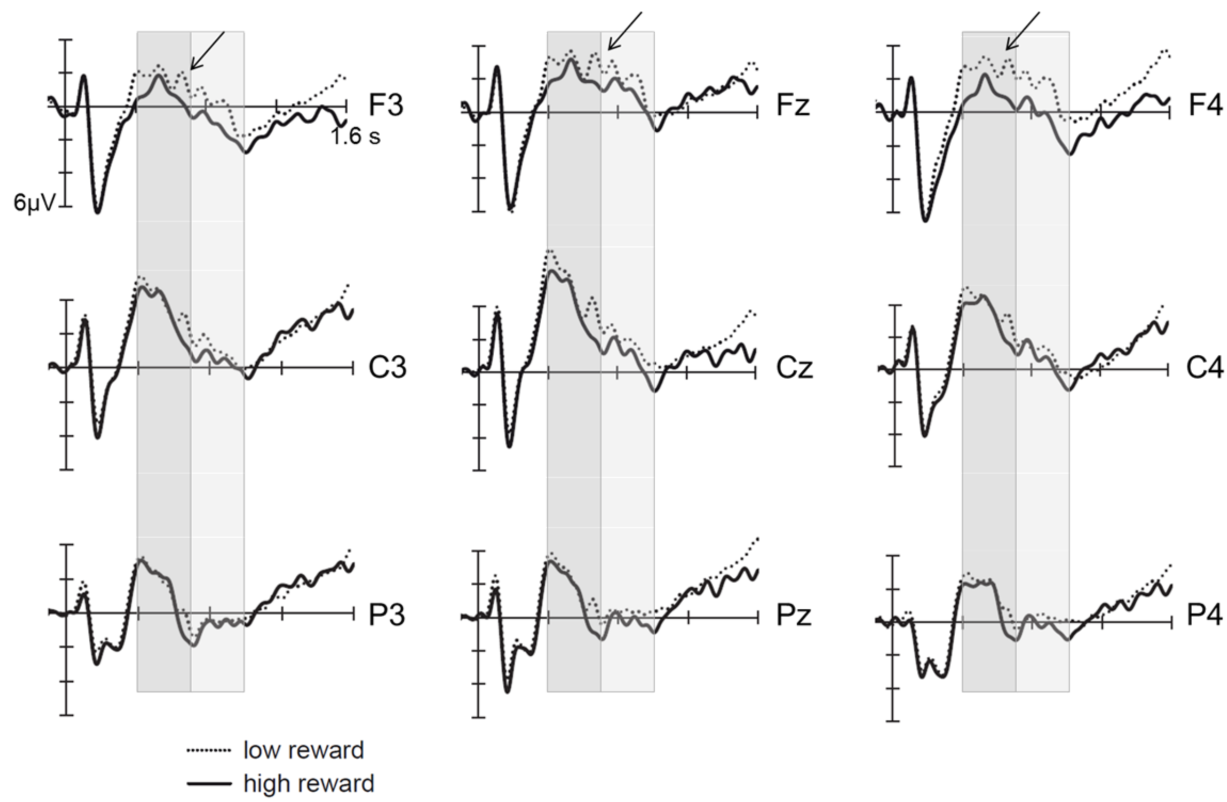



**Figure 2.3a** Upper panel: Grand average ERPs elicited by correct rejections in the target-word and target-picture blocks for the high reward condition. Lower panel: Grand average ERPs elicited by correct rejections in the target-word and target-picture blocks for the low reward condition. In both panels, data are shown for 9 electrodes over frontal (F3, Fz, F4), central (C3, Cz, C4) and parietal (P3, Pz, P4) scalp sites. Arrows mark the electrodes at which the effects were maximal. For visual presentation, all depicted waveforms in the figures in Chapter II and Chapter III were low-pass filtered at 12 Hz. Negative values are plotted upwards.

**Target – Picture Condition**




**Target – Word Condition**

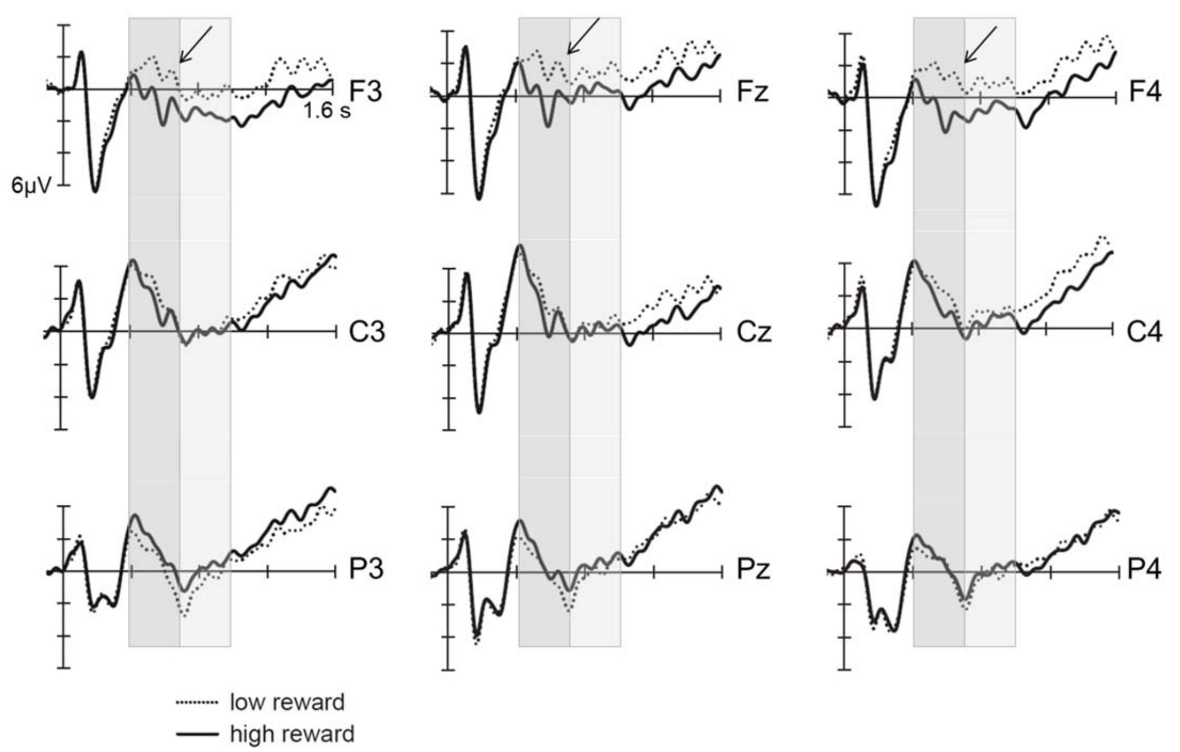



**Figure 2.3b** Upper panel: Grand average ERPs elicited by correct rejections in the two reward conditions for the target-picture condition. Lower panel: Grand average ERPs elicited by correct rejections in the two reward conditions for the target-word condition. In both panels, data are shown for 9 electrodes over frontal (F3, Fz, F4), central (C3, Cz, C4) and parietal (P3, Pz, P4) scalp sites.

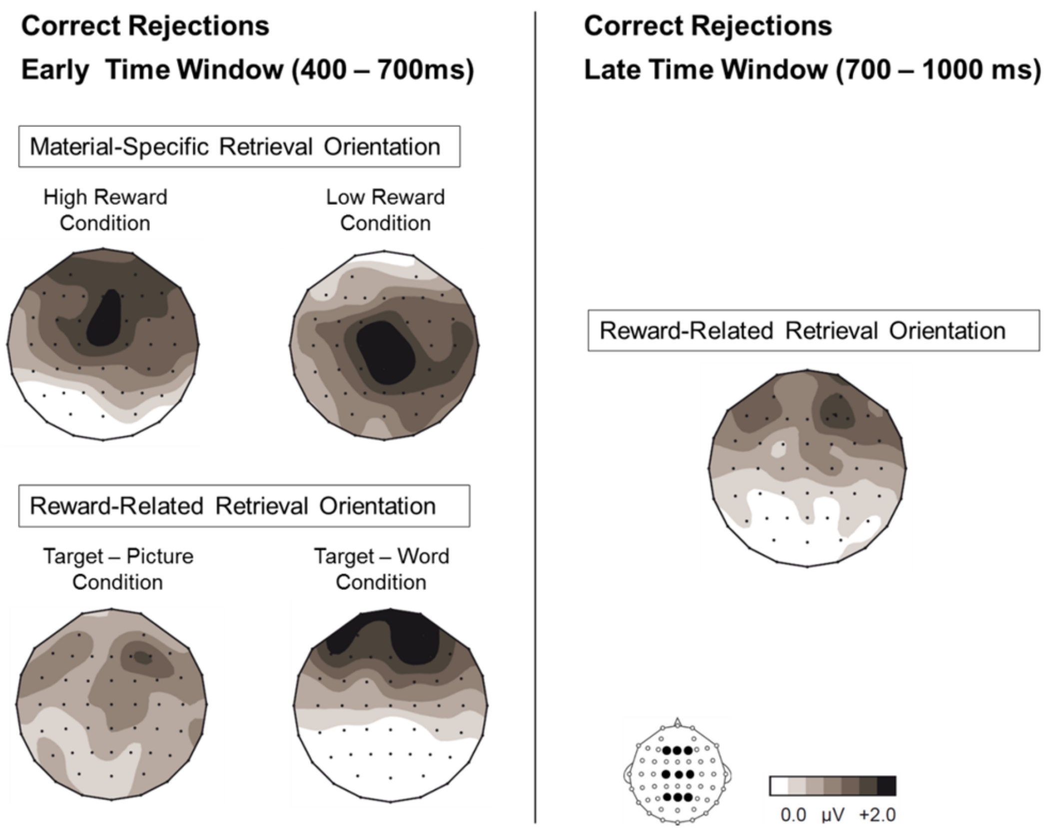



**Figure 2.4** Upper left panel: Topographic difference maps showing the scalp distribution of the differences between neural activity elicited by new test words for the target-word and target-picture blocks in the high and low reward condition in the early time window from 400 - 700 ms (material-specific retrieval orientation). Lower left panel: Topographic difference maps showing the scalp distribution of the differences between neural activity elicited by new test words for the target-word and target-picture blocks in the high and low reward condition in the early time window from 400 - 700 ms (reward-related retrieval orientation). Right panel: The topographic map shows the scalp distribution of the differences between neural activity elicited by new test words in the high and low reward condition in the late time window from 700 - 1000 ms (reward-related retrieval orientation). The locations of the used electrodes sites are indicted on the insert.

### *2.4.3 ERP data – Old versus New items*

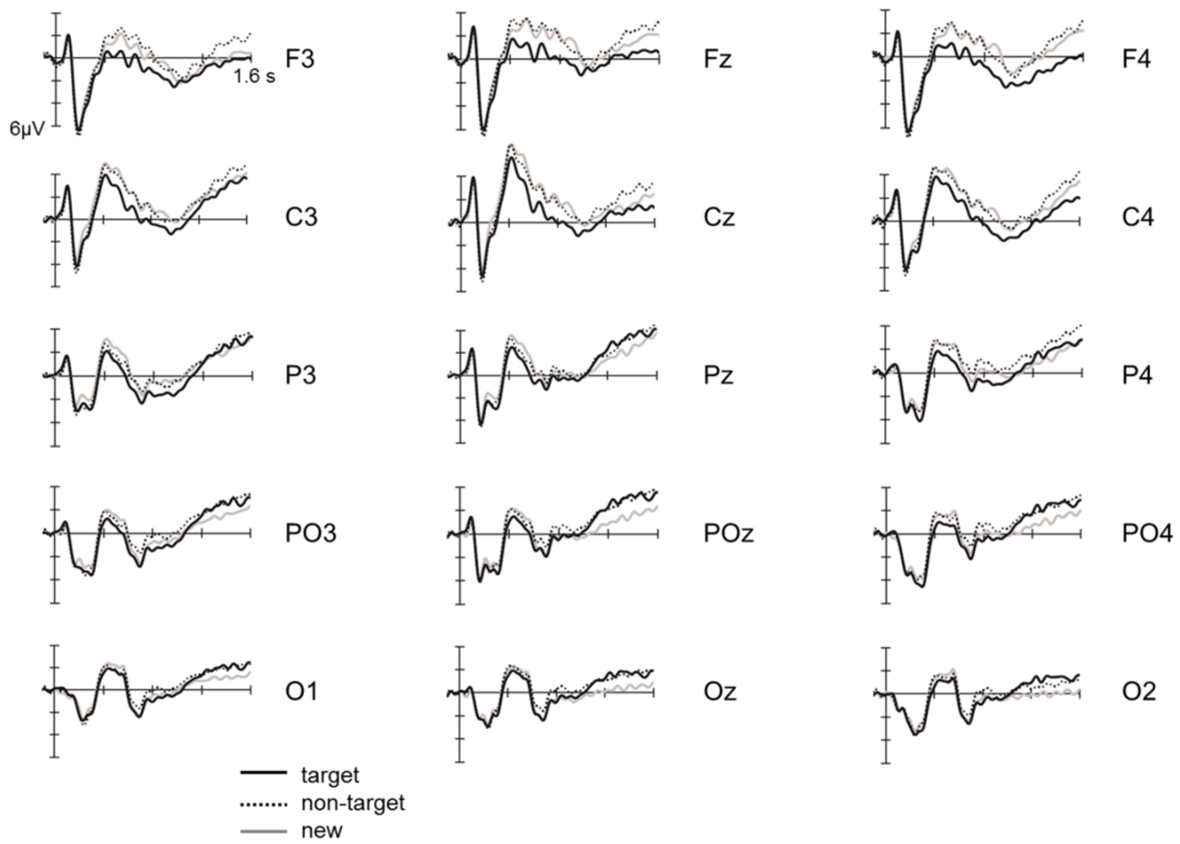
The investigation of old/new effects was motivated by the aim to examine neural correlates of the retrieval ‘contents’ between the two material as well as between the two reward conditions. For this purpose, next to the ERPs to new items, ERPs to correctly classified old items (targets and non-targets) were additionally included in the analyses. The inclusion of new items is crucial in the analysis of retrieval contents as ERPs to old items alone might, apart from retrieval content, be confounded by effects of retrieval orientation. This follows the same logic as outlined in Paragraph 1.4.2 in which the exclusive focus on new items in analyses of retrieval orientations was justified by the aim to keep processes of retrieval orientation separated from those related to successful memory retrieval.

However, this second part of the ERP analysis was primarily guided by the data as no 'classical' and characteristic old/new effects that represent neural correlates of retrieval success - neither late left parietal nor early frontal old/new effects - were observed (see Figure 2.5 and 2.7 which show ERPs elicited by targets, non-targets and new items separately for each material and reward condition). That is, ERPs to items to which a correct source judgment was made (i.e. correctly identified targets or non-targets) did not clearly diverge from those to new items in time windows and locations in which they were commonly found. Therefore, the focus of the analysis lay on possible post-retrieval processes - i.e. late, right frontal old/new effects and late posterior 'reversed' old/new effects (also called 'late posterior negativity' (LPN).

Grand average waveforms elicited by correct responses to targets and non-targets in the two material conditions superimposed on waveforms elicited by new items (these were already depicted in Figure 2.3a and 2.3b), are illustrated in Figure 2.5. As can be seen in this figure, ERPs to targets in the target-picture condition were relatively more positive-going than those to new items and non-targets. This effect starts around 300 ms, extends until the end of recording epoch (1600 ms) and shows a frontal topographical distribution (also see Figure 2.6). At occipital sites, the effect together with the ERPs to non-targets reverses in polarity from around 1000 ms onwards.

As is evident from the lower panel of Figure 2.5, waveforms in the target-word condition for targets and non-targets appear to be more positive-going than waveforms for new items from approximately 300 ms post-stimulus. More specifically detailed however, the waveforms for non-targets in the early 300 - 700 ms latency range first appear to virtually overlap with those for the targets but start to diverge and become closer to the waveforms for the new items from 700 ms onwards. The effect shows a right-frontal topographical distribution (lower panel, Figure 2.6) for both contrasts, but was most pronounced for the targets (target vs. new items; non-targets vs. new items). Polarity changes at parieto-occipital sites, as waveforms for targets become relatively more negative-going than those for new items and non-targets at about 1000 ms post-stimulus.

**Target – Picture Condition**



## Target – Word Condition

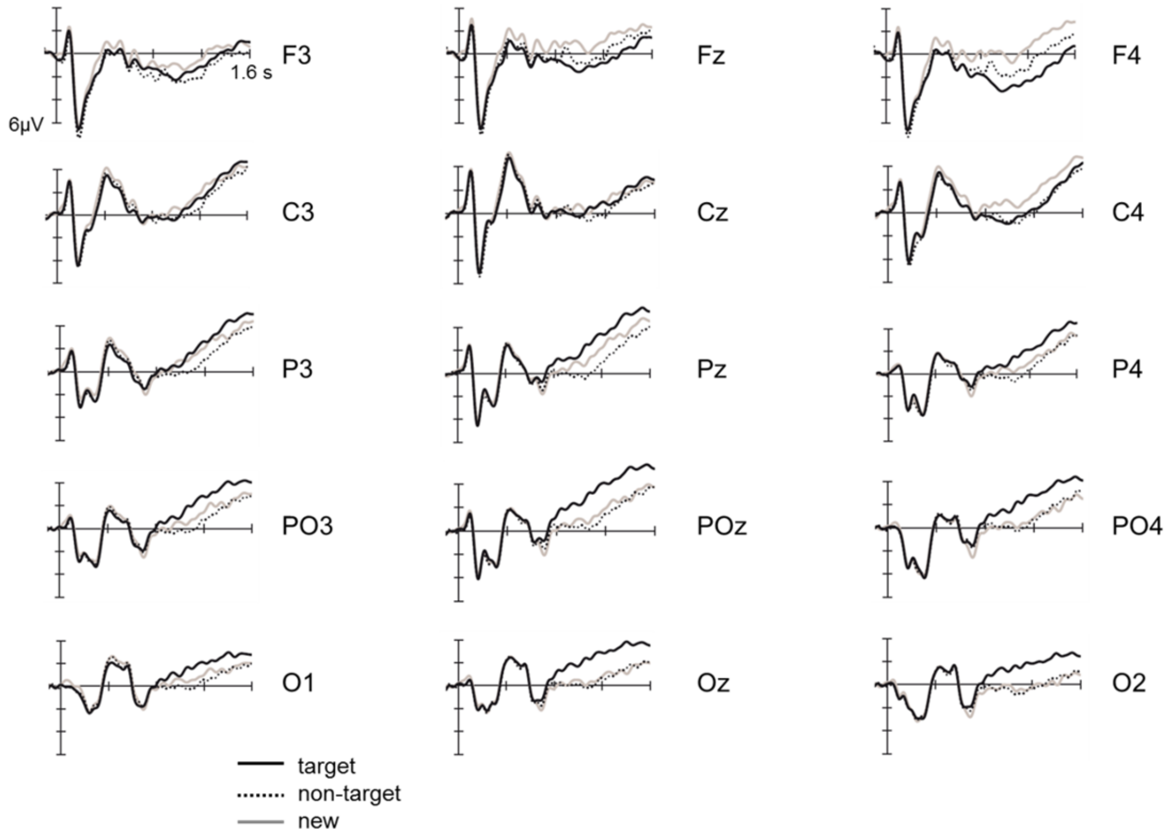



**Figure 2.5** Upper panel: Grand average waveforms elicited in the target-picture condition by targets, non-targets, and new words. Lower panel: Grand average waveforms elicited in the target-word condition by targets, non-targets, and new words. In both panels, data are shown for twelve electrodes over frontal (F3, Fz, F4), central (C3, Cz, C4), parietal (P3, Pz, P4, PO3, POz, PO4) and occipital (O1, Oz, O2) scalp sites.

