Age-related Differences in Episodic Memory Retrieval

ERP Evidence for Differential Developmental Changes in Item and Source Recognition Memory

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 Tübingen

Saarbrücken, 2011

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Tag der Disputation: 3. November 2011

TABLE OF CONTENTS

Abbreviations

ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
BESA	Brain Electrical Source Analysis
DLPFC	Dorsolateral Prefrontal Cortex
EEG	Electroencephalography
EOG	Electrooculogram
ERP	Event-Related Potential
fMRI	Functional Magnetic Resonance Imaging
LPN	Late Posterior Negativity
MRI	Magnetic Resonance Imaging
MTL	Medial Temporal Lobe
PFC	Prefrontal Cortex
PPC	Posterior Parietal Cortex
ROC	Receiver Operating Characteristics
VLPFC	Ventrolateral Prefrontal Cortex
WM	Working Memory
WMC	Working Memory Capacity

Abstract

Episodic memory abilities continue to develop throughout childhood until young adulthood. Still an important question is whether age-related changes in overt performance are due to different memory functions developing at different rates. One functional distinction can be made between item and source memory, the assumption being that source memory relies to a relatively greater extent on strategic control processes engaged during retrieval. Previous developmental research suggests that these strategic retrieval processes follow a relatively protracted trajectory of maturation into adolescence, while, however, this research is limited by the fact that it has predominantly focused on immaturities in strategic retrieval processing in children. The present work aimed at providing a more comprehensive developmental account of episodic memory by comparing event-related potential (ERP) correlates of item and source memory retrieval between 7-8 year-old children, 13-14-year-old adolescents, and young adults. Study 1 confirmed the notion that item and source memory follow different developmental trajectories. While no age differences were found for the ERP correlate of recollection in the item memory task, the source memory task revealed that neural correlates of strategic recollection emerge with adolescence only. Notably, however, only adults showed ERP evidence for post-retrieval control, suggesting further refinements in the network underlying strategic memory retrieval during adolescence. Study 2 extended the empirical basis for this latter view, as adolescents did not show ERP correlates of selective recollection, which, however, were observed for adults. As different operational definitions of strategic memory retrieval were used in the two studies, these findings therefore provide support for the view that adolescence is critical for the development of various facets of strategic retrieval processing. Together, the findings reported in the present thesis provide new insights into how functionally distinct components of episodic memory evolve over development.

1 Episodic Memory Retrieval and its Neural Correlates

1.1 Introduction to human memory

The ability to remember past events is considered a hallmark of human mental abilities (Tulving, 1983, 2002). Contemporary models of human long-term memory have agreed on the assumption that memory is composed of several functionally different systems which are mediated by separate brain systems (Henke, 2010). An influential model that guides various lines of research on memory has distinguished declarative (i.e. explicit) from non-declarative (i.e. implicit) memory (Squire & Zola, 1996). Declarative memory refers to the conscious access and flexible use of stored information and is assumed to depend on neural structures within the medial temporal lobe (MTL) memory system, including the hippocampus, perirhinal, entorhinal, and parahippocampal cortices. Conversely, non-declarative memory refers to an ensemble of unconscious learning and retrieval abilities that are less flexible, expressed through behavioral performance, and independent of the MTL (Squire & Zola, 1996). There is generally broad consensus regarding the distinction between declarative and non-declarative memory (but see Henke, 2010, for an alternative view). Amnesic patients with damage to the MTL provide support for this distinction, as these patients often show impaired declarative memory but spared non-declarative memory abilities, such as the learning of perceptuomotor skills (Reber & Squire, 1994).

Within the declarative memory system, a further distinction is made between episodic and semantic memory (Squire & Zola, 1996). Episodic memory refers to memory for specific autobiographical episodes which includes information about the content of experiences as well as the spatial and temporal contexts in which these occurred. Semantic memory refers to the noncontextual content of experience, including general knowledge about the world (Tulving, 1972, 1983) as well as facts about ourselves (‘personal semantics’; Moscovitch et al., 2005). Although both episodic and semantic memory are held to rely on the hippocampus and extrahippocampal structures within the MTL, there is also evidence for a distinction between these two forms of memory. For example, Vargha-Khadem and colleagues (1997) found that children whose hippocampi were damaged shortly after birth could acquire considerable amounts of semantic knowledge even though their memory for autobiographical episodes was impaired. Consistent with this dissociation are single case reports of relative sparing of semantic compared to episodic memory in amnesic adults with hippocampal lesions, suggesting that semantic memory may be at least partially independent of hippocampally mediated episodic memory (Van der Linden et al., 2001; Westmacott & Moscovitch, 2001). However, the evidence regarding the neuropsychological and functional distinction between episodic and semantic memory is far from conclusive, and discussion of this distinction has centred the possibility that it may be not pure, such that either type of memory contains both episodic and semantic elements (Moscovitch et al., 2005).

1.2 Neurocognitive models of episodic memory retrieval

Of central importance in this thesis is the capacity of the human mnemonic system to rapidly select episodic information that is relevant for current task demands. This capacity is thought to rely on strategic control processes which enable individuals to employ memory retrieval in a goal-directed manner. One approach to investigating the operating characteristics of these strategic retrieval processes is provided by recognition memory tasks. Generally, recognition memory describes a particular mnemonic ability of episodic long-term memory and refers to the ability of becoming aware that a particular event has been encountered in the past upon presentation of a retrieval cue. As discussed later on, an increasing number of data from neuroscientific research implicates a functional role for strategic control processes in recognition memory.

This section is intended to introduce the key concepts that guide and constrain contemporary research on episodic memory retrieval and the work presented in this thesis. The section first introduces a general framework for the study of recognition memory and its underlying retrieval processes. The section then addresses models which have been developed to describe the role of strategic processes for episodic retrieval.

1.2.1 Dual-process models of recognition memory

According to the dual-process framework of recognition memory, recognizing past events involves at least two functionally distinct processes: recollection and familiarity (Mandler, 1980; Yonelinas, 2002). Recollection refers to memory which is accompanied by retrieval of contextual details, while familiarity refers to knowing that an item has been studied previously, without remembering any details about the study episode. The processing characteristics of recollection and familiarity have been formalized by a variety of dual-process models, with each proposing different operational definitions of both processes (Yonelinas, 2002). Among the most prominent models are those which have distinguished between recollection and familiarity in terms of response confidence (Yonelinas, 1994, 1997), conscious awareness (Tulving, 1985), and conscious control (Jacoby, 1991).

Yonelinas (1994, 1997) described recollection as a threshold process by which qualitative information about an event is retrieved. By contrast, familiarity is considered a signal detection process which serves to assess quantitative strength information. The relative contributions of recollection and familiarity to recognition performance can be estimated by fitting a model-based equation to recognition confidence data, such as *receiver operating characteristics* (ROCs; Yonelinas & Parks, 2007). Conversely, Tulving (1985) argued that recollection supports *autonoetic* consciousness (i.e. episodic remembering), while familiarity is associated with *noetic* consciousness (i.e. mere knowledge about the study event). On the basis of this model, dual-process estimates can be derived from participants' reports about their memory states through application of the *remember/know procedure*.

Jacoby (1991) defined recollection as a process which supports contextual discrimination, whereas familiarity is thought to support old/new discrimination only. Both processes are measured on the basis of memory performance in the *process-dissociation procedure.* In this procedure, participants first study items in one of two encoding conditions (e.g. visual vs. auditory presentation). In a subsequent recognition memory test, they are asked to either accept all items from both conditions as "old" (i.e., *the inclusion task*) or to accept only items from one condition while excluding the items from the other condition (e.g., accepting only the heard items; i.e., *the exclusion task*). Recollection is thought to be indexed by accurate exclusion performance, while familiarity can be estimated by removing the contribution of recollection from overall task performance.

Past research across a variety of experiments in which the three methods presented here were employed has established the notion that recollection and familiarity represent functionally distinct processes (Diana, Reder, Arndt, & Park, 2006; Yonelinas, 2002). For example, across all three measurement procedures, recollection has been found to benefit more than familiarity from elaborative encoding, with the convergence observed across the three methods suggesting that both processes differ in terms of response confidence, conscious awareness, and conscious control (Yonelinas, 2001). Moreover, in accordance with the generally held assumption that familiarity becomes available more quickly than does recollection, studies using response speed manipulations have shown that recollection decreases more than familiarity under speeded compared to nonspeeded response conditions, suggesting that familiarity operates faster (Benjamin & Craik, 2001; Toth, 1996; Yonelinas & Jacoby, 1994).

Correlates of recollection and familiarity can also be identified at the neural level, as both processes have been found to rely on different brain regions within the MTL memory system. Several neuronally informed dual-process models postulate that recollection depends primarily on the hippocampus, whereas the anterior part of the parahippocampal region centring on the perirhinal cortex is considered relevant for familiarity-based recognition (Aggleton & Brown, 2006; Eichenbaum, Yonelinas, & Ranganath, 2007; Rugg & Yonelinas, 2003; see, for example, Norman & O'Reilly, 2003, for a neural network model which uses the specific physiological properties of the hippocampus and anterior MTL structures as constraints for the computational principles of recollection and familiarity).

The proposed functional dissociation between the hippocampus and anterior MTL regions receives support from a number of empirical findings. For example, neuropsychological studies have shown that mildly hypoxic patients with expected hippocampal atrophy exhibit deficits in recollection but normal familiarity as measured through the remember/know and ROC methods (Yonelinas et al., 2002; see

Manns, Hopkins, Reed, Kitchener, & Squire, 2003 and Yonelinas et al., 2004, for discussions). Evidence for the reverse dissociation comes from a case study which has reported impaired familiarity but intact recollection for a patient with lesioned perirhinal cortex but spared hippocampus (Bowles et al., 2007).

In addition, neuroimaging studies have demonstrated that activity within the hippocampus increases when recognition is accompanied by recollection, whereas familiarity does not modulate hippocampal activity, as measured through response confidence (Daselaar, Fleck, & Cabeza, 2006) and the remember/know procedure (Eldridge, Knowltown, Bookheimer, & Engel, 2000). Conversely, activity within rhinal cortex has been found to decrease with increasing familiarity as modeled through response confidence (Daselaar et al., 2006). This decreasing activity within rhinal cortex is paralleled by animal studies which have demonstrated that neurons in the perirhinal cortex of monkeys show reduced responses to repeatedly presented objects, suggesting that these neurons code the relative novelty or familiarity of events (Brown & Aggleton, 2001). The pattern 'repetition suppression' of perirhinal neurons has also been taken as evidence for a 'gatekeeper' function of the rhinal cortex, such that high firing rates (low familiarity) may signal the need for the allocation of encoding resources to novel information (Fernandez & Tendolkar, 2006).

Thus, although opponents of the dual-process framework have interpreted some of the dissociations reported here within 'single-process' models on the assumption that recollection and familiarity primarily reflect different memory strengths (Squire, Wixted, & Clark, 2007), this framework has proven useful for addressing a variety of issues regarding the functional organization of recognition memory.

1.2.2 Models of strategic retrieval processing

In theories of memory, a generally held view is that remembering not only encompasses recognition but critically depends on constructive processes which enable individuals to retrieve episodic details with a high degree of specificity (Roediger, 1996; Schacter, Norman, & Koutstaal, 1998). For example, when asked whether a particular person is familiar from either a visit to the cinema or a sports event, one might search for specific recollections that make one of these two possibilities more probable. This process would include the internal generation of further retrieval cues to guide retrieval and a constant monitoring of the retrieval process. The ensemble of operations at these stages is referred to as *strategic retrieval processing*, as they are thought to be strategically employed in the service of the particular demands of the task at hand. A related concept is that of *retrieval orientation* which describes a cognitive state that optimizes retrieval cue processing depending upon the nature of the sought-for information (e.g. pictures vs. words; Rugg & Wilding, 2000).

One form of memory that strategic retrieval processes have been linked with is *source memory*, which is defined as memory for the contextual characteristics that are associated with the conditions under which a memory was acquired (e.g. the spatial and temporal context, perceptual characteristics, and cognitive operations). According to the source monitoring framework (Johnson, Hashtroudi, & Kwon, 1993), source attributions rely on two general types of judgment processes. Individuals can either use a heuristic, nondeliberative process (e.g. evaluating the amount of perceptual detail) or they can use a more deliberate, systematic process (e.g. evaluating the plausibility of an ongoing source judgment). For example, in so-called reality monitoring tasks, the discrimination between memories that originate from perceived events and those which have been internally generated (i.e. by imagination) might rely on evaluating the amount of remembered perceptual detail, assuming that perceptually rich memories are likely to be externally derived (Johnson & Raye, 1981). Conversely, the decision that a statement was said by person A rather than B might rely on a more controlled evaluation of the characteristics of remembered auditory information and the known voice qualities of the potential sources (Ferguson, Hashtroudi, & Johnson, 1992; Johnson, Nolde, & De Leonardis, 1996).

The source monitoring framework has motivated a great deal of behavioral research on the variables that influence the accuracy with which judgments about the origin of memories can be made (Johnson et al., 1993). For example, one determinant is the degree of similarity between the possible sources, as participants have been found to experience greater difficulties in discriminating between memories of imagined and actual actions that involve the same actor as compared to actions involving different actors (Lindsay, Johnson, & Kwon 1991). Moreover, the view that source monitoring depends on adequate decision criteria has been confirmed by studies showing that false memory effects obtained with old/new recognition tests can be reduced by orienting participants toward evaluating task-relevant source information (Dodson & Johnson, 1993; Lindsay & Johnson, 1989).

Apart from such behavioral approaches, neuroscientific research has provided important insights into the functional and, most of all, neuroanatomical organization of source recollection. This research has typically highlighted executive control processes mediated by the prefrontal cortex (PFC) as one critical neurocognitive function for accurate source memory (Simons, 2009). Executive or cognitive control are terms which describe a set of interrelated, but distinct, processes that underlie goal-directed behavior (Miyake et al., 2000). These include inhibitory control (i.e. filtering of task-irrelevant distractors, behavioral response inhibition), working memory (WM; maintaining and manipulating information online), and shifting (attention and task switching). According to several models of cognitive control, these processes are implemented by the PFC which guides neural activity in subordinate cortical systems through the establishment of task-appropriate pathways and stimulus-response mappings (e.g. Miller & Cohen, 2001).

An earlier model of episodic memory which incorporates a specific role of executive control has been developed by Moscovitch (1992) who distinguished between the associative and the strategic components of memory. In this model, the associative component refers to lower-level routines attributed to the hippocampus. These include binding mechanisms that integrate features within a memory trace at encoding, in addition to automatic retrieval processes by which a retrieval cue interacts mandatorily with stored memory representations. Conversely, the strategic component refers to prefrontal executive functions which are responsible for organizing and evaluating memories with regard to their spatial and temporal context. It is thought that these strategic operations are especially engaged in cases when proximal retrieval cues are ineffective, and retrieval processing must be further constrained and guided towards more direct cues that can trigger associative routines to recover an appropriate memory (Moscovitch & Melo, 1997; Moscovitch & Winocur, 2002).

This latter and similar further models of strategic retrieval processing (e.g. Burgess & Shallice, 1996) have been widely used as reference systems for the exploration of *confabulation*, a pathology which is characterized by statements or actions that involve various forms of memory distortion, including impairments in source memory (Metcalf, Langdon, & Coltheart, 2007). Confabulation is often observed in individuals with frontal-lobe damage, particularly following anterior communicating artery aneurisms, the consequence of which is that one branch of neuropsychological research was guided by the hypothesis that lesions to the frontal system lead to disproportionate deficits in source memory (Schacter, Kagan, & Leichtman, 1995). Methodologically, these neuropsychological studies have largely drawn on the dissociation made by cognitive theories between source recollection and memory for the content of events irrespective of source. This latter form of memory is usually referred to as *item memory* and can be assessed through old/new recognition and fact recall.

For example, patients with frontal lobe lesions have been demonstrated to show relatively accurate memory for recently learned facts, while they have great difficulties in remembering the context in which the facts had been learned (Janowsky, Shimamura, & Squire, 1989). Further evidence comes from the study of source memory deficits in older adults as a correlate of age-related decline in frontal lobe functioning. These studies have shown that under conditions in which older and younger adults show equal item memory performance, older adults have greater difficulty in remembering the source of learned facts (Janowsky et al., 1989; Schacter, Kaszniak, Kihlstrom, & Valdisseri, 1991), from which of two speakers they learned a word (Ferguson et al., 1992), and whether learned information was presented in a male or female voice (Glisky, Polster, & Routhieaux, 1995).

Beyond such neuropsychological approaches, increasingly detailed insights into the operating characteristics of source recollection come from neuroimaging studies using functional magnetic resonance imaging (fMRI). On the basis of this data, Simons and Spiers (2003) have proposed a framework of how anatomically distinct regions within the PFC exert top-down control over retrieval-related activity in the MTL memory system. This model is based on a hypothesis which is common to a number of cognitive models of strategic retrieval and assumes that several distinct control processes mediate retrieval processing in a stage-like fashion (Burgess & Shallice, 1996; Moscovitch & Melo, 1997; Norman & Bobrow, 1979; Schacter et al., 1998). Simons and Spiers (2003) thus proposed an initial stage of cue specification, in which criteria for retrieval success is set up and task-dependent characteristics of the retrieval cue are specified by ventrolateral PFC (VLPFC). Following this stage, a strategic search for matching memory representations in the MTL system is initiated. At output, reactivated representations are maintained in VLPFC, while dorsolateral PFC (DLPFC) is involved in monitoring and evaluating the retrieval outputs against the specified verification criteria. These processing stages, together with their underlying neural substrates, are illustrated in Figure 1.

This model is able to account for a large body of experimental data, including those showing that left VLPFC is engaged during semantic encoding and source retrieval but not during item recognition, consistent with its role in semantic cue specification processes which are necessary for source recollection but not for item memory (Dobbins, Foley, Schacter, & Wagner, 2002). Conversely, DLPFC was engaged during source retrieval but not during semantic encoding, confirming its role in monitoring processes that operate during source retrieval only (Dobbins et al., 2002). Further proposals regarding contributions of the PFC to source retrieval have emphasized that left and right PFC hemispheres are differentially involved in the monitoring of specific and undifferentiated information, respectively (Dobbins, Simons, & Schacter, 2004; Ranganath, 2004), and that anterior PFC regions may be especially involved in reality monitoring judgments (Simons, 2009).