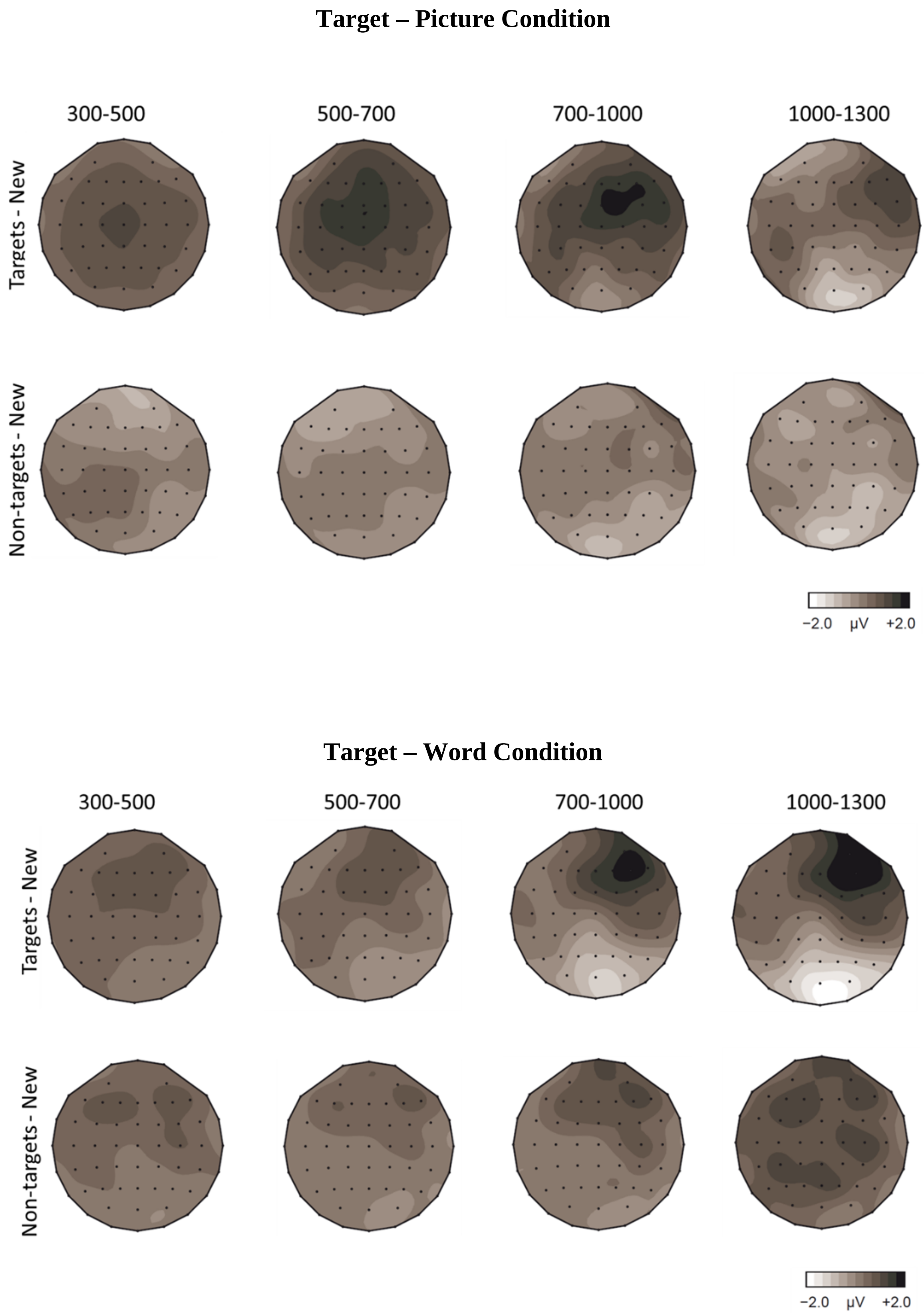
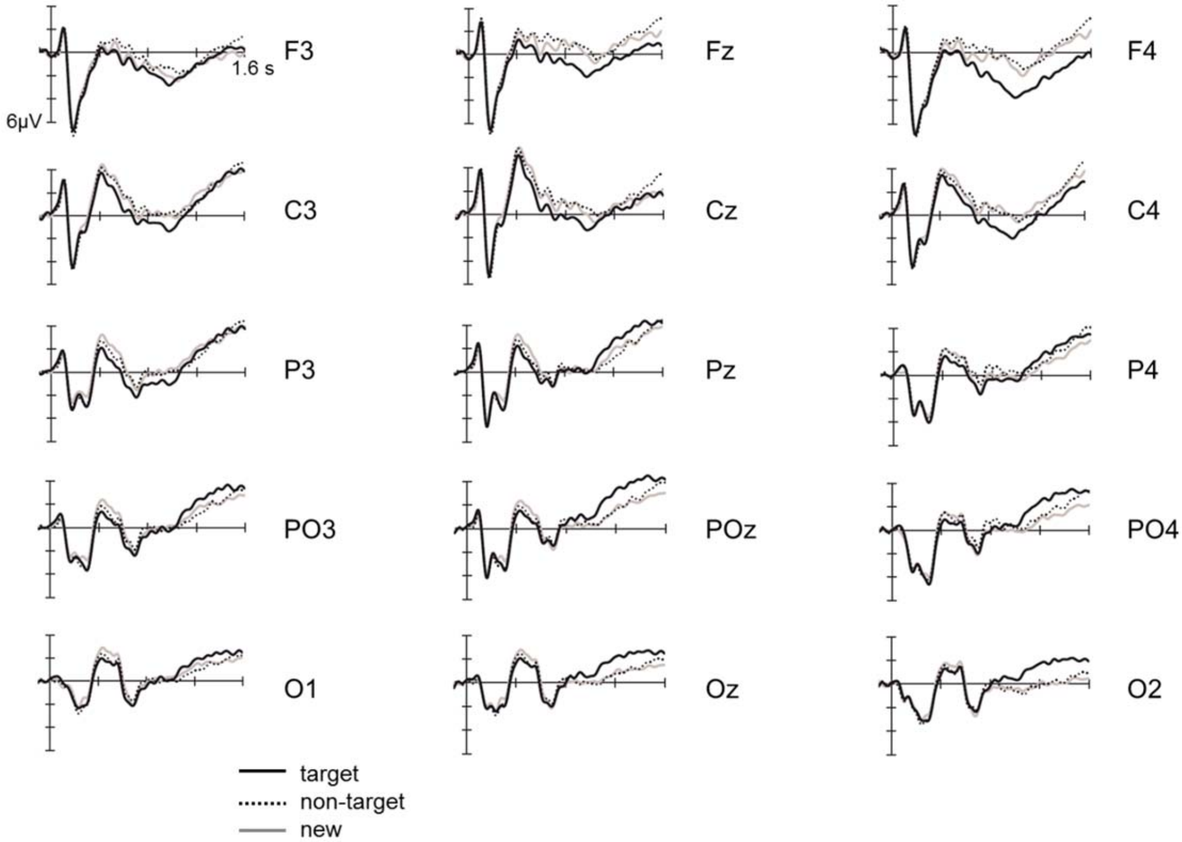



**Figure 2.6** Topographic maps showing scalp distributions in the 300 - 500, 500 - 700, 700 - 1000, and 1000 - 1300 ms ranges separately for target old/new effects and for non-target old/new-effects: upper panel: target-picture condition; lower panel: target-word condition. Each map is proportionally scaled between the maxima (black) and minima (white) of the depicted effect.

ERPs elicited by correct responses to targets and non-targets in the two reward conditions superimposed on those to new items are illustrated in Figure 2.7**.** As can be seen from the figure**,** ERPs to targets in the high reward conditions were relatively more positive-going than those to new items and to non-targets. This effect starts around 300 ms, extends until the end of recording epoch (1600 ms) and shows a broad topographical distribution but becomes more right-frontally distributed from around 700 ms onwards (also see upper panel of Figure 2.8). This effect reverses in polarity at occipital sites from about 1000 ms.

In the low reward condition, ERPs to targets and non-targets were relatively more positive-going than those to new items in a similar time window as the ERP-differences in the high reward condition. Whereas the non-target ERPs first virtually overlap with the target ERPs, they become closer to the new item ERPs from 1000 ms onwards. The effect shows a right-frontal topographical distribution (also see lower panel of Figure 2.8) for both contrasts (targets vs. new items; non-targets vs. new items). Polarity changes at parieto-occipital sites, such that ERPs to targets become relatively more negative-going compared to the ERPs to new items and non-targets at about 1000 ms.

**High Reward Condition**



**Low Reward Condition**

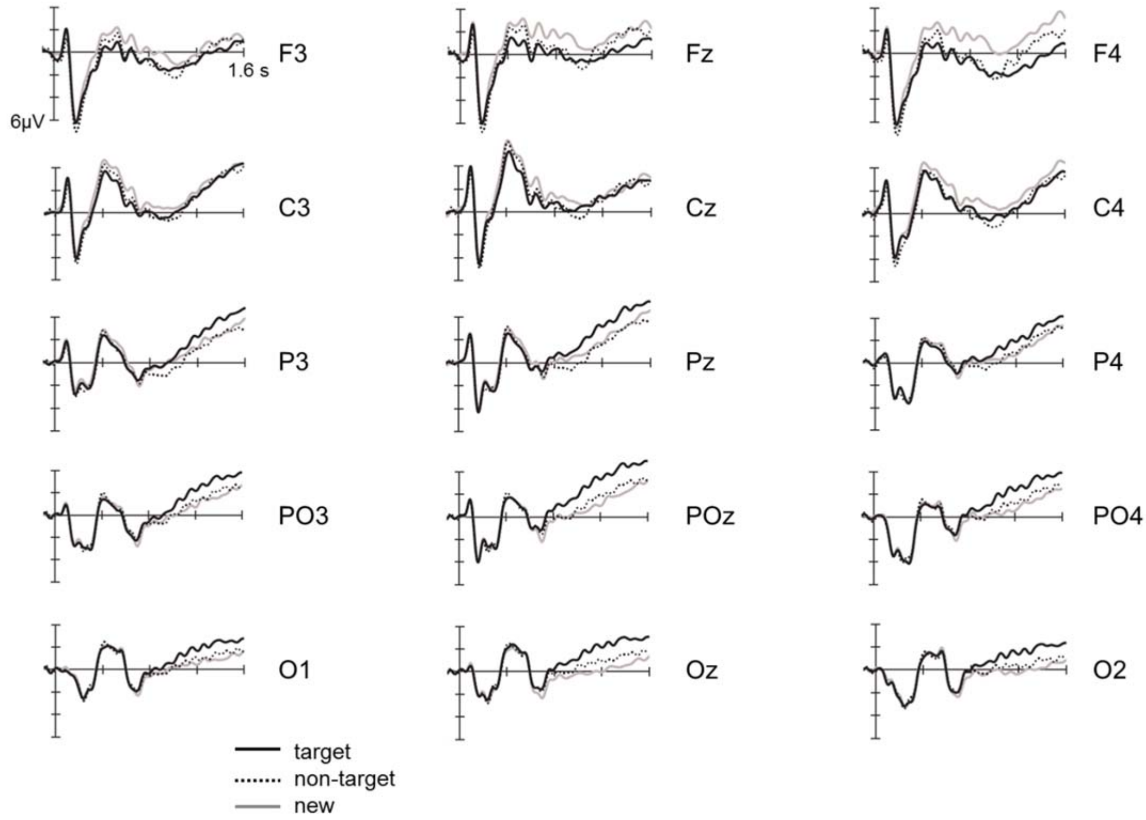



**Figure 2.7** Upper panel: Grand average waveforms elicited in the high reward condition by targets, non-targets, and new words. Lower panel: Grand average waveforms elicited in the low reward condition by targets, non-targets, and new words. In both panels, data are shown for twelve electrodes over frontal (F3, Fz, F4), central (C3, Cz, C4), parietal (P3, Pz, P4, PO3, POz, PO4) and occipital (O1, Oz, O2) scalp sites.

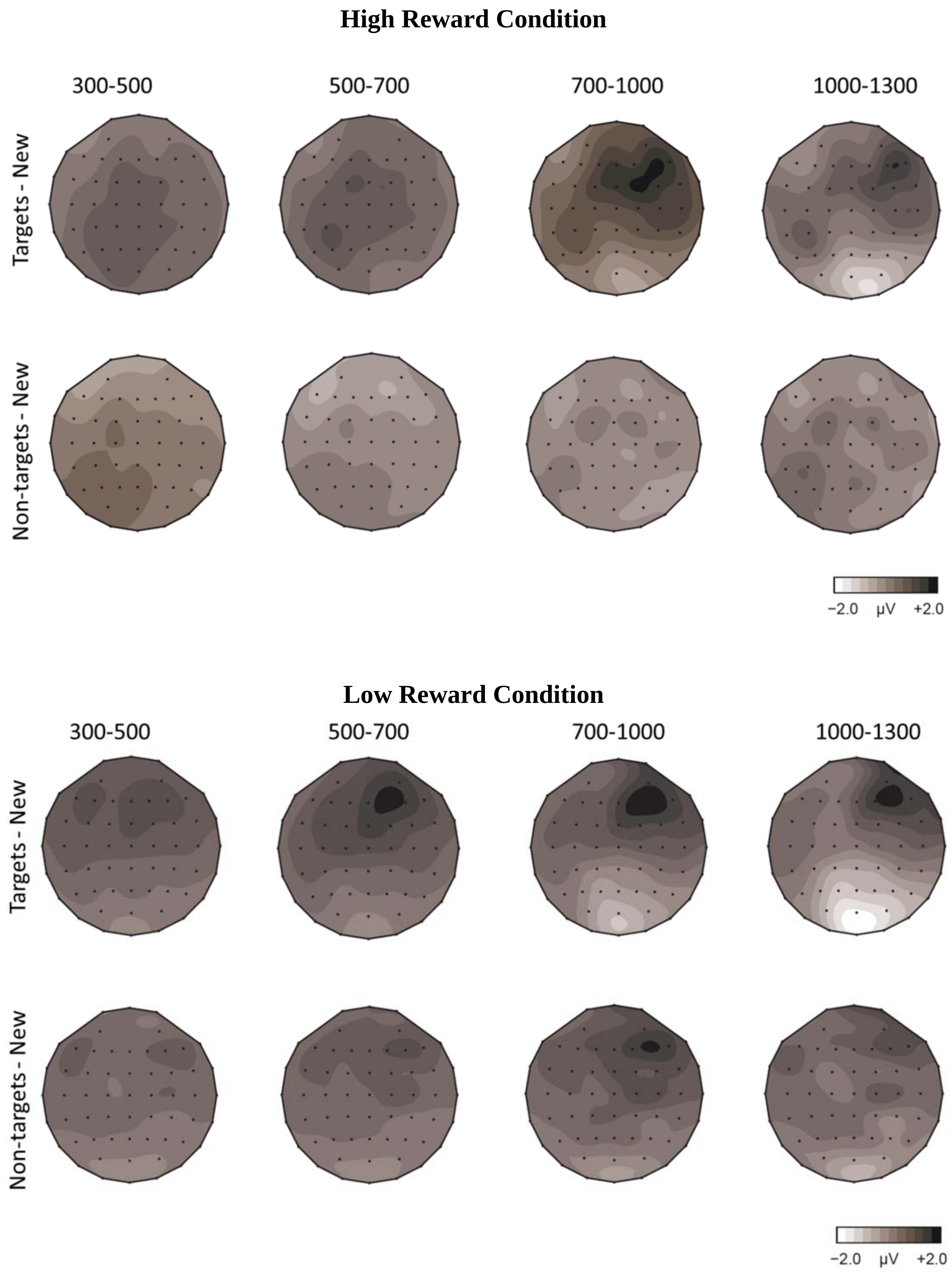



**Figure 2.8** Topographic maps showing scalp distributions in the 300 - 500, 500 - 700, 700 - 1000, and 1000 - 1300 ms ranges separately for target old/new effects and for non-target old/new-effects: upper panel: high reward condition; lower panel: low reward condition. Each map is proportionally scaled between the maxima (black) and minima (white) of the depicted effect.

Initial statistical analyses were conducted on the mean ERP amplitudes for correct responses to targets, non-targets and new items, separately for the material (target-picture;

target-word) and reward (high; low) conditions over four latency regions: 300 - 500 ms, 500 - 700 ms, 700 - 1000 ms, and 1000 - 1300 ms post-stimulus onset. More precisely, these analyses employed ANOVAs with factors of Item Type (target, non-target, new), Location (frontal, central, parietal electrodes) and Laterality (left, middle, right electrodes). The complete outcomes of the analyses of old/new effects separated for the two target designations and for the two reward conditions can be found in Appendix A. They correspond directly to the outcomes of the paired contrasts reported below and contain the Tables A2.2a, A2.2b, A2.2c, A2.2d, A2.3a, A2.3b, A2.3c and A2.3d.

**Right frontal ERP old/new effects.** As is evident from Table A2.2a (see Appendix A), ANOVA of the data from the target-picture condition revealed significant target old/new effects in the 300-1000 ms latency regions which were broadly distributed over the scalp. More specifically, for the 700 - 1000 ms latency region, the effect was accompanied by a marginally significant interaction between the factors of Item Type and Location. This interaction arose because the old/new effect was most pronounced at anterior electrode sites in this later time window. No old/new effects for non-targets were found.

In the target-word condition, ANOVA revealed significant target old/new effects at right frontal electrode sites in the 300 - 500 ms, 700 - 1000 ms and 1000 - 1300 ms latency regions (Table A2.2b). For non-targets, topographically widespread old/new effects were found in the 300 - 500 ms (marginally significant) and in the 1000 - 1300 ms latency regions.

ANOVA of the data from the high reward condition (see Table A2.2c) revealed significant target old/new effects in the latency regions from 300 - 1300 ms. Whereas the old/new effects in the first two latencies were broadly distributed over the scalp, they became most pronounced at right frontal electrode sites from 700 ms onwards. No old/new effects for non-targets were found.

In the low reward condition, ANOVA revealed target old/new effects in all four latency regions (300 - 1300ms, Table A2.2d). In the first two time windows, the effects were most pronounced at fronto-central electrode sites, between 700 - 1000 ms they became more frontally distributed and between 1000 - 1300 ms, the effects showed a right-frontal distribution. For non-targets, a topographically widespread marginally significant effect for 500 - 700 ms latencies and a significant right-frontal effect for 700 - 1000 ms and 1000 - 1300 ms latencies was found.

In sum, a late, right-frontal old/new effect for targets in all four conditions (target-picture, target-word, high reward, low reward) was found. In the target-word condition, as well as in the low reward condition also non-target old/new effects were found, as in these conditions ERPs to non-targets were more positive-going than ERPs to new items.

**Late posterior old/new effects.** As noted above, Figure 2.5 and Figure 2.7 also suggest that ERPs to correctly identified old and new items in the material and reward conditions diverge from one another at parieto-occipital electrode sites in the 1000 - 1600 ms interval, suggesting late-onsetting, negative-going old/new ERP effects. This was quantified by measuring the mean amplitudes of the 1000 - 1300 ms and 1300 - 1600 ms latency regions. In light of its apparent maximum at posterior and occipital sites, the electrode sites employed to characterize the effect differed from those used in the preceding analyses and consisted of electrodes PO3, POz, PO4, O1, Oz and O2.

ANOVA with the factors of Item Type (target, non-target, new), Location (parietal, occipital electrodes) and Laterality (left, middle, right electrodes) in the target-picture condition revealed a negative-going ERP effect for targets at midline sites for the 1000-1300 ms latencies and a more broadly distributed posterior effect for the 1300 - 1600 ms latencies (see Table A2.3a). With regard to the non-targets in this condition, only an effect at parietal electrode sites (PO3, POz and PO4) in the earlier time window was found (however the effect became marginally significant in the later time window).

In the target-word condition, ANOVAs yielded significant effects for targets at midline and right posterior electrodes sites in both time windows (Table A2.3b). No effects were found with respect to the non-target ERPs.

In the high reward condition, ANOVAs yielded significant effects for targets at midline and right posterior electrode sites in both time windows. No effects were found with respect to the non-target ERPs in this condition (Table A2.3c).

In the low reward condition, ANOVA revealed that target ERPs were significantly more negative-going than those to new items in both time windows but with a slightly more midline and right-sided distribution in the earlier time window (Table A2.3d). No effects were found with respect to the non-target ERPs.

In summary, these results reflect an LPN that was prevalent in all four conditions. Next to these target old/new effects, non-target old/new effects were exclusively found for the target-picture condition at posterior electrode sites.

### *2.4.4 ERP data – High versus Low Reward Cues at Study*

In order to investigate reward cue processing in the study phase, we compared the cue-locked ERP waveforms elicited by high and low reward cues, which can be seen in Figure 2.9. The ERPs in the high reward cue condition appear to be more positive-going compared to those in the low reward cue condition. This effect was visible between 300 and 500 ms and was broadly distributed over the scalp. To confirm these observations, a three-way repeated measures ANOVA with factors Reward (high, low), Location (frontal, central, parietal electrodes) and Laterality (left, middle, right electrodes) was conducted in the 300 - 500 ms time window where the effects were most marked. There was a main effect of Reward $F(1,18) = 33.53$, $p < .001$), suggesting that the participants processed encoding cues differently depending upon the promised amount of reward.

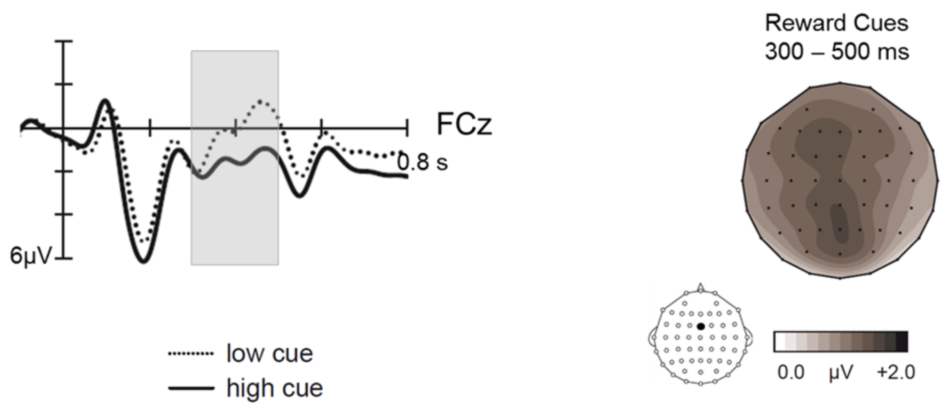



**Figure 2.9** Grand average ERPs elicited by the high and low reward cues at encoding. Data are shown for one representative electrode location over central electrode sites (FCz). The topographic difference map shows the scalp distribution of the differences between neural activity elicited by high and low reward cues at study in the time window from 300 - 500 ms.

In a next step it was examined whether reward-related neural activity at study was related to later memory performance. ERPs to low- and high reward cues in a time window of 450 - 750 ms after cue onset were separately contrasted depending upon whether the subsequent word or picture was correctly remembered or forgotten at test (Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980). In an initial analysis, a four-way repeated measures ANOVA with factors Subsequent Memory (remembered, forgotten), Reward (high, low), Location (frontal, central, parietal electrodes) and Laterality (left, middle, right electrodes) across all nineteen participants was conducted. No subsequent memory effects in any of the two reward conditions (all $p$-values > .1) were found. However, similar analyses were also conducted on data from nine participants for whom reward cues were most likely to be task-relevant, that is, for those whose memory performance for items in the high reward conditions was superior to that in the low reward condition. Results showed a main effect of subsequent memory in the high reward condition ($F(1,8) = 5.76$, $p < .05$) but not in the low reward condition ($p = .68$). That is, for those participants that showed reward-sensitivity in memory performance, a positive-going, topographically widespread subsequent memory effect was found for items from the high reward condition only (Figure 2.10).

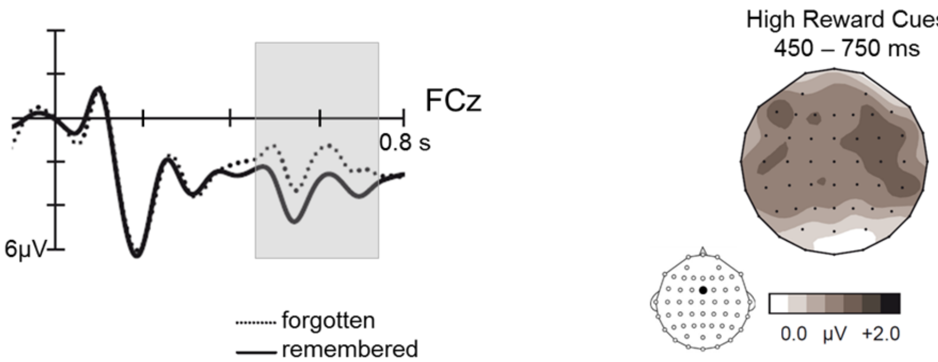



**Figure 2.10** Grand average ERPs elicited by the high reward cues, overlaid according to whether the following picture or word was later remembered (given a remember judgment) or forgotten (judged as new or non-target). Data of 9 participants are shown at one representative electrode location over central electrode sites (FCz). The topographic difference map shows the scalp distribution of the differences between neural activity elicited by high reward cues separated as a function of later memory performance to the following pictures and words in the time window from 450 - 750 ms.

## 2.5 Discussion

The main goal of Experiment 1 was to investigate the influence of reward-motivated learning on retrieval orientations. Relevant to this was whether the incentive to memorize an item would enhance the material-specific orientation effect or whether it would elicit a separate retrieval orientation effect. In the latter case this would presumably reflect the engagement of additional retrieval cue processes engaged as a consequence of the possibility of retrieving items studied with a high incentive.