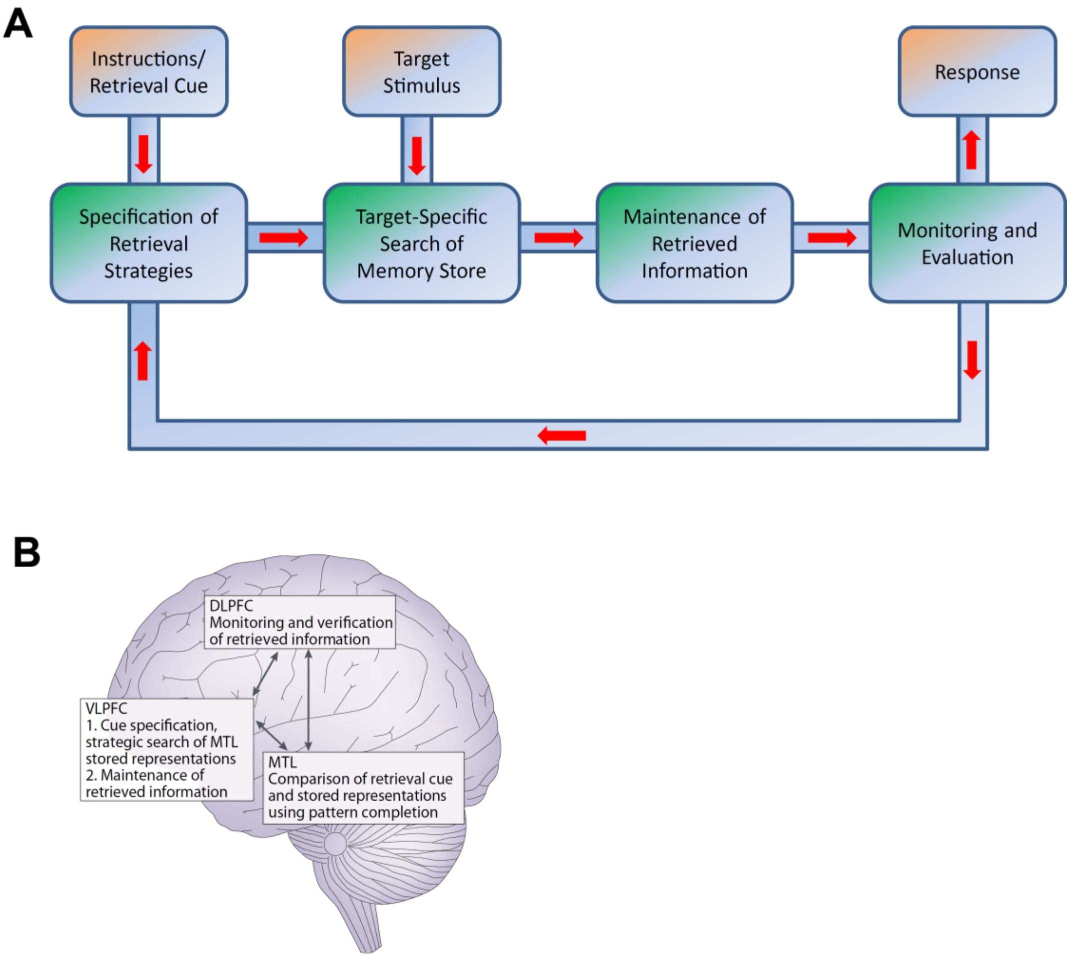

Figure 1. *(A) Diagram illustrating the sequential, iterative processing stages thought to be involved in strategic memory retrieval. Retrieval cues and verification criteria are specified, before a strategic search of the memory store is initiated. Retrieved memory representations are maintained in WM while various monitoring processes are undertaken. If retrieval criteria are met, a response is executed. Otherwise, retrieval strategies are modified in order to undertake subsequent searches (adopted from Simons, 2009). (B) Illustration of the principal interactions between PFC and MTL in source recollection. VLPFC is thought to be involved in retrieval cue specification, the interrogation of MTL for matching representations, and in the maintenance of retrieved information in WM. Monitoring and evaluative processing is thought to be subserved by dorsolateral DLPFC (adopted from Simons and Spiers, 2003).*

An additional model of strategic memory retrieval which in some respects extends those presented so far has been proposed by Mecklinger (2010). This model builds on a framework proposed by Anderson and Bjork (1994) and distinguishes between two broad classes of cognitive mechanisms which operate either before or after the presentation of a retrieval cue. The first is *cue bias*, an ensemble of processes which is applied to the internal representation of a retrieval cue in order to optimize its interaction with the targeted class of memory. This concept provides a further elaboration on cue specification processes proposed by Simons and Spiers (2003) and describes processes that serve to constrain and maintain task-dependent retrieval cue representations. These processes are also involved in monitoring operations that evaluate the outcome of the retrieval process. Empirical support for the existence of cue bias processes comes from ERP memory studies in which neural activity elicited by new items has been shown to differ across task conditions that vary in retrieval demands (e.g. Herron & Rugg, 2003a; Hornberger, Morcom, & Rugg, 2004). As new items have not been studied before, contrasts of this kind are thought to index cue bias strategies which in turn support *retrieval orientations* that participants adopt in pursuit of selective memory retrieval (Rugg & Wilding, 2000).

The second mechanism described by Mecklinger (2010) is *target bias*, a process which bears similarities to selective attention and can be employed even before a retrieval cue is presented. The primary function of target bias strategies is a modulation of the accessibility of memory traces depending on their task-relevance. In contrast to processes associated with prefrontal control functions, target bias is described in relation to attentional functions mediated by the posterior parietal cortex (PPC; Corbetta & Shulman, 2002). The PPC is thought to be involved in allocating attentional resources to mnemonic representations (Cabeza, Ciaramelli, Olson, & Moscovitch, 2008), which in turn may enhance their saliency for selection mechanisms mediated by the PFC.

A further model of strategic retrieval presented here was developed by Schnider (2003) who conceptualized a prefrontal control mechanism which is particularly concerned with memory for temporal context, namely, the capacity to monitor the relation between reactivated memories and the reality of ‘now’. A paradigmatic case of that model is a continuous recognition task which assesses the ability to discriminate between currently relevant and irrelevant items. This task has reliably dissociated confabulating patients from both healthy controls and non-confabulating amnesics, as confabulators have relatively greater difficulties in suppressing previously presented but currently irrelevant distracter items in this task

(Schnider, von Däniken, & Gutbrod, 1996; Schnider & Ptak, 1999). This has been taken to reflect deficits in suppressing memory traces that interfere with ongoing reality. Based on the anatomical basis of confabulation and on the pattern of brain activity observed in healthy participants performing this paradigm, the posterior orbitofrontal cortex has been suggested to be involved in this kind of memory control (Schnider, 2003).

To summarize, strategic memory retrieval can be conceived as a multi-stage process which includes a variety of cognitive control operations, such as the specification of task-relevant cue features, the enhancement of relevant memory representations, and various forms of monitoring and evaluation processes. These control processes are thought to be involved in source memory to a greater extent than in item memory and have been associated with a distributed cortical network that includes interactions between PFC, MTL, and PPC association areas. An outstanding role in the control of episodic retrieval is commonly ascribed to the PFC.

Before turning to discussion of the neural correlates of episodic memory retrieval, a final issue here addresses a further class of models of strategic retrieval processing. These models describe processes which are thought to act by suppressing the activation of irrelevant memories during retrieval processing, a mechanism that is also included in the concept of target bias described by Mecklinger (2010). The idea here is that processes of *retrieval inhibition* can assist selective retrieval by making non-target memories less available than target memories. The following section briefly reviews the major concepts and empirical findings that can contribute to discussion of inhibitory processes that participate in episodic retrieval.

Role of cognitive inhibition in strategic memory retrieval

One line of evidence for processes that act by reducing the accessibility of memories comes from research using behavioral paradigms of retrieval-induced forgetting (Anderson, Bjork, & Bjork, 1994; Bäuml, Zellner, & Vilimek, 2005). In this paradigm, participants first learn lists of category-exemplar pairs (e.g. Fruit-Orange). Subsequently, retrieval of half of the items from some categories is practiced in a series of cued recall tests (e.g. Fruit-Or__). In a final recall test, participants are asked to recall all exemplars of a category upon presentation of the respective category name. While recall performance is typically highest for practiced items, the retrieval-induced forgetting phenomenon describes the fact that non-practiced exemplars from the practiced category (e.g. Apple) are less likely to be recalled than baseline items from unpracticed categories (e.g. Scotch). Practicing retrieval of some aspects of learned material, therefore, appears to impair recall of unpracticed materials.

Another form of experimentally induced forgetting focuses on intentional processes and can be observed in the Think/No-Think paradigm (Anderson & Green, 2001; Golding & McLeod, 1998), a mnemonic version of the Go/No-Go task or in paradigms of list-method directed forgetting (Bjork, 1989). In the Think/No-Think task, participants are instructed to stop retrieval attempts for certain exemplars of previously learned items (no-think trials), whereas other exemplars have to be retrieved (think trials). Relative to baseline items, recall of items from no-think trials is typically impaired.

Different proposals have been made to model the inhibition mechanisms which are thought to underlie these phenomena, with the general assumption being that such mechanisms reduce the overall activation level of those materials for which forgetting is observed (Anderson, 2001). One class of models assumes a mechanism of lateral inhibition that acts complementarily to activation and suppresses cognitive representations when target representations are selected (Anderson & Spellman, 1995). Such concepts are also referred to as indirect suppression models and are partially based on an analogy to the mechanism of lateral inhibition in the nervous system by which the activation of a neuron results in the inhibition of adjacent neurons via interneurons (e.g. MacKay, 1987). Lateral inhibition has been proposed to play a role in the resolution of interference and selection in various cognitive domains, such as perception and selective attention (McClelland & Rumelhart, 1981).

Conversely, direct suppression models assume that inhibitory processes can be applied flexibly and directly to any representation that competes with the desired trace (Levy & Anderson, 2002). In a recent elaboration on this theory, Levy and

Anderson (2002, 2008) suggested that retrieval inhibition relies on the same prefrontal executive control mechanisms that are involved in overriding inappropriate responses in paradigms of behavioral inhibition, such as Go/No-Go tasks (see also Anderson & Green, 2001). This assertion receives support from an ERP study showing that memory suppression in a Think/No-Think paradigm and behavioral suppression in a Stop-Signal task are associated with similar neural correlates (Mecklinger, Parra, & Waldhauser, 2009). Moreover, as the magnitudes of these ERP effects were found to be correlated positively with each other, this has been taken to indicate that the processes reflected by these effects operate in the same way and are supported by anatomically overlapping brain systems (Mecklinger et al., 2009).

Although the notion that inhibitory processes that participate in cognitive function has received considerable empirical support, cognitive concepts of inhibition are surrounded by several limitations. One problem lies in the close relationship between processes of inhibition and those of activation, which has complicated the empirical distinction between both mechanisms (Tipper, 1985, 2001). A further problem is that the assumed processes cannot be observed directly and therefore can only be inferred from behavioral impairments observed in conditions thought to engage inhibition. Regarding retrieval inhibition, issues such as these have raised discussions as to whether forgetting phenomena can also be explained in terms of associative interference (Anderson et al., 1994). Specifically, noninhibitory (i.e. associative) theories assume that retrieval-induced forgetting results from a strengthening of cue-target associations during retrieval practice, which in turn interferes with retrieval of non-practiced items.

Findings from experiments with the independent-probe technique, however, speak against this account, as they indicate that retrieval-induced forgetting also occurs for items that are semantically related to practiced items but were studied and tested with a different category cue (Anderson & Spellman, 1995). Such cross-category forgetting effects provide little support for associative accounts which would predict forgetting effects only for those competitors that were studied and tested under the retrieval-practice cue. These and similar findings have been taken as evidence for the existence of processes that act be suppressing the activation of the forgotten item itself (Levy & Anderson, 2002).

There is a further model of retrieval inhibition which links inhibition to general cognitive abilities and attentional resources (Conway & Engle, 1994). Presentation of this model at this point is necessary because its basic assumptions and operational definitions will be used to constrain the functional interpretations of some of the ERP effects reported in this thesis. The model emphasizes that retrieval inhibition is an effortful process and heavily depends on individual resources available for cognitive control. This resource-dependent view of inhibition was developed on the basis of differences between individuals with high and low working memory capacity (WMC) in a memory task that required the resolution of interference (Conway & Engle, 1994). This view is consistent with other domains of research on WMC, such as those relating aging-related decline in WM functioning to deficits in the ability to inhibit irrelevant information (Hasher & Zacks, 1988; Zacks & Hasher, 1994).

WMC has been defined as the amount of domain-general executive attentional resources available and is commonly measured through WM span tasks, such as counting, operation, and reading span tasks (Conway et al., 2005; Kane & Engle, 2002). These tasks require the maintenance of information during the execution of secondary processing tasks, such as comprehending sentences or verifying arithmetic equations. The hypothesized link between WMC as an index of attentional resources and inhibition is supported by data suggesting that WMC is associated with performance in various cognitive tasks that require inhibition, such as the anti-saccade task and the Stroop task (Redick, Heitz, & Engle, 2007). As discussed later on, to the extent that inhibition plays a role for episodic memory retrieval, it may be hypothesized that high-WMC individuals have greater capacities to engage in strategic retrieval processing than low-WMC individuals, as revealed by their neural correlates of strategic retrieval.

1.3 Neural correlates of episodic retrieval: Evidence from event-related potentials

ERPs provide real-time measures of neural activity associated with cognitive processing and by this allow for the identification of electrophysiological markers of distinct classes of retrieval process. ERPs that are time-locked to the onset of a test stimulus in a recognition memory task show different waveforms for old compared to new conditions, often taking the form of a greater positivity for old items. This ERP old/new effect onsets around 300 ms, extends for several hundred milliseconds, and comprises different portions which can be distinguished on the basis of scalp-topography, time-course, and sensitivity to experimental conditions. This has permitted ERPs to speak to a range of issues concerning the retrieval and post-retrieval processes thought to be involved in item and source memory (Friedman & Johnson, 2000; Mecklinger, 2000). The following two subsections give an overview of findings which have contributed to identifying the electrophysiological correlates of item and source memory.

1.3.1 ERP correlates of item memory

The ERP correlates of item memory have primarily been identified by research guided by the dual-process framework of recognition memory. This research has accumulated considerable evidence that recollection and familiarity can be associated with two functionally dissociable ERP old/new effects. While recollection is thought to be indexed by a *parietal old/new effect* that onsets around 400 to 500 ms post-stimulus and often shows a left-sided maximum, familiarity-based remembering has been associated with an earlier *mid-frontal old/new effect* between 300 and 500 ms (also referred to as FN400 effect).

The evidence linking the parietal old/new effect to recollection comes from a number of demonstrations that the effect is sensitive to common operational definitions of recollection (Rugg & Curran, 2007). Nonetheless, the precise cognitive operations reflected by the parietal old/new effect are still a matter of debate. It has been suggested that it reflects the orientation of attention towards recollected information (Wagner, Shannon, Kahn, & Buckner, 2005) or the representation of recollected information in WM (Vilberg & Rugg, 2008). Consistent with the latter proposal are findings that the parietal old/new effect is sensitive to the amount of information recollected, as its amplitude co-varies with the number of correct source judgments (Wilding, 2000; Wilding & Rugg, 1996), with encoding time of recollected information (Vilberg & Rugg, 2009), and with participants' perceptions of the amount of contextual information recovered (Vilberg, Moosavi, & Rugg, 2006). These results supports the view that the parietal old/new effect is related to the maintenance of recollected information, perhaps reflecting processes akin to what Baddeley (2000) has termed the 'episodic buffer' of working memory (Vilberg & Rugg, 2008, 2009).

Conversely, support for the view that the early mid-frontal old/new effect reflects familiarity-based recognition has been adduced from the fact that the effect is sensitive to variables influencing familiarity strength, such as response criterion (Azimian-Faridani & Wilding, 2006) or name frequency (Stenberg, Hellman, Johansson, & Rosén, 2009). Moreover, the effect is elicited by new words that share perceptual and conceptual features with studied words and are erroneously endorsed as "old" (Curran, 2000; Nessler, Mecklinger, & Penney, 2001). This latter finding has been taken as evidence that the effect reflects the assessment of the global similarity between the retrieval cue and the contents of a memory trace (Mecklinger, 2006). However, the link between the mid-frontal old/new effect and familiarity has been challenged by arguing that it may reflect N400 signals of conceptual priming (e.g. Voss & Federmeier, 2011). Nonetheless, on the basis of data showing that the mid-frontal effect can be dissociated from conceptual priming (Stenberg et al., 2008), it has been suggested that the effect is not limited to implicit memory (see Rugg & Curran, 2007, for a discussion).

A number of empirical findings provide evidence for an electrophysiological dissociation between recollection and familiarity (Mecklinger & Jäger, 2009). For example, the observation that the parietal old/new effect cannot be observed under speeded response conditions, whereas the mid-frontal effect is not influenced by manipulations of response speed (Mecklinger, Brunnemann, & Kipp, 2011), is consistent with the view that recollection decreases more than familiarity under speeded response conditions (Yonelinas & Jacoby, 1994). Further examples for a neural dissociation between both processes come from studies showing that the mid-frontal effect is sensitive to response confidence (Woodruff, Hayama, & Rugg, 2006) and name frequency (Sternberg et al., 2008), whereas the parietal effect is not.

In addition to these findings based on the dual-process framework, several ERP studies of item recognition memory have reported an even earlier frontal old/new effect around 200 ms (Jäger, Mecklinger, & Kipp, 2006), which often appears as a modulation of the P200 component (Curran & Dien, 2003; Evans & Federmeier, 2007; van Strien, Glimmerveen, Martens, & de Bruin, 2009). This P200 repetition effect has been found to be restricted to conditions in which words were studied and tested in the visual modality (Curran & Dien, 2003), and is often found in tasks with relatively short retention intervals. Although the precise functional significance of the P200 effect is still unclear, discussion of this effect has centred the possibility that it reflects perceptually-based matching processes related to implicit memory (Curran & Dien, 2003; Mecklinger & Jäger, 2009).

1.3.2 ERP correlates of source memory

The fact that the parietal ERP old/new effect acts as an index of the amount of information recollected has been used for addressing several questions concerning the strategic control of retrieval. The data relevant to this issue comes from ERP experiments employing the memory exclusion task (Jacoby, 1991). As described above, this paradigm includes a study phase in which participants have to encode items that are associated with one of two different contexts. During the test phase, participants respond “old” to items belonging to one context (*targets*) and “new” to items from the second context (*non-targets*) as well as to new items. According to Jacoby (1991), a hallmark of recollection is the capacity to discriminate between items from different sources and can therefore be assessed via the ability to reject familiar non-target items. Support for this assumption comes from ERP studies which have reported reliable parietal old/new effects for non-targets in addition to targets using source features such as color (Cycowicz, Friedman, & Snodgrass, 2001), voice (Wilding & Rugg, 1997), encoding operations (Dzulkifli, Herron, &

Wilding, 2006) or item presentation modality (Czernochowski, Mecklinger, Johansson, & Brinkmann, 2005).

The reason why this data is relevant to the issue of strategic retrieval processing is the proposal that exclusion tasks can be completed by adopting a target-selective retrieval strategy, such that non-targets can be successfully rejected solely on the basis of a failure to retrieve target information (Wilding & Herron, 2006). Notably, this account can be identified with the view promoted by Johnson et al. (1993), which asserts that assessing the availability of only one kind of task-relevant information can provide a basis for making accurate source judgments. Data in support of this view comes from paradigms where parietal old/new effects were obtained for targets only, indicating that recollection of targets can be prioritized over non-targets under certain conditions (Dwyan, Segalowitz, & Arsenault, 2002; Dzulkifli & Wilding, 2005; Evans, Wilding, Hibbs, & Herron, 2010; Herron & Wilding, 2005).

There has been a great interest in identifying the variables that influence the resolution with which this selective control of recollection can be exerted. This line of research has revealed that target-selective retrieval is facilitated by high levels of cue-target compatibility (Herron & Rugg, 2003a), target/non-target distinctiveness (Herron & Wilding, 2005), and the availability of target memories (Herron & Rugg, 2003b). Consistent with the latter view is a series of demonstrations that the parietal old/new effect for non-targets is correlated inversely with the accuracy of target judgments. That is, reliable non-target effects were obtained in conditions where target accuracy was relatively low (Dzulkifli, et al., 2006; Fraser, Bridson, & Wilding, 2007; Herron & Rugg, 2003b; Wilding, Fraser, & Herron, 2005). For example, Wilding et al. (2005) observed that across two experiments that differed in task difficulty, low target accuracy was associated with parietal old/new effects for targets and non-targets, while high accuracy was associated with target effects only. The preferred interpretation of these and related findings is that when target memories become insufficiently reliable to support a target-selective retrieval strategy, participants engage in strategic recollection of information about non-targets in addition to targets.

In addition to the latter view, target-selective retrieval processing in exclusion tasks has been proposed to involve processes of retrieval inhibition which operate directly on non-target information (Wilding & Herron, 2006). Following this line of reasoning, Elward and Wilding (2010) hypothesized that the degree to which participants engage in selective retrieval processing is related to their resources available for cognitive control as indexed by WMC. Consistent with this proposal was their finding that the degree to which left-parietal ERP old/new effects for targets were larger than for non-targets was correlated positively with WMC. In light of the proposal linking WMC to resources available for cognitive inhibition (Conway & Engle, 1994), this outcome provides support for the assumption that the degree of engagement in target-selective recollection is related to these resources, possibly resulting in greater efficiency in the inhibition of non-targets.

Post-retrieval processes

Two further ERP old/new effects have been found to correlate with strategic memory retrieval. These effects usually occur after the parietal old/new effect has terminated and have been associated with processes that act downstream of retrieval (i.e., *post-retrieval* processes). The major empirical findings that have been used to make inferences about the significance of these two late ERP effects, the *right-frontal old/new effect* and the *late posterior negativity (LPN)*, are reviewed below.

The right-frontal effect is often observed in a post-response period and has been taken as a correlate of monitoring and/or evaluation processes that operate on retrieved information in the service of task demands. However, the right-frontal effect has been found to vary considerably in its topography and time-course across studies, which has complicated a precise identification of the different subprocesses supporting the effect (Friedman & Johnson, 2000). The right-frontal effect is elicited by correct as well as incorrect source judgments (Trott, Friedman, Ritter, Fabiani, & Snodgrass, 1999; Wilding & Rugg, 1996), which has led to the conclusion that it is not limited to successful retrieval but may instead be related to decisional processes which are assumed to apply to all kinds of old items in a source memory task (Friedman & Johnson, 2000).

Consistent with a monitoring-based account of the right-frontal effect is the observation that it occurs predominantly in tasks that require a high degree of retrieval monitoring due to high decision uncertainty (Rugg, Allan, & Birch, 2000; Werkle-Bergner, Mecklinger, Kray, Meyer, & Düzel, 2005). Moreover, the magnitude of the effect has been found to correlate positively with the number of low confidence source judgments, consistent with the view that greater monitoring is required when the quality of recovered information decreases (Cruse & Wilding, 2009). Other work, however, has shown that the right-frontal ERP effect can be elicited by items that require a semantic judgment regardless of their old/new status (Hayama, Johnson, & Rugg, 2008). This has been taken to indicate that the effect reflects generic monitoring processes in multiple cognitive domains, rather than processes dedicated to the evaluation of episodic information (Hayama et al., 2008).

Retrieval monitoring accounts are furthermore consistent with the topography of the late right-frontal old/new effect. Although it is not appropriate to relate ERP activity recorded from one electrode to the most proximal cortical region, the scalp-distribution of the effect has been considered consistent with the putative role of right dorsolateral PFC for various kinds of monitoring operations (Hayama & Rugg, 2009). This latter suggestion is consistent with fMRI results showing that activity in a candidate PFC region for the generators of the right-frontal effect was associated with episodic and semantic evaluative processing of old items (Hayama & Rugg, 2009). In fact, as Cruse and Wilding (2009) have pointed out, some of the divergences in the scalp-distribution of the right-frontal effect across studies may be attributable to the functional and anatomical heterogeneity of the PFC (Fletcher & Henson, 2001; Ranganath, 2004). In this way, it is possible that not entirely the same right-frontal effects have been captured across experiments, consistent with the view that different memory tasks are associated with different kinds of retrieval monitoring demands.

The final ERP correlate of source memory to be presented here is the LPN which shows similar temporal characteristics as the right-frontal effect and is often maximal over the mid-posterior site at Pz. This negative-going old/new effect is observed in a variety of recognition memory paradigms and has also been related to evaluative aspects of episodic retrieval processing. Previous accounts of the LPN have suggested that it comprises several functionally distinct subcomponents which are differentially sensitive to stimulus and response-related factors (Herron, 2007). In an influential review of the LPN, Johansson and Mecklinger (2003) distinguished between two functionally dissociable task conditions in which the LPN is usually observed. The first is item recognition tasks which are characterized by high response conflict (e.g. Nessler & Mecklinger, 2003). Because the LPN associated with this type of task has been observed in both, stimulus and response-locked ERPs, it has been related to action monitoring processes induced by response conflict (Johansson & Mecklinger, 2003).

The second type of memory task producing LPNs is source memory paradigms which require retrieval of specific perceptual information (e.g. Johansson, Stenberg, Lindberg, & Rosén, 2002). Since the LPN observed in source memory tasks can be observed in stimulus but not in response-locked ERP averages, Johansson and Mecklinger (2003) suggested that it is unlikely to reflect action monitoring processes but may rather be related to the search for and/or retrieval of attribute conjunctions from a prior study episode. These processes are thought to be primarily engaged in situations where task-relevant attributes need continued evaluation. Moreover, they are assumed to operate independently of successful retrieval, which is consistent with the observation that the LPN does not differ between accurate and inaccurate source judgments (Cycowicz et al., 2001; Friedman, Cycowicz, & Bersick, 2005). The LPN has furthermore been suggested to reflect mnemonic functions of the PPC, consistent with the hypothesized role of this region in allocating attentional resources to item-context associations (Mecklinger, 2010).

2 Development of Episodic Memory and its Neural Correlates in Childhood and Adolescence

This chapter is intended to provide an overview of the theoretical accounts and empirical findings which can contribute to discussion of developmental change in episodic memory. In the first section, the purpose is to provide a framework for the study of the development of episodic memory retrieval on the basis of several lines of evidence from developmental cognitive neuroscience, including research on memory development. The chapter then reviews previous behavioral and ERP findings on the development of the retrieval processes underlying item and source memory.

2.1 A neurocognitive framework of episodic memory development

Episodic memory functions are assumed to emerge later in development than both non-declarative (Nelson, 1995) and semantic memory (de Haan, Mishkin, Baldeweg, & Vargha-Khadem, 2006; Tulving & Markovitsch, 1998), due to prolonged maturation of the hippocampus during infancy, especially the dentate gyrus (Richmond & Nelson, 2007, 2008). While early recognition skills can already be observed in newborns (e.g. Pascalis & de Schonen, 1994), episodic memory shows steep improvements during infancy in various aspects of encoding, retention, and retrieval (Hayne, 2004).

During later childhood and adolescence, episodic memory functions have been suggested to become increasingly influenced by the maturing PFC (de Haan et al., 2006). For example, using MRI data collected from children aged 7-16 years, Sowell, Delis, Stiles, and Jernigan (2001) found that frontal lobe maturation was more predictive of verbal memory functioning than MTL maturation. Using functional neuroimaging, Chiu, Schmithorst, Brown, Holland, and Dunn (2006) found encoding-related activity in left PFC to be associated with successful sentence recognition in 10-18-year olds but not in 7-8-year olds. Similarly, brain activity associated with successful memory encoding has been found to gradually increase with age from 8 to 24 years in specific PFC but not in MTL regions, suggesting a relatively slower developmental course for PFC memory functions (Ofen et al., 2007).

The latter view receives support from research on structural brain maturation during childhood and adolescence. When studied by volumetric methods using magnetic resonance imaging (MRI), cortical gray matter density has been found to follow an inverted U-shaped developmental course, with steep increases in early childhood followed by decreases in later childhood and adolescence (Lenroot & Giedd, 2006). Conversely, cerebral white matter shows a linear increase. The apparent loss of cortical gray matter during adolescence presumably reflects the combined result of regressive (pruning of unused synapses) and progressive (myelination) cellular changes (O'Hare & Sowell, 2008). Notably, the PFC, particularly dorsolateral PFC, has consistently been found among the last cortical regions to mature (Giedd, 2004; Sowell, Thompson, Tessner, & Toga, 2001), whereas MTL regions mature at faster rates (Gogtay et al., 2004; Ofen et al., 2007). For example, Gogtay et al. (2004) used MRI for a longitudinal assessment of cortical maturation in participants aged 4 to 21. Gray matter loss first appeared in dorsal parietal and primary sensorimotor cortices, then spread in temporal cortices, and finally extended into superior temporal gyrus and dorsolateral PFC. Sowell et al. (2001) also described a post-adolescent gray matter loss which occured primarily in dorsal frontal cortex. While hippocampal volume has been found to be stable from 8 to 24 years (Ofen et al., 2007), there is also evidence for ongoing functional maturation within different hippocampal subregions during this age range (Gogtay et al., 2006).

Of particular interest here are the functional correlates of the prolonged PFC maturation, i.e., the developmental course of executive/cognitive control functions. Several researchers have emphasized the difficulty in extracting a general trajectory of developmental change in executive function, due to the heterogeneity of the construct which includes several independent components of cognitive control, such as inhibitory control and WM (Best & Miller, 2010; Best, Miller, & Jones, 2009; Luna, Garver, Urban, Lazar, & Sweeney, 2004). These functions have been associated with slightly different courses of maturation, which has been related to the possibility of regional differences in the trajectories of neural maturation within different PFC regions (Olson & Luciana, 2008). Nonetheless, performance on a wide variety of tasks has been found to show rapid improvements in late childhood, which is followed by gradual and protracted improvements through adolescence (Best & Miller, 2010).

For example, Paus (2005) described a dramatic improvement around 10-12 years in the anti-saccade task which measures inhibitory control in the oculomotor domain. This is consistent with the onset of frontal gray matter loss around 11-12 years (Giedd et al., 1999). Regarding adolescent development, the time-course of progression is largely influenced by the measured cognitive process and task complexity. For example, WM functions that demand high levels of executive control have been found to mature later during adolescence than those that require less control (Luciana, Conklin, Hooper, & Yarger, 2005). Regardless of task complexity, however, adolescence has been found to be critical for the functional maturation of a number of executive functions for which adult-levels of performance are reached between 14 and 20 years of age (DeLuca et al., 2003; Luciana et al., 2005; Luna et al., 2004).

These behavioral improvements correlate with two types of refinement in functional brain activity, as documented by developmental research using fMRI (Luna, Padmanabhan, & O’Hearn, 2010). First, cortical activity underlying cognitive control develops from diffuse to being focalized during adolescence. For example, young adolescents’ PFC activity increases with age in those regions that support task performance, whereas PFC activity uncorrelated with performance decreases with age (Durston et al., 2006; Scherf, Sweeney, & Luna, 2006). This pattern of functional specialization within PFC has been suggested to result from synaptic pruning which increases local processing efficiency (Durston et al., 2006). Second, the PFC becomes increasingly integrated with posterior regions supporting cognitive control during adolescence (Scherf et al., 2006; Velanova, Wheeler, & Luna, 2008), possibly reflecting increased functional connectivity of fronto-parietal pathways afforded by myelination (Velanova et al., 2008).

In order to integrate the evidence on neurocognitive maturation reviewed here into research on memory development, Shing, Werkle-Bergner, Li, and Lindenberger (2008) introduced a developmental framework which is based on the distinction between the strategic and the associative components of memory (Moscovitch, 1992). The model rests upon the assumption that the mechanisms that underlie episodic memory change from childhood to adolescence, due to a later maturation of the strategic relative to the associative component. In their seminal study, Shing et al. (2008) compared recognition memory performance for word pairs between 10-12-year-old children, 13-15-year-old adolescents, and young adults (20-25 years). Demands on the associative component were manipulated by using word pairs with (a) high and (b) low associative demands (i.e. German-Malay "GM" vs. German-German "GG" word pairs) while encoding instructions manipulated strategic demands by emphasizing (a) incidental item-encoding, (b) intentional pair-encoding, and (c) elaborative strategic encoding. Inferences on the development of the strategic and the associative components were drawn on the basis of performance gains across these encoding conditions.

Results showed poorer performance for children compared to adolescents and adults in all conditions. In the low associative-demand condition (GG word pairs), adolescents and adults improved their performance mainly following pair-encoding instructions, whereas children showed highest performance gains only following elaborative strategy instructions. This was taken to indicate that children's latent potential in associative binding can only be revealed when they are provided with an appropriate encoding strategy, in support of the view that the strategic component matures later than the associative component. A different picture emerged in the high associative-demand condition (GM word pairs) where adults improved their performance mainly after elaborative strategy instructions, whereas adolescents did so only after they had extensively practiced applying elaborative encoding strategies in a follow-up study. This in turn was taken to reflect that the strategic component, while relatively mature in adolescence, continues to undergo protracted development into adulthood (Shing et al., 2008).

Together, these results are consistent with a framework which postulates that the mechanisms that support memory performance differ across different age periods (Shing & Lindenberger, 2011). While children's recognition performance is largely supported processes that rely on the associative component, episodic memory during adolescence becomes increasingly influenced by the evolving strategic component, due to the prolonged maturation of the PFC (Shing et al., 2008). Notably, the developmental course observed for the strategic component - strong improvements in late childhood followed by ongoing maturation through adolescence - closely corresponds to that reported for the core control processes, such as WM and inhibitory control, as outlined above. In this way, the findings reviewed here may provide a framework for the present studies, as they give reasons to expect a similar developmental course of the strategic retrieval processes underlying source memory.

2.2 Development of item and source recognition memory

On the basis of the prolonged maturation of prefrontal control functions, Cycowicz (2000) hypothesized a longer developmental trajectory for source compared to item recognition memory. However, while early source memory deficits during middle childhood and their link to frontal lobe maturation have been well characterized (e.g. Schacter et al., 1995), still little is known about source memory development through late childhood and adolescence. The following two subsections are intended to review the available evidence from previous behavioral and ERP studies on the development of item and source recognition memory from middle childhood to adulthood.

2.2.1 Behavioral findings

Source memory develops from 6 years of age onwards (Ruffman, Rustin, Garnham, & Parkin, 2001) and typically shows greater developmental change than item memory (Cycowicz, 2000; Lindsay et al., 1991). For example, Cycowicz, Friedman, Duff, and Snodgrass (2001) directly compared item and source memory performance in 8-year-old children and adults. Source memory was defined as the ability to remember the color of line drawings studied in a recognition memory task. Results showed statistically independent age-related improvements in item and source memory, with a relatively steeper increase in source memory. In addition, adults performed better than children in tests assumed to tap frontal lobe functioning (e.g. verbal fluency) but not in those reflecting MTL function (i.e. story memory), supporting the relationship between source memory development and maturation in executive control (Cycowicz et al., 2001).

In line with the latter view are reality monitoring experiments which indicate that 6-year-old children have greater difficulty than adults in judging whether they performed an action or only imagined performing the action (Foley & Johnson, 1985), and that such age differences in reality monitoring increase when the sources are highly similar (Lindsay et al., 1991). For example, 8-year-old children were found to make more source misattributions than adults when discriminating between imagined and actual actions that involved the same actor but not if these actions involved different actors (Lindsay et al., 1991). Presumably, as source similarity increases, so does the need to draw upon strategic processes that select and evaluate task-relevant information. This account is consistent with the view that memory control processes are less matured in pre-adolescent children.

Another line of research has investigated the development of item recognition memory from a dual-process perspective by examining age differences in recollection and familiarity. The available evidence from this research across different stimulus materials and process estimates suggests that recollection shows more developmental change throughout childhood than does familiarity (Anooshian, 1999; Billingsley, Smith, & McAndrews, 2002; Ghetti & Angelini, 2008; Ofen et al., 2007). For example, Ghetti and Angelini (2008) used ROC data as a means to investigate age differences in recollection and familiarity independently of children’s ability to provide subjective reports of both processes. Results showed an age-related increase in recollection from childhood to adolescence, whereas familiarity increased only from 6 to 8 years. This pattern of findings converges with those of other studies (Ofen et al., 2007), which suggest that familiarity-based remembering is relatively mature at 8 years of age.

2.2.2 ERP findings

ERPs provide a valuable approach for present purposes as they allow determining whether the observed age differences in source memory performance are related to differences in strategic retrieval processing. While developmental ERP studies addressing this issue are scarce and heterogeneous in their methodologies, the evidence from these studies nonetheless allows for certain conclusions regarding the development of the processes underlying item and source memory.

Regarding source memory, one account for which two ERP studies provide reliable support is that the ability to strategically recollect non-target information in exclusion tasks develops beyond late childhood (Czernochowski, Mecklinger, & Johansson, 2009; Czernochowski et al., 2005). For example, Czernochowski et al. (2005) examined memory for the modality of item presentation during study (photos vs. spoken words) with line drawings as retrieval cues in 6-12-year-old children and adults. While all age groups showed reliable parietal old/new effects for targets, only adults showed a non-target retrieval effect. This latter effect in adults was even larger when studied photos served as non-targets which due to their high perceptual similarity with the test cues could more easily be retrieved than targets. This is consistent with the view that in cases of high cue - non-target compatibility adults recollect non-targets along with targets (Herron & Rugg, 2003a). Notably, this non-target retrieval effect was absent in children, suggesting that this kind of strategic retrieval processing is still immature in late childhood.