Consistent with previous studies (Herron & Rugg, 2003; Hornberger et al., 2004; Hornberger et al., 2006; Robb & Rugg, 2002), the findings confirm the view that different retrieval orientations are adopted as a function of the targeted memory representation. ERPs to correctly rejected new items in the target-picture condition were more negative-going relative to ERPs in the target-word condition. This material-specific retrieval orientation effect was present from 400 - 700 ms post-stimulus and was most pronounced at central scalp sites. Notably, whilst the current effect showed a more anterior distribution in high reward blocks, neither its magnitude nor its temporal characteristics differed between the two reward conditions, indicating that the requirement to adopt a material-specific retrieval orientation was only minimally influenced by motivation.

Whilst the results replicate the standard material-specific orientation effect reported previously (e.g. Hornberger et al., 2004), they also revealed a distinct reward-related effect. That is, the principal contribution of this first experiment is that high compared to low monetary reward cues during study led to the adoption of a reward-associated retrieval orientation at test. In the high reward condition of the memory exclusion task, ERPs to correctly rejected new test items were more positive compared to those in the low reward condition between 400 and 1600 ms after presentation of the retrieval cue. This reward-associated retrieval orientation effect was present in both the target-picture and target-word conditions although the distribution was less anterior in the target-picture condition in the early time window of 400 - 700 ms. Beyond 700 ms the reward effect became most pronounced at anterior electrode sites irrespective of target material. That is, from that point in time, reward generated a spatio-temporally distinct ERP effect (see Figure 2.4). This change in retrieval cue processing in the different phases may have come about, in part, because of a tendency to retrieve more information in the high than in the low reward condition as a consequence of the learned association between high reward cues and items at study than in the low reward condition. The recovery of information associated with high reward at test might then have led to the re-engagement of reward-related processes comparable to those engaged during study, in line with the cortical reinstatement hypothesis (Rugg et al, 2008) and the associated principle of transfer appropriate processing (Morris et al, 1977).

Although the main interest in this study lay in the investigation of reward-modulating effects on neural correlates of retrieval orientations, old/new-effects were also examined as they reflect processes related to retrieval success. Especially when different types of study materials was required to retrieve at test, differences in ERP old/new effect might refer to content-specific retrieval. However, in the present study, no indices of early right-frontal or late left-parietal old/new effects in the four different conditions at test could be found. This missing effects that were often found in recognition test before might be accounted for by the relatively high difficulty level of the memory exclusion task, together with the 24 hours retention interval between study and test. An indication substantiating this idea might be reflected by the generally low memory performance that made it difficult to find neural correlates of recollection in this experiment. An open issue is hereby whether the ERPs to correctly identified old items (i.e. targets) or the ERPs to new items were the underlying reason for the missing effect between them.

Nevertheless the analysis of old/new effects revealed neural correlates of post-retrieval processes, i.e. indices of late onsetting right-frontal old/new effects and the LPN. In contrast to and with regard to the latency, rather inconsistent right-frontally distributed old/new effects in the target-word condition, reliable, topographically widespread effects were found in the target-picture condition that started around 300 ms post-stimulus and lasted until about 1000 ms. These relatively long lasting old/new effects in the target-picture condition might be interpreted as a reflection of additional post-retrieval processing that was needed in this target designation and as neural correlates corroborating the behavioral reward effect that was selectively found for the target-pictures and. It might be conceivable that in contrast to the target-word condition, additional capacity was left when participants were asked to identify formerly studied pictures as target which, as a consequence, enabled the additional retrieval of reward cue information for pictures. Strikingly, it can be seen from the ERPs in the high reward condition (Figure 2.7, upper panel) that the ERPs to the non-targets clearly overlap with those to the new items, whereas in the low reward condition the non-target-ERPs first overlap with the target-ERPs but from 1000 ms onwards they become closer to the new item ERPs. A possible explanation for this might by that participants were more certain in discriminating targets from non-targets in the high reward condition. By contrast, in the low reward condition additional post-evaluative processes might have been required in order to discriminate between targets and non-targets. This assumption is based on the findings suggesting that the right-frontal old/new effect, mainly due to its anterior distribution, might reflect strategic, monitoring processes required to process task-relevant information in order to pursue a specific task goal (Rugg et al., 2000).

Apart from right-frontal old/new effects, late-posterior negativity effects in all conditions were found that started at about 1000 ms after a retrieval cue had been presented and lasted until the end of the recording epoch (1600 ms). Interestingly, in the present experiment, the LPN for targets appeared to be biggest in the target-word and in the low-reward condition (see lower panels of Figure 2.6 and Figure 2.8). An underlying reason for this finding which was already stated by Johansson and Mecklinger (2003) before might be that in these two conditions additional task-relevant information such as the additional retrieval of attribute conjunctions from the prior study phase was required and therefore needed continued evaluation. Even though these effects were not directly compared between the conditions, it might be conceivable, also with regard to the prevalent reward effect in the behavioral data of the target-picture condition, that less evaluative processes were needed in the high reward as well as in the target-picture condition.

Previous results of fMRI-studies have shown that encoding-related activity can be influenced by reward-related activity (Adcock et al., 2006). In the present study, cue-locked ERPs elicited a broadly distributed positive slow wave for high reward cues compared to low reward cues. This is consistent with the findings of Gruber and Otten (2010), who reported two separate reward-related cue-locked ERP effects, of which only the later occurring (600-2000 ms) predicted whether stimuli were later remembered. The authors interpreted this functional dissociation as the reflection of two processing steps. The first, starting a few hundred milliseconds after presentation of a reward cue, is proposed to reflect effort mobilization by a high reward cue in order to facilitate the processing of perceptual information. Afterwards, in a second step, reward- and encoding-related processes might interact by holding relevant information in working memory in order to facilitate the encoding of new information into long-term memory. The reward-related cue effect observed in the present study is more likely to correspond with the first step of their model - the facilitated perceptual processing account - because the differences in the processing of reward information were initiated by high, positively valenced reward cues and also occurred in a relatively early time window after cue onset. Moreover, this effect is similar to findings reported by Koenig and Mecklinger (2008) who investigated the influence of emotional pictures (negative, neutral or positive) on encoding and retrieval. Results showed that during study, positive, low-arousing pictures gave rise to more positive anterior and posterior slow wave activity in contrast to negative, high-arousing, and neutral pictures. According to the authors, these findings reflect a top-down controlled facilitated processing of positive low-arousing materials (Koenig & Mecklinger, 2008; see also Kensinger & Corkin, 2004). It is assumed that the monetary rewards used in the present study might be similarly motivating for the brain as positively valenced, low arousing pictorial materials.

An interesting additional question is whether the modulation of reward-related cue effects by subsequent memory performance that was reported by Gruber and Otten (2010) also extends to the current dataset. There are, however, a number of aspects of the current paradigm which make it less than ideal for analyzing subsequent memory effects. This is because response requirements in memory exclusion tasks (i) do not comprise confidence judgments which can be used to increase the power of subsequent memory contrasts (see Otten & Rugg, 2001) and (ii) because the binary response requirement allows for the possibility that a forgotten target could in fact be a falsely remembered non-target. Even though the validity of a subsequent memory analysis is open to debate in the present study, our data support the findings of Gruber and Otten (2010) to some extent. Subsequent memory analyses collapsed across target-material conditions were conducted on data from nine participants for whom reward cues were most likely to be task-relevant, that is, for those whose memory performance for items in the high reward conditions was superior to that in the low reward condition. A reliable subsequent memory effect was found for items from the high reward condition but not for those studied with low reward. This pattern indicates that not all participants were equally sensitive to the incentives, but that those who were more sensitive to this manipulation, prepared themselves to encode high reward items in a more efficient way. A further possible reason, next to the use of a memory exclusion task, for the fact that no subsequent memory effects modulated by reward across all participants were found might be that in contrast to the study of Gruber & Otten (2010), a longer retention interval between the study and test phase (24 hours) was used.

Taken together, the reward-related cue and subsequent memory effects in the study phase of the present experiment corroborate the findings reported by Gruber and Otten (2010), and support the role of differential processing of the monetary reward cues via facilitated perceptual processing and the efficient encoding for cues which predict high reward. More importantly, the findings of the present study provide the first evidence that participants can adopt distinct retrieval orientations, not only as a function of the targeted information (material-specific retrieval orientation effect) but also as a function of reward anticipation (reward-specific retrieval orientation effect). This suggests that incentives during learning facilitate the adoption of a reward-specific retrieval orientation in a delayed memory test in order to retrieve perceptual details of highly motivational information in an efficient way.

With regard to the reward-associated retrieval orientation effect found in this first experiment, an alternative interpretation to the cortical reinstatement hypothesis (Rugg et al, 2008) and the associated principle of transfer appropriate processing (Morris et al, 1977) - the recovery of information associated with high reward at test might have led to the re-engagement of reward-related processes comparable to those engaged during study - may account for this effect. As it was assumed that the most efficient retrieval strategy for earning the greatest amount of money would be to prioritize retrieval processes towards the recovery of high reward items, possibly, the recovery of information associated with high reward may have led to the engagement of more effortful retrieval operations at test for these items in order to increase retrieval cue specificity for items that were studied with high incentives. This possibility is supported by the similarity in scalp distribution between this frontally distributed reward-associated effect and prefrontally distributed retrieval effects reported by Ranganath and Paller (1999) and Werkle-Bergner, Mecklinger, Kray, Meyer, and Düzel (2005). In those studies, retrieval tasks that differed in their demands on the maintenance and specification of retrieval cue features were compared. More positive ERPs were found for responses in the tasks with higher retrieval cue specification demands and greater relative task difficulty. Accounts based on these data assume that the distribution of these effects reflect the greater engagement of pre-frontally supported strategic control mechanisms required for retrieval under such circumstances. With these findings in mind, it might be reasonable to assume that the reward manipulation in Experiment 1 led participants to initiate more extensive retrieval cue processing in order to increase the likelihood with which items studied with high incentives were retrieved. This account raises the issue of whether the term ‘reward-related’ is appropriate for this temporally extended frontal effect, or whether it is primarily a reflection of effort or control-related processes that, in this instance, are elicited by the reward manipulation at study. With this in mind, a second experiment was conducted designed to explicitly address whether these effects relate generally to reward-manipulations at study or to the effortful processing of retrieval cues in test blocks with high reward items.

# Chapter III: Experiment 2

# The Impact of Monetary Rewards on Strategic Memory Retrieval Processes in an Incidental Learning Paradigm – an ERP Study

## 3.1 Introduction

The results from Experiment 1 suggest that participants can adopt distinct retrieval orientations as a function of the anticipation of high or low monetary incentives. This temporally extended, frontal retrieval orientation effect may come about because of the reinstatement of reward-related encoding processes at retrieval which consequently enabled the recovery of greater learned associations between high reward cues and study items than in the low reward condition. Alternatively, these data can be reconciled with the proposal that the reward-associated retrieval orientation effect mainly reflects differences in retrieval effort or control-related processes elicited by the reward manipulation at study. One way to test whether this effect reduces to an index of retrieval effort would be to determine whether it is also present in a comparable task in which the reward manipulation at study is not associated with later memory performance but is instead linked to the accuracy of the study task. An incidental reward paradigm of this kind would obviate the need for increasing effort-related resources in retrieval conditions associated with high reward. Thus, the observation of a comparable frontally-based ERP effect in this incidental task would speak against an effort account and in favor of a reward-related retrieval orientation that is elicited in line with the principles of transfer appropriate processing and the value of re-engaging encoding processes at retrieval.

To test this, a follow-up experiment was conducted which replicated the paradigm employed in Experiment 1 in all respects, except that the reward manipulation during study was directly related to accuracy in the study task, rather than later memory performance. By this, high and low rewards were present during study and associated with specific study items, but participants were not aware that they would be required to perform a later memory test and did not receive rewards for correct target retrieval. At test, a correct response was again followed by positive feedback however no monetary reward was delivered anymore.

Main advantages of this kind of incidental reward paradigm are that it firstly generates a more natural learning situation as reward was delivered immediately after a correct response at study and not after a one day delay. Presumably, this is a more ecologically valid induction of reward as it is directly linked to the immediately following performance in the same study trial and not to memory performance after a relatively long delay. Second, this paradigm obviates the need for increasing effort-related resources in high reward retrieval orientations, as learning of reward cue-study item associations would not be beneficial anymore (i.e. to earn more money) due to the reward delivery taking place at study already.

## 3.2 Hypotheses

A behavioral reward effect was expected reflected by higher memory accuracy for items that were previously studied with a high compared to a low reward cue despite the fact that in Experiment 1 global behavioral reward effects in memory accuracy were missing. This hypothesis was made because it was assumed that especially the higher incentives during learning would be more effective due to immediate, reward-specific feedback that was not given in Experiment 1 before. Moreover, after the practice run and at the end of each study list the amount of money gained was presented on the screen in the form of a colored bar chart to increase reward salience. Such presumption would be compatible with previous findings of an fMRI-study conducted by Zink and colleagues (Zink, Pagnoni, Martin-Skurski, Chappelow, & Berns, 2004) according to which monetary rewards, independent from the value, became more salient when its receipt actively depended on participant's performance than when the task was rather passive such that participants had no direct influence on the outcome. The degree of reward salience was measured as a function of neural activity in the striatum (i.e. caudate and nucleus accumbens).

If the hypothesis that the reward-related retrieval orientation effect found in Experiment 1 reflects the re-engagement of reward-dependent encoding processes is correct, a comparable frontally-based ERP effect should be obtained under these conditions. If, the effect observed in Experiment 1 reflects the differential engagement of retrieval effort then the effect should no longer be present in Experiment 2 in which the reward manipulation at study provides no monetary incentive to increase retrieval effort for items associated with high reward.

Furthermore, a replication of the material-specific retrieval orientation effect similar to the one obtained in Experiment 1 and in previous studies (e.g. Herron & Rugg, 2003;

Hornberger et al., 2004) was expected in which ERPs to correctly rejected new items in the target-picture condition would be more negative-going relative to the ERPs in the target-word condition. The adoption of such a material-specific orientation at retrieval is again assumed to emerge because it is assumed to support the increase of resemblance between retrieval cues and targeted memory representations in each test phase (Hornberger et al., 2004).

Finally, to investigate whether ERP differences related to reward were also present at encoding (similar to Experiment 1), ERP activity elicited by a cue preceding the stimulus presentation was again explored in order to find out whether those ERPs differed between high and low reward conditions (Gruber & Otten, 2010). In contrast to the analyses performed in Experiment 1, no analyses of old/new effects and subsequent memory effects in Experiment 2 were conducted. First of all, this was primarily based on the idea that incidental learning would not or to a much lesser extent led to the development of strategic retrieval effects than in Experiment 1 and would therefore make an analysis of old/new effects unnecessary. Second and as already mentioned in the discussion of Experiment 1, there are a number of reasons why the paradigm of the memory exclusion task used in the experiments of this research project is less suitable for analyzing subsequent memory effects (i.e. binary response requirement for three classes of items). Third, as no reliable old/new and subsequent memory effects were found in Experiment 1 and because the main reason for carrying out this second study was to further investigate reward-related retrieval orientation effects, further (explorative) examinations in this direction were abandoned.

## 3.3 Experimental Procedure

### *3.3.1 Participants*

Twenty-four healthy students (11 men) from Saarland University, Saarbrücken, Germany participated and gave written informed consent. Exclusion/inclusion criteria were the same as in Experiment 1. Participants were paid between 34 and 55 € (including the earned reward). A maximum of 25 € of the to-be-earned money was predefined before the start of the experiment. Data from 3 participants were discarded because of excessive eye movement artifacts (1) or because behavioral test performance was below chance level (2). Data are reported and analyzed for twenty-one participants (10 men; 25 years, range 19 – 36 years).

### *3.3.2 Stimuli and Procedure*

The experimental materials and procedure were the same as those employed in Experiment 1 except that a correct size judgment of a study item was rewarded with the amount of money indicated before the study item was presented. As in Experiment 1, correct responses at test were followed by positive feedback but no monetary reward was given for recognition memory performance. After each of the four test blocks, general performance (in %) was shown and a brief rest interval was provided. In order to provide participants with sufficient rest breaks during study, four 85-item study lists instead of two 170-item lists (Experiment 1) were formed. Participants took part in two sessions, an incidental study phase on the first day and an unexpected test phase on the following day (range: 23 - 26 hours after study).

Before the study and the test phase, each participant performed a short practice run to become familiar with the experimental task. Items presented in the practice runs were not used during the experimental sessions. In the practice run prior to the study phase, mean RTs and standard deviations for each subject were calculated in order to determine the individual time outs during size judgment task at study (i.e. response deadline, see for more details next paragraph).

Study trials consisted of the presentation of a fixation character (“+”) for 300 ms, followed by a blank screen for 200 ms and by either a low (“€” = 0.05€) or a high reward cue (“€€€” = 0.50€) for 400 ms. The remaining cue interval was filled with the presentation of another blank screen for 400 ms. Then, either a picture or word appeared on the screen for 2000 ms, followed by a blank screen for 200 ms. After that, a feedback cue appeared for 400 ms, notifying participants about the amount of money they had either gained or not ( “€” or “€€€” crossed out in red for incorrect low and high reward trials, respectively, or these same symbols encircled and presented in green for a correct response). The screen remained blank for 1400 ms before the next trial began. The participants’ task was to decide as quickly and accurately as possible whether the real life size of the shown object (depicted as a picture or a word) would be larger or smaller than the size of the monitor. Judgments were signaled by pressing one of two response keys with either the left or right index finger. The response deadline was adjusted individually based upon the average reaction time of the preceding 20 trials in order to ensure correct response rates were no higher than 80%. Participants thus received negative feedback after each incorrect or too slow response and were otherwise given positive feedback.

Participants were told that the reward cues preceding each item indicated the money they would gain if the size judgment was made correctly and within time. They were additionally instructed to pay attention to both the cues (in order to be aware of the reward status) and the pictures and words. They were also told that they would be penalized for incorrect or too slow responses although the exact amount of money subtracted was not announced to the participants (-1.00€). Short breaks were provided between each of the four study lists and the Edinburgh Handedness Inventory (Oldfield, 1971) together with a questionnaire on demographic information were completed half way through the study phase. At the end of each study list the amount of money gained was presented on the screen (depicted as a colored bar chart). To help insure the incidental nature of the task, participants received the cumulative total of the gained amount of money (in €) that was presented on the screen at the end of the entire study phase. They were told that they were to participate in another EEG-experiment on the next day which would take up a similar amount of time. The accumulated hourly rate for participation was not paid out until the second part of the experiment at the second day was accomplished.

The procedures for test phase, EEG acquisition and analyses were identical to those of Experiment 1. To equate the analyses of the behavioral and the ERP data all study trials (rewarded and non-rewarded) were included in the test phase analyses.

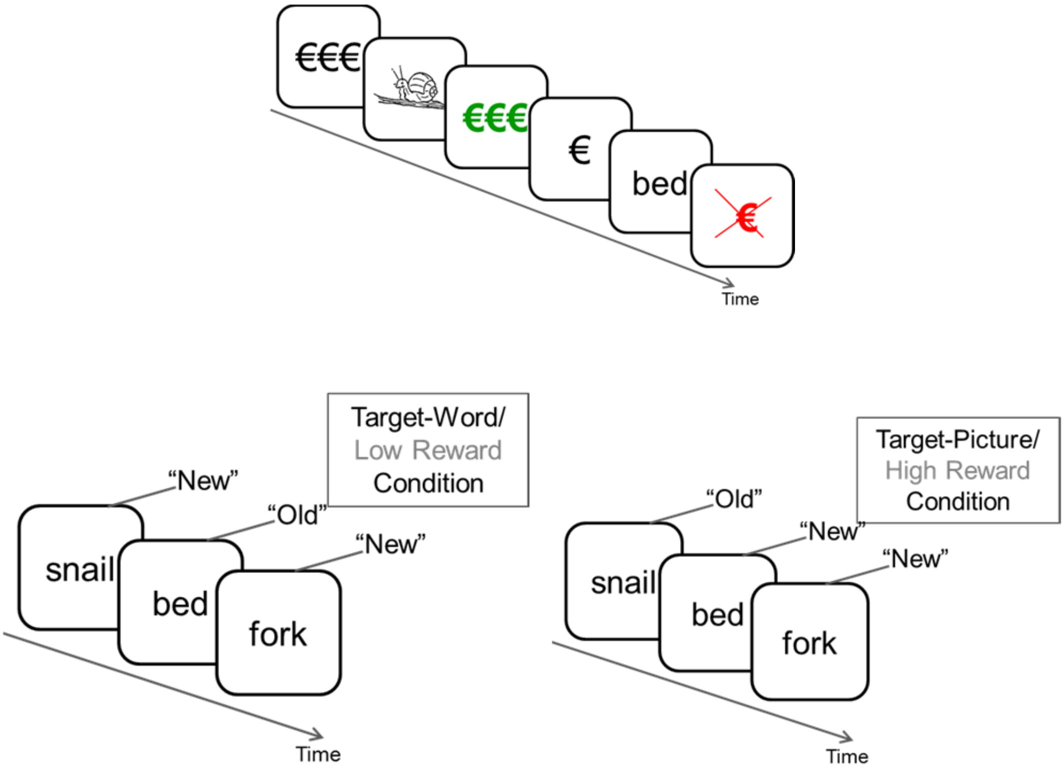



**Figure 3.1** Schematic illustration of sample items per condition of study (on top) and test phase (below). In the study phase, reward cues (high, low) and items (pictures, words) were randomly intermixed with each other. In the test phase, four test blocks were used and reward conditions were nested within target condition. That is, one of the blocks in each target-picture or target-word condition contained items that had been accompanied by low reward cues in the study phase (lower left figure) while the other block contained items that had been accompanied by high reward cues (lower right figure). More details can be seen in Figure 2.1 in Chapter II.

### *3.3.3 Data Analyses*

In the test phase, the mean numbers of trials (range in brackets) forming individual subjects' ERPs for correctly rejected new items were 41 (28-55) and 39 (27-51) for the target-picture and target-word condition and 41 (30-51) and 39 (27-51) for the high and low reward condition, respectively.

In the study phase, the mean number of trials for ERPs elicited by high- and low-reward cues were 121 (60-157) and 124 (64-157), respectively.

## 3.4 Results

### *3.4.1 Behavioral Data*

**Study phase.** With the implemented response deadline during study, the mean likelihood of a correct response in the size judgment task was .79 (*SD* ± 0.05) and the mean latency of responding was 722 ms (*SD* ± 89 ms). That is, participants' performance approached 80% accuracy as was intended by the individually-adjusted reaction time limit.