In addition to these data, two ERP studies shed light on the development of post-retrieval control processes supporting source memory (Cycowicz, Friedman, & Duff, 2003; de Chastelaine, Friedman, & Cycowicz, 2007). Cycowicz et al. (2003) used an exclusion task which required the discrimination between line drawings according to their study color. While adults showed an LPN for targets, 10-year-old children showed a late target negativity that was focused to frontal electrodes. This age-related topographic difference was taken to reflect less refined activity within children's PFC and its integration with posterior networks, resulting in less successful search for and/or retrieval of source information. Interestingly, 13-year-old adolescents showed a scalp topography that overlapped with those of adults and children, suggesting a transition towards an adult-like pattern of neural activation (Cycowicz et al., 2003). In a reanalysis of the data from the latter study, de Chastelaine et al. (2007) found correlates of response inhibition for non-targets and of post-retrieval monitoring for targets in the response-locked ERPs of adults but not in those of children and adolescents. This latter result emphasizes the view that post-retrieval control processes do not reach maturity before adolescence.

By contrast, consistent with the hypothesized earlier maturation of item compared to source memory, the ERP correlate of recollection is reliably observable in school-aged children in item memory tasks (Cycowicz et al., 2003; Czernochowski, Brinkmann, Mecklinger, & Johansson, 2004; Mecklinger et al., 2011; van Strien, et al., 2009). For example, employing a memory task with picture items, Czernochowski et al. (2004) demonstrated left-parietal old/new effects for children aged 6 to 12 years, albeit at a longer latency relative to young adults. Similarly, using pictures as retrieval cues, Mecklinger et al. (2011) showed parietal old/new effects in 9-year-old children and adults in the non-speeded response condition of their response-deadline procedure. These findings suggest that recollection is available for item memory judgments by middle childhood.

However, in contrast to the behavioral evidence suggesting relative stability of familiarity after the age of 8 years (Ghetti & Angelini, 2008), the ERP correlate of familiarity is less reliably observed in younger age groups (Czernochowski et al., 2009; Friedman, de Chastelaine, Nessler, & Malcolm, 2010; Hepworth, Rovet, & Taylor, 2001). Different explanations have been evoked in relation to the lack of ERP evidence for familiarity in children, including the setting of conservative decision criteria by children (Czernochowski et al., 2005; Friedman et al., 2010). Nonetheless, in a recent study, an early frontal old/new effect was observed in 9-year-old children and adults when ERPs were recorded under speeded response conditions that fostered familiarity-based remembering (Mecklinger et al., 2011). This suggests that the ERP correlate of familiarity is observable in children under experimental conditions in which recollection is not available.

Further data relevant to the latter issue comes from a study in which a version of the continuous recognition paradigm introduced by Schnider and Ptak (1999) was employed to compare ERP indices of item and source memory between 11-year-olds and adults (Czernochowski et al., 2009). In the item memory task, only adults showed an early old/new effect reflecting familiarity-based remembering. A second age-related difference was that a large frontally distributed negativity associated with new items in the children's group was positively correlated with memory accuracy. The specificity of this finding to new items allows for the possibility that children adopted a task-specific encoding strategy by which more attention is devoted to the novelty than to the oldness of the test items. Specifically, Czernochowski et al. (2009) suggested that the frontal negativity, an often observed characteristic of children's visual ERPs (e.g. Marshall, Drummey, Fox, & Newcombe, 2002), is related to the detection of novel events that are especially salient for children with respect to semantic learning.

The latter view receives support from ERP studies in which a similar frontal negative deflection in response to unfamiliar events, the Nc, has been linked to novelty or saliency processing in infants and preschool children (Carver et al., 2003; de Haan, Johnson, & Halit, 2003). It is possible, therefore, that the frontal negativity in children reflects a similar process as the visual 'novelty N2' which has been described in adults (Folstein & van Petten, 2008). This component is particularly sensitive to the mismatch between an unfamiliar stimulus and pre-experimentally existing knowledge (Daffner et al., 2000).

Taken together, the behavioral and ERP findings reviewed here are largely consistent with the view that source memory follows a longer developmental trajectory as compared to item memory (Cycowicz, 2000). While recollection and familiarity-based retrieval processes underlying item memory appear relatively mature at early school age, strategic retrieval processes, including source recollection and post-retrieval control, are still immature in late childhood and continue to develop into adolescence. In this way, the data fit with the model which posits a longer maturation of the strategic relative to the associative component of episodic memory (Shing et al., 2008).

3 Objectives and Research Questions of the Present Studies

The global aim of the studies presented in this thesis was to investigate the development of strategic retrieval processes underlying source memory during childhood and adolescence. While previous evidence suggests that the processes underlying source recollection and post-retrieval control are still immature in late childhood, little is known about the development of these processes through adolescence, the period which is crucial for the maturation of cognitive control. Thus, for a comprehensive understanding of the maturational course of strategic memory retrieval, it is vital to provide ERP data on the mechanisms mediating source memory in adolescents. Moreover, investigating how these late changes in source memory relate to those observable in item memory is crucial for a more complete understanding of episodic memory development. These objectives were addressed by means of two developmental ERP studies

Study 1 addressed the issue of developmental changes in source memory from childhood over adolescence to adulthood, and whether these changes differ from those occurring in item memory. This was achieved by comparing behavioral and ERP correlates of item and source memory retrieval across three age groups (children, adolescents, and adults). A second goal addressed in Study 1 was to explore electrophysiological correlates of visual novelty processing in children. Based on the suggestion that children's frontal negativity is specifically sensitive to the novelty of events (Czernochowski et al., 2009), it was explored whether ERP correlates of generic novelty processing would differ across the three age groups.

The objective of Study 2 was to investigate the development of strategic recollection during adolescence in more detail. This was achieved by comparing ERP correlates of strategic retrieval processing between young adolescents and adults in a paradigm that allowed for investigating differences in selective memory retrieval. A further interest was to determine the effects on strategic retrieval in both age groups caused by varying task difficulty. Finally, it was investigated whether adolescents differ from adults in the degree of engagement in strategic retrieval processing as revealed by the availability of cognitive control resources.

4 Methodological Rationales

This chapter provides the general methodological rationales for the studies presented in this thesis. The chapter will deal with general aspects related to the interpretation of ERPs in adults and children, in addition to more specific issues raised by the experiments presented here, including the research design, the examined age stages, and the memory tasks and test stimuli used. Detailed descriptions of the experimental settings used in the present studies are given in the respective method parts.

4.1 Using ERPs for examining neurocognitive development

ERPs provide a functional neuroimaging technique that is advantageous for the study of neurocognitive development for several reasons. First, ERPs are relatively easy to record and they deliver robust signals. For example, compared to other neuroimaging methods such as fMRI, ERPs are less sensitive to movement artifacts and therefore are better suited for studying infants and children (de Haan & Thomas, 2002). Second, ERPs are noninvasive and can be obtained independently from behavioral responses, such that the same dependent measure can be used across a broad range of age and ability levels (de Haan, 2008). Furthermore, a particular merit for current concerns is that ERP correlates of recognition memory are less dependent on specific theoretical constraints as compared to behavioral dual-process measures (Mecklinger & Jäger, 2009), which renders ERP measures better suited for studies with children.

Most notably however, ERPs permit to study aspects of neurocognitive change that cannot be studied with behavioral measures alone, as they provide information about the timing and some information about the spatial distribution of the neural processes underlying behavior. For example, due to the excellent temporal resolution of ERPs, ERP latency measures have been compared across ages as a means to uncover changes in the timing of cortical function (Taylor & Baldeweg, 2002). Likewise, age-specific patterns in the topography of ERP activity have been taken to draw inferences about the functional reorganization in the networks underlying source memory (Cycowicz et al., 2003; de Chastelaine et al., 2007). For these reasons, in the present thesis an ERP-based approach was taken to study the development of the neurocognitive mechanisms underlying episodic retrieval.

4.1.1 Electrophysiological brain activity and ERPs in adults

Electroencephalography (EEG) is a widely used noninvasive method for the measurement of the electric activity of the human brain (Lutzenberger, Elbert, Rockstroh, & Birbaumer, 1985). The spontaneous EEG measured through scalp electrodes contains information about changes in brain activity at the ms time scale, while derived measures, such as ERPs, relate this information to cognitive processes in which the brain is engaged. The spontaneous EEG reflects the summated postsynaptic activity of pyramidal cells that are synchronously active and whose dipoles must have a similar orientation to produce an electric field that can be measured at the scalp. It is traditionally classified into several frequency bands ranging from 0 to 100 Hz which are influenced by the alertness of the individual. The placement of scalp electrodes conventionally follows the 10-20 system which specifies electrode positions according to their relative distances along the nasion-inion axis and the coronal axis (Jasper, 1958). The EEG is measured as the voltage difference between the active electrodes and a reference electrode, whereby the latter is usually placed at the most electrically neutral possible site.

The primary advantage of this technique is its ability to measure cortical activity in real time, which makes it amenable to study changes in activity during the processing of specific events through the measurement of ERPs (Coles & Rugg, 1995; Luck, 2005). ERPs recorded in the time domain plot the change in voltage as a function of time in a predefined epoch relative to a particular event, such as the presentation onset of a stimulus or the execution of a behavioral response. Since the voltage fluctuations plotted by the ERP consist of only a few microvolts compared to the background EEG, the desired ERP is obtained by means of averaging the EEG across a sufficient number of repetitions of the same class of events. By this, the noise inherent to the EEG is reduced, while the ERP waveform related to information processing remains.

ERPs span several components which can be described in terms of physiological features of the observed waveform, including polarity, latency, topography, and amplitude. The peak latency of a waveform is thought to index the time at which a particular cognitive process is engaged to the greatest degree, whereas ERP amplitudes, often measured relative to a baseline period that is not influenced by the event, reflect the magnitude of the activity in question. Due to the high temporal resolution of ERPs, it is possible to differentiate between exogenous components (i.e. components that occur within the first 200 msec after stimulus onset and are mainly influenced by the physical characteristics of the eliciting event) and endogenous components (i.e. components thought to reflect cognitive processing related to the event; Näätänen, 1992).

However, using only the physiological attributes of ERPs to define components is surrounded by difficulties which come about because of the "inverse" problem (Coles & Rugg, 1995). That is, due to the fact that brain activity at a given spatial location can be propagated through the tissue and thus produces measurable fields at multiple scalp locations, a given waveform can reflect multiple overlapping components generated by multiple sources activated at the same time. Therefore, ERPs can provide little information about the location of the neural generators of a scalp-recorded signal. Nonetheless, there exist ERP localization methods, such as brain electrical source analysis (BESA), which take advantage of the fact that not all possible generators of a given ERP are equally likely.

Alternatively, ERP components can be indentified on the basis of a functional approach, accounting for the fact that multiple generators may constitute a functionally homogenous system (e.g. Donchin, 1981). For example, one method of identifying ERP components is to subtract waveforms across experimental conditions which are thought to vary in the degree to which they engage a specific cognitive process (Coles & Rugg, 1995). This approach rests upon the critical assumption that conditions can be designed so that they differ in the degree to which they engage only one cognitive process.

The primary inference that can be taken from a reliable ERP difference between conditions is that the degree to which a specific cognitive process is engaged differs between the conditions. Moreover, the time point at which ERPs start to differ can be used as an estimate of the time at which differential processing begins. A final class of functional inference is based on the interpretation of the scalp distribution of an ERP effect (i.e., a difference between conditions). That is, if ERP effects measured across different situations or time points show different scalp distributions, it can be inferred that different patterns of neural activity are associated with these situations or time points (Urbach & Kutas, 2002). In turn, this information can contribute to the determination of whether functionally equivalent or non-equivalent processes are employed across situations or time, even in the absence of knowledge about the generators of the ERP effects in question (Wilding, 2006).

For example, differences in scalp distribution between ERP old/new effects across time intervals have been used to make inferences about functional distinct retrieval processes that operate at different time points (Rugg & Wilding, 2000). However, the question of whether the lack of a difference in topography across different ERP contrasts reflects functional equivalence across these contrasts is less clear (Otten & Rugg, 2005). That is, it is possible that the processes that differentiate between conditions or time points remain undetected in scalp-recorded activity, because ERPs are sensitive to only a subset of neural activity with specific dynamic and geometric properties. More detailed discussions of possible caveats surrounding the functional interpretation of ERPs and the assumptions upon these interpretations rest can be found at Coles and Rugg (1995) and Otten and Rugg (2005).

4.1.2 Development of ERPs in children and adolescents

ERPs are sensitive to developmental changes in both brain function and structure, while it is usually not possible to clearly separate these two sources of alteration in the ERP (Segalowitz, Santesso, & Jetha, 2010). That is, structural brain changes (e.g. synaptic pruning and myelination) may either directly alter the ERP response or may refine cognitive processing and by this produce changes in the functional ERP. For example, based on temporal coincidence, changes in ERP amplitude have often been related to synaptic maturation, as synaptic density and ERP amplitudes show parallel inverted U-shaped developmental changes with rapid increases during infancy and early childhood followed by gradual decline over later childhood (Csibra, Kushnerenko, & Grossmann, 2008). Additional reasons for larger ERP amplitudes in children than in adults may be maturational changes in skull thickness as well as children's greater effort expended to meet task demands, resulting in larger cortical activation (DeBoer, Scott, & Nelson, 2005). Conversely, latencies of most ERP components constantly decrease with age at rates that depend on the complexity of the cognitive processing they reflect (Taylor & Baldeweg, 2002). While these decreases in ERP latency have typically been related to refinements in myelination and/or synaptic efficiency (de Haan, 2008), increases in the consistency of brain responses, resulting in lower trial-to-trial variability, may also contribute to shorter ERP latencies with age (Csibra et al., 2008).

Thus, the overall picture of developmental change is a decrease in amplitude and latency of most ERP components which can be identified around 4 years of age (Nelson & Monk, 2001). One example of an early visual ERP component is the Nc, a negative deflection which is most prominent over fronto-central electrodes between 400 and 800 ms, showing deceasing peak latencies from the first year of life onwards and decreasing amplitudes during the third year of life (de Haan, 2007). Regarding its functional significance, the evidence from a range of studies with young children suggests that the Nc reflects attentional processes that are sensitive to novelty, recognition, and the emotional salience of events (de Haan et al., 2003). For example, one study found that in children younger than 24 months the Nc is larger for the mother's face compared to a stranger's face, while children older than 45 months show a larger Nc for the stranger's face compared to the mother's face (Carver et al., 2003). This has been taken to reflect a change in the relative salience of the caregiver's face, with older children allocating more resources to processing strangers' faces (Carver et al., 2003). On the basis of this data, Czernochowski et al. (2009) speculated that the Nc in young children could reflect a similar process as the frontal negativity observed in school-aged children, as this latter component also appears to be sensitive to the novelty or saliency of events.

Regarding adolescence, a number of studies have documented profound alterations in several cognitive ERP components (Segalowitz et al., 2010). For example, the functional maturation of inhibitory control has been associated with a reduction of the amplitude of the frontal NoGo N2 component (Johnstone, Pleffer, Barry, Clarke, & Smith, 2005; Jonkman, 2006), a change which has been dissociated from the influence of physiological factors such as skull thickening (Lamm, Zelazo, & Lewis, 2006). This decrease in frontal N2 activity during adolescence has been attributed to improved neural efficiency and refinements of processing within PFC, presumably resulting from synaptic pruning (Jonkman, Sniedt, & Kemner, 2007; Lamm et al., 2006). In a similar vein, Cycowicz et al. (2003) have attributed children's larger and more widespread negative frontal ERP activity compared to adults to their less refined PFC circuits that support source memory retrieval. Thus, though scalp-recorded ERPs remain ambiguous with regard to their underlying neural generators, these findings illustrate the sensitivity of ERPs to the functional reorganization of neurocognitive control networks over development.

4.1.3 Methodological concerns associated with developmental ERP studies

The age-related changes in cognitive ERPs considered above entail a number of methodological challenges that need to be faced when comparing ERPs between different age groups. For example, special care must be taken when interpreting age differences in ERP amplitude which may not only reflect changes in cognitive function but also the influence of unspecific age-related factors (e.g. skull thickness). This concern is also relevant for present purposes, because the factors causing larger amplitudes in children do not necessarily produce additive effects and might therefore not be eliminated by analyzing difference amplitudes. There exist several techniques to address this particular challenge in developmental ERP studies, such as to treat performance-related variables as covariates when analyzing age differences in activity (Lamm et al., 2006) or to relate ERP correlates of cognitive function to independent assessments of the function of interest (Segalowitz & Davies, 2004). In the present experiments however, the main focus is on the presence of ERP old/new effects in the different age groups, respectively on differences in the scalp distribution of these effects, whereas age differences in amplitude are not interpreted.

Conversely, in order to account for changes in ERP latency and resulting age differences in the timing of old/new effects (Marshall et al., 2002), these effects are evaluated in age-specific time-windows under consideration of differences in processing speed as indexed by reaction times (RTs).

A related issue concerns the influence of structural brain maturation on cognitive ERPs. To date, it is not well established what the predicted change in ERPs would be when considering brain maturational changes such as synaptic pruning. As outlined above, more efficient processing afforded by pruning might lead to less noisy computations and less effort, resulting in decreased amplitudes with age (Segalowitz et al., 2010). On the other hand, synaptic pruning may lead to functional specialization, which may allow for the recruitment of regions for a specific task that would not be recruited in the immature system, resulting in increased neural activity in these regions with age (Luna et al., 2010). These aspects of developmental cognitive neuroimaging illustrate the necessity to include an adult group in cross-sectional studies. By this, adults are considered the model system, and the pattern of immaturities in children and adolescents can be characterized on the basis of observed deviation from this system.

Related to changes in amplitude and latency is also the requirement to make group ERP averages over no more than 1-2 years in developmental samples, because averaging across a wide age range would obscure developmental changes due to high data variability (Taylor & Baldeweg, 2002). A similar problem concerns the usually larger between-subject variability in children's waveforms, resulting from their greater number of movement artifacts and/or their lower number of trials completed (DeBoer et al., 2005). In order to obtain equivalent signal-to-noise ratios across age groups and conditions, the current heuristic is to require each participant to contribute at least 16 artifact-free trials in each condition to the individual ERP average (Picton et al., 2000). Moreover, children may also show higher within-subject ERP variability, reflecting state changes (e.g. alertness) during the experiment (DeBoer et al., 2005). This issue is addressed by removing distracting items from the testing room, introducing short breaks between blocks, and giving visual performance feedback after each trial to maintain motivation (Study 1). A more detailed discussion of methodological concerns associated with developmental ERP research is provided by DeBoer et al. (2005) and de Haan (2008).

4.2 Research design

By comparing different ages measured simultaneously, a cross-sectional design was used to address the developmental research questions in the present thesis. Therefore, by analyzing age group differences, the present work is not able to precisely disentangle the relative contributions of the parameters which according to Schaie (1965) define developmental change, namely, age, time of measurement, and cohort. That is, compared to longitudinal designs, cross-sectional designs are afflicted with several possible limitations, such as the question of equivalence of measurement across ages or confounds with historical/cultural differences between cohorts (Miller, 2007). Nonetheless, cross-sectional studies provide economic data which have proven useful for generating and clarifying hypotheses about changes in a range of developmental processes such as memory (Robinson, Schmidt, & Teti, 2005).

This thesis aimed to model the developmental trajectories of item and source memory on the basis of a parametric approach by which three age groups (children, adolescents, and adults) were compared to each other. This approach allows for a more detailed characterization of the developmental trajectory of episodic memory in comparison to studies in which only two age groups are examined. That is, comparing three age groups for item and source memory retrieval may provide information about changes in the mechanisms that underlie episodic memory from childhood to adolescence. Moreover, this approach can provide insights into the sequences and levels through which children move when acquiring new retrieval strategies and into the rate of development through childhood and adolescence. In this way, it is possible to determine whether age differences in strategic retrieval processing map onto the developmental course of cognitive control.

4.3 Selection of the age groups

The rationale for selecting the age groups was based on the time-course of maturation in cognitive control and strategic memory functions from middle childhood to adulthood as outlined in the framework discussed above (see Chapter 2). Given that in late childhood (i.e. around 10-12 years) strong improvements are made in cognitive control (Paus, 2005) and in strategic memory functions (Shing et al., 2008), children's and adolescents' ages were set so that they spanned this possible 10-year divide. At the same time, care was taken to detect developmental changes in source memory during adolescence, again based on the evidence for protracted maturation in cognitive control (Luna et al., 2010) and strategic memory processes (Shing et al., 2008) during this period. Thus, ensuring that children would be old enough to perform the task, their age was set at 7-8 years, while that of adolescents was set at 13-14 years. In order to minimize variability in the ERPs, age ranges were restricted to 2 years for both groups (Taylor & Baldeweg, 2002). Both studies also included a group of young adults whose data profile served as a model to characterize neurocognitive immaturities in children and adolescents.

4.4 Memory tasks and stimuli

In both studies, memory exclusion tasks were employed to investigate strategic retrieval processing. In Study 1, this task was provided by a continuous recognition memory paradigm which has been designed to assess temporal source monitoring, defined as the ability to make correct judgments to currently irrelevant distracter (non-target) items (Schnider, 2003). Previous studies using this paradigm have demonstrated high false alarm rates for these non-target items in confabulating patients (Schnider & Ptak, 1999) and children (Czernochowski et al., 2009), which licenses the use of this task to assess developmental changes in source memory. In addition, this paradigm allows obtaining an independent measure of item memory which was also in the focus of Study 1. In Study 2, an ordinary study-test paradigm was used, in line with other developmental ERP studies of strategic retrieval processing (e.g. Cycowicz et al., 2003).

As mentioned above, differences in task difficulty provide a possible confound of observed age-related changes in ERP activity. That is, when performance differs by age, differences in neural activity could either reflect the use of different strategies due to limitations in accessing the correct neural circuitry or the use of the correct circuitry in different degrees (Luna et al., 2010). While both possibilities are crucial for understanding cognitive development, it is necessary to distinguish between both in order to accurately characterize changes in functional activity. One step towards addressing this issue is to use a parametric approach where task difficulty in manipulated, and to analyze age differences in the neural correlates sensitive to this manipulation. This approach was followed in Study 2, in order to determine the extent to which age differences in strategic retrieval processing vary with task demands. In Study 1, differences in cognitive effort were minimized by setting task parameters at a level that ensured that even children would be able to perform above chance level. By this, Study 1 allowed for investigating age differences in ERP activity as a function of behavioral performance, in order to draw inferences about the functional development of retrieval processing.

In Study 1, picture items served as test stimuli in order to exclude possible confounds with reading skills which could be expected if words were used with children in the age range examined here. In Study 2, however, words were used, allowing better comparability with previous studies of strategic retrieval processing in which difficulty manipulations were used (e.g. Herron & Wilding, 2005). However, in order to avoid age-related confounds with word familiarity, only high frequency words were used in Study 2.

5 Studies

5.1 Study 1

Developmental Changes in Item and Source Memory: Evidence from an ERP Recognition Memory Study with Children, Adolescents, and Adults[1]

5.1.1 Background and rationale

The main goal of Study 1 was to examine the developmental trajectories of item and source memory and their respective ERP correlates during childhood and adolescence. While item recognition memory can be based on differences in the relative familiarity of old and new items, source memory retrieval heavily depends on strategic control processes mediated by the PFC (Simons & Spiers, 2003). Strategic retrieval processes include the specification of the task-relevant contextual details to be retrieved, search operations for source-defining attributes in the memory store, and the monitoring and evaluation of retrieved information in the service of task demands (Simons, 2009).

Previous developmental ERP studies have provided evidence that strategic retrieval processes, including recollection of non-target information in exclusion tasks (Czernochowski et al., 2009, 2005) and post-retrieval control operations (de Chastelaine et al., 2007), are still immature in late childhood and can therefore be expected to mature during adolescence. Conversely, data suggesting a relatively earlier maturation of item memory is provided by findings that retrieval of item information in 6-10-year-old children is associated with ERP correlates of recollection (e.g., Czernochowski et al., 2004) and familiarity (Mecklinger et al., 2011), although the latter finding appears to be contingent upon the use of an appropriate operational definition of familiarity. In addition, P200 repetition effects have been found in school-aged children performing a continuous word recognition memory task (van Strien et al., 2009).

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[1] The data reported in this study are also reported in the following article: Sprondel, V., Kipp, K.H., & Mecklinger, A. (in press). Developmental changes in item and source memory: Evidence from an ERP recognition memory study with children, adolescents, and adults. *Child Development*.

The relatively protracted development of source as opposed to item memory has been related to the functional and structural maturation of the PFC during adolescence (Cycowicz et al., 2001). In fact, this brain region undergoes profound changes throughout childhood and adolescence in the form of synaptic pruning and myelination (Gogtay et al, 2004). These changes are associated with rapid improvements in cognitive control functions around 10-12 years of age (Paus, 2005) followed by ongoing refinements in behavioral performance and in the underlying neural networks (Luna et al., 2010).

Study 1 addressed the question of how these changes map onto the development of source memory. A special focus of the study, therefore, was on the early adolescent years, achieved by comparing the behavioral and ERP correlates of item and source memory in children (7-8 years), adolescents (13-14 years), and young adults. To this end, two runs of the continuous recognition memory task introduced by Schnider and Ptak (1999) were employed. The first run served as a measure of item memory, whereas source memory was defined as the ability to reject non-target items during the second run. The ERP comparisons for item memory were guided by the dual-process framework of recognition memory and thus focused on recollection and familiarity, while those for source memory focused on non-target recollection and post-retrieval monitoring.

To examine age-related changes in the neural correlates of generic novelty processing, two kinds of pictures were employed in the memory task: unfamiliar non-objects and familiar objects. ERP comparisons were made between first presentations of non-objects and first presentations of objects (in the following: *generic novelty effect*).

Throughout the task, non-object and object items were presented in an intermixed fashion and with the same number of repetitions. As the majority of previous developmental ERP memory studies have used pre-experimentally familiar stimulus materials, all predictions regarding the effects of item and source memory were tested with object items only, in order to assure comparability with these studies.

5.1.2 Hypotheses

Based on the hypothesized longer developmental trajectory for source compared to item memory, different age-related patterns of behavioral performance for item and source memory were expected, characterized by particularly low source discrimination abilities for children. Adolescents were expected to perform better relative to children especially for source memory, consistent with the strong improvement in cognitive control functions in late childhood (Paus, 2005). On the other hand, regarding the prolonged course of cognitive maturation throughout adolescence (Luna et al., 2010), the adolescents' source memory performance might fall in between those of the child and the adult groups.

Based on previous developmental ERP studies of source memory (e.g., Czernochowski et al., 2005), the ERP correlate of strategic recollection, defined as the parietal old/new effect for non-targets, was expected for adults but not for children. Furthermore, a late right-frontal old/new effect reflecting post-retrieval monitoring should be present for non-targets in the adult group only. In keeping with the predictions for source memory performance, adolescents were expected to exhibit ERP evidence for both strategic recollection and post-retrieval monitoring, although these effects might be less evident compared to adults.

Regarding item memory, parietal old/new effects reflecting recollection were expected for all age groups. Conversely, in line with the lack of ERP evidence for familiarity in children in previous studies using standard item memory tasks (e.g., Czernochowski et al., 2009), the possibility that only adults show an early mid-frontal old/new effect reflecting familiarity was taken into consideration. Since P200 repetition effects have been reported in school-aged children (van Strien et al., 2009), comparable old/new modulations were expected irrespective of age.

Regarding the examination of generic novelty processing, it was hypothesized that if frontal ERPs in children are particularly sensitive to generic novelty, there should be larger negativities to non-objects compared to objects. Moreover, this effect should be different from the ERP correlate of relative novelty/familiarity processing, i.e., the comparison between first and second presentations of familiar objects.

5.1.3 Method

5.1.3.1 Participants

Eighteen 7-8-year-old children (*M* = 8.1; *SD* = .5; 10 male), twenty 13-14-year-old adolescents (*M* = 13.7; *SD* = .6; 10 male), and twenty 20-29-year-old adults (*M* = 24.4; *SD* = 3.6; 9 male) participated in the study. Seven additional subjects (5 children, 2 adolescents) were excluded from the analyses, because a relatively low performance level and a high level of electrooculogram (EOG) artifacts led to an insufficient number of artifact-free ERP trials in at least one of the relevant experimental conditions. The data from one other child was excluded because of extremely low performance. All participants were right-handed and native German speakers. They reported to be in good health and having normal or corrected-to-normal vision. Participants (respectively children's and adolescent's parents) gave informed consent and received € 8/hour for participation.

5.1.3.2 Stimuli

Two kinds of visual stimuli were used for the memory task: objects and non-objects. 86 object stimuli were selected from a colored version of the Snodgrass and Vanderwart line drawings (Roisson & Pourtois, 2004). 86 non-object stimuli were created by rearranging various colored pictures forming pre-experimentally novel pictorial information. Figure 2 provides two examples from each of the two stimulus categories. In each category, 14 items were used as practice items, 30 as filler items, and 42 as experimental items. Each picture was framed within an area of 200 x 200 pixels.

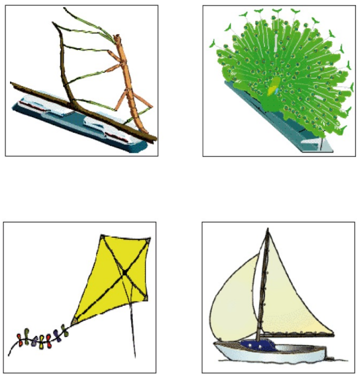

Figure 2. *Two examples of the non-object stimuli (Top Row) and the object stimuli (Bottom Row) used in the task.*

5.1.3.3 Design and Procedure

Participants sat in a comfortable chair located 1 m in front of a 19-inch computer monitor throughout the experiment. The whole session lasted for approximately two and a half hour, including setting up the EEG cap.

Before the first run, participants were told that they would see pictures depicting either known objects or rather fanciful figures, and that the pictures would be repeated at various points. The task instructions were to attend carefully to the pictures and to judge each item for its repetition status by pressing the “new” button for first presentations and the “old” button for repetitions. Each index finger was assigned to one of two keys on an external key pad and the assignment of response key to old/new status was balanced across participants.

In the first run, 42 object and 42 non-object items were presented in randomized order and repeated with lags varying between 10 and 15 intervening items. In order to include the lag manipulation and meet the experimental constraint that items featuring the same repetition status did not occur more than four times consecutively, 30 additional filler items (15 object and 15 non-object items) were included. These items were also repeated at variable lags. The experimental conditions in the first run entering subsequent analyses were first presentations (new) of both object and non-object stimuli and the repetitions (old) of objects. Non-object repetitions were included in the procedure in order to equalize old/new probabilities.

Both runs were separated by a 10 minute break. Prior to the second run, participants were told that they would now be presented with pictures, some of which either had already been seen in the first run or were new. The task instruction was to judge each item solely according to its within-run repetition status and to ignore across-run repetitions. That is, items repeated from the first run and presented for the first time in the second run had to be judged as “new” (non-targets). When these items were repeated within the second run, they had to be judged as “old” (targets).

Thus, each of the 42 objects and the 42 non-objects studied in the first run was repeated two more times in the second run in a pseudo-randomized order. In addition, 30 additional filler items (15 object and 15 non-object items) were presented and repeated at variable lags. Items repeated as non-targets together with entirely new items (i.e., the filler items) had to be classified as “new”, whereas target repetitions and repeated filler items had to be classified as “old”.

In both runs, each stimulus was presented for 1000 ms at the center of the computer screen on a white background and was preceded by a fixation cross (300 ms) followed by a blank screen baseline period (200 ms). Responses were recorded within a period of 1500 ms after stimulus onset. Following each response, visual feedback was presented for 500 ms in the form of a happy face (correct) or a sad face (incorrect). The next trial began after a fixed inter-trial interval of 1000 ms.

To ensure participants’ understanding of the procedure, practice phases with 28 items per phase were run prior to each of the two runs. Children and adolescents were encouraged to explain instructions to the experimenter in their own words and were corrected if necessary.

5.1.3.4 EEG recording

EEG was recorded with 27 Ag/AgCl- electrodes (at the following sites, adapted from the standard 10-20 system: FP1, FP2, F7, F3, FZ, F4, F8, FC5, FC3, FCZ, FC4, FC6, T7, C3, CZ, C4, T8, CP3, CPZ, CP4, P7, P3, PZ, P4, P8, O1, O2) at a sampling rate of 250 Hz with a left mastoid reference, and was re-referenced offline to the mean of both mastoids. EOG was recorded with additional electrodes located above and below the right eye and outside the outer canthi of both eyes. Electrode impedance was kept below 5 kΩ. EEG and the EOG were recorded continuously and were A-D converted with 16-bit resolution.

Offline data processing involved low-pass filtering at 30 Hz and high-pass filtering at 0.2 Hz. Prior to averaging, each recording epoch (1400 ms, including a 200 ms prestimulus interval for baseline correction) was scanned for artifacts which were identified whenever the standard deviation in a sliding 200 ms time-window exceeded ±25 μV in one of the EOG channels. Ocular artifacts were corrected using a linear regression approach (Gratton, Coles, & Donchin, 1983). Trials containing muscular and/or technical artifacts were removed before averaging.

For each group, ERP averages were formed for correct judgments to new items, separately for objects and non-objects. As mentioned before, ERPs to correctly judged old and non-target items were averaged only for objects. Mean trial numbers (range) for new items (objects, non-objects) were: children, 27 (19-39), 23 (18-33); adolescents, 30 (23-39), 28 (18-36); adults, 33 (34-39), 33 (23-41). For old items the mean trial numbers (range) were: children, 23 (18-33); adolescents, 29 (21-35); adults, 32 (18-40). Mean trial numbers (range) for non-targets were: children, 21 (17-33); adolescents, 28 (21-37); adults, 29 (18-40). Although average trial numbers differed across conditions for children, the number of trials used for ERP averaging was in the range used in previous developmental ERP studies (Cragg, Fox, Nation, Reid, & Anderson, 2009; Czernochowski et al., 2005; Friedman et al., 2010) and was large enough to obtain equivalent signal-to-noise ratios across conditions and age groups (Picton et al., 2000).

5.1.3.5 Data analysis

Trials that were not responded to were removed from behavioral analysis. Analogous to the analyses of the ERP data, memory accuracy was evaluated only for object stimuli, using Snodgrass & Corwin's (1988) discrimination index Pr where Pr = p(hit) – p(false alarm). For item memory accuracy, the proportion of false alarms to new items were subtracted from the proportion of hits in the first run, [Pr_Item = p(hit) – p(new item false alarm)]. For source memory accuracy, the proportion of false alarms to non-targets were subtracted from the target hit rates in the second run [Pr_Source: *p*(target hit) – *p*(non-target false alarm)]. Response times were measured separately for new, old, non-target and target items. Response bias was defined as Br (Snodgrass & Corwin, 1988) and was calculated separately for the item memory task [Br_Item = *p*(false alarms) / 1 – Pr_Item], and the source memory task [Br_Source = *p*(non-target false alarms) / 1 - Pr_Source]. To examine age effects, repeated-measures analyses of variance (ANOVAs) with the factor Age (children, adolescents, adults) were conducted.

ERP data were collected from nine electrodes that covered trilateral frontal, central, and parietal recording sites (frontal: F3, Fz, F4, central: C3, Cz, C4, parietal: P3, Pz, P4), the regions at which old/new effects can be reliably recorded. Repeated measures ANOVAs were conducted on average amplitudes within specified time windows (see below) including the factors Condition, and, as topographical factors, anterior-posterior (AP) (frontal vs. central vs. parietal) and Laterality (left vs. central vs. right). In order to examine age differences in the ERP measures, the initial ANOVAs included the factor of Age (children vs. adolescents vs. adults). Subsidiary ANOVAs were then used to elucidate interactions between Age, Condition, and the topographical factors. Only effects including the Condition factor are reported. In cases of violation of the sphericity assumption, Greenhouse-Geisser corrections (Greenhouse & Geisser, 1959) were applied to *p*-values. To compare effect sizes across electrodes, treatment magnitudes (η_p^2) were calculated.

The predictions of this study were tested with a variety of analyses: For the test of generic novelty, first presentations of objects and non-objects were contrasted in the Condition factor (object v. non-object). For item memory analysis, the early and the late old/new effects were evaluated in the Condition factor (old vs. new). For source memory analysis, the Condition factor was specified according to the non-target old/new effect (non-target vs. new). In the second run, the overall probability of new items (i.e., the filler items) was much lower than the probability of non-target items (15 vs. 42, i.e. 36%). Thus, consistent with the study by Czernochowski et al. (2009) in which the same ERP analysis was performed, the probabilities of old and new stimuli were held constant for the analysis of the non-target old/new effect by contrasting non-targets with new items from the first run.

As the P200 repetition effect, the effect of generic novelty, and the early old/new effect showed similar temporal characteristics across groups, these effects were examined in the same time windows across the three age groups (P200: 160 to 240 ms; generic novelty and early old/new effect: 350 to 450 ms). Visual inspection of grand average ERP waveforms showed that the parietal old/new effect was delayed for children relative to the two other groups. Similarly, there was a delay of the non-target old/new effect for children and adolescents relative to adults. Therefore, group-specific time-windows were used for the analyses of the latter effects (see Marshall et al., 2002). In the item memory analysis, the late old/new effect was measured between 650 and 800 ms for children and between 450 and 600 ms for adolescents and adults. In the source memory analysis, the time-windows used for evaluating the non-target old/new effect were 800 to 950 ms (children), 750 to 900 ms (adolescents), and 450 to 600 ms (adults). These time-windows were selected on the basis of visual inspection of the waveforms for the time intervals in which the old/new differences were largest.