Between conditions, an ANOVA gave rise to a significant main effect of Target Material ($F(1,20) = 4.58$, $p < .05$) and an interaction between Target Material and Reward, $F(1,20) = 9.14$, $p < .01$. Pairwise t-tests revealed that accuracy was higher for pictures of the high than the low reward condition, as reflected by an effect that approached significance ($p = .07$). There were no significant reward-related differences found in the word condition. Furthermore, task performance in the low reward condition was higher for words than for pictures ($t(20) = 3.39$, $p < .01$). No material effects were found in the high reward condition ($p = .96$).

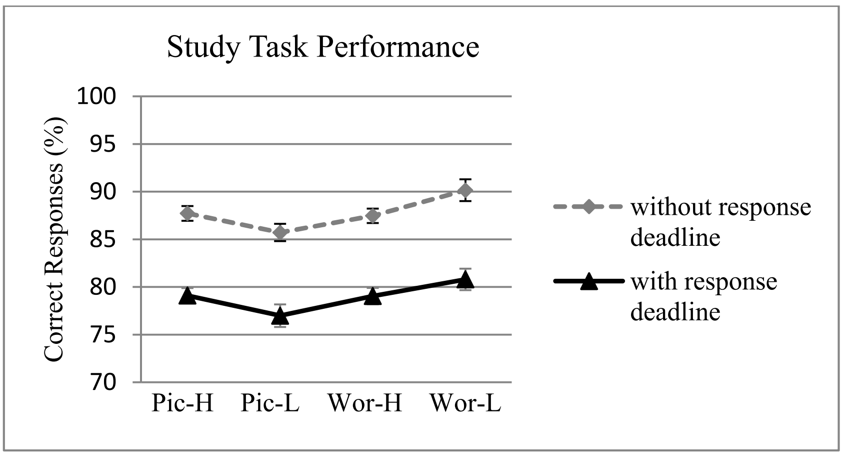
With regard to the reaction times for the size judgment task, ANOVA revealed a significant main effect of Material ($F(1,20) = 14.44$, $p < .01$) and an interaction between Material and Reward, $F(1,20) = 8.59$, $p < .01$. Pairwise t-tests revealed that in both reward conditions, RTs to pictures were shorter than to words (high reward: $t(20) = 2.24$, $p < .05$; low reward $t(20) = 5.10$, $p < .001$). Separately for the picture condition, a trend was found for shorter RTs in the high than in the low reward condition ($p = .088$) whereas no reward-related differences were found in the word condition ($p = .25$).

When the response deadline was not taken into account, highly similar effects between study conditions were found and only the mean likelihood of a correct response in the size judgment task across conditions was higher (.88, SD ± 0.04) and the mean latency of responding was longer (744 ms, SD ± 95 ms) compared to the results with the response deadline. An ANOVA of the accuracy data without the response deadline, with factors of Target Material (picture vs. word) and Reward (high vs. low) gave rise to a significant main effect of Target Material ($F(1,20) = 7.20$, $p < .05$) and an interaction between Target Material and Reward, $F(1,20) = 8.29$, $p < .01$. Pairwise t-tests revealed that in the word condition, accuracy was higher for words that were preceded by low than by high reward ($t(20) = 2.12$, $p < .05$, two-tailed). This effect was reversed in the picture condition, as accuracy was higher for pictures preceded by high than by low reward which approached significance ($t(20) = 2.04$, $p = .054$, two-tailed). Separately for reward condition, a material effect, that is a higher accuracy for words than for pictures was found for the low reward condition only ($t(20) = 3.61$, $p < .01$) as this effect was not obtained for the high reward condition ($p = .81$).

With regard to the reaction times for the size judgment task without the response deadline, a significant main effect of Material ($F(1,20) = 9.47$, $p < .01$) and an interaction between Material and Reward, $F(1,20) = 6.41$, $p < .05$ was found. Pairwise t-tests revealed that in both reward conditions reactions times to pictures were shorter than to words (high reward: $t(20) = 1.90$, $p = .073$, approaching significance; low reward $t(20) = 3.75$, $p < .01$). No reward-related differences in reaction times were found separately for the word or picture condition ($p > .13$).

The mean likelihood and the mean latency of correct responses in the size judgment task with and without response deadline are depicted in Figure 3.2a and 3.2b separately for each condition. As can be seen from that figure, study task performance differed between the conditions with and without response deadline. These observations were confirmed by conducted pairwise *t*-tests. Accuracy for all items was significantly higher compared to the accuracy for those items that were still correct after the response deadline ($t(20) = 11.15$, $p < .001$, two-tailed). Furthermore, as was intended, reaction times were shorter for responses to items with than without response deadline ($t(20) = 13.36$, $p < .001$, two-tailed). Interestingly but by this speaking in favor of the implemented response deadline regulation, the pattern between the material and reward conditions remained alike. That is, accuracy for words was generally higher and RTs were longer than for pictures, irrespective of response deadline.

**A)**



**B)**

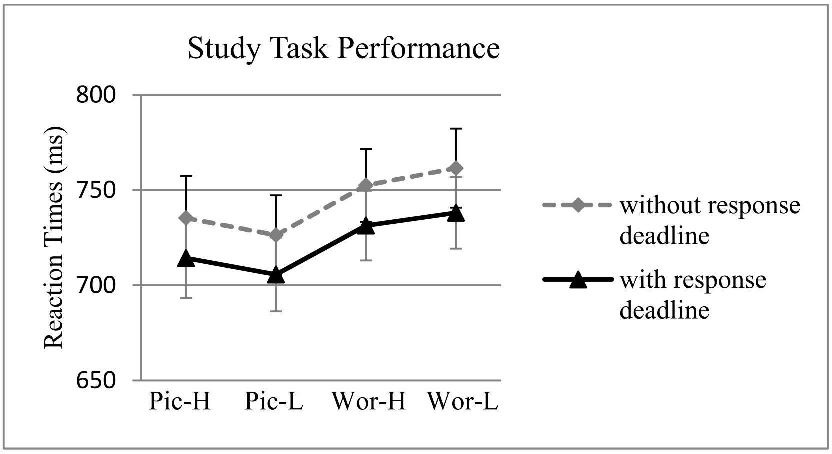



**Figure 3.2** Mean proportions of correct size judgments (part A) and mean reaction times (part B) to study items, separately for performance with (dashed grey line) and without response deadline (solid black line). In both figures, results are depicted for pictures that were preceded by a high reward cue (Pic-H), pictures preceded by a low reward cue (Pic-L), words preceded by a high reward cue (Wor-H) and words preceded by a low reward cue (Wor-L). Bars depict standard errors of the mean.

**Test phase.** Table 3.1 shows the mean reaction times and likelihoods of correct responses to targets, non-targets and new (unstudied) words in the four test blocks. *Pr*-values were .25 (pictures-high reward), .20 (pictures-low reward), .21 (words-high reward) and .22 (words-low reward). An ANOVA with the factors Target Material (pictures, word) and Reward (high, low) did not result in any significant differences (all $p$-values > .23).

Additional hypothesis-driven analyses were included on the basis of the outcomes of Experiment 1 in which *Pr*-values were higher for target-pictures studied with high than with low reward. Pairwise t-tests revealed a marginally significant trend for higher *Pr*-values for target-pictures studied with high than with low reward in the target-picture blocks ($t(20) = 1.53$, $p = .071$, one-tailed), but no indication of reward-related differences for these values in target-word blocks ($p = .43$). As was the case in Experiment 1, this trend towards a reward effect in the target-picture blocks was primarily due to a lower false alarm rate for non-targets in the high (.29) compared to the low (.34) reward condition ($t(20) = 2.53$, $p < .05$, two-tailed) (see also Table 2). No reward-related differences were found for non-target false alarms in the target-word blocks ($p = .63$).

An ANOVA for the accuracy data with the factors Target Material (picture, word), Reward Condition (high, low) and Item Type (target, non-target, new) revealed a main effect of Item Type ($F(2,40) = 25.72$ , $p < .001$), only. Follow-up t-tests showed that accuracy to new words was higher than to non-targets ($p < .01$) and to targets ($p < .001$) and that accuracy to non-targets was higher than to targets ($p < .05$). An ANOVA of the reaction time data with the same factors revealed a main effect of Item Type ($F(2,40) = 7.52$ , $p < .01$) due to shorter reaction times to new items than to non-targets ($p < .01$) and targets ($p < .01$). Reaction times to targets and non-targets did not differ ($p = .70$).

To examine whether the pattern of effects would change if correct responses selectively to those items were included that were actually rewarded at study, a second ANOVA including only those previously rewarded items was conducted. Again, a main effect of Item Type ($F(2,40) = 25.49$, $p < .001$) was found. Follow-up *t*-tests revealed that accuracy to new items was higher than to non-targets ($p < .01$) and targets ($p < .001$) and that accuracy to non-targets was higher than to targets ($p < .01$). An ANOVA of the RT data did not reveal any significant differences (all *p*-values > .12).

In sum, the behavioral data correspond well with the pattern of data reported in Experiment 1. Firstly, performance was better for new items than for non-targets or targets but did not differ as a function of target material. Secondly, there was little indication of a global effect of reward across both target conditions, but a trend towards a reward effect was found when pictures were targets. Finally, the pattern of effects in the memory test remained similar irrespective of whether performance data were analyzed across all items or only for those items that were indeed previously rewarded at study. Thus, similar to the conducted analyses of Experiment 1, the following ERP-analyses focus on correct responses to all test items.

**Table 3.1** Mean proportions of correct responses (*p*(correct) and reaction times (RTs in ms) to targets, new items and non-targets separated according to target material and reward condition (N = 21). Standard deviations in parentheses.

| | | Item Type | | |
|---|---|---|---|---|
| Test Block | | Target | Non-target | New |
| Pictures – High Reward | *P*(correct) | .54 (12) | .71 (12) | .77 (11) |
| | RT | 942 (135) | 954 (133) | 939 (141) |
| Pictures – Low Reward | *P*(correct) | .54 (15) | .66 (14) | .77 (13) |
| | RT | 961 (102) | 965 (103) | 945 (99) |
| Words – High Reward | *P*(correct) | .56 (13) | .65 (12) | .72 (11) |
| | RT | 939 (130) | 945 (131) | 942 (122) |
| Words – Low Reward | *P*(correct) | .58 (15) | .64 (14) | .71 (9) |
| | RT | 940 (150) | 940 (150) | 933 (126) |

### *3.4.2 ERP Data – New Items*

Given the hypotheses concerning retrieval orientation, ERPs elicited by correctly classified new words in the test phase were analyzed first. These were followed by analyses of cue-locked ERPs during encoding.

Grand average waveforms elicited by correctly rejected new words in the two material conditions are illustrated in Figure 3.3a. As in Experiment 1, ERPs differed markedly according to whether items were studied as words or pictures. These effects onset around 400 ms post-stimulus, extend for about 600 ms and take the form of a topographically widespread negative-going deflection for the target-picture condition compared to the target-word condition (see also the topographical maps depicted in Figure 3.4). Figure 3.3b shows the grand average waveforms elicited by correctly rejected new words in the two reward conditions. ERPs elicited by high reward items show a relative positivity from approximately 400 ms compared to ERPs elicited by low reward items. As was the case in Experiment 1, this topographically widespread effect remains until the end of the recording epoch, but appears to be most robust between 400 and 1000 ms post-stimulus. Analyses of ERP data followed that reported in Experiment 1, in order to enable comparisons between the two experiments. These began with an initial analysis focused upon the 400 - 1000 ms time window when both effects were present, and then a subsequent analysis in the 1000 - 1600 ms specific to the reward-related contrasts.

For the initial contrasts in the earlier time windows, mean amplitude measures were subjected to a five-way repeated measures ANOVA with factors of Target Material (picture, word), Reward (high, low), Location (frontal, central, parietal electrodes), Laterality (left, middle, right electrodes) and Time Window (400 – 700 ms, 700 – 1000 ms). This revealed a main effect of Target Material ($F(1,20) = 6.85$, $p < .05$) and a main effect of Reward ($F(1,20) = 4.72$, $p < .05$). Separate follow-up ANOVAs focusing on the factors of Target Material and Reward respectively, did not reveal any interactions between these factors and factors of electrode location for either contrast. Comparisons of effect sizes (partial $\eta^2$) at each level of the Location factor, however, revealed that both effects were greatest at frontal sites (Target Material: frontal = .33, central = .22, parietal = .17; Reward: frontal = .29, central = .13, parietal = .21. The results confirm comparable material-specific ERP effects in both reward conditions, and comparable reward-associated ERP effects in the two material conditions that were both topographically widespread but largest at frontal recording sites.

Reward effects were then examined in a five-way repeated measures ANOVA with the same factors as in the initial analysis but focused on the two later time windows (1000 - 1300 ms, 1300 - 1600 ms) revealed a main effect of Reward only ($F(1,20) = 5.12$, $p < .05$). This analysis confirms that the reward-associated ERPs continued to diverge from 1000 ms onwards, indicating a temporally protracted reward-related effect.

## Material-Specific Contrast

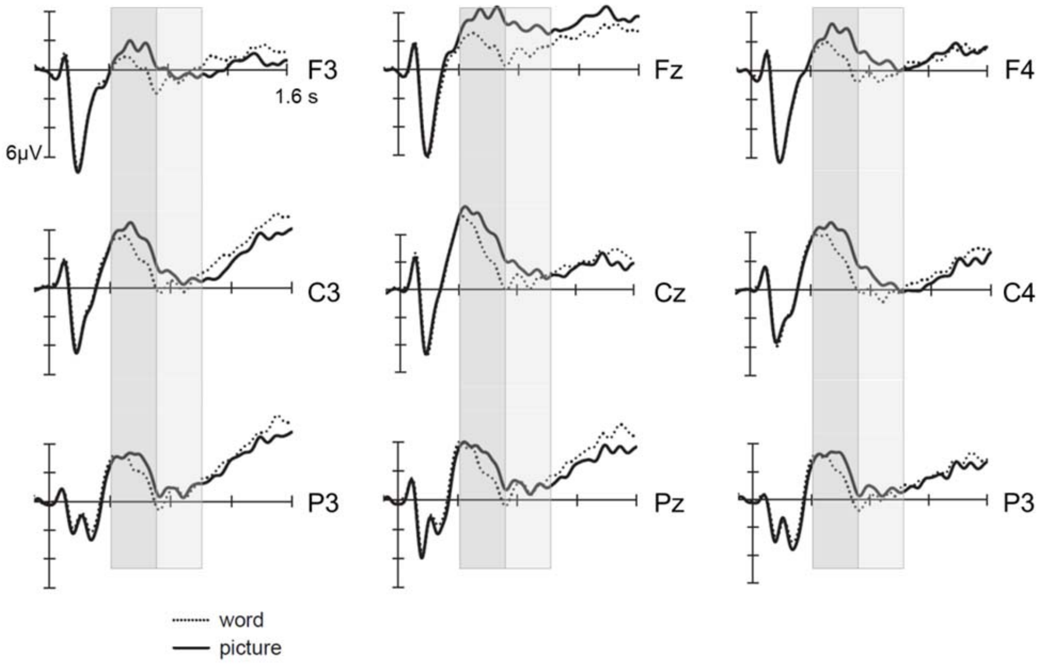



**Figure 3.3a** Grand average ERPs elicited by correct rejections in the target-word and target-picture blocks. Data are shown for 9 electrodes over frontal (F3, Fz, F4), central (C3, Cz, C4) and parietal (P3, Pz, P4) scalp sites.

## Reward-Specific Contrast

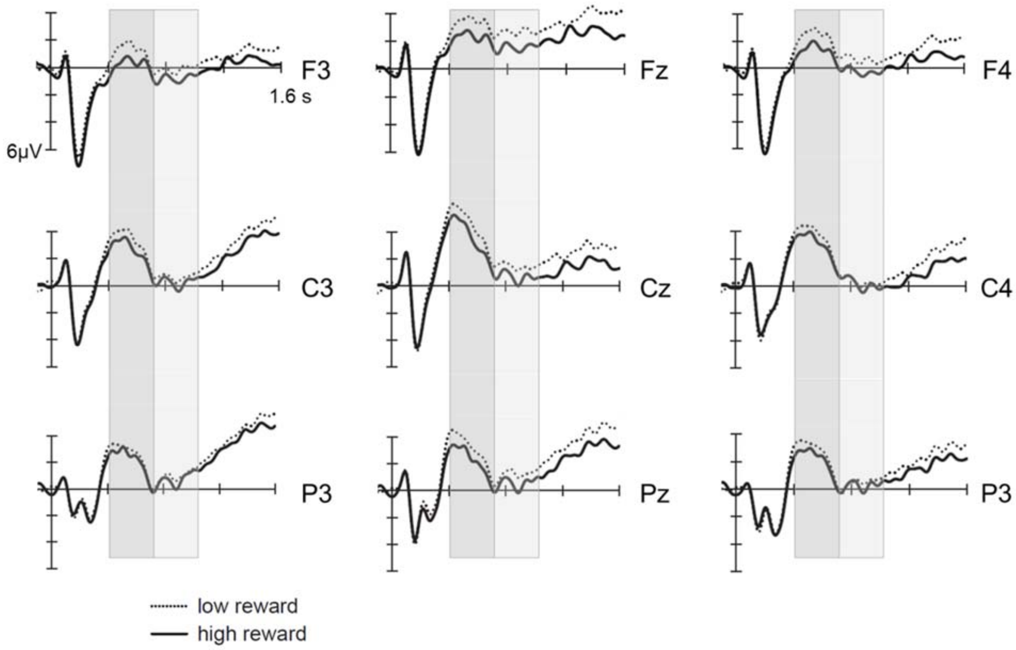



**Figure 3.3b** Grand average ERPs elicited by correct rejections in the two reward conditions. Data are shown for 9 electrodes over frontal (F3, Fz, F4), central (C3, Cz, C4) and parietal (P3, Pz, P4) scalp sites.

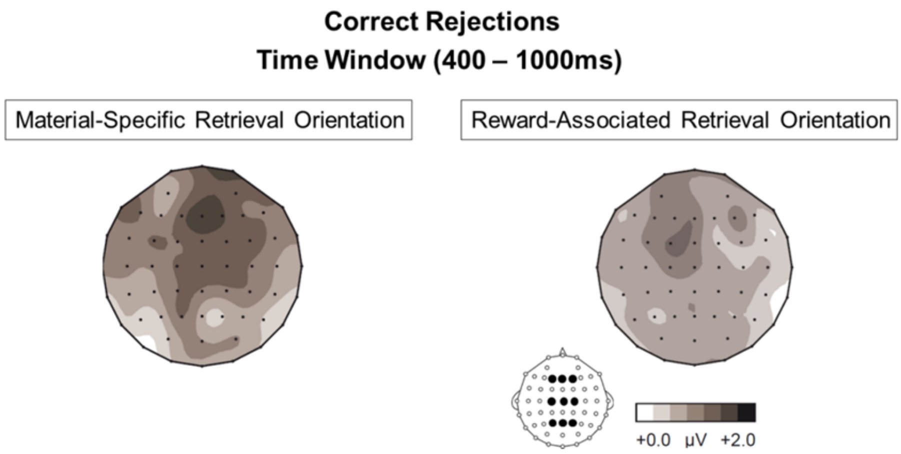



**Figure 3.4** Topographic maps showing the scalp distribution of the differences between neural activity elicited by new test words in the target-material conditions (left panel; material-specific retrieval orientation) and in the reward conditions (right panel; reward-associated retrieval orientation). Both contrasts are shown for the time window from 400 - 1000 ms.

### *3.4.3 ERP data – High versus Low Reward Cues at Study*

In order to investigate reward cue processing in the study phase, the cue-locked ERP waveforms elicited by high and low reward cues were compared, which can be seen in Figure 2.5. The ERPs in the high reward cue condition appear to be more positive-going compared to those in the low reward cue condition. This effect was visible between 350 and 550 ms and was broadly distributed over the scalp, but seemed to be biggest at parietal sites. To confirm these observations, a three-way repeated measures ANOVA with factors Reward (high, low), Location (frontal, central, parietal electrodes) and Laterality (left, middle, right electrodes) was conducted in the 350 to 500 ms time window where the effects were most marked.

The analysis gave rise to a main effect of Reward ($F(1,20) = 23.37$, $p < .001$), an interaction between Reward and Location ($F(1,40) = 8.30$, $p < .01$, $\varepsilon = .56$) and a marginally significant interaction between Reward and Laterality ($F(1,40) = 3.33$, $p = .055$, $\varepsilon = .85$). The first interaction was further deconstructed by examining reward effects at each level of the Location factor. Reliable effects of Reward were found at frontal ($F(1,20) = 14.22$, $p < .01$), central ($F(1,20) = 22.03$, $p < .001$) and parietal sites ($F(1,20) = 28.36$, $p < .001$). Similarly, after deconstruction of the second interaction, reliable reward effects were found at left ($F(1,20) = 18.26$, $p < .001$), middle ($F(1,20) = 23.22$, $p < .001$) and right electrode sites ($F(1,20) = 27.02$, $p < .001$).

This reward effect in the cue-interval of the study phase which was broadly distributed over the scalp suggests that the participants processed encoding cues differently depending upon the promised amount of reward.

Figure 3.5 also indicates that ERPs to high reward cues already diverge from ERPs to low reward cues in the earlier 150 - 250 interval. To test this observation, cue effects were examined in this additional time window. A three-way repeated measures ANOVA with the same factors as in the initial analysis revealed a main effect of reward ($F(1,20) = 28.48$, $p < .001$), suggesting that already at this early time point cue processing differed as a function of reward.

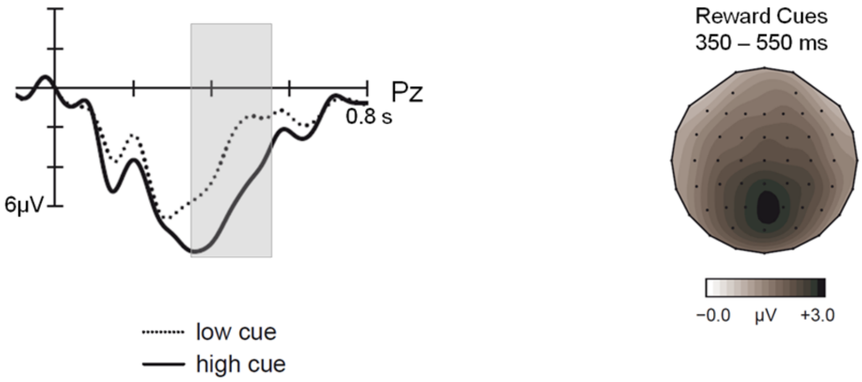



**Figure 3.5** Grand average ERPs elicited by the high and low reward cues at encoding. Data are shown for one representative electrode location over parietal electrode sites (Pz). The topographic difference map shows the scalp distribution of the differences between neural activity elicited by high and low reward cues at study in the time window from 350 - 550 ms.