Finally, visual inspection of the waveforms suggested that only adults showed a late right-frontal old/new effect for non-targets. This effect for adults was evaluated between 850 and 1000 ms. Since the effect extended to more lateral recording sites, six additional recording sites were included in the analysis (F7, T7, P7, F8, T8, P8), and the resulting 15 electrodes were grouped into AP (3 levels) and Laterality (5 levels) factors.

5.1.4 Results

5.1.4.1 Behavioral data

The behavioral data are summarized in Table 1. The ANOVA with the factors Memory Task (item vs. source) and Age on the Pr-measures yielded an effect of Age [$F(2, 55) = 22.06$, $p < .001$] and an interaction between Memory Task and Age [$F(2, 55) = 3.40$, $p < .05$]. Follow up analyses revealed that children performed lower than adolescents and adults in both tasks (*p*-values < .001). Adolescents performed lower than adults in the item memory task (*p* < .05), whereas there was no difference between these groups for source memory (*p* = .54). Children performed lower in the source than in the item memory task (*p* < .05), while this difference was not found for adolescents or adults (*p*-values > .21). Thus, consistent with the prediction, the effects of age on memory performance differed between the two tasks, and children showed particularly poor source discrimination performance.

The distinct age-related increase in source memory performance was verified in an analysis of covariance (ANCOVA) on the source memory estimate in which item memory performance was introduced as a covariate. An effect of Age was obtained [*F*(2, 54) = 5.24, *p* < .01]. The adjusted means for Pr_Source after the influence of the covariate was partialled out were .67, .80, and .75 for children, adolescents, and adults, respectively. These source memory scores differed between children and adolescents (*p* < .01), on a marginally significant level between children and adults (*p* = .06), but not between adolescents and adults (*p* = .26). These results confirm that the observed age differences in source memory are independent from the differences in item memory.

Regarding response bias, the ANOVA with the factors Memory Task (item vs. source) and Age revealed no age differences (*F*-values < 1.00). An effect of Memory Task indicated that the criterion for "old" judgments was more liberal across all three age groups in the source compared to the item memory task [*F*(1, 55) = 8.10, *p* < .01].

For response times, the ANOVA with the factors Condition (new vs. old vs. non-target vs. target), and Age yielded main effects of Condition [*F*(3, 165) = 6.51, *p* < .01] and Age [*F*(2, 55) = 55.16, *p* < .001]. Across groups, correct responses to new items were reliably faster than correct responses to old items (*p* < .001), non-targets (*p* < .01), and targets (*p* < .05). Children responded more slowly than adolescents and adults (*p*-values < .001), whereas the difference between the adolescents' and adults' response times was only marginally significant (*p* = .06).

Table 1. Overview of Memory Performance Data

	Children	Adolescents	Adults
Performance Estimates			
Pr_Item	.63 (.17)	.78 (.11)	.87 (.08)
Pr_Source	.57 (.19)	.81 (.14)	.84 (.09)
Response Times Correct Rejections			
New	822 (64)	650 (67)	611 (51)
Non-Target	837 (92)	680 (73)	629 (75)
Response Times Hits			
Old	845 (85)	692 (66)	633 (65)
Target	854 (91)	672 (60)	616 (78)
Bias Estimates			
Br_Item	.38 (.16)	.41 (.21)	.42 (.19)
Br_Source	.52 (.12)	.45 (.20)	.52 (.20)

Note. Accuracy was calculated separately for item memory [Pr_Item = p(hit) – p(new item false alarm)] and source memory [Pr_Source: p(target hit) – p(non-target false alarm)]. Response bias was also calculated separately for item memory [Br_Item = p(false alarms) / 1 – Pr_Item] and source memory [Br_Source = p(non-target false alarms) / 1 - Pr_Source]. Reaction times (ms) are given for correct responses to new, old, non-target, and target items. Standard deviations of means are given in parentheses.

Post-hoc analysis of non-target forgetting rates

In the exclusion task, it is not possible to correctly distinguish between retrieved and forgotten non-targets, because some non-targets may be misclassified as “new”. One possible consequence of this is that source memory performance for adolescents may have been overestimated because the forgetting rate for old items in the item memory task was higher for this group than for adults. This possibility was explored in a post-hoc analysis in which response accuracy for non-targets was evaluated according to their repetition lag. This lag was defined as the number of items that intervened between old items in the first run and non-target presentations in the second run. Non-targets were divided into two categories: The 21 items with the shortest repetition lags (mean lag = 185 items) were compared to the 21 items with the longest lags (mean lag = 246 items). As memory strength declines over time, a stronger amount of non-target forgetting in adolescents compared to the other groups should be reflected in an Age by Lag (short vs. long) interaction for non-target response accuracy. For children, adolescents, and adults, the proportions of correct non-target judgments were .83, .96, .96 for the short-lag condition, and .74, .91, .87 for the long-lag condition, respectively. The ANOVA revealed no significant interaction between the factors Age and Lag (p = .35), making a non-target forgetting account for the adolescents' non-target retrieval performance unlikely.

5.1.4.2 ERP data

Generic novelty effect

The ERPs for first presentations of non-objects and objects at Fz for each age group are shown in Figure 3A. For children and adolescents, a large negative-going deflection, peaking around 400 ms, was larger for non-objects than objects from around 150 ms onwards. Starting from around 200 ms, non-objects were also more negative-going than objects in adults.

As can be seen from the topographical maps in Figure 3B, all age groups showed similar ERP effects of generic novelty which were most pronounced at anterior recording sites. This suggests few developmental differences in the neural mechanisms of novelty processing, albeit the generic novelty effect appeared to be lateralized to left-frontal recording sites for children. These observations were confirmed by a series of statistical analyses.

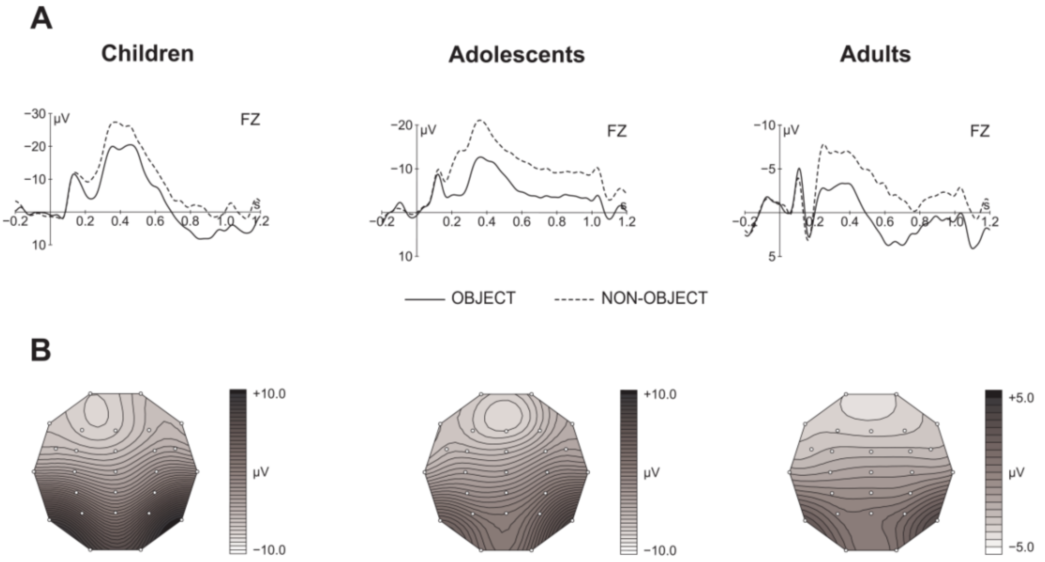

Figure 3. *(A) ERP waveforms at Fz to first presentations of objects and non-objects for children, adolescents, and adults. ERPs to objects are depicted in solid lines and ERPs to non-objects in dashed lines. Note the different amplitude scaling across age groups. (B) Scalp topographies of the generic novelty effect (non-object minus object) for children, adolescents, and adults.*

The initial ANOVA with the factors Age, Condition, AP, and Laterality revealed an effect of Condition [F(1, 55) = 17.92, p < .001] and reliable interactions involving the Age factor, among them the four-way interaction Condition x AP x Laterality x Age [F(8, 220) = 2.34, p < .05]. To dissolve this interaction, follow up analyses were performed separately for each group.

For children, an interaction of Condition and AP was obtained [F(2, 34) = 68.56, p < .001] reflecting larger negativities to non-objects than to objects at frontal sites [F(1, 17) = 25.46, p < .001]. Additionally, a three-way interaction (Condition x AP x Laterality) was found [F(4, 68) = 3.95, p < .01]. Follow up analyses revealed that the difference between non-objects and objects was largest at F3 ($\eta_p^2 = .613$). For adolescents, an effect of Condition was found [F(1, 19) = 12.38, p < .01]. A Condition by AP interaction [F(2, 38) = 45.04, p < .001] indicated a reliable generic novelty effect at frontal sites [F(1, 19) = 38.81, p < .001]. For adults, an effect of Condition [F(1, 19) = 8.38, p < .01] was embedded in a Condition by AP interaction [F(2, 38) = 77.37, p < .001], reflecting more negative ERPs for non-objects compared to objects at frontal electrodes [F(1, 19) = 37.99, p < .001].

Item memory

Grand average ERPs for new and old items at Fz, Cz, and Pz for each age group are depicted in Figure 4. The topographies of the P200 repetition effect and the early and the late old/new effects are illustrated in Figure 5. For all groups, ERPs to old items were more positive-going than for new items. At fronto-central regions, an old/new difference was seen for the P200 component across all three groups. From around 350 to 450 ms, adults showed more positive waveforms for old relative to new items, and this effect was especially pronounced at frontal sites. For children and adolescents, old/new effects in this time range were most pronounced at posterior recording sites. In a later time interval (650 to 800 ms in children, 450 to 600 ms in adolescents and adults), there was a pronounced parietal old/new effect for children and adolescents and a broadly, though right-frontally accentuated effect for adults. The statistical analyses are described first for the P200 repetition effect, then for the early and the late old/new effects.

P200 repetition effect

In the ANOVA with the factors Age, Condition, AP, and Laterality, an effect of Condition [$F(1, 55) = 36.12$, $p < .001$] was embedded in interactions between Condition and AP [$F (2, 110) = 8.20$, $p < .01$] Condition and Laterality [$F(2, 110) = 3.72$, $p < .05$] and Condition, AP, and Laterality [$F(4, 220) = 3.74$, $p < .05$]. Apart from an Age by Condition interaction [$F(2, 55) = 5.16$, $p < .01$] indicating that children had the largest overall old/new difference ($\eta_p^2 = .597$) as compared to adolescents ($\eta_p^2 = .239$) and adults ($\eta_p^2 = .269$), there was no other interaction involving the Age factor (F-values < 1.40). Across groups, the P200 effect was largest at fronto-central recordings (Fz: $\eta_p^2 = .376$; Cz: $\eta_p^2 = .338$).

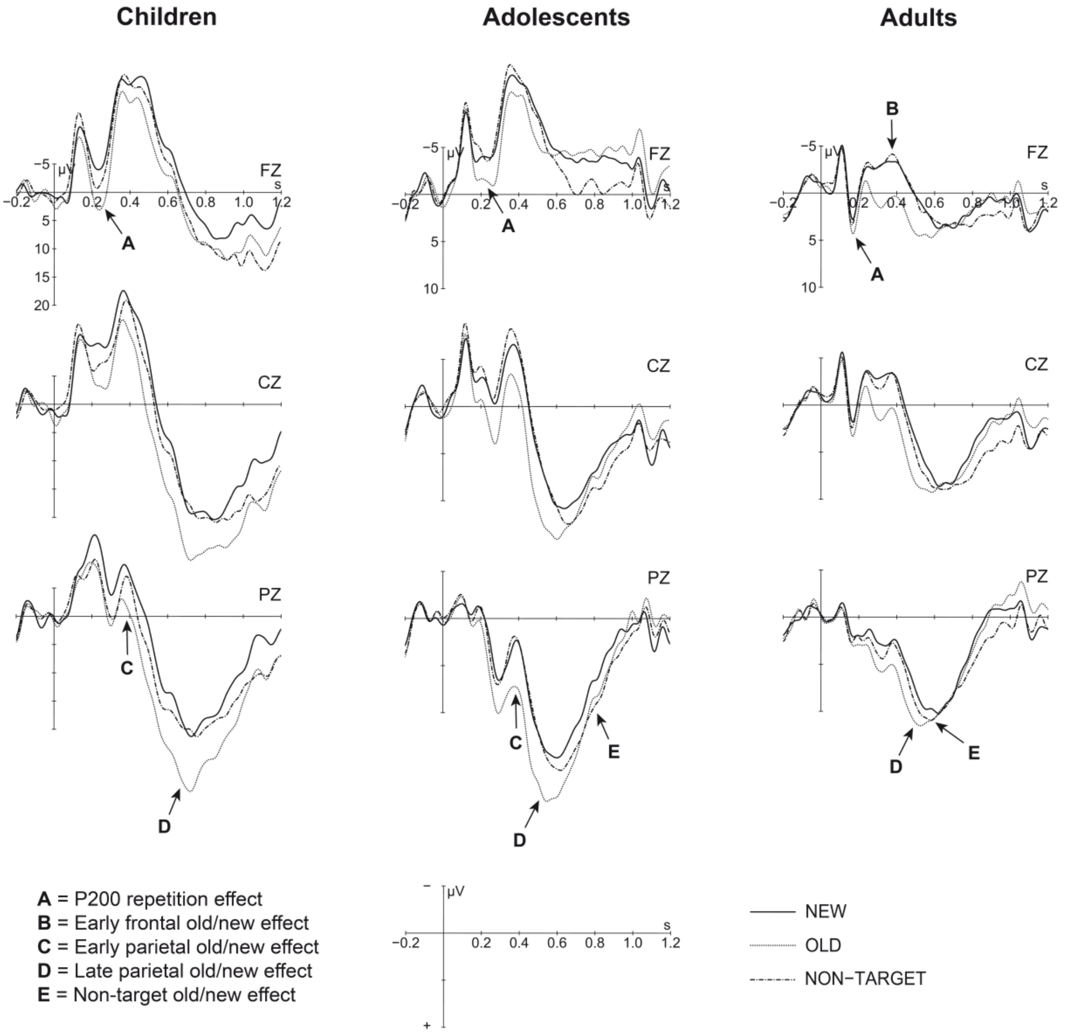

Figure 4. *ERP waveforms at midline electrodes (Fz, Cz, Pz) for children, adolescents, and adults. For the item memory task, ERPs to new items are depicted in solid lines and ERPs to old items in dotted lines. For the source memory task, ERPs to non-targets are depicted in dashed lines. Note the difference in amplitude scaling between children and the two older groups. Arrows indicate the ERP effects identified in each age group, and the letters (A-E) indicate the type of ERP effect along the time axis of processing (but note that effects B and C were measured in the same time-window).*

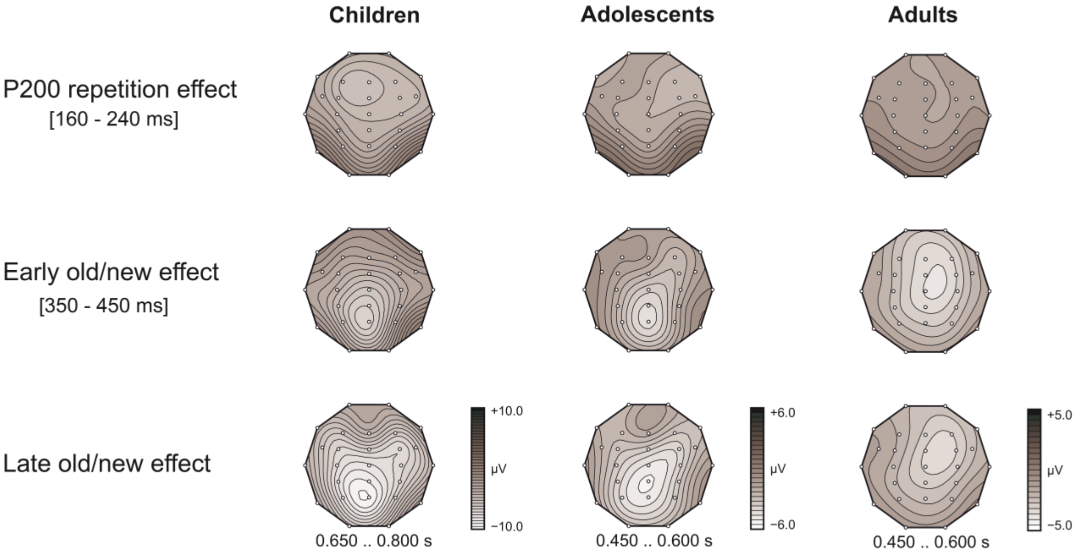

Figure 5. *Scalp topographies of the P200 repetition effect and the early and the late old/new effects for children, adolescents and adults. All maps were computed on the basis of difference scores obtained by subtracting mean amplitudes of the ERPs elicited by old items from those elicited by new items. For the late old/new effect, data are shown for the 650-800 ms time-window for children and for the 450-600 ms time-window for adolescents and adults.*

Early old/new effect

The initial ANOVA including the factors Age, AP, and Laterality revealed an effect of Condition [*F*(1, 55) = 46.69, $p < .001$] and the four-way interaction Condition x AP x Laterality x Age [*F*(8, 220) = 2.32, $p < .05$]. This interaction suggests that the early old/new effect differed in its topographic distribution across age groups. Further analyses conducted separately for each age group confirmed this view, as only adults showed an early mid-frontal old/new effect, the putative ERP correlate of familiarity-based processing. In contrast, for children and adolescents, the early old/new effect was restricted to central and parietal locations.

For children, an effect of Condition [*F*(1,17) = 12.70, $p < .01$] and an interaction between Condition, AP, and Laterality [*F*(4, 68) = 2.99, $p < .05$] were obtained. No reliable old/new difference was obtained at Fz ($p = .08$), and effect size analyses revealed that the early old/new effect was largest at Pz ($\eta_p^2 = .544$). For adolescents, an effect of Condition [*F*(1, 19) = 11.43, $p < .01$] and an interaction between Condition, AP, and Laterality [*F*(4, 76) = 10.24, $p < .001$] were found. As for children, the old/new difference at Fz was non-significant ($p = .16$), and the strongest old/new effect was obtained at PZ ($\eta_p^2 = .611$). For adults, an effect of Condition [*F*(1, 19) = 38.88, $p < .001$] indicated more positive ERPs for old relative to new items across electrodes. A Condition by Laterality interaction [*F*(2, 38) = 7.42, $p < .01$] resulted from the fact that the early old/new effect was largest across midline sites ($\eta_p^2 = .708$).