## 3.5 Discussion

The main goal of this second experiment was to determine whether a frontally-based, reward-associated retrieval orientation effect comparable to that reported in the first experiment would be observed when the reward manipulation at study does not induce a strategic use of more effortful encoding and retrieval processes. This manipulation also elicited a reward-associated retrieval orientation effect at test, as reflected by a reliable difference between ERPs elicited by correctly rejected new items from the high and low reward conditions, irrespective of the target material. Very similar to the reward-associated retrieval orientation effect that was found in the first experiment, this effect began around 400 ms, was temporally protracted and was broadly distributed with a maximum over frontal regions. Finding this reward-related effect in a retrieval task in which performance at retrieval is not related to the reward manipulation at study makes it unlikely that this effect is a reflection of a simple increase in the effort of retrieval cue and strategic encoding processes. Instead, an account is favored which argues that these effects represent the reinstatement of non-strategic reward-related processes that were active when these items were encoded (Rugg et al., 2008).

In both ERP-experiments presented in this and in the previous chapter, the main question was whether rewards influence retrieval processes. This was examined by using ERPs to new items as markers for retrieval orientations. In the first experiment, an intentional study-test paradigm was employed in which a correct target response in the memory exclusion task was rewarded with a high or low amount of money as indicated in the study phase. By contrast, in the second experiment, reward manipulation at study was linked to the accuracy of the study task and memory performance at test on the next day was no longer directly related to reward. Reward manipulations did not modulate the classic material-specific retrieval orientation effect usually observed for contrasts of this kind but instead led to the adoption of distinct reward-associated retrieval orientations during test.

The reward-related retrieval orientation effect took the form of a fronto-centrally distributed, temporally protracted ERP effect elicited by differences in the amount of reward related to later memory performance (Experiment 1 described in Chapter II) or performance on the study task (Experiment 2). In the high reward condition of the memory exclusion task, ERPs to correctly rejected new test items were more positive-going compared to those in the low reward condition from 400 ms after presentation of the retrieval cue. This reward-related retrieval orientation effect was present in both the target-picture and target-word conditions. This suggests that, irrespective of the type of targeted memory representations (either pictures or words), the retrieval of items that were linked to a high monetary reward during study was associated with distinct retrieval cue processing compared to when low monetary reward items were to be retrieved. The presence of comparable effects in both experiments, even in Experiment 2 when the study reward manipulation was no longer related to memory test performance makes it unlikely that these effects are a simple reflection of effort-related processing elicited by changes in reward. Although this claim is made on the basis of the broad correspondences between the effects in the two paradigms, it is not possible to completely discount the contribution of effort-related processes in the first experiment, and the slightly more anterior maximum of the effect in that experiment might reflect a partial contribution of processes of this kind. Whilst this possibility cannot be entirely excluded for the first study, it is difficult to make this argument for the effect in this second experiment and thus the differences between new item ERPs from the high and low reward tests are taken to reflect reward-related retrieval processes rather than changes in effort elicited by reward manipulations.

The account is favored which claims that the differences in ERPs between items associated with high and low reward reflect the re-engagement of non-strategic reward-related encoding processes at retrieval. It is assumed that the reward manipulation at study influenced the encoding of a subsequent study episode perhaps by increasing the strength of highly rewarded memory representations and/or by leading to distinct kinds of representations according to whether items were associated with a high or low reward cue. The recovery of such information including the associated reward cue might then lead participants to re-engage processes analogous to those employed during the initial encoding phase. This reasoning is in line with the cortical reinstatement hypothesis (Rugg et al, 2008) and the associated principle of transfer appropriate processing (Morris et al, 1977), which emphasize the interdependent nature of encoding and retrieval processes. The incidental nature of the study phase in the second experiment is likely to have reduced the contribution of deliberate learning processing during this task, thus ensuring that any processes recapitulated at test are principally related to reward and not to explicit learning strategies. The current data thus provides the first demonstration that reward-related processing at study modulates the retrieval processes engaged during test.

The extent to which the engagement of these processes directly contributes to behavioral reward-related memory benefits is not yet clear, however, because whilst a reward-related ERP effect was observed that was not modulated by target material, the behavioral reward effect was specific to the target-picture test blocks. In both experiments, high monetary incentives during learning promoted memory performance after a delay compared to low incentives, but only when pictures served as targets. This reward effect for the target-picture block came about primarily because of an increase in the correct rejection rate for non-targets (words) which had been studied with high reward. It is assumed that this is in part because non-targets in this target designation were perceptually identical at test from their studied format (copy cues), a factor which is known to boost the accuracy of responding to old items (Hornberger et al., 2004; see also Herron & Rugg, 2003). This means that whilst high reward cues may provide better memory representations for both picture and word items, the retrieval of these representations is likely to be further boosted for words in light of the perceptual overlap from study to test. This cannot account entirely for the current findings, however, because there was not a comparable boost in responding for these items when they were designated as targets, indicating that the extent to which copy cue presentation is beneficial depends upon the particular target designation. In order to outline how changes in the current retrieval requirements might influence this, we first describe the differences between new item ERPs from the two target designations and the way in which these can inform understanding of the retrieval processes engaged in the two tasks.

Taken together, the results from Experiment 2 provide the first evidence that participants can adopt distinct retrieval orientations, not only as a function of the targeted information (material-specific retrieval orientation effect) but also as a function of reward (reward-associated retrieval orientation effect). This suggests that incentives during learning facilitate the adoption of a reward-associated retrieval orientation in a delayed memory test in order to retrieve perceptual details of highly motivational information in an efficient way.

Previous studies (Adcock et al., 2006; Wittmann et al., 2005) have shown that recognition accuracy was boosted when items were studied in anticipation of high monetary incentives compared to items studied with low or no rewards. In Experiment 1 and Experiment 2 that were presented in the preceding chapters, memory performance after a 24 hours delay was enhanced when items were preceded by high monetary rewards during learning compared to low rewards, but only when pictures were the targets. There was no indication of a global behavioral effect of reward across both target conditions (words and pictures). That is, while the reward-related ERP effect that was similarly observed in both studies was not modulated by the two types of target material, the behavioral reward effect was restricted to the target-picture test blocks. What might have been the reason for these results which were counter to the expectations? One possibility, (others, e.g. possible copy-cue effects were reported in Chapter III before) that might be considered is that the amount of presented items in the study phase (340 study items) might have exceeded the limit of correctly recognizing a high number of them later. This, together with the long study-test delay rendered the memory test relatively difficult, the consequence being that memory accuracy was relatively low. One assumption is that possibly not enough resources were left in order to process additional reward-dependent information, particularly in the target-word condition.

Therefore, a series of four experiments was conducted designed to explicitly address whether these missing global behavioral reward effects might be present in an easier study-test paradigm. The main focus in these experiments was however on the extension of the previous findings by the cross-cultural analysis of influences on memory accuracy not only after reward but also after avoidance learning. Special emphasis was devoted to the investigation of potential differences in the processing of reward cues (i.e. potential gain of money) or punishment cues (i.e. potential loss of money) during learning and episodic memory formation between Chinese and German participants. To my knowledge, there are no published reports that compared impacts of reward expectancy and punishment avoidance learning on memory performance in a cross-cultural context.

# Chapter IV: Experiments 3a-d

# Influences of Approach and Avoidance Learning on Memory Performance: a Cross-Cultural, Behavioral Study

## 4.1 Introduction

The social environment profoundly influences not only people's lifestyle but also their cognitive processes. In many psychological processes, the phenomena of approach and avoidance motivations play a fundamental role in the attempt to investigate the impact of cultural backgrounds on cognition. And as these two types of motivations are seen as processes that are not stable across cultures but are rather influenced by culture-specific experiences (Norenzayan & Heine, 2005), they are of great interest particularly in cross-cultural research (e.g. Elliot & McGregor, 2001; Lee, Aaker, & Gardner, 2000). For instance, Lee et al. (2000) could show that when Chinese imagined themselves playing in a tennis game which was framed as a chance to avoid a loss, they rated it as more important than a game framed as a chance to win. The reverse pattern was found among American participants.

Additionally, findings of Heine et al. (2001) suggest that Westerners (i.e. North Americans) react and respond differently to negative self-relevant feedback as East Asians (i.e. Japanese). Whereas the former sample uses strategies of self-enhancing motivation with the focus on positive outcomes, the latter one is more motivated by situations that enable self-improvement (focus on negative aspects). In summary, these findings indicate that the processing of self-relevant information such as a potential win or loss of something desirable differs between cultural societies.

In sum, Western societies were found to adopt more approach-oriented goals (e.g. potential win) and to become more motivated to work hard on task in which they are good at. This was interpreted as a strategy to enhance the positivity of the self (Bandura, 1999) by identification of the self with positive, self-relevant and self-confirming information. By contrast, East Asians pursued more avoidance-oriented goals (e.g. potential loss) because they perceived failures as an important indication for required corrective efforts in order to improve the self (Kitayama & Markus, 1999).

According to these accounts, it is predicted that Westerners would benefit more from reward-motivated learning, East Asians more from punishment-avoidance learning. Experiments 3a-d were designed to provide for the first time a direct test of this proposal by conducting identical experiments (one reward-motivated learning experiment, one punishment-avoidance experiment) in China as well as in Germany. Reward and punishment were defined in terms of positive incentives (potential gain of money) and negative incentives (potential loss of money) respectively, either in a high or a low value condition. Per country, the incentive condition was manipulated between subjects that is, 20 subjects of each country participated in a reward and 20 in a punishment experiment. This procedure offered the additional opportunity to compare two experiments within as well as between the countries to take potential cross-cultural differences explicitly into account.

This series of behavioral experiments replicated the same experimental paradigm employed in Experiment 1, except for four modifications. First, 30% fewer study and test items were presented to the participants. Second, in half of the experiments negative incentive cues (indicating potential loss of money) were used instead of cues of positive incentives. In these 'punishment' experiments, participants were given a fixed amount of cash money and with a correct target response at test they could avoid losing either a high or low amount of money that would otherwise be subtracted of their starting capital. Third, half of the experiments (one with positive, one with negative incentives) were conducted in China, while the other half were conducted in Germany and finally the experiments consistently employed behavioral instead of electrophysiological measures. By this, the paradigm enabled the examination of (i) effects of easier study-test conditions on behavioral memory reward effects, of (ii) influences of positively and negatively motivated learning on later memory performance and (iii) on a cross-cultural level, the comparison of effects of approach and avoidance learning on memory accuracy between Chinese and German participants.

## 4.2 Hypotheses

First of all, replicating previous studies, learning should be facilitated through high incentives during encoding which is expected to enhance memory performance. That is, participants in this experiment were expected to achieve higher memory accuracy for stimuli that were preceded by high value cues (indicating either high reward or high punishment cues) compared to those preceded by low value cues. This memory enhancing effect for stimuli of the high value condition is expected to be found irrespective of the type of experiment (reward anticipation or punishment avoidance) and of people's origin (China versus Germany).

Second, previous findings were aimed to be extended by the expectation that in case of the confirmation of the first hypothesis, motivated-learning effects should be modulated by cross-cultural differences. In particular, the possibility was considered that the processing of reward cues (potential gain of money) and punishment cues (potential loss of money) during learning and their influences on episodic memory formation should differ between Chinese and German participants. More precisely, Chinese participants were expected to be more sensitive in the reaction to potential loss of money (punishment cues) such that they would try harder to avoid losing money compared to German participants. By contrast, German participants were expected to respond in a more sensitive way to potential gain of money (reward cues) because they should be more motivated to gain money compared to the Chinese participants. Based on these assumptions, the cross-cultural influence should be reflected by a greater difference in memory performance between the high/low value conditions in the punishment avoidance experiment for the Chinese than for the German participants whereas the reverse pattern was expected to be found in the results of the German participants (increased hedonic response to rewarding outcomes).

Third, as the behavioral activation system (BAS) is considered as a motivational system that mainly responds to rewarding and generally non-punishing stimuli and the behavioral inhibition system (BIS) is conceptualized as an attentional system that is associated with the reaction to punishing and generally non-rewarding stimuli (e.g. Carver & White, 1994; but see Corr, 2004 for a review) the following was expected: Across both countries the more extravert participants who score high on the “Behavioral Activation System” (BAS) Scale should show a more sensitive reaction to items that were studied with a positive, high monetary incentive and therefore achieve a higher memory performance for these items. By contrast, more introvert participants scoring high on the “Behavioral Inhibition System” (BIS) Scale should achieve a higher memory performance for items that were preceded by a high punishment cue during study.

## 4.3 Experimental Procedure

### *4.3.1 Participants and Design*

Forty native Chinese-speaking undergraduate students in China (19 men; mean age = 20.8 years, range 17 – 28 years) as well as forty native German-speaking undergraduate students in Germany (20 men; mean age = 23.4 years, range 18 – 39 years) were randomly, but with similar sex ratio assigned to either a reward or punishment experiment, such that per country twenty different participants took part in each of the two experiments. Originally, 98 participants were tested but eighteen participants' data were discarded because behavioral performance either in the study phase (4), the test phase (11) or in both (3) was below chance level, leaving a total of 80 participants. The majority of the excluded participants (11) were those tested in China. This might me due to the fact that in spite of the permanent assistance of a Chinese doctoral student during testing, the additional verbal explanations for each participant in English and Chinese were maybe sometimes difficult to understand and probably not as clear as the rather direct German explanations in Germany. All participants had normal or corrected-to-normal vision and gave written informed consent to participate in the study after the procedures had been fully explained. Within each country, the two participant groups (reward experiment vs. punishment experiment) did not differ with respect to mean age or sexes (independent *t*-test, $t < 1$). Between the two countries, German participants were significantly older than those of the Chinese (independent *t*-test, ($t(19) = 3.33$, $p < .01$, two-tailed) but all participants were undergraduate students. Chinese participants were recruited from Forestry University, Chinese Agricultural University and Capital University of Economic and Business in Beijing and German participants from Saarland University in Saarbrücken. Participants were paid between 87 and 164 ¥ in China and between 20.5 and 39 € in Germany according to their individual memory accuracy at test.

### *4.3.2 Materials and Procedure*

The materials were identical to those used in Experiment 1 and 2 and the procedure was identical to that of Experiment 1 with the following exceptions: an additional between-subject factor Experiment (reward vs. punishment experiment) was included, that is in half of the experiments negative incentive cues (indicating potential loss of money) were used instead of cues of positive incentives, study and test consisted of approximately 30% fewer trials which implied the possibility of somewhat stricter stimuli criteria and the provision of a longer response time window at test (as the fast succession of trials and relatively small response time window was criticized before by the participants in Experiment 1 and 2).

320 pictures and words that were a subset of those items used in Experiment 1 and 2 were used in each of the four experiments. The computer screens used in China and Germany were similar in size. With regard to the German stimuli, the pictures had a mean name agreement of 89% (min. > 50%; German raters; word length did not exceed 11 characters (mean = 6). For the Chinese stimulus lists, the same pictures as for the German lists were used

with a mean name agreement of 83% (min. > 50%; Taiwanese raters). To ensure the equivalence of the words referring to the object pictures in both countries, a "back-translation" was implemented: (1) the existing data set of the object words in Mandarin spoken in Taiwan were translated and adapted into Mandarin spoken in Mainland China by two native Chinese-speakers; and (2) the translated version of the word list was back translated into English by a native Chinese-speaker and compared with the original English word list of the data base (Szekely et al., 2004) to determine the similarities between the two versions. Word length did not exceed 4 characters (mean = 2).

Two 120-item study lists were formed for each participant by randomly intermixing 60 pictures and 60 (non-corresponding) words. The test list consisted of 320 items and was divided into four blocks of 80 items each. Each test block was composed of 40 target words, 20 non-target words and 20 new words.

Participants took again part in two sessions, a study phase on the first day and a test phase on the following day (range: 24 - 25 hours after study). Prior to the study and test phase, subjects were given written and oral task instructions and completed a short practice run until they became familiar with the experimental task. At the end of the practice run at test, the amount of gained money was presented on the screen. Items presented in the practice run were not used during the experimental sessions.

Study trials consisted of the presentation of a fixation character ("*") for 500 ms which was followed in the reward experiments by either a high ("+ + +") or a low ("+") reward cue for 300 ms or in the punishment experiments by either a high ("- - -") or a low ("-") punishment cue. The remaining cue-interval was filled with a fixation character for 500 ms. Then, either a picture or a word appeared on the screen for 1000 ms, followed by a fixation character ("*") for 500 ms. After that, the word "size?" was presented for 2000 ms during which time interval the participant responded. Next, the screen was blanked for 500 ms before the next trial began. Whenever the question "size?" appeared on the screen, participants had, exactly as in Experiment 1 and 2, to decide whether the real life size of the shown object (depicted as a picture or a word) would be larger or smaller than the size of the monitor and to press one of the two response keys as quick and accurate as possible. Each value cue preceding an item indicated the money participants would gain or avoid losing in case of correct recognition of the item in the later memory test. Thus, participants in the reward experiment were informed that they would be rewarded (either with 0.50 / 0.05€ in Germany or with 2 / 0.2¥ in China) for each correctly recognized target item in the memory test the following day. The participants of the punishment experiment were penalized (either with –

0.50 / – 0.05€ in Germany or with -2 / -0.2¥ in China) for each forgotten target item in the later memory test. Participants in the reward experiments started with 0€/0¥, whereas participants in the punishment experiments were given 44€ (Germany) or 176¥ (China). The choice for these sums of money was based on the idea to use (i) identical amounts in Germany compared to those previously used in Experiment 1 and Experiment 2 for the purposes of comparison and to use (ii) amounts in China that were of similar value compared to the amounts in Germany, that is care has been taken to choose amounts with which similar products would be buyable in Germany (with 0.50€) and in China (with 2¥ i.e. in Beijing).

In both types of experiments participants were explicitly encouraged to try to earn or to keep as much money as possible and to use the cues in order to prepare themselves memorizing the upcoming study items. In between the two study lists a short rest was given and after the whole study phase, subjects were asked to fill out the BIS/BAS personality questionnaire (Carver & White, 1994, described below), either as a German (Strobel, Beauducel, Debener, & Brocke, 2001) or a Chinese Version (Loxton et al., 2008) and a questionnaire on demographic information.

Test trials began with the presentation of a fixation character for 500 ms, after which a test word was presented for 400 ms. This interval was followed by the presentation of a fixation character for 1200 ms and the trial ended with a feedback cue presented for 300 ms (red, frowning 'smiley' for incorrect or too slow response; green 'smiley' for correct response).

Participants were told that they would be rewarded or could avoid loss in case of correctly recognizing the item in the later memory test. They were also shown the money in cash that they could gain or avoid losing by performing the task successfully. After each of the four test blocks, general performance (in %) was shown and a brief rest interval was provided. At the end of the test, the cumulative total of the gained amount of money was presented on the screen (either in € or in ¥).

Additionally, participants were asked to fill out the Behavioral Inhibition/Behavioral Approach Activation Scales (BIS/BAS, Carver & White, 1994) before the start of the study phase on the first day. For the German participants a German Version of the questionnaire (Strobel et al., 2001) and for the Chinese a Chinese Version (Loxton et al., 2008) was used. Both versions equally comprised 24 items that each belonged either to the BIS or to one of the three related BAS subscales. Per item an answer on a 4-point Likert scale (1 = "I strongly agree"; 4 = "I strongly disagree") was asked to be given.

### 4.3.3 Data Analysis

Analyses of the behavioral data included measures of reaction times and accuracy. All analyses were limited to correct responses and follow-up analyses were restricted to Target Material (picture vs. word), Cue (high vs. low), Country (China vs. Germany) and Experiment (reward vs. punishment).

Only the results of the German questionnaire data were further analyzed. This was due to the fact that the mean scores of the BAS and the BIS Scales of both Chinese samples were unusually low compared the German sample but also when compared with Chinese samples (Loxton et al., 2008). Additionally, a detailed factor analysis of reliability and validity as well as of possible intercorrelations of the scales of the Chinese BIS/BAS questionnaire did not exist. With regard to data from the German version of the questionnaire, Strobel et al. (2001) proposed to use only a two factor analysis instead of using the BIS-scale and the three subscales of the BAS separately. Therefore, further analysis were performed with the BIS Scale and a single BAS Scale which included the three BAS subscales “Drive”, “Reward Responsiveness”, and “Fun seeking”. Mean BIS score of German reward experiment was 21.8 (*SD* 3.5), for the BAS 41.8 (*SD* 4.8). Those of the punishment experiment had a mean BIS-score of 21.8 (*SD* 3.7, for the BAS 41.4 (*SD* 3.0). These mean scores obtained from the two German samples are comparable to other studies using larger samples drawn from a general population (Carver & White, 1994; Holzwarth & Meyer, 2006) and did not differ between the two samples. No significant correlation between the BIS and the BAS Scales were observed (reward experiment: $r = .25$, $p = .30$; punishment experiment: $r = -.05$, $p = .85$) which is in line with previous reports (Carver & White, 1994). To examine the relationship between the BIS/BAS scores and the differences scores between the high versus low cue conditions in memory performance, simple bivariate correlations were performed.

## 4.4 Results

### 4.4.1 Study Phase

Figures 4.1a and 4.1b show the mean likelihood of and mean reaction times (RTs) for correct responses in the size judgment task. Across countries and experiments, the mean likelihood of correct responses in the size judgment task was .85 (standard deviation ± 0.04) and the mean latency of responding was 588 milliseconds (SD ± 216 ms).

To investigate whether the accuracy in the size judgment task differed between conditions, an ANOVA with within-subject factors Study Material (picture vs. word) and Cue (high vs. low) and with between-subject factors Experiment (Reward vs. Punishment) and Country (China vs. Germany) was conducted. It gave rise to a main effect of Study Material ($F(1,76) = 9.04$, $p < .01$), suggesting that participants showed a higher study task performance for words than for pictures. Furthermore, ANOVA revealed a main effect of Country ($F(1,76) = 11,78$, $p < .01$) and a two-way interaction between Country and Experiment ($F(1,76) = 4.28$, $p < .05$). Further contrasts revealed that this interaction was obtained because German participants in the punishment experiment achieved a higher study task accuracy than the Chinese participants ($F(1,38) =11,73$, $p < .01$). No differences between the two countries with regard to the performance in the reward experiments were found ($p = .26$).

To investigate whether the RTs in the size judgment task differed between conditions, an ANOVA with factors Study Material (picture vs. word), Cue (high vs. low), Experiment (Reward vs. Punishment) and Country (China vs. Germany) was conducted. The analysis revealed a significant main effect of Material only ($F(1,76) =4,78$, $p < .05$), suggesting that participants responded faster to words than to pictures.

In sum, the results from the study phase indicate that independent of the country or type of experiment, study task accuracy was higher and RTs were shorter for words than for pictures. Additionally, in the punishment experiments performance of the German participants was higher than of the Chinese. No cue effects in performance were found.

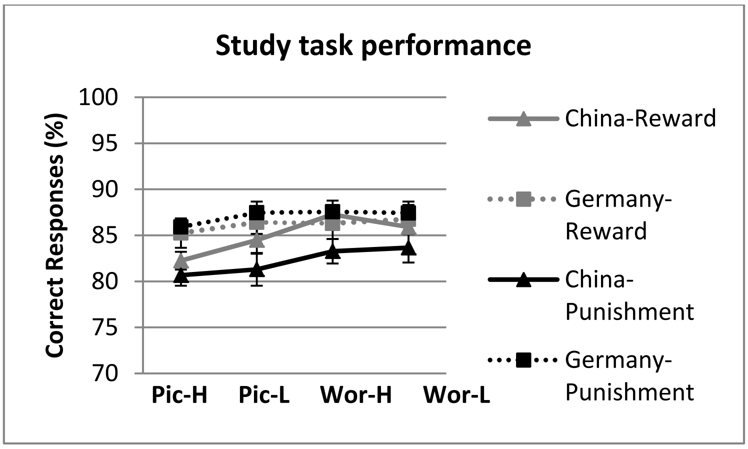



**Figure 4.1a** Mean proportions of correct size judgments to study items, separately for the reward and punishment experiments conducted in China and Germany. Depicted are the results for pictures preceded by a high reward/punishment cue (Pic-H), pictures preceded by a low reward/punishment cue (Pic-L), words preceded by a high reward/punishment cue (Wor-H) and words preceded by a low reward cue (Wor-L). Bars depict standard errors of the mean.

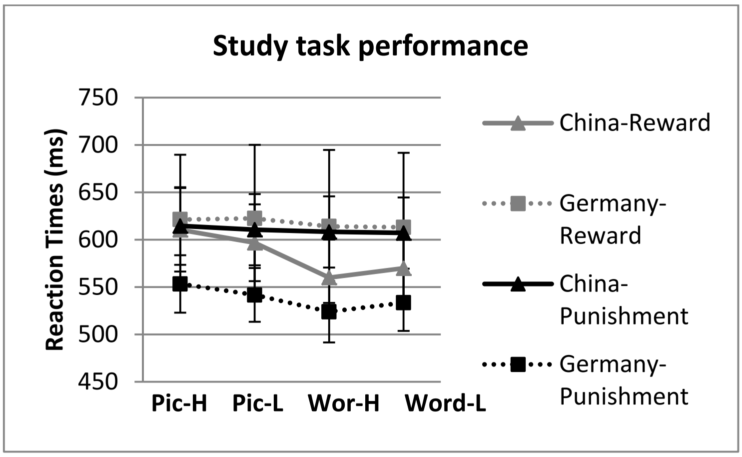



**Figure 4.1b** Mean reaction times of correct responses to study items, separately for the reward and punishment experiments conducted in China and Germany. Depicted are the results for pictures preceded by a high reward/punishment cue (Pic-H), pictures preceded by a low reward/punishment cue (Pic-L), words preceded by a high reward/punishment cue (Wor-H) and words preceded by a low reward cue (Wor-L). Bars depict standard errors of the mean.

### *4.4.2 Test Phase*

Table 4.1 shows mean reaction times for and probabilities of correct responses to targets, new (unstudied) words and non-targets in the four test blocks. An ANOVA for the accuracy data with the factors Cue (high, low), Target Material (picture vs. word), Item Type (target, non-target, new), Country (China vs. Germany) and Experiment (reward vs. punishment) gave rise to main effects of Cue ($F(1,76) = 29.83$, $p < .001$), Country ($F(1,76) = 5.91$, $p < .05$) and Item Type ($F(2,152) = 20.67$, $p < .001$). Interactions were found between Cue and Item Type ($F(2,152) = 5.22$, $p < .05$, $\varepsilon = .94$), Target Material and Country ($F(1,76) = 5.51$, $p < .05$) and Target Material and Item Type ($F(2,152) = 5.25$, $p < .05$, $\varepsilon = .79$). The first interaction was broken down by examining size effects at each level of the Item Type factor. The ANOVAs yielded significant cue effects for non-targets ($F(1,76) = 4.99$, $p < .05$) and targets ($F(1,76) = 68.74$, $p < .001$), but not for new items ($p = .66$). Deconstruction of the second interaction by examining target material effects separately for each country revealed that the German participants exhibited a higher accuracy for items of the target-picture than of the target-word blocks ($F(1,76) = 7.51$, $p < .05$). No differences in accuracy between the target material conditions were found for the Chinese participants ($p = .47$). Comparing the two countries separately for the accuracy in the target-word and target-picture blocks gave rise to a main effect of Country for the target-picture blocks ($F(1,76) = 11.61$, $p < .01$). That is, German participants achieved a higher accuracy in the target-picture blocks than Chinese participants. This accuracy difference between the countries was not prevalent in the target-word blocks ($p$ = .52). Finally, the third interaction was broken down by examining target material effects at each level of the Item Type factor. ANOVAs yielded significant target material effects for new items only ($F(1,79) = 13.93$, $p < .001$), indicating that new item accuracy was higher in the target-picture than in the target-word blocks. No material effects were found for targets or non-targets ($p > .11$).

Taken together, in all four experiments, thus irrespective of participants' origin, memory accuracy was significantly higher for targets and non-targets that were preceded by a high cue during study than accuracy for targets and non-targets preceded by a low cue. No effects involving the factor Experiment were obtained.

**Table 4.1** Mean proportions of correct responses to targets, non-targets and new items separated according to cue (high/low), experiment (reward/punishment), country (China/Germany) and collapsed across target material. Corresponding reaction times are also shown. Standard deviations in parentheses.

| **Country - Experiment** | | **Item Type** | | |
|---|---|---|---|---|
| **Cue** | | **Target** | **Non-target** | **New** |
| **1. China – Reward** | | | | |
| High | *p(correct)* | 0.67 (0.08) | 0.64 (0.12) | 0.74 (0.10) |
| | RT | 1464 (193) | 1473 (187) | 1468 (179) |
| Low | *p(correct)* | 0.62 (0.11) | 0.61 (0.12) | 0.72 (0.09) |
| | RT | 1474 (191) | 1484 (201) | 1485 (195) |
| **2. China - Punishment** | | | | |
| High | *p(correct)* | 0.68 (0.06) | 0.66 (0.08) | 0.70 (0.10) |
| | RT | 1518 (204) | 1536 (215) | 1533 (238) |
| Low | *p(correct)* | 0.60 (0.06) | 0.62 (0.12) | 0.69 (0.11) |
| | RT | 1505 (199) | 1514 (215) | 1520 (189) |
| **3. Germany - Reward** | | | | |
| High | *p(correct)* | 0.67 (0.08) | 0.68 (0.11) | 0.73 (0.11) |
| | RT | 1375 (246) | 1372 (234) | 1376 (244) |
| Low | *p(correct)* | 0.60 (0.09) | 0.67 (0.13) | 0.75 (0.08) |
| | RT | 1375 (264) | 1391 (253) | 1364 (269) |
| **4. Germany - Punishment** | | | | |
| High | *p(correct)* | 0.69 (0.09) | 0.72 (0.09) | 0.75 (0.13) |
| | RT | 1422 (241) | 1437 (274) | 1416 (250) |
| Low | *p(correct)* | 0.65 (0.10) | 0.69 (0.11) | 0.73 (0.11) |
| | RT | 1410 (262) | 1458 (284) | 1442 (290) |

Memory exclusion task performance was operationalized with the discrimination index *Pr* (*p*[target hit] – *p*[non-target false alarm]; derived from Snodgrass & Corwin, 1988). Figure 4.2 shows the *Pr*-scores of all four experiments to targets that were previously studied with a high or a low cue. An ANOVA with the factors Cue (high, low), Target Material (picture vs. word), Country (China vs. Germany) and Experiment (reward vs. punishment) gave rise to a main effect of Size only, $F(1,76) = 45.41$, $p < .001$, indicating that *Pr*-values for items of the high cue condition were higher than for those of the low cue condition. No significant cross-cultural effects were found.

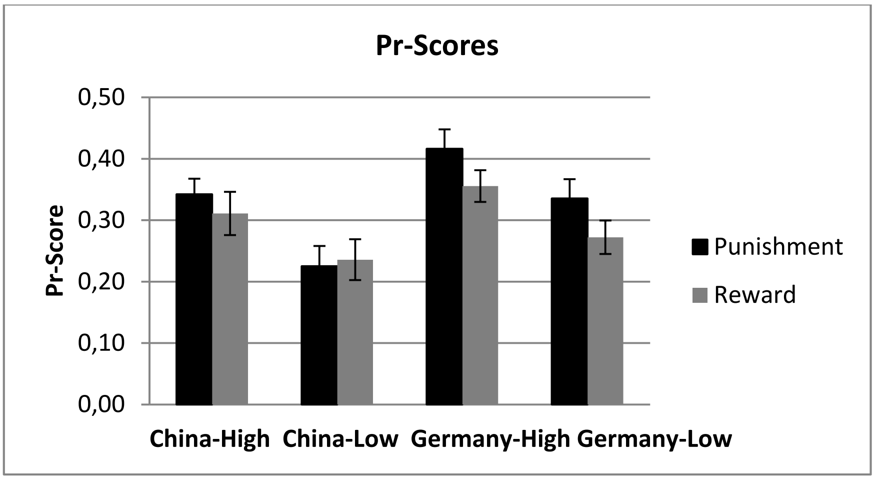



**Figure 4.2** *Pr*-scores (target hits – non-target false alarms) separated according to country, experiment and size of cue. Bars depict standard errors of the mean.

According to one of the hypotheses, a cross-cultural effect of memory performance, that is an interaction between the factors Cue, Country and Experiment was expected. However, it is conceivable that this interaction would be present for targets only because differences in memory accuracy between items that were preceded by high and low reward or high and low punishment cues (cue effect) for this type of items would presumably be largest. Targets were particularly meaningful for the participants as a correct response decided about a gain or a prevented loss of money respectively. Furthermore, a clear distinction between the allocation of responses to non-targets and new items is impossible due to the binary response requirement in memory exclusion tasks. This is not the case for correct responses to targets, as a single response button can be used for target response only. Therefore, further analyses of potential cross-cultural effects were conducted by taking memory performance for targets only into account.

Therefore, in a second step, only accuracy differences to targets between high and low value cues were subjected to an ANOVA. The accuracy differences in correct target response were obtained by subtracting accuracy to targets in the low value condition from accuracy to targets in the high cue condition (target hit high cue - target hit low cue). These differences, separately for each type of experiment and country are depicted in Figure 4.3.

An ANOVA for the accuracy difference data with the factors Country (China vs. Germany) and Experiment (reward vs. punishment) gave rise to a marginally significant interaction between Country and Experiment ($F(1,76) = 3.73$, $p = .057$). Follow-up t-tests revealed that in the punishment experiments only, the difference scores were significantly higher for the Chinese than for the Germans ($t(38) = 2.14$, $p < .05$, two-tailed). No country effects were found in the reward experiments ($p > .41$). No experiment effects were found either for the Chinese participants or for the German participants (all *p*-values > .14) This effect in the punishment experiments points to a greater difference for Chinese participants in memory accuracy for targets that were previously studied with a high than a low punishment cue compared to the German participants that took part in the same type of experiment.

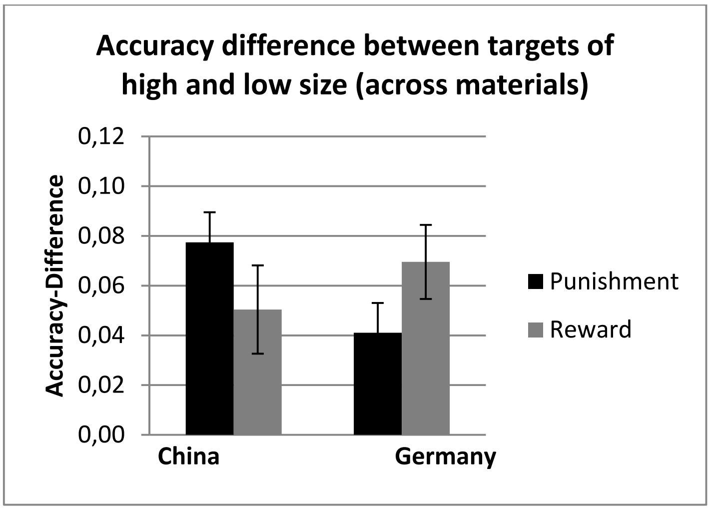



**Figure 4.3** Difference scores in target-accuracy calculated by the subtraction of the accuracy to targets of the low cue condition from accuracy to targets in the high cue condition separated according to experiment (reward/punishment) and country (China/Germany) and collapsed across target material.

Analyses of the RT data were conducted via ANOVA with factors of Cue (high, low), Target Material (picture vs. word), Item Type (target, non-target, new), Country (China vs. Germany) and Experiment (reward vs. punishment). The analysis revealed significant main effects of Material ($F(1,76) = 16.24$, $p < .001$), Item Type ($F(2,152) = 3.74$, $p < .05$). Additionally a marginally significant main effect of Country ($F(1,76) = 3.61$, $p = .061$) was found, reflecting a trend for faster RTs for responses to the test items of the German compared to the Chinese group. Furthermore the factors Target Material, Country and Experiment interacted ($F(1,76) = 4.06$, $p < .05$). Deconstruction of the interaction by examining material effects at each level of the Experiment and Country factor revealed an interaction between

Material and Experiment for the German participant group only ($F(1,38) = 5.40$, $p < .05$). This effect indicates that the German participants in the punishment experiment showed faster reaction times for items of the target-picture than of the target-word blocks ($F(1,19) = 12.10$, $p < .01$). Reactions times of the Chinese participants between the two types of experiments did not differ ($p = .64$), nor were any no interaction effects found that involved the factors Cue, Country and Experiments ($p > .20$).

To summarize the data of the test phase, memory performance across all four experiments was higher for items that were preceded at study by a high than by a low cue. Furthermore, a cross-cultural difference was found, as cue effects of targets in the punishment avoidance experiment were significantly larger for the Chinese participants than for the German participants.

With regard to the BIS/BAS Scales, it was expected that in the reward experiment, participants scoring high on the BAS Scale should show a greater accuracy difference between targets that were previously studied with high than with low reward cues compared to participants scoring low on the BAS Scale. By contrast, in the punishment experiment, participants scoring high on the BIS-scale were expected to show a greater accuracy difference between target items that were previously studied with high than with low punishment cues compared to participants scoring low on the BIS Scale.

Results indicate that only in the reward experiment, a marginally significant positive correlation between the mean scores on the BAS Scale and the difference in target memory performance between items previously studied with high compared to low reward cues was found (see table 4.2). That is, in this experiment, the German participants scoring high in BAS system tended to have a higher sensitivity for reward-motivated learning compared to participants scoring low in BAS which is reflected by a better memory for items that were preceded by high than by low reward cues during study. No significant correlations were found between the BIS/BAS Scores and performance data of the punishment experiment. That is, the additional analysis of the individual German BIS/BAS Scores in relation with the memory performance provided no clear additional insights into the nature of the relation between personality differences and differences in individual sensitivity to negative incentives during learning and subsequent memory retrieval.

**Table 4.2** Pearson Correlations between the BIS/ BAS Scales and the difference in target memory accuracy (target accuracy high cue condition – target accuracy low cue condition: ACC-T-Diff.) and the target RTs respectively, separately for the German reward and for the German punishment experiment.

| | BIS-scale | BAS-scale |
|---|---|---|
| **Reward experiment** | | |
| ACC-T-Diff. | .083 (n.s.) | .33 (p = .078, one-sided) |
| Target RTs | *.11 (n.s.)* | *-.03 (n.s.)* |
| **Punishment experiment** | | |
| ACC-T-Diff. | -.17 (n.s.) | -.04 (n.s.) |
| Target RTs | *-.26 (n.s.)* | *.42 (p =.033, one-sided)* |

## 3.5 Discussion

In order to determine whether positive and negative incentives during memory encoding influence later performance in a memory recognition exclusion task and whether this effect would differ between cultures, eighty Chinese and German participants took part either in a reward anticipation or a punishment avoidance experiment. All old items (targets and non-targets) were associated with one material condition (picture or word) as well as with one cue condition (high versus low reward cue condition or high versus low punishment cue condition). Of importance hereby was again that subjects were only informed about the blocked nature of the target material prior to each test block and not about the blocked nature of the reward or punishment condition.

Firstly, the results of the series of behavioral experiments showed clear reward and punishment effects in later memory performance, independently of the country. That is, Chinese as well German participants were better in remembering items that were preceded either by a high reward or a high punishment cue during study. It can be inferred from these results that motivational variables, like reward anticipation or punishment avoidance during study can indeed enhance memory performance, even after a long study-test delay.

Second, and with regard to the cross-cultural comparison the more interesting finding was, that even though participants of both countries in the punishment experiments achieved higher memory accuracy for items of the high compared to the low punishment condition, this effect was significantly bigger for the Chinese than for the German participants. By contrast, despite the fact that this cross-cultural effect in target memory accuracy did not become statistically significant in the reward experiments, the results went in the direction of an opposite effect. The difference between targets that were studied with a high and with a low reward cue was slightly higher in the German than in the Chinese sample. Possibly this study might have lacked the statistical power to further investigate this numerical difference between the two conducted reward experiments.

These hypotheses-confirming findings of the series of cross-cultural experiments provide, at least to my knowledge, the first evidence that participants of two different countries diverge in sensitivity to punishment avoidance learning. The cross-cultural effect between the two conducted punishment experiments might be interpreted in terms of a higher motivational source for Chinese participants to perform the task successfully by avoiding punishment. Chinese in contrast to German participants apparently have been more eager and motivated to especially avoid high losses of money. Therefore, it might be conceivable that they engaged additional retrieval supporting processes for items that were previously studied with high punishment cues. Consequently this might have led to higher memory accuracy particularly for these high value items in this type of experiment.

While the present study was a behavioral one, with the results of the two EEG-studies (Experiment 1 and 2) that were described before in mind, one might speculate that possibly the adopted punishment-specific retrieval orientations in this study might have differed not only between the low and high punishment conditions but also between the two countries. In line with this hypothetical assumption, it might be that larger punishment-specific retrieval orientation effects would have been found for the Chinese than for the German participants as it was previously found that an adopted retrieval orientation was related to memory performance (Bridger et al., 2009; Herron & Rugg, 2003; Herron & Wilding, 2004). This would imply that Chinese would be more effective in the initialization and adoption of a motivation-specific or associated retrieval orientation in order to keep punishments within limits. If this assumption would be correct, it would raise again the question whether motivation-specific retrieval orientation effects reflects effort-related processing, this time elicited by changes in punishment or whether such an effect would reflect the re-engagement of non-strategic punishment-related encoding processes at retrieval. Did the Chinese made a greater effort to mobilize resources in this punishment condition than the Germans? However, based on the findings of Experiment 2, in which a reward-related ERP retrieval orientation effect was found even though performance at retrieval was not related to the reward manipulation at study, the latter account of the re-engagement of processes analogous to those employed during the initial encoding phase would be more plausible here.

By contrast, the general behavioral results do not show a better memory performance for the Chinese participants in the punishment experiment, the results point rather to the opposite direction, but they showed a much higher memory performance for stimuli they previously studied with a high than with a low punishment cue. Therefore, adoption of a retrieval orientation especially for high punishment items might have facilitated controlled memory retrieval and consequently increased memory performance particularly for those items. By contrast, the high study task performance in the punishment experiment that was achieved by the German participants than by the Chinese possibly indicates that Chinese participants were more engaged or concentrated at encoding than the Germans as the punishments cues were of higher saliences for them.

Due to the very similar experimental design as the one used in Experiment 1 in which also an intentional rather than an incidental study phase was used, influences of potential learning strategies on test phase performance cannot entirely be excluded. Furthermore, it might be that especially the Chinese participants of the present study applied more effortful and control-related processes at test that were actually already elicited before, namely by the punishment manipulation at study. But based on the findings of Experiment 2 in which the reward-specific retrieval orientation effect was replicated even though an incidental reward paradigm was used, it can rather be assumed that participants in the present study again adopted punishment- as well as reward-specific retrieval orientation. This would be in line with the principles of transfer appropriate processing (Tulving & Thomson, 1973) according to which the retrieval of information at test is closely related to how it was initially encoded. With regard to the role of possible learning strategies on test phase behavioral effects, it might still be the case that participants in general paid more attention to items that were preceded by high instead of low value cues, however study task performance was similar across the two cue conditions, irrespective of the type of experiment or participants' origin.

The reasons for cultural differences in motivational influences on memory retrieval, for instance the higher sensitivity to punishment cues of the Chinese compared to the German participants, might be difficult to fully reconcile as multiple factors could play a role. German and Chinese cultures differ in several aspects with regard to for example the socio-cultural as well as the natural environment. Additionally, the moral, social and cognitive development especially of young people might be influenced by factors such as parenting style, value system, life style, history and climate (Cook & Chi, 1984; Domino, 1992). Apparently, Chinese participants were more eager avoid loss of money than the Germans. Possible reasons for this might be that the Chinese students were on average poorer than the German students, and by this increased the value of the in other aspects very similar amounts of loss of money. Also noteworthy is that the Chinese participants were generally a bit younger than the Germans which does not allow to preclude influences of the younger age on the increased sensitivity especially to negative incentives.

Furthermore, it should be mentioned that the experimental testing conditions in the two countries were not exactly the same. But great care was for example taken for the use of comparable cash value of the high and low reward and punishment cues in the two countries and similar computer screen sizes as they were important for the size judgment task at study. Nevertheless, testing conditions differed in the way that in Germany, participants were tested in separated cabins under supervision of one male experimenter and only two participants were tested at the same time. In contrast, in China, six participants were tested all at once under supervision of two female experimenters (one Chinese and one German) and in the same room. So, it might be that Chinese participants felt more competitive pressure, as at the end of the test phase they might have compared their earned amount of money with the one of the five other participants and also as they possibly felt observed by the two present experimenters. But within the methodological restrictions of this research, i.e. differences in testing conditions between the two countries, it does not explain the cross-cultural differences in sensitivity to punishment cues and its influence on later memory performance, as testing conditions were very similar between the reward and punishment experiment within a country.