Late old/new effect

The initial ANOVA including the factors Age, Condition, AP, and Laterality revealed an effect of Condition [*F*(1, 55) = 36.72, $p < .001$] and an interaction between Condition, AP and Laterality [*F*(4, 220) = 9.92, $p < .001$]. The four-way interaction Age x Condition x AP x Laterality was only marginally significant [*F*(8, 220) = 1.18, $p = .07$]. Due to the current interest in age-related patterns of retrieval activity, group-specific analyses were performed. These showed reliable late old/new effects at parietal sites for all age groups, suggesting that the ERP correlate of recollection was not altered by age. Moreover, the analyses confirmed the late old/new effect for adults to be additionally elevated at right-frontal electrodes (see Figure 5).

For children, an effect of Condition was found [*F*(1, 17) = 12.81, $p < .01$]. A Condition x AP x Laterality interaction [*F*(4, 68) = 4.17, $p < .05$] indicated that, although old/new differences were significant across sites, the largest effect size was evident at Pz ($\eta_p^2 = .455$). The identical pattern was found for adolescents, for whom an effect of Condition [*F*(1, 19) = 14.78, $p < .01$] and a Condition x AP x Laterality interaction [*F*(4, 76) = 4.86, $p < .01$] were obtained. The old/new effect was largest at Pz ($\eta_p^2 = .602$). For adults, an effect of Condition [*F*(1, 19) = 12.58, $p < .01$] and a marginally significant Condition x AP x Laterality interaction were obtained [*F*(4, 76) = 3.12, $p = .05$]. While the late old/new effect was significant at all nine electrodes, it was largest at F4 ($\eta_p^2 = .586$).

Topographic analyses

The strong topographic similarity of the early and the late old/new effects in children and adolescents may suggest that the early effect reflects an early onsetting late parietal effect. Therefore, a topographic profile analysis was performed in order to assess for each age group whether the early and the late old/new effect differed in topography. Differences in scalp distribution between the early and the late effect after amplitude normalisation can be attributed to different neural generators and by this to different cognitive processes supporting both effects (McCarthy & Wood, 1985). For both children and adolescents, an ANOVA on the re-scaled old/new difference waveforms including the factors Time Window (early vs. late), AP, and Laterality revealed no interactions involving the factor Time Window (F-values < 1.71). Thus, even though the old/new effects in children and adolescents spanned different ERP components during the early and the late time-window, the topographic distribution patterns of these effects were highly similar across time-windows. This suggests that the early parietal effect in children and adolescents most likely reflects early onsetting recollective processing. In contrast, for adults, an interaction between Time Window and Laterality [$F(4, 76) = 4.04$, $p < .05$] indicated that the early and the late effects reflect qualitatively distinct processes.

Source memory

Figure 4 shows the ERPs elicited by non-targets in the source memory task, together with the ERPs for new and old items for each age group. For adults, non-targets were more positive-going than new items at centro-parietal sites between 400 and 600 ms, an effect that was not seen for children and adolescents. Visual inspection suggests that for children and adolescents the ERP difference between non-targets and new items was delayed by about 300 to 400 ms.

As can be seen from Figure 6A, adults showed a late onsetting, right-frontally accentuated positivity to non-targets, presumably reflecting the ERP correlate of post-retrieval monitoring processes. Figure 6B depicts the topography of the non-target/new difference for adults between 850 and 1000 ms, the time interval in which this effect was largest.

The source memory analyses revealed an increasing refinement of the ERP correlates of source memory as a function of age. As predicted, there was no ERP evidence of strategic recollection for children. For adolescents, a broadly distributed pattern of more positive non-target ERPs compared to new items was found. For adults, two different old/new effects to non-targets were observed, i.e., a centro-parietal and a later right-frontal effect, presumably reflecting strategic recollection and post-retrieval monitoring processes, respectively.

These observations were again confirmed by a series of statistical analyses. The ANOVA with the factors Age, Condition, AP, and Laterality revealed an effect of Condition [$F(1, 55) = 7.05$, $p < .05$] but no reliable interactions with the Age factor (F-values < 1.30). Nevertheless, within-group ANOVAs were performed, because the behavioral analysis suggests that children differ remarkably from the other groups in source memory accuracy. The ERP non-target effects were therefore expected to vary across age groups.

For children, no effects involving the Condition factor were obtained (F-values < 1.71). For adolescents, an effect of Condition without further interactions was found [$F(1, 19) = 4.89$, $p < .05$], indicating a topographically widespread non-target old/new effect between 750 and 900 ms. For adults, an interaction between Condition, AP, and Laterality emerged [$F\ (4, 76) = 4.84$, $p < .01$], reflecting more positive waveforms for non-targets relative to new items at Cz [$F(1, 19) = 5.19$, $p < .05$] and Pz [$F(1, 19) = 4.40$, $p = .05$].

The ANOVA performed to evaluate the late right-frontal non-target effect in adults revealed an effect of Condition [$F(1, 19) = 20, 55$, $p < .001$]. A three-way interaction between Condition, AP, and Laterality was also found [$F(8,152) = 2.19$, $p < .05$], indicating that the non-target/new effect was reliable at F4 [$F(1, 19) = 9.4$, $p < .01$] but not at F3 ($p = .07$).

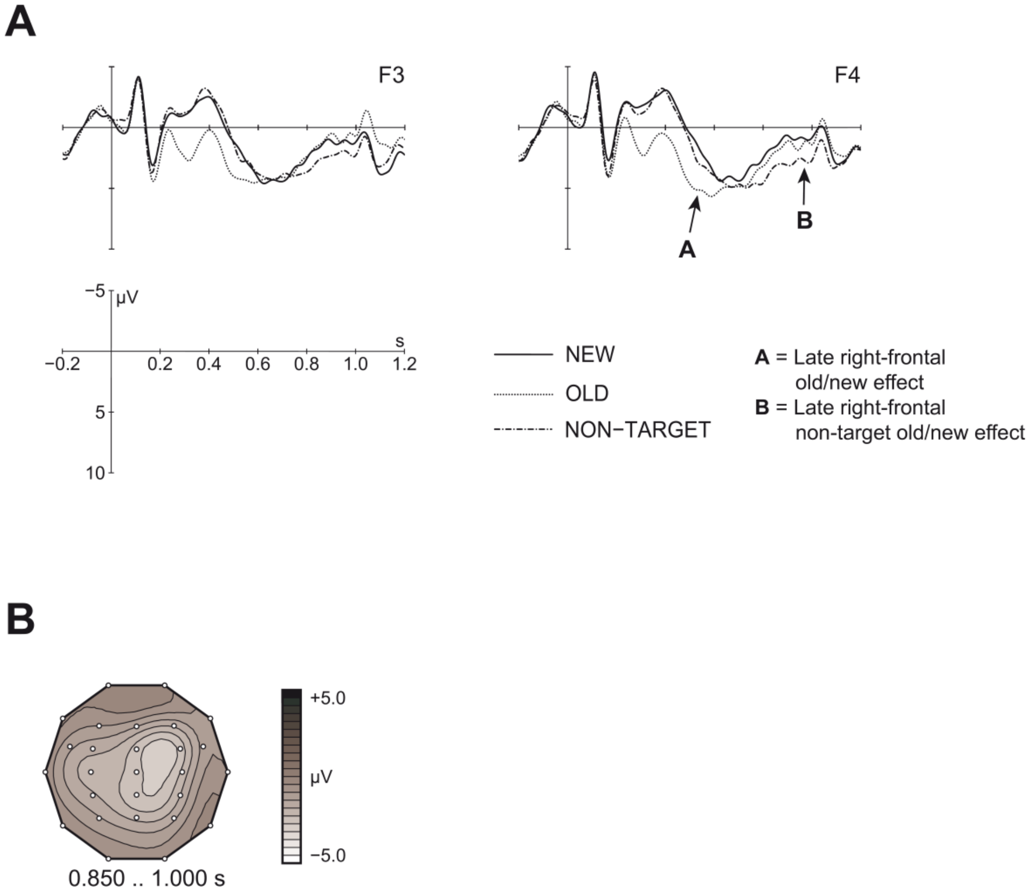

Figure 6. ***(A)*** *ERP waveforms at left-frontal (F3) and right-frontal (F4) electrodes for adults. ERPs to new items are depicted in solid lines, ERPs to old items in dotted lines, and ERPs to non-targets in dashed lines. Arrows at F4 point to right-frontal old/new effect indentified in the item memory task and the source memory task.* ***(B)*** *Scalp topography of the late right-frontal non-target old/new effect for adults in the source memory task. The map was computed on the basis of difference scores obtained by subtracting mean amplitudes of the ERPs elicited by non-target items from those elicited by new items.*

5.1.5 Discussion

The goal of the present investigation was to examine the development of item and source memory and their respective ERP correlates during childhood and adolescence. In addition, it was examined how the frontal negativities in children and adolescents were modulated by the generic novelty of events. The behavioral results regarding item and source memory performance in the three age groups will be discussed first, followed by the ERP effects of generic novelty, and of item and source memory.

5.1.5.1 Behavioral results

Seven-to-eight-year-old children, 13-14-year-old adolescents and young adults performed a continuous recognition memory task in which item memory was tested by the recognition of repeated picture items. Source memory in this paradigm was operationalized in the second run by means of an exclusion task which required discriminating across-run repetitions from within-run repetitions of the pictures. This task addresses the capacity for temporal source monitoring, especially with regard to non-target items repeated across runs (Schnider, 2003). Consistent with the initial prediction, memory performance improved with age and showed distinct age-related changes for item and source memory. As expected, in comparison to adolescents and adults, children showed particularly poor source discrimination abilities.

However, due to the relatively long duration of the experiment, there may have been disproportional effects of fatigue on the children's source memory performance. However, when measured separately for the first, second, and last third of the second experimental run, there was no evidence for Pr_Source to decrease as a function of time for either age group.[2]

The absence of age differences between adolescents and adults in source memory performance was further substantiated by a post-hoc analysis of non-target items repeated with short and long repetition lags. This analysis revealed that the

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[2] For children, the mean values for Pr_Source were .63, .54, and .53 for the first, second, and last third of the run, respectively. For adolescents, the corresponding values were .81, .81, and .81. For adults, the corresponding values were .83, .84, and .87. Although there was some evidence for decreasing source memory performance in children from the first to the last third, an ANOVA with the factors Age (children vs. adolescents vs. adults) and Time On Task (1st third vs. 2nd third vs. last third) neither revealed a main effect of Time On Task (p = .58) nor a significant interaction between Time On Task and Age (p = .17).

high source memory performance in adolescents did not result from enhanced non-target forgetting. This suggests that the adolescents' ability to recollect source information was relatively mature. The implication of these behavioral results will be discussed further in light of the ERP findings.

5.1.5.2 ERP effects of generic novelty

The exploratory analysis of ERP correlates of generic novelty processing revealed that for all age groups, novelty processing was associated with larger negativities to unfamiliar non-objects compared to familiar objects, with this effect being focused at frontal locations. The similarity of this pattern across the age groups suggests little developmental changes in the ERP correlate of generic novelty processing.

Importantly, the topography of the generic novelty effect was different from the ERP effect reflecting immediate novelty processing (the difference between first and second presentation of objects) which showed a more posterior distribution across all age groups (see Figure 5). In this regard, the generic novelty effect bears similarities to the frontal novelty N2 (Folstein & van Petten, 2008). This N2 is more pronounced for generically unfamiliar than for familiar events, even when the latter occur with low probability in the immediate context (Daffner et al., 2000). Thus, the frontal negativity observed across age groups could reflect the allocation of attention to unfamiliar events that have no match in stored object representations.

In children, there was a left-frontal focus of the generic novelty effect that was not evident for adolescents and adults. In mental letter rotation tasks, a similar left lateralized ERP modulation in 7-8-year old children has been taken to reflect a developmental shift from an analytic to a holistic mental rotation strategy in this age range (Heil & Jansen-Osmann, 2007; Jansen-Osmann & Heil, 2007). Thus, though preliminary, it is conceivable that the left lateralization of the generic novelty effect in children reflects a transition towards a more holistic processing mode in visual novelty detection.

5.1.5.3 ERP effects of item memory

Item memory was associated with a P200 repetition effect that exhibited a similar fronto-central topography across age groups. This result is consistent with data reported by Van Strien et al. (2009) who also found P200 effects for verbal material in children which was taken to reflect the processing of visual word forms. Thus, to the extent that the account linking this effect to the matching of perceptual stimulus aspects to stored memory contents is correct (Evans & Federmeier, 2007), the pattern observed here suggests that such processes are fully matured at 8 years of age and also extend to non-verbal information.

With respect to the early and late old/new effects, three developmental differences of note between children and adolescents on the one hand and adults on the other hand were observed. First, while only adults produced a reliable frontal old/new effect reflecting familiarity-based remembering, all age groups showed the ERP correlate of recollection. By this, the current findings add to the existing evidence that recollection-based processes are mature in school-aged children (e.g., Mecklinger et al., 2011). Frontal old/new effects in children and adolescents were less evident in the current study, a finding which is consistent with previous studies that found no ERP evidence of familiarity-based remembering in children in standard item memory tasks (e.g., Czernochowski et al., 2009). However, these findings are difficult to reconcile with studies using behavioral dual-process measures, which suggest that familiarity is available for children within the age range of the current study (Billingsley et al., 2002; Ghetti & Angelini, 2008; Ofen et al., 2007) and even for pre-school children (Anooshian, 1999).

A possible reason for this discrepancy may be that the majority of previous ERP studies with children were not sensitive enough to dissociate the ERP correlates of recollection and familiarity. For example, the current study as well as others that have used continuous recognition paradigms (Czernochowski et al., 2009; Hepworth et al., 2001; van Strien et al., 2009) employed highly familiar stimuli materials, for which the ERP correlate of familiarity is less reliably observed (Stenberg et al., 2008). Thus, due to a combination of relatively short retention intervals and high stimulus familiarity, familiarity may not have been sufficiently diagnostic to inform children's recognition judgments. Consistent with this suggestion, the ERP correlate of familiarity has been observed in school-aged children when an adequate operational definition of familiarity, derived from its temporal dynamics, was employed (Mecklinger et al., 2011).

However, some of the available evidence nonetheless suggests, at least to some extent, a developmental change in familiarity-based processing in late childhood. Using a memory task in which unfamiliar symbols were repeatedly studied and tested over four cycles, Friedman et al. (2010) observed similar mid-frontal old/new effects in 13-14-year-old adolescents and adults but not in 9-10-year old children. The absence of familiarity in children was also reflected by lower behavioral estimates of familiarity compared to adults. Thus, at least in some task situations, children appear to recruit familiarity-based processes for their memory decisions to a lesser extent than either adolescents or adults do. It remains to be determined whether the development of recognition memory is related to an increasing flexibility in the ability to use different retrieval processes with age.

The second observation was that children and adolescents showed an early parietal old/new effect presumably reflecting the early onset of recollection-based processes. Early onsetting recollective activity also occurred in the Friedman et al. (2010) study following multiple item repetitions. It is conceivable that in the present study recollection occurred earlier because participants may have used conceptual as well as perceptual retrieval cues (colored line drawings of objects). These presumably enhanced recollective processing and memory performance in children and adolescents. Thus, facilitated recollection supported by multiple retrieval cues may account for the early onsetting ERP correlate of recollection in children and adolescents.

Finally, the topographical distribution of the late old/new effect differed as a function of age. Children and adolescents showed the parietal topography often observed in developmental studies (Czernochowski et al., 2004, 2009). For adults, the late old/new effect showed an unexpected right-frontal accentuation. This suggests that recollective processing in adults was temporally overlapped with post-retrieval monitoring processes (Hayama et al., 2008). As this right-frontal positivity was not present in children and adolescents, it is possible that the adult‘s stronger use of familiarity relative to these groups increased response uncertainty and the need for monitoring memory decisions.

5.1.5.4 ERP effects of source memory

The examination of non-target ERP old/new effects revealed evidence for developmental changes across all age groups in the neural correlates of source memory. A parietal non-target old/new effect, the ERP correlate of strategic recollection, was obtained for adolescents and adults but not for children. This pattern closely parallels the age differences in source memory performance observed in this study. By this, the present study replicates previous findings that the ability to strategically recollect source information is less matured in pre-adolescent children (Czernochowski et al., 2009, 2005). Most notably however, the present results, based on the combined analysis of changes in behavioural performance and neural activity, extend previous findings as they suggest that strategic retrieval processes greatly improve in late childhood and emerge with adolescence. In this way, the approach followed here has revealed a close correspondence between functional changes in source memory and those which have been suggested to occur in other domains of cognitive control in this age range (Paus, 2005). This suggestion is attested to by studies which have demonstrated that the transition from childhood to adolescence is marked by strong improvements in inhibitory control in the oculomotor domain (Munoz, Broughton, Goldring, & Armstrong, 1998; Williams, Ponesse, Schachar, Logan, & Tannock, 1999).

Notwithstanding this suggestion, an important finding of the current study is that the very pattern of ERP effects in adults was neither observed in children nor in adolescents. That is, while the non-target old/new effect showed the expected centro-parietal distribution in adults, this effect was topographically more diffuse in adolescents. Above all, however, only adults showed the putative ERP correlate of post-retrieval monitoring (i.e., the late right-frontal non-target old/new effect), consistent with previous reports of prolonged maturation in post-retrieval control processes (de Chastelaine et al., 2007). However, one caveat to the latter suggestion is raised by the fact that in the present study there is no evidence that the effect observed in the adults' ERPs is related to control processes governing the behavioural output.

Therefore, in order to provide support for the interpretation of the late non-target effect favoured here, the effect was analyzed separately for non-targets repeated with short and long repetition lag (see Behavioral Results section). The behavioral analysis reported above has revealed that long-lag non-targets elicited a greater proportion of incorrect responses (.13) and longer response times (659 ms) compared to short-lag non-targets (.04; 583 ms) for adults. This suggests that long-lag non-targets were associated with relatively higher response uncertainty and also with higher monitoring demands. Accordingly, it was hypothesized that the right-frontal old/new effect between 850 and 1000 ms would be larger for long-lag compared to short-lag non-targets.

This hypothesis was confirmed by an analysis of non-target ERPs averaged separately for long-lag and short-lag items. After excluding two participants due to low trial numbers, the ANOVA with the factors Condition (new vs. non-target), AP (frontal vs. central vs. parietal), and Laterality (5 levels) revealed a reliable three-way interaction for long-lag non-targets [$F(8, 136) = 2.59$, $p < .05$]. As illustrated in Figure 7, this interaction reflects the fact that long-lag non-target ERPs were reliably more positive-going than new items at right-frontal (F8, F4: *p* values < .05) but not at left-frontal sites (F7, F3: *p* values > .11). Conversely, for short-lag non-targets, a Condition by Laterality interaction [$F(4, 68) = 6.12$, $p < .01$] indicated that a reliable old/new difference was only present across midline electrodes [$F(1, 17) = 5.66$, $p < .05$]. This outcome confirms the prediction that the late right-frontal effect is modulated by non-target repetition lag and is linked to behavioral performance in a way which supports the view that it is related to post-retrieval monitoring demands and coping with response uncertainty (Hayama et al., 2008).