In summary, the findings of the present study suggest that cross-cultural differences in motivated learning through anticipation of potential gain (reward) or through avoidance of potential loss of money (punishment) and later memory performance exist. The similarity of the cue size effects in the reward as well as in the punishment experiments in both countries might be interpreted as indicating similar levels of motivation. Items that were previously preceded by a high reward or punishment cue were in all groups better remembered than items that were studied with the corresponding low value condition. A new finding, which was obtained due to the cross-cultural approach implemented in this series of experiments, is that the level of motivational learning might also depend on cultural influences, at least with regard to learning through the avoidance of potential loss of money. By this, these results suggest that cross-cultural influences with respect to reward and punishment sensitivity during learning and its influences on later memory performance should be taken into account in the future.

# Chapter V: General Discussion

Success of an episodic retrieval attempt not only depends on the way an event was encoded into memory before but also on processes engaged around the time before and after an retrieval attempt is made (Craik & Lockhart, 1972). Of principal interest in the work presented in this thesis was to determine whether monetary incentives during learning influence memory retrieval processes engaged by healthy adult participants. This research topic lies at the intersection of memory and motivational psychology. The general intention hereby was to examine whether and how motivational incentives might influence and improve learning efficiency and memory performance, how this would be reflected in electroencephalic activity in the human brain and whether cross-cultural differences might have an influence on these processes. With these aims in mind, three studies were conducted and presented in this thesis.

In Experiment 1, an intentional study-test paradigm was employed in which a correct target response in the memory exclusion task was rewarded with a high or low amount of money as indicated in the study phase. Participants were informed about the memory test before they started with the study phase. By contrast, in Experiment 2, reward manipulation at study was linked to the study task accuracy, that is memory performance at test on the next day was no longer directly related to reward. Learning in this experiment was incidental, which means that participants were left uninformed about the subsequent memory test. Finally, in a series of four cross-cultural, behavioral Experiments 3a-d, a shortened version of the intentional study-test paradigm employed in Experiment 1 was used. In China and in Germany respectively, an experiment was conducted in which a correct target response in the memory exclusion task was again rewarded with a high or low amount of money as indicated in the study phase, whereas correct target responses in a second, separate experiment prevented loss of high or low amounts of money.

The participant's task across all conducted experiments presented in this thesis was at study to encode pictures and words that were either preceded by a high or a low positive or negative incentive. Then, on the next day, they were encouraged to utilize the information provided by a word retrieval cue to select specific parts of the previously encoded information. The general response requirements in the recognition tasks that were employed in all three studies of the presented work were according to the paradigm of Jacoby's (1991) exclusion test. The test consisted of four different test phases in which new word items were intermixed with old word items. These old items were previously studied in either a word or a picture format with either a preceding high or low incentive cue. Participants were asked to classify old items only as old when the study material (e.g. formerly studied pictures) was in fact the one requested in that particular test phase, that is, when this class of items was designated as targets. Old items studied in the other material (e.g. studied words) had to be rejected on the same response key as the new items. Which of these classes of old information were designated as targets was manipulated across test phases. This means that in each test block, participants were asked to temporally 'exclude' one class of actually old items, whereas the other class had to be correctly identified as old. Incentive cues were only presented once at study just before a study item was shown.

The following sections include a summary and general discussion of the behavioral findings with regard to memory performance after reward-motivated learning, electrophysiological results reflecting specifically adopted retrieval orientations after reward-motivated learning, influences of cultural differences in effects of incentives on long-term memory accuracy, and an overview of limitations of the conducted studies and elaborations on prospects of neuropsychological research. A general conclusion is given at the end.

## 5.1 Reward-Motivated Learning and Memory Performance

An important behavioral finding in both ERP-studies was that high rewards during learning promoted memory performance after a delay compared to low rewards, but only when pictures served as targets. That is, the behavioral reward effect was specific to the target-picture test blocks. This effect was primarily due to an increased correct rejection rate for non-targets (words) which had been studied with high reward. As already mentioned in Chapter III, this is thought to be in part because non-target words were easier to retrieve as they were identical in study and retrieval cue formats (copy cues) for this target designation (i.e., the non-target words were perceptually identical to their study representation). Additionally, memory is generally better for test materials that resemble the study material (Hornberger et al., 2004; Herron & Rugg, 2003). Thus, this finding might reflect less prioritization of target-pictures as a consequence of facilitated retrieval of non-target words because when both target-pictures and non-target words were exposed to high reward cues in this target-picture designation, encoding is likely to have provided a better memory representation for these items. At test, therefore, this is manifest primarily by a more effective use of a recall-to-reject strategy for non-target items, in part due to the copy cue condition for this target designation. From this it might be inferred that motivational variables, like high monetary incentives, may provide better memory representations for both picture and word items, and that the retrieval of these representations is presumably further boosted for words because of the perceptual overlap from study to test. However, there was not a comparable boost in responding for these word items when they were designated as targets, which means that this assumption cannot account entirely for the findings of the work presented here. The target-picture specific reward effect might rather indicate that the extent to which copy cue presentation is beneficial depends upon the particular target designation.

On the one hand, a logical presumption would be to expect better overall memory performance after intentional than after incidental learning as participants during intentional learning were given the possibility to prepare themselves for effective encoding of the presented study items. However, this was not indicated by the current results presented in this thesis, as memory performances across the two conducted ERP-studies were highly similar. Comparison of the behavioral results of Experiment 1 and Experiment 2 in fact appeared to indicate a trend in the opposite direction (see Table 2.1 and Table 3.1). Whereas memory accuracy to targets was somewhat higher in Experiment 1 than in Experiment 2, accuracy to non-targets and new items was slightly lower. Statistically, however, there was no significant difference in accuracy and reaction times between the two conducted experiments (all *p*-values > .21). These similarities in memory accuracy across the two studies cannot be explained by the exclusion of more participants in Experiment 2 whose test performance was below chance level, as in both experiments the same number of participants were excluded (2).

On the other hand, the similarity in memory performance across both studies might be unsurprising if the following thought is taken into consideration. Even though participants in Experiment 1 were informed beforehand that their memory performance would be tested on the following day, they were not informed about either the specific aspects of the study items that would be most relevant to encode nor about the precise nature of the memory test (e.g. simple old/new recognition, recall or a memory exclusion test). This implies that even though participants in Experiment 1 may have used strategies to learn the items (e.g. by naming the pictures, grouping reward cue with study item, rehearsing), these strategies might not have been particularly appropriate for carrying out a memory exclusion task. Apparently and in accordance with Craik and Lockhart (1972), instructions or intentions to learn might be efficient only to the extent that they generate suitable learning operations and consequently outperform those encoding processes that would be involved during incidental learning. Furthermore, there is even the possibility that individually chosen encoding strategies might hinder elaborative processing of new information needed for subsequent, successful memory retrieval. For example, in one of the earliest studies that compared memory performance after intentional and incidental learning by Eagle and Leiter (1964), participants were tested with a free recall test or a recognition test, either in an intentional or incidental learning condition. The authors observed that free recall test subsequent memory performance was facilitated in the intentional but not in the incidental condition. However, this effect was reversed after recognition testing. Memory performance here was instead superior after incidental learning. The authors' main conclusion from these results was that optimal processing during encoding depends on how memory is tested afterwards. That is, whether intentional encoding outperforms incidental encoding with respect to later memory performance depends on factors such as the degree of effectiveness of the applied encoding strategy, characteristics of the study task and the type of retrieval task at test, because different memory tests require slightly different learning operations.

For participants that took part in Experiment 1 (and in Experiments 3a-d), the best way to earn or to keep the most money was to retrieve all items regardless of the level of incentives. But because of the relatively high task difficulty and the long retention interval between study and test (24 hours), a suitable compromise would have been to focus on highly rewarding or highly punishing items respectively. This means that the most efficient retrieval strategy would be to adapt retrieval processes specifically towards the high value items. By contrast in Experiment 2, a deliberately engaged strategic account on later memory performance cannot be made because firstly, the delivery of reward was related to performance in the study task and not to performance at test and secondly, the testing situation was incidental.

## 5.2 Reward-Motivated Learning and Retrieval Orientations

The first two experiments (Experiment 1 and Experiment 2) were conducted in order to analyze ERPs to new items between different recognition memory tasks. These contrasts are considered to provide markers for retrieval orientations (Rugg & Wilding, 2000). ERP correlates of retrieval orientations were of particular interest in the work presented in this thesis because they are assumed to reflect strategic retrieval processes that optimize the resemblance between cue and memory representation and selectively constrain retrieval to a subset of information held in memory. In order to outline how changes in current retrieval requirements of a memory exclusion task might influence neural processes taking place before and during a response at test, first described are the differences between new item ERPs from the two target designations and the way in which these can inform understanding of the retrieval processes engaged in the two tasks.

First of all and consistent with several other studies (Dzulkifli & Wilding, 2005; Herron & Rugg, 2003; Hornberger et al., 2004; Hornberger et al., 2006; Robb & Rugg, 2002), the data of the two ERP-studies confirm the view that different retrieval orientations are adopted as a function of the targeted memory representation. ERPs to correctly rejected new items in the target-picture condition were more negative-going relative to ERPs in the target-word condition. This material-specific retrieval orientation effect was present from 400 - 700 ms post-stimulus and was most pronounced at central scalp sites in Experiment 1, with a somewhat more anterior distribution and temporal extension in Experiment 2. Notably, whilst there was some indication that the effect showed a more anterior distribution in high reward blocks in Experiment 1, neither its magnitude nor its temporal characteristics differed between the two reward conditions in either experiment, indicating that the requirement to adopt a material-specific retrieval orientation was only minimally influenced by reward.

What might be the functional significance of this material-specific retrieval orientation effect obtained in Experiments 1 and 2? In line with previous studies, the view is taken that this effect reflects the adoption of processes that help increase the resemblance between retrieval cues and targeted memory representations in each test phase in order to facilitate the recovery of targeted information (Hornberger et al., 2004). In other words, these reliable differences between ERPs to new items in the memory exclusion task are assumed to indicate changes in retrieval cue processing due to the adoption of distinct retrieval orientations in each test phase. In the case of low retrieval cue-target overlap, when words serve as retrieval cues to target-pictures, retrieval cue processing is thought to be constrained to conceptual features of the retrieval cue because these are the only features shared by the retrieval cue and the targeted memory representations (Hornberger et al., 2004). Such processing is not necessary in the target-word condition where all old items can, in principle, be correctly responded to on the basis of the success or failure of perceptual matching.

Support for this proposal comes also from a study conducted by Rugg and colleagues (2000) in which the study history of items was manipulated rather than the study material.

Participants in that experiment were encouraged to study words either in a “deep”/semantic condition in which they had to generate a sentence that included the presented word or in a “shallow”/alphabetic condition in which they were asked to judge whether the first and last letter of a word in alphabetical order. A yes/no recognition test followed in which different lists of studied and new items were presented. More negative-going ERPs to new items were found in the deep encoding condition relative to those in the shallow condition. This retrieval orientation effect was interpreted as a reflection of different retrieval cue processing according to whether retrieval cues needed to be aligned with more semantic memory representations of test items or not. This implies that a fixed and typical retrieval orientation for instance for the retrieval of pictorial information does not exist as the manifestation of an ERP retrieval orientation effect varies according to the level of similarity between material of retrieval cue and targeted memory. Low similarity results in more negative-going ERPs than when similarity is high.

An account which posits a change in the relative emphasis on the processing of conceptual aspects of items is in line with the temporal and topographic correspondences between the current effect and the N400 component, a robust and centralized negativity around 400 ms post-stimulus elicited in conditions that require greater semantic processing of items (see Kutas & Federmeier, 2011 for a review). Whilst reasoning of this kind has been similarly outlined elsewhere (e.g. Hornberger et al., 2004; Hornberger et al., 2006), the additional possibility is considered that an increased emphasis on the conceptual features of items in the target-picture condition (compared to the target-word condition) might also bolster the recollection of non-target items in this retrieval condition. This combined with the benefits that arise from the presentation of copy cues for non-target words in this condition (see above), might therefore account for the specificity of the behavioral reward-related boost to these items.

The differences between new item ERPs from the two target designations (either pictures or words) that were observed in Experiment 1 and Experiment 2 were referred to as material-specific retrieval orientation effects. The use of this term might be seen to contradict the claim that was previously made in the work of Hornberger et al. (2004) in which the effect was interpreted as an index of the employment of retrieval cues that differed in form from the sought-for information (cue similarity effect) rather than merely a reflection of differences in the form of the sought-for material (material effect). However to simplify matters and to differentiate between the two separate ERP-retrieval orientation effects that were presented in this thesis - one effect specific to the sought-for material and a second effect associated with reward (further described below) - the terms ‘material-specific effect’ and ‘reward-associated effect’ were deemed appropriate here. “Material-specific” in this context does not contradict the interpretation of the findings of Hornberger et al. (2004) because it still refers to an effect based on a difference in similarity between the form of presented retrieval cues and the two types of sought-for information rather than solely to an effect that depends on the particular type of target material that is attempted to be retrieved. Therefore, this retrieval orientation effect is rather due to the interplay of the form of target material (e.g. auditory, visual, verbal information) and retrieval cue material (e.g. words) which determine how a particular retrieval orientation effect might look. This implies that the ERP-effect varies according to the degree of similarity between a particular memory representation and retrieval cue in line with the idea that the functional role of an adopted retrieval orientation is to maximize the overlap between a retrieval cue and a particular memory representation in order to facilitate the recovery of targeted information

As mentioned above, the main goal of the conducted ERP-studies presented in this thesis was to investigate whether and, if so, how the ERP correlates of retrieval orientations are modulated by reward expectancy. It was expected that reward might affect retrieval processing via retrieval orientation either by enhancing the material-specific orientation effect (by eliciting a larger material-specific ERP effect for pictures and words encoded with high than with low reward expectancy) or by eliciting a reward-associated retrieval orientation effect (an ERP difference between high and low reward trials, irrespective of target material).

Interestingly, the results of both ERP-studies presented in this thesis indicated that reward manipulations did not modulate the classic material-specific retrieval orientation effect usually observed for contrasts of this kind. Reward manipulations instead led to the adoption of distinct reward-associated retrieval orientations during test. The reward-associated retrieval orientation effect took the form of a fronto-centrally distributed, temporally protracted ERP effect elicited by differences in the amount of reward related to later memory performance (Experiment 1) or performance on the study task (Experiment 2). In the high reward condition of the memory exclusion task, ERPs to correctly rejected new test items were more positive-going compared to those in the low reward condition from 400 ms after presentation of the retrieval cue. This effect was present in both the target-picture and target-word conditions. This suggests that, irrespective of the type of targeted memory representations (either pictures or words), the retrieval of items that were linked to a high monetary reward during study was associated with distinct retrieval cue processing compared to when low monetary reward items were to be retrieved.

The presence of comparable effects in both experiments, even in Experiment 2 when the study reward manipulation was no longer related to memory test performance makes it unlikely that these effects are a simple reflection of effort-related processing elicited by changes in reward. Although this claim is made on the basis of the broad correspondences between the effects in the two paradigms, it is not possible to completely discount the contribution of effort-related processes in Experiment 1, and the slightly more anterior maximum of the effect in that experiment might reflect a partial contribution of processes of this kind. Whilst this possibility cannot be entirely excluded for Experiment 1, it is difficult to make this argument for the effect in Experiment 2 and the differences between new item ERPs from the high and low reward tests can thus be taken to reflect reward-related retrieval processes rather than changes in effort elicited by reward manipulations.

An account is favored here, which claims that the differences in ERPs between items associated with high and low reward reflect the re-engagement of non-strategic reward-related encoding processes at retrieval. The assumption is that the reward manipulation at study influenced the encoding of a subsequent study episode perhaps by increasing the strength of highly rewarded memory representations and/or by leading to distinct kinds of representations according to whether items were associated with a high or low reward cue. The recovery of such information including the associated reward cue might then lead participants to re-engage processes analogous to those employed during the initial encoding phase. This reasoning is in line with the cortical reinstatement hypothesis (Rugg et al, 2008) and the associated principle of transfer appropriate processing (Morris et al, 1977), which emphasize the interdependent nature of encoding and retrieval processes and the benefit from reactivating processes that were engaged at encoding during memory retrieval. The incidental nature of the study phase in Experiment 2 is likely to have reduced the contribution of deliberate learning processing during this task, thus ensuring that any processes recapitulated at test are principally related to reward and not to explicit learning strategies. The current data thus provide the first demonstration that reward-related processing at study modulates the retrieval processes engaged during test. The extent to which the engagement of reward-modulated retrieval processes that were found in Experiments 1 and 2 directly contributes to behavioral reward-related memory benefits is not yet clear however, because whilst a reward-related ERP effect was observed that was not modulated by target material, the behavioral reward effect was specific to the target-picture test blocks.

Furthermore, it is necessary to think about the functional significance of the relative negativity of ERPs elicited by retrieval cues usually found in ERP-retrieval orientation effects. As already mentioned in Chapter I and above, this relative ERP-negativity was previously interpreted in terms of a mismatch in modality between retrieval cue format and the items format at study (Hornberger et al., 2004), irrespective of which particular type of material was presented at study or test. In case of low overlap in form between retrieval cues and sought-for memory representations, the retrieval cue representation is assumed to be conceptually constrained in the direction of more similar representation level of the sought-for memory representation. Consequently, this is thought to result in a greater negativity of the associated ERPs. The material-specific retrieval orientation effect that was observed in Experiment 1 and 2 was characterized by relatively more negative-going ERPs in the "nonmatching" target-picture condition than in the "matching" target-word condition. In this case, the adoption of a conceptually constrained retrieval orientation was required for effective retrieval of the targeted picture information, resulting in relatively more negative-going ERPs to new items.

By contrast, with regard to the reward-associated retrieval orientation effect, ERPs to low reward items were more negative-going relative to ERPs elicited by high reward items. This leaves open the question of the functional interpretation of this relative negativity of ERPs to low reward items and of the specific aspects of retrieval cue processing that were being modulated here. According to the account given above, the recovery of information that was previously associated with a low reward cue might have led participants to reactivate processes analogous to those employed during the initial encoding phase. By this, these processes constrained retrieval cue representation in the direction of a representation level of a target low reward memory representation that was different from the one of the targeted high reward memory representation. Conceivably, and in line with the interpretation of the classic material-specific effect, items that were associated with a high reward cue presumably increased the overlap with a retrieval cue at retrieval, possibly due to an increased strength particularly for these highly rewarded memory representations.

Furthermore, it was also indicated by Hornberger et al. (2004) that ERP retrieval orientation effects can be found even in the absence of a copy cue condition (explained above). In their study, retrieval cue material at test (e.g. visual words) did not match perceptually with either class of studied material (e.g. auditory words and pictures). The results showed that ERPs to new items were more negative-going when formerly studied pictures rather than auditory words formed the target condition. This was hypothesized by the authors to be because subjects were expected to process the retrieval cues differently depending on whether they were conceptually constraining their search for auditory words or for pictures in order to maximize the overlap between retrieval cue and respective memory representations. More precisely, the potential conceptual overlap in phonological and lexical processing between visual words and previously studied auditory words was assumed to be greater than when pictures had to be retrieved. Accordingly, retrieval cue representations would need to be less constrained to a semantic process level in the auditory word - visual word condition. By this, the findings of Hornberger et al. (2004) not only indicated that retrieval orientation effects were independent from copy cue conditions but also that similarity between retrieval cues and targeted memory representations is not limited to the level of surface form but can be generalized to other representation levels as well (e.g. input phonology, lexical processing; Price, 2000).

Additionally, retrieval orientation effects appear to be independent from differences in test difficulty or test performance (e.g. Robb & Rugg, 2002; Herron & Rugg, 2004; Hornberger et al., 2004). For instance, in the study of Robb and Rugg (2002), difficulty at test was manipulated by changing study-test delay and study list length in order to manipulate easy and hard retrieval conditions either for targeted word- or picture material. Irrespective of difficulty level, ERPs to new test words reliably differed according to whether pictures or words formed the target designation. These findings receive support from the behavioral results of both ERP-studies that were presented in this work, as both retrieval orientation effects were observed even though memory accuracy and reaction times to new items did not differ as a function of the target material or reward level. This is a crucial requirement in experiments of strategic retrieval processing in order to ensure retrieval effort does not confound effects of retrieval orientation.

## 5.3 Cultural Differences in Effects of Incentives on Long-Term Memory

In the series of behavioral cross-cultural experiments presented in this thesis (Experiments 3a-d) conducted in China and in Germany, the paradigm employed was identical to the one used in Experiment 1, except that in half of the studies a punishment instead of a reward manipulation was included. In this way, participants could prevent loss of either high or low amounts of money by a correct target response in the memory exclusion task. The main goal was to investigate whether reward cues (potential gain of money) or punishment cues (potential loss of money) would be differently processed during learning and episodic memory formation between Chinese and German participants. In particular and among others, findings from Heine et al. (2001) have indicated that Westerners react and respond differently to negative self-relevant information than East Asians.

This proposal receives support from the results obtained in the presented work. First of all, alongside the clear reward and punishment effects in memory performance that were found in both countries, this memory-enhancing effect was significantly bigger in the punishment avoidance experiments for the Chinese that for the German participants. The findings therefore suggest that cross-cultural differences in motivated learning through avoidance of potential loss of money and later memory performance exist. This indicates that different levels of motivational influences during learning might not only depend on personality differences but also on cultural differences, at least with respect to learning through the avoidance of negative incentives. These results suggest that cross-cultural influences with respect to reward and punishment sensitivity during learning and their influence on later memory performance should be taken into account in the future.

Experiments 3a-d comprised a series of behavioral studies. It would be interesting to examine in the future by the use of EEG whether reward-associated ERP-retrieval orientation effects could also be observed in conditions in which instead of positive, monetary incentives, the avoidance of negative incentives would serve as a motivating factor during learning. On the basis of the behavioral results which indicated that participants' memory accuracy was boosted for highly rewarding as well as highly punishing study events, the adoption of a reward-specific retrieval orientation in the punishment experiments across both countries, similar to the effect found in Experiment 1 and 2, is plausible. This would also be in line with previous findings from Kim et al. (2006) according to which successful avoidance of a punishing event was cognitively processed in a similar way as during the receipt of rewards. Additionally, it might be interesting to incorporate more details of individual's demographic and personal details, such as the number of siblings, educational style and rural/urban location, more extensively into future cross-cultural ERP or general experimental research. For instance, of potential interest in the field of educational psychology would not only be to investigate cross-cultural influences on reward and punishment sensitivity during learning and long-term memory but also to take particular differences within, for example, the East-Asian culture on these learning and retrieval processes into account. Experiments might be conducted that would compare Chinese-raised participants that grew up in a village with participants that grew up in a city. Another idea would be to compare reward and punishment sensitivity during learning between Chinese participants who were the only child at home with those with one or more siblings.

## 5.4 Assorted Caveats and Outstanding Issues

An aspect of the present data which needs consideration is the difficulty of manipulating motivational levels across many individuals to a similar degree simply by changing externally presented cues. Personality together with different life experiences presumably influence individual coping and learning strategies, as well as reactions to positively or negatively motivating events. The experiments presented in this work might therefore be seen as a procedure to influence high and low levels of motivation in a rather artificial, yet controlled way. This should not discount the relevance of the obtained results as they considerably extended previous findings of basic research in this domain and at the same time will serve as a crucial starting point for future studies. It remains to be determined however whether the results obtained in the three studies that were presented in this thesis would also be obtained in everyday learning and retrieval situations outside of a controlled laboratory environment. Additionally, the present analyses apply to memory for rather simple events (words, black-and-white drawing pictures) of the kind frequently used in and typical for experimental studies. By this and the fact that the dependent and independent variables of interest were kept as simple as possible and in a relatively low, assessable number, advantage was taken of the possibility to control for potential confounding of less or uncontrollable variables that might influence an effect. The disadvantage of this is that laboratory memory studies usually differ to a large extent from everyday life situations, e.g. by the use of EEG-equipment, the requirement for participants to sit in front of a computer monitor and to respond via button press on the keyboard. Therefore, it remains to be explored whether similar reward-associated retrieval orientation effects would also be obtained in more ecologically valid learning and retrieval situations. This would permit further generalization of the experimental findings that were presented in this thesis.

A further issue in this context is that the test phases in the conducted experiments were, next to the target-material conditions always blocked by high and low reward. This design aspect was employed on the basis of the findings of Werkle-Bergner et al. (2005) which showed that ERP retrieval orientation effects disappeared under frequently changing testing conditions and high task-switching demands. However, designs that are optimal for recording separate contrasts between reward and material conditions at retrieval are not always compatible with one another. Therefore, it may be more appropriate to conduct experiments that try to use memory tests in which test items of different conditions would be interleaved within a single test block but in such a way that sequences of same items are still presented in order to provide enough time and resources for participants to adopt specific retrieval orientations. Moreover, by this the possibility that some participants might have uncovered the reward blocking conditions in the test phase would be ruled out, although the outcomes of the participant's questionnaire indicate that this was unlikely in the current design.

Furthermore, it might be that the limited amount of time to give a response in the memory exclusion task negatively influenced the recognition outcome for some individuals or some trials due to excessive time pressure. Despite the fact that limiting respondents' answering time for example in memory tests might discount large individual differences in the time needed to give a response, the particular time parameters employed in the studies presented in this work were chosen in order to reduce uncontrolled influences of distraction, body movements or boredom. It is very likely however that if more time was given to answer, participants would have been able to correctly recognize more targets, non-targets and new items. Support for this comes from the improved memory performance that was attained in the series of the four cross-cultural, behavioral experiments (Experiments 3a-d). However, the extent to which longer response times might have led to increased memory accuracy remains ambiguous because alongside longer response time windows, these experiments also consisted of approximately 30% fewer trials at study and test compared to the experimental designs used in Experiment 1 and Experiment 2.

Whether better memory for items that were preceded by a high reward or a high punishment cue during study as observed most clearly in the behavioral experiments (Experiments 3a-d) is purely based on the fact that participants were highly motivated especially during encoding is also open to question. A probable disadvantage of the relatively long 24-hours retention interval between study and test might be that additional time was given to retrieve the newly learned information at several, uncontrolled time points. This implies that participants may have additionally strengthened the memory trace selectively for highly motivating information by the repeated search for internal or external retrieval cues in order to reactivate the trace. This possibility would extend the scope of the present research project, but it would be highly interesting to disentangle the factors that contribute most to memory enhancing retrieval processing.

In a broader sense, it might be of interest for clinical purposes to further develop the results obtained in basic research in order to increase their implications for neuropsychological research and patient studies. For example, the present findings might indicate a way to improve successful memory retrieval, i.e. in the healthy elderly that undergo normal decreases in long-term memory performance with increasing age. This could be done perhaps by improving the way retrieval cues are processed to increase their similarity with targeted memory representation as well as to optimize retrieval cues' dissimilarity with irrelevant and non-targeted memory representations. A possibility would be to ameliorate the fit between adopted retrieval orientations to particular retrieval goals by including motivational factors during learning and maybe by focusing attention on those features of a retrieval cue that overlap with those of a targeted memory representation. By this, processing resources might be minimized. Therefore, studies with elderly participants that attempt to integrate present and prospective findings with regard to critical factors that impact positively on learning and strategic retrieval processing, would be desirable in the future.

Finally, the findings of reward-associated ERP-retrieval orientation effects presented in this thesis imply that current concepts about the functional role of retrieval orientations should be extended to the possibility of aligning retrieval cue processing to types of memory representations which did not differ either in the material encoded at study (e.g. words versus pictures) or with regard to the task requirements at test (e.g. retrieval of 'general' versus 'specific' features of studied items) but differed solely in motivational level during learning. This means that for optimal retrieval of information, retrieval orientations are not only adopted in order to constrain retrieval cue processing at a conceptual/semantic level but also to more contrasts of retrieval conditions in which retrieval cue processing might be constrained in different ways. The observed reward-associated retrieval orientations demonstrate that incentives to memorize an item influence not only encoding but also retrieval processes.

A general requirement in empirical research is the future replication of newly presented findings to increase their validity. Of importance here is that this requirement has to some extent already been fulfilled because the critical findings of the presented work - ERP indices of adopted, reward-associated retrieval orientations - have been successfully replicated across the two ERP-studies reported in this thesis. However, replication, especially with regard to the cross-cultural changes in sensitivity to negative learning events, would be highly desirable.

*'[…] we make search in our memory for a forgotten idea, just as we rummage our house for a lost object. In both case we visit what seems to us the probable neighborhood of that which we miss. We turn over the things under which, or within which, or alongside of which, it may possibly be; and if it lies near them, it soon comes to view (James, 1890, p. 654).'*

More than a century ago, William James described with this metaphor memory retrieval as a search process, an influential description which still influences the contemporary understanding of memory retrieval. In the context of the studies presented in this work in which the main goal was to examine how motivated learning, either through positive or negative monetary incentives, might influence strategic memory retrieval processes, William James' metaphor might be extended to the figurative example of a further search process in one's own house but now for lost and very valuable objects. As a consequence, the search process through the house might be more efficient in time and space, but the extent to which the object is likely to be found would vary depending upon the amount of value bestowed upon the object when it was originally left. This value would then affect the retrieval operations engaged during the search for it.

## 5.5 General Conclusions

Taken together, the findings of the present studies comprise the first demonstration of the fact that participants can adopt distinct retrieval orientations, not only as a function of the targeted information (material-specific retrieval orientation effect) but also as a function of reward (reward-associated retrieval orientation effect). This suggests that incentives during learning facilitate the adoption of a reward-associated retrieval orientation in a delayed memory test in order to retrieve perceptual details of highly motivational information in an efficient way.

Evidence of a relationship between cross-cultural differences and the processing of negative incentive cues during learning and episodic memory formation was found across four different behavioral experiments that were conducted in China and in Germany. The results indicate for the first time that whereas clear reward and punishment effects in memory were found in both countries, this incentive effect was bigger in the punishment condition for the Chinese than for the German participants. The findings provide evidence that participants of two different countries appear to diverge in sensitivity to punishment avoidance learning.

The results of work in this thesis thus provide evidence for the fact that reward-related processing at study modulates the retrieval processes engaged during test and that the degree of sensitivity to negative incentives during learning with regard to later memory performance might differ as a function of cultural background.

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# Appendix A

## Experiment 1: Analyses of ERP Old/New Effects Separated According to Target Material and Reward Condition

Table A2.2a and Table A2.2b show the ANOVA results of within-condition ERP analyses, separately for the target-picture and the target-word condition. Table 2.2c and Table 2.2d depict the results separately for the high reward and the low reward condition. Marginally significant effects are marked in grey font.

In Table A2.3a and Table A2.3b ANOVA results of the ERP-analyses of parietal electrodes can be found for the target-picture and the target-word condition respectively. Table A2.3c and Table A2.3d depict the results for the high and the low reward condition respectively. Marginally significant effects are marked in grey font.

**Table A2.2a** ANOVA results of within-condition ERP analyses for targets, new items and non-targets for each latency range in the **target-picture condition** (N = 19). IT = item type (target, non-target, new), LOC = location (frontal, central, parietal electrodes), LAT = laterality (left, middle, right electrodes).

| Material condition | Comparison | Effect | 300-500 ms | 500-700 ms | 700-1000 ms | 1000-1300 ms |
|---|---|---|---|---|---|---|
| Pictures | Targets vs. Non-targets vs. New | IT | *F*(2,36) = 5.19, *p* < .05 | *F*(2,36) = 10.88, *p* < .001 | *F*(2,36) = 5.36, *p* < .05 | - |
| | | IT/LAT | *F*(4,72) = 2.37, p = .079 | - | | - |
| | | IT/LOC/LAT | - | *F*(8,144) = 2.38, *p* = .053 | *F*(8,144) = 2.15, *p* = .093 | - |
| | Targets vs. New | IT | *F*(1,18) = 8.21, *p* < .05 | *F*(1,18) =16.41, *p* < .01 | *F*(1,18) = 7.72, *p* < .05 | - |
| | | IT/LOC | - | - | *F*(2,36) = 2.97, *p* = .09 | - |
| | | IT/LOC/LAT | - | - | - | *F*(4,72) = 2.86, *p* = .069 |
| | Non-targets vs. New | IT | - | - | - | - |
| | | IT/LOC | *F*(2,36) = 3.70, *p* = .057 | - | - | - |
| | | IT/LAT | *F*(2,36) = 4.27, *p* < .05 | - | - | - |
| | | IT/LOC/LAT | *F*(4,72) = 2.56, *p* = .065 | *F*(4,72) = 3.33, *p* < .05 | *F*(4,72) = 3.26, *p* < .05 | *F*(4,72) = 3.27, *p* < .05 |
| | Targets vs. Non-targets | IT | *F*(1,18) = 7.55, *p* < .05 | *F*(1,18) = 18.55, *p* < .001 | *F*(1,18) = 6.97, *p* < .05 | - |
| | | IT/LOC | *F*(2,36) = 3.01, *p* = .088 | *F*(2,36) = 4.69, *p* < .05 | - | - |

**Table A2.2b** ANOVA results of within-condition ERP analyses for targets, new items and non-targets for each latency range in the **target-word condition** (N = 19). IT = item type (target, non-target, new), LOC = location (frontal, central, parietal electrodes), LAT = laterality (left, middle, right electrodes).

| Material condition | Comparison | Effect | 300-500 ms | 500-700 ms | 700-1000 ms | 1000-1300 ms |
|---|---|---|---|---|---|---|
| Words | Targets vs. Non-targets vs. New | IT | - | - | - | - |
| | | IT/LOC | - | - | $F(4,72) = 8.48$, $p < .01$ | $F(4,72) = 11.75$, $p < .001$ |
| | | IT/LOC/LAT | - | $F(8,144) = 2.94$, $p < .05$ | $F(8,144) = 4.08$, $p < .01$ | $F(8,144) = 5.19$, $p < .01$ |
| | Targets vs. New | IT/LOC | $F(2,36) = 3.05$, $p = .088$ | $F(2,36) = 3.51$, $p = .073$ | $F(2,36) = 13.60$, $p < .01$ | $F(2,36) = 15.06$, $p < .01$ |
| | | IT/LAT | - | - | $F(2,36) = 2.84$, $p = .074$ | - |
| | | IT/LOC/LAT | $F(4,72) = 2.69$, $p = .063$ | $F(4,72) = 3.68$, $p < .05$ | $F(4,72) = 4.91$, $p < .01$ | $F(4,72) = 6.84$, $p < .01$ |
| | Non-targets vs. New | IT | $F(1,18) = 3.43$, $p = .081$ | - | - | $F(1,18) = 5.14$, $p < .05$ |
| | | IT/LOC | - | - | $F(2,36) = 3.99$, $p = .055$ | - |
| | Targets vs. Non-targets | IT/LOC | - | - | $F(2,36) = 6.02$, $p < .05$ | $F(2,36) = 18.11$, $p < .001$ |
| | | IT/LOC/LAT | | $F(4,72) = 3.98$, $p < .05$ | $F(4,72) = 4.57$, $p < .01$ | $F(4,72) = 5.46$, $p < .01$ |

**Table A2.2c** ANOVA results of within-condition ERP analyses for targets, new items and non-targets and for each latency range in the **high reward condition** (N = 19). IT = item type (target, non-target, new), LOC = location (frontal, central, parietal electrodes), LAT = laterality (left, middle, right electrodes).

| Reward condition | Comparison | Effect | 300-500 ms | 500-700 ms | 700-1000 ms | 1000-1300 ms |
|---|---|---|---|---|---|---|
| High reward | Targets vs. Non-targets vs. New | IT | $F(2,36) = 2.66, p = .085$ | $F(2,36) = 5.63, p < .01$ | $F(2,36) = 4.40, p < .05$ | $F(2,36) = 3.79, p < .05$ |
| | | IT/LOC | - | - | $F(4,72) = 3.11, p = .052$ | - |
| | | IT/LAT | - | - | $F(4,72) = 2.50, p = .080$ | - |
| | | IT/LOC/LAT | - | $F(8,144) = 2.68, p < .05$ | $F(8,144) = 4.77, p < .01$ | $F(8,144) = 4.63, p < .01$ |
| | Targets vs. New | IT | $F(1,18) = 5.12, p < .05$ | $F(1,18) = 5.06, p < .05$ | $F(1,18) = 4.29, p = .053$ | - |
| | | IT/LOC | - | - | $F(2,36) = 3.20, p = .078$ | $F(2,36) = 3.00, p = .093$ |
| | | IT/LOC/LAT | - | $F(4,72) = 3.40, p < .05$ | $F(4,72) = 5.97, p < .01$ | $F(4,72) = 6.51, p < .01$ |
| | Non-targets vs. New | IT/LOC | $F(2,36) = 2.84, p = .098$ | - | - | $F(2,36) = 2.27, p = .086$ |
| | Targets vs. Non-targets | IT | $F(1,18) = 3.36, p = .083$ | $F(1,18) = 11.46, p < .01$ | $F(1,18) = 11.52, p < .01$ | - |
| | | IT/LOC | - | - | $F(2,36) = 5.57, p < .05$ | $F(2,36) = 7.98, p < .01$ |
| | | IT/LAT | - | - | $F(2,36) = 3.72, p < .05$ | $F(2,36) = 2.78, p < .092$ |
| | | IT/LOC/LAT | - | $F(4,74) = 3.08, p < .05$ | $F(4,74) = 5.39, p < .01$ | $F(4,74) = 4.09, p < .05$ |

**Table A2.2d** ANOVA results of within-condition ERP analyses for targets, new items and non-targets and for each latency range in the **low reward condition** (N = 19). IT = item type (target, non-target, new), LOC = location (frontal, central, parietal electrodes), LAT = laterality (left, middle, right electrodes).

| Reward condition | Comparison | Effect | 300-500 ms | 500-700 ms | 700-1000 ms | 1000-1300 ms |
|---|---|---|---|---|---|---|
| Low Reward | Targets vs. Non-targets vs. New | IT | $F(2,36) = 3.01, p = .064$ | $F(2,36) = 3.16, p = .060$ | - | - |
| | | IT/LOC | $F(4,72) = 2.92, p = .058$ | $F(4,72) = 3.04, p = .067$ | $F(4,72) = 4.64, p < .01$ | $F(4,72) = 8.02, p < .01$ |
| | Targets vs. New | IT | $F(1,18) = 6.54, p < .05$ | $F(1,18) = 6.72, p < .05$ | - | - |
| | | IT/LOC | $F(2,36) = 4.92, p < .05$ | $F(2,36) = 4.13, p = .054$ | $F(2,36) = 14.84, p < .01$ | $F(2,36) = 10.96, p < .01$ |
| | | IT/LOC/LAT | - | - | - | $F(4,72) = 3.31, p < .05$ |
| | Non-targets vs. New | IT | - | $F(1,18) = 3.52, p = .077$ | $F(1,18) = 6.65, p < .05$ | - |
| | | IT/LOC | - | - | $F(2,36) = 4.81, p < .05$ | - |
| | | IT/LOC/LAT | - | - | $F(4,72) = 3.32, p < .05$ | $F(4,72) = 2.742, p = .056$ |
| | Targets vs. Non-targets | IT/LOC | - | - | $F(2,36) = 4.65, p < .05$ | $F(2,36) = 8.18, p < .01$ |

**Table A2.3a** ANOVA results of within-condition ERP analyses **at parietal electrode sites** for targets, new items and non-targets for each latency range in the **target-picture condition** (N = 19).

| Material condition | Comparison | Effect | 1000-1300 ms | 1300-1600 ms |
|---|---|---|---|---|
| Pictures | Targets vs. Non-targets vs. New | IT | - | *F*(2,36) = 2.77, *p* = .088 |
| | | IT/LAT | *F*(4,72) = 4.35, *p* < .01 | - |
| | Targets vs. New | IT | *F*(1,18) = 3.53, *p* = .076 | *F*(1,18) = 6.57, *p* < .05 |
| | | IT/LAT | *F*(2,36) = 5.54, *p* < .01 | - |
| | Non-targets vs. New | IT | *F*(1,18) = 3.35, *p* = .084 | - |
| | | IT/LOC | *F*(1,18) = 4.67, *p* < .05 | *F*(1,18) = 4.69, *p* < .05 |
| | Targets vs. Non-targets | | - | - |

**Table A2.3b** ANOVA results of within-condition ERP analyses **at parietal electrode sites** for targets, new items and non-targets for each latency range in the **target-word condition** (N = 19).

| Material condition | Comparison | Effect | 1000-1300 ms | 1300-1600 ms |
|---|---|---|---|---|
| Words | Targets vs. Non-targets vs. New | IT | *F*(2,36) = 7.92, *p* < .01 | *F*(2,36) = 7.82, *p* < .01 |
| | | IT/LAT | *F*(4,72) = 4.37, *p* < .05 | *F*(4,72) = 3.94, *p* < .05 |
| | Targets vs. New | IT | *F*(1,18) = 6.21, *p* < .05 | *F*(1,18) = 8.14, *p* < .05 |
| | | IT/LAT | *F*(2,36) = 5.47, *p* < .05 | *F*(2,36) = 5.17, p < .05 |
| | Non-targets vs. New | | - | - |
| | Targets vs. Non-targets | IT | *F*(1,18) = 15.46, p < .01 | *F*(1,18) = 16.23, *p* < .01 |
| | | IT/LAT | *F*(2,36) = 4.84, p < .05 | *F*(2,36) = 4.00, *p* < .05 |

**Table A2.3c** ANOVA results of within-condition ERP analyses **at parietal electrode sites** for targets, new items and non-targets and for each latency range in the **high reward condition** (N = 19).

| Reward condition | Comparison | Effect | 1000-1300 ms | 1300-1600 ms |
|---|---|---|---|---|
| High Reward | Targets vs. Non-targets vs. New | IT | $F(2,36) = 4.77, p < .05$ | $F(2,36) = 3.78, p < .05$ |
| | | IT/LAT | $F(4,72) = 6.58, p < .01$ | $F(4,72) = 4.60, p < .01$ |
| | Targets vs. New | IT | $F(1,18) = 6.31, p < .05$ | $F(1,18) = 6.58, p < .05$ |
| | | IT/LAT | $F(2,36) = 9.39, p < .01$ | $F(2,36) = 6.67, p < .01$ |
| | Non-targets vs. New | IT/LAT | $F(2,36) = 3.89, p < .05$ | - |
| | Targets vs. Non-targets | IT | $F(1,18) = 7.58, p < .05$ | $F(1,18) = 5.68, p < .05$ |
| | | IT/LAT | $F(2,36) = 4.42, p < .05$ | $F(2,36) = 3.32, p = .057$ |

**Table A2.3d** ANOVA results of within-condition ERP analyses **at parietal electrode sites** for targets, new items and non-targets and for each latency range in the **low reward condition** (N = 19).

| Reward condition | Comparison | Effect | 1000-1300 ms | 1300-1600 ms |
|---|---|---|---|---|
| Low Reward | Targets vs. Non-targets vs. New | IT | $F(2,36) = 4.18, p < .05$ | $F(2,36) = 4.78, p < .05$ |
| | | IT/LAT | $F(4,72) = 2.76, p = .050$ | - |
| | Targets vs. New | IT | $F(1,18) = 5.34, p < .05$ | $F(1,18) = 6.71, p < .05$ |
| | | IT/LAT | $F(2,36) = 4.61, p < .05$ | - |
| | Non-targets vs. New | | - | - |
| | Targets vs. Non-targets | IT | $F(1,18) = 6.57, p < .05$ | $F(1,18) = 10.06, p < .01$ |

# Acknowledgments

The mainstay of my supervision was characterized by valuable feedback, patience and encouragement to meet one research challenge after another due to Prof. Dr. Axel Mecklinger. I'm especially grateful for his support and the invaluable work experience in his lab.

I thank Prof. Dr. Hubert Zimmer for being my second supervisor of this thesis.

A special thanks goes to Dr. Nicola Ferdinand and Dr. Emma Bridger. Their omnipresent assistance and feedback have allowed me to work in a fulfilling and productive environment.

I'm thankful to the members of the International Research Training Group "Adaptive Minds" who have ensured that coming to work remained a great pleasure.

Thanks to all subjects from near and far who patiently participated in the studies presented in this thesis and without whom this research could not have been realized.

I am deeply thankful for the enormous, almost limitless support and encouragement and for unforgettable "trips across life" to my family, friends and C. H. E.

# Curriculum Vitae

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| 08/2008 – heute | **Universität des Saarlandes, Saarbrücken** |
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| | Dissertation zum Einfluss motivationalen Lernens auf den Gedächtnisabruf |
| 09/2002 – 05/2008 | **Rijksuniversiteit Groningen (Niederlande)** |
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# PUBLIKATIONEN

**Zeitschriften (mit „peer review"-Verfahren):**

*Halsband, T.M., Ferdinand, N.K., Bridger, E.K., & Mecklinger, A. (2012). Monetary rewards influence retrieval orientations. Cognitive, Affective, and Behavioral Neuroscience, 12, 430-445. DOI 10.3758/S13415-012-0093-Y*

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Halsband, T.M., Ferdinand, N.K., & Mecklinger, A. (2011). *Monetary rewards influence strategic memory retrieval: an event-related potential study.* International Conference on Cognitive Neuroscience (ICON XI).

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Saarbrücken, 16. August 2012