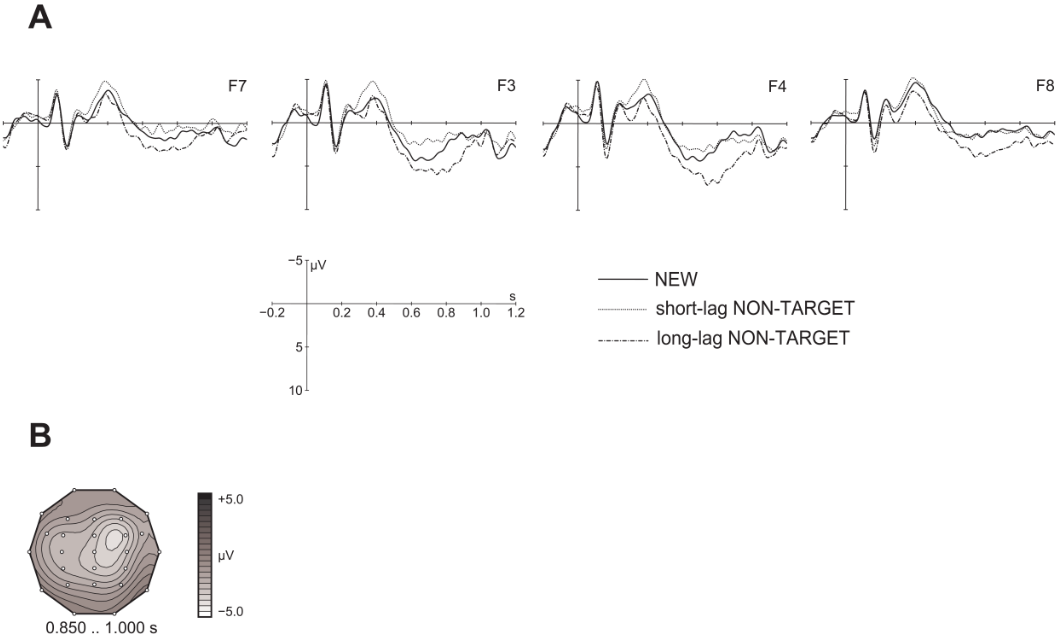

Figure 7. (A) *ERP waveforms associated with correct judgments to new items, short-lag non-targets, and long-lag non-targets at left-frontal (F7, F3) and right-frontal (F4, F8) electrodes for adults (N = 18). The figure shows that only long-lag non-targets were associated with a right-frontal old/new effect between 850 and 1000 ms.* ***(B)*** *Scalp topography of the late right-frontal old/new effect for long-lag non-targets observed for adults. The map was computed on the basis of difference scores obtained by subtracting mean amplitudes of the ERPs elicited by long-lag non-targets from those elicited by new items.*

These latter results, together with the absence of this effect for adolescents, are compatible with the view that neural development is characterized by increased localization of activity to those brain regions that are functionally relevant for task performance (Durston et al., 2006). Most notably however, given the adolescents' relatively mature behavioral performance, the present findings suggest a developmental change in strategic retrieval processing that would not have been uncovered by using behavioral data alone. Consistent with this suggestion are results reported by de Chastelaine et al. (2007) who used response-locked ERPs to investigate the development of post-retrieval control processes. As was the case with the present findings, no significant age differences in source discrimination between 13-year-old adolescents and adults were evident in the latter study, however, a target positivity prior to the response showed a right-frontal distribution in adults and was evenly distributed in adolescents. In line with the present results, this result points to the maturation and refinement of the neural systems supporting post-retrieval control, changes which are not necessarily accompanied by improvements in memory performance.

Taken together, while source recollection in adults was associated with two temporally and topographically distinct ERP effects, adolescents lacked this refined pattern of activity, presumably reflecting structural and functional immaturity in the network underlying strategic retrieval processing. This is in line with the view that following steep improvements in late childhood, cognitive control continues to functionally mature throughout adolescence well into adulthood (Best & Miller, 2010). An important endeavour for future research is to explore the conditions under which these changes lead to parallel changes in the behavioral and neural correlates of source memory.

5.1.5.5 Conclusions

The present findings provide further evidence for distinct developmental trajectories of item and source memory. The ERP old/new effects in adults suggested the presence of recollection and familiarity during item recognition and the use of control processes for item and source memory retrieval. The ERP effects in children and adolescents reflected a strong reliance on recollection-based processes for item recognition, while familiarity-based processes were attenuated. The development of source memory was reflected by an increase in strategic recollection between childhood and adolescence. Developmental changes in source memory during adolescence were borne out in terms of increasing topographic distinctness of the ERP correlate of strategic recollection and the electrophysiological manifestation of post-retrieval monitoring. It therefore appears that the network underlying strategic retrieval is available for young adolescents but still lacks the refinement to support post-retrieval processing as evident in the adult system.

5.1.6 Open issues

An open issue concerns the exact nature of the development of strategic retrieval processes during adolescence. In light of the extant evidence that the control processes supporting strategic retrieval do not reach maturity before mid-adolescence (e.g. Luna et al., 2004), one might have expected that specialization of cognitive control circuitries goes in parallel with at least some improvement in source memory performance and also greater change in the ERP correlate of strategic recollection. Although the more widespread distribution of the ERP non-target old/new effect in adolescents could be an indication of greater retrieval effort exerted, one explanation for the adolescents' relatively mature behavioral and ERP correlates of source recollection could be derived from evidence that prefrontal functions that demand high levels of executive control mature later than those requiring less control (Best & Miller, 2010). For example, Luciana et al. (2005) found that basic WM maintenance processes matured around 11 years, whereas high-demand strategic WM operations improved until age 16.

Therefore, one possibility is that recollecting non-targets in the current paradigm required only moderate amounts of cognitive resources in adolescents, given that the contexts associated with non-targets and targets were temporally clearly segregated (i.e. 1st vs. 2nd experimental run). This temporal segregation could have increased target/non-target distinctiveness and thus facilitated strategic recollection (Herron & Wilding, 2005). It is also possible that the requirement to discriminate across-run from within-run item repetitions has encouraged participants to employ recency information for this discrimination as opposed to temporal context information, which additionally might have facilitated source discrimination. In fact, the current task has previously been used to investigate more severe memory impairments observable in children (Czernochowski et al., 2009) and confabulating patients (Schnider & Ptak, 1999), and while the paradigm's suitability for such purposes has been confirmed here, it might be the case that it is not sensitive enough to detect changes in strategic recollection during adolescence.

A further argument here is a particularly interesting possibility to investigate, since strategic retrieval has been conceptualized as a retrieval orientation, the consequence of which is prioritization of recollection of one form of mnemonic content over other forms (Herron & Rugg, 2003b). As outlined above (see section 1.3.2), it has been argued that binary source judgments in exclusion tasks can be made by adopting a strategy which is based on selective retrieval of information about targets only, and this kind of selective recollection has been related to the availability of cognitive control resources (Wilding & Herron, 2006). This in turn makes selective retrieval processing valuable for addressing developmental issues. Therefore, the maturation of memory control processes observed here may translate into age differences in behavior and in ERP indices of source recollection when task difficulty is increased and/or when a more stringent operational definition of strategic recollection is used.

5.2 Study 2

Electrophysiological Evidence for Late Maturation of Strategic Episodic Retrieval Processes[3]

5.2.1 Background and rationale

Study 1 has revealed a developmental difference between adolescents and adults in the ERP correlates of source memory that was predominantly evident at the post-retrieval processing stage of retrieval processing. This leaves open the question as to whether maturation also occurs in strategic recollection. The present study addressed this question by means of a paradigm in which strategic retrieval was defined as prioritization of recollection of task-relevant (target) information over irrelevant (non-target) information, a retrieval strategy that has been suggested to put particular demands on cognitive control (Wilding & Herron, 2006). This latter view receives support from data showing a positive correlation between the magnitude of the ERP index of target-selective recollection in an exclusion task and WMC as an estimate of cognitive control resources (Elward & Wilding, 2010). Moreover, WMC has been taken as an index of resources available for cognitive inhibition (Conway & Engle, 1994), which allows for the possibility that the processes that serve to implement selective retrieval strategies improve along with cognitive inhibitory control resources during adolescence.

The approach followed here allows for addressing an issue that has not yet been addressed in ERP studies on memory development before, namely, the effects of task demands on developmental differences in source recollection. As outlined above (see section 1.3.2), it has been argued that target-selective retrieval strategies are most likely to be implemented when target memories are sufficiently reliable to support such a strategy (Herron & Rugg, 2003b). Support for this argument has been adduced from findings that ERP evidence for target-selective retrieval processing is

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[3] The data reported in this study are also reported in the following article: Sprondel, V., Kipp, K.H., & Mecklinger, A. (in press). Electrophysiological Evidence for Late Maturation of Strategic Episodic Retrieval Processes. *Developmental Science.*

most likely to be observed when memory for targets is relatively high (Fraser et al., 2007). Additional ERP data have helped to refine this view, with the findings suggesting that target-specific retrieval strategies are also facilitated when targets and non-targets are sufficiently distinct, such as when targets are studied in an elaborative encoding task (Herron & Wilding, 2005).

Thus, the rationale for the present study is as follows: On the basis of the protracted maturation of cognitive control functions (Luna et al., 2010), capacities for selective retrieval processing can be expected to be generally less matured in young adolescents compared to young adults. Nonetheless, adolescents may show ERP evidence for target-selective recollection when target discriminability is relatively high. This latter possibility is based on the proposal that in easier test situations (when target accuracy is high), a greater amount of cognitive resources is available in order to exert the kind of control which is necessary for the prioritization of target recollection (Elward & Wilding, 2010).

To adjudicate between these accounts, adolescents in the same age range as in Study 1 (i.e. 13-14 years) were compared to young adults with regard to their neural correlates of target-selective recollection, as measured through ERP old/new effects for targets and non-targets. The difficulty of target/non-target discrimination was varied across two conditions of a memory exclusion task. In both conditions, target/non-target judgments were made for words according to the color in which they had been studied, but in the easy condition shorter study and tests lists and a smaller degree of similarity between the study colors as compared to the difficult condition were used. In addition, in order to encourage target-selective retrieval processing in both adults and adolescents, an elaborative encoding task was used for all study words.

In order to further explore the development of strategic recollection, the relationship between an estimate of WMC and the parietal ERP amplitude difference between targets and non-targets was determined for both age groups. Under the assumption that this ERP measure indexes the degree to which strategic retrieval processing is engaged (Elward & Wilding, 2010), it was considered informative as to whether it would be differentially related to WMC in adolescents and adults. As such, an age-related difference in this association could be a reflection of changes in the ability to allocate cognitive control resources to strategic recollection.

5.2.2 Hypotheses

The manipulation of task difficulty was expected to result in a higher likelihood to discriminate targets from non-targets in the easy compared to the difficult condition for both age groups. Furthermore, adults were expected to perform more accurately in target/non-target discrimination than adolescents. This latter prediction is based on the fact that in the present study targets and non-targets were presented in an intermixed fashion within the same study phases, possibly resulting in a smaller degree of source distinctiveness and thus higher task difficulty as compared to Study 1.

Regarding the neural correlates of this developmental difference, for adults, parietal ERP old/new effects for targets were expected for both difficulty conditions. Conversely, non-target effects, if they occur, should be restricted to the difficult condition for adults. By contrast, adolescents were expected to show parietal old/new effects for targets and non-targets in both difficulty conditions, supporting the view that the neural network supporting target-selective recollection is generally immature at that age. However, it is also conceivable that adolescents show evidence of non-target recollection in the difficult but not in the easy condition, indicating that the network is mature enough to support tasks with high target discriminability. In keeping with the outcomes of Study 1, right-frontal ERP old/new effects reflecting post-retrieval monitoring should occur in adults but not in adolescents. Likewise, LPNs were expected to occur in adults, consistent with previous ERP memory studies in which color information was used as the source defining feature (e.g. Cycowicz et al., 2001). For adolescents, LPN effects should be less consistently present or should exhibit a different topography, consistent with previous results suggesting refinements in the networks underlying the processes reflected by the LPN (Cycowicz et al., 2003).

Finally, while the magnitude of the parietal ERP target/non-target difference was expected to correlate positively with WMC in both difficulty conditions for adults, an interesting issue to explore is whether this kind of relationship would also be observed for adolescents.

5.2.3 Method

5.2.3.1 Participants

Twenty-six adolescents and twenty-four young adults participated in the study. The data of eight adolescents and four adults were discarded due to insufficient trials in at least one response category, resulting from a combination of low performance levels and excessive movement artifacts. Thus, eighteen 13-14-year-old adolescents (*M* = 13.44, *SD* = .51; 8 male), and twenty 19-29-year-old adults (*M* = 24.10, *SD* = 2.80; 11 male) were included in the analysis. All participants were native German speakers, right-handed, had normal or corrected-to-normal vision, and reported not to suffer from color blindness. Adolescents were recruited from the immediate vicinity. Adults were undergraduate students from Saarland University. Participants (respectively adolescents' parents) gave informed consent and received € 8/hour for participation.

5.2.3.2 Stimuli

Exclusion task

The stimuli comprised high-frequency words (CELEX psycholinguistic database: >7/million) denoting concrete objects. Words ranged between three and ten letters in length; 180 words were used in the difficult condition and 150 words were used in the easy condition. Words were presented in colored letters in the study phases and white letters in the test phases on a black background at the center of a monitor 1 m from participants.

WMC measurement

WMC was measured by means of an operation span task (Turner & Engle, 1989). Stimuli consisted of 42 arithmetic operations, followed by a word, such as "Is (8/2) – 2 = 1? Wire". Participants were asked to read the equation aloud, to indicate whether the solution was correct and then to read the word aloud while remembering it for a later recall test. Each test required recall of words presented in one of 12 items, with 3 items each consisting of two, three, four, and five operation-words pairs, presented in random order. For scoring, partial-credit load scoring by which one point is awarded for every correctly recalled word was used (Conway et al., 2005). The maximum possible score was 42.

5.2.3.3 Design and procedure

The manipulation of task difficulty was blocked in the experiment, so that the difficult and the easy conditions were completed in two successive sessions. The order of these sessions was counterbalanced across participants. In the difficult condition, the 180 words were equally distributed between six study-test cycles, each containing 20 study words (10 target and 10 non-target words) and 30 test words (20 old and 10 new words). In the easy condition, the 150 words were equally distributed between 10 study-test cycles, each containing 10 study words (5 target and 5 non-target words) and 15 test words (10 old and 5 new words). In both conditions, the words were rotated to ensure that each word served equally often as target, non-target, and new word across participants. By this, three different task-lists were created for both conditions which were completed by an equal number of participants. The order of word presentation in all study and test phases was determined randomly for each task-list.

The colors in which the words were presented during the study phases were set at a level that ensured that the perceptual target/non-target distinctiveness was lower in the difficult compared to the easy condition. Therefore, words in the difficult condition were presented in either pink (RGB: 255-0-120) or red (RGB: 255-0-0), and words in the easy condition were presented in either pink (RGB: 255-0-120) or green (RGB: 0-176-80). In both conditions, the color to designate target words was the same in half of the study-test cycles (3 in difficult and 5 in easy). To control for the number of times in which response requirements changed from one study-test-cycle to the subsequent cycle, two fixed sequences of target color were created for both conditions (Difficult: red-pink-pink-red-red-pink and pink-red-red-pink-pink-red; Easy: green-green-green-pink-pink-pink-green-green-pink-pink and pink-pink-pink-green-green-green-pink-pink-green-green). These sequences were counterbalanced across participants.

Participants were fitted with an electrode cap before the experiment. A practice phase with 15 additional words was used to familiarize participants with the task instructions. They were informed that there are several study-test cycles in which they would have to remember the colors of previously learned words. The to-be-discriminated colors were announced prior to each of the two sessions which were separated by a 3 min break. In each study phase, participants were asked to vividly image each object in the same color as the denoting word was presented and to rate via key press whether or not the object was plausible in this color. A 4-point scale was used for this judgment: 1 = “very realistic”, 4 = “very unrealistic”. For the test phases, they were instructed to respond with one hand to words previously presented in the target color (targets) and to respond with the other hand to words presented in the other color (non-targets) as well as to new words. Responses were made on a response box with the left and right index fingers, and response hands were counterbalanced across participants. They were informed that the target color would be revealed at the start of each test phase and might differ across cycles. Participants were encouraged to balance speed and accuracy of their responses equally.

Study trials began with a fixation cross (300 ms), followed by a blank screen (200 ms) after which the study word was presented (600 ms). The screen was then blanked for 2300 ms during which participants made the plausibility judgment. There was an interval of approximately 1 min between each study and test phase, during which participants performed a counting task (40 sec) and were informed about the target color for the test phase (10 sec).

Test trials also began with a fixation cross (300 ms), followed by a 200 ms baseline blank screen period. Test words were presented for 400 ms after which the screen was blanked. Responses were recorded within 2000 ms after stimulus onset, and the next trial began 1000 ms after the response.

After the experiment, participants completed a color discrimination task in which the color of a stimulus (XXXXX) presented on black background had to be indicated via key press. There were two successive blocks, requiring either pink/red or pink/green judgments. The RGB codes used for these colors were the same as in the memory task, as was the way in which the order of the blocks was counterbalanced across participants. Each block contained 40 trials, half of which were presented in one color and the remainder in the alternate color. Trials began with the stimulus (400 ms), followed by a 1100 ms blank screen period during which participants made the response. After another 400 ms, the following trial began. Task instructions emphasized speed and accuracy equally. Finally, the Operation Span task was administered to participants. The whole session lasted for approximately two hours.

5.2.3.4 EEG recording

EEG was recorded from 27 Ag/AgCl- electrodes located at the following sites (adapted from the standard 10-20 system): FP1, FP2, F7, F3, FZ, F4, F8, FC5, FC3, FCZ, FC4, FC6, T7, C3, CZ, C4, T8, CP3, CPZ, CP4, P7, P3, PZ, P4, P8, O1, O2. Electrode impedance was kept below 5 kΩ. EEG was acquired continuously at 500 Hz with the left mastoid as the reference electrode, and was re-referenced offline to the average of both mastoids. EOG was recorded from above and below the right eye and from the outer canthi of both eyes. EOG artifacts were corrected using a linear regression estimate (Gratton et al., 1983), whereas trials containing muscular and/or technical artifacts were rejected. The epoch lengths were 1400 ms for adults and 1700 ms for adolescents, including in each case a 200 ms prestimulus baseline relative to which all mean amplitudes were computed.

Averaged ERPs were formed for correct judgments at test to target, non-target, and new words for each participant in each condition. In both conditions, the ERPs were collapsed across target color. For adults, the mean trial numbers (range) for target, non-target, and new words were: difficult, 36 (19-52), 36 (20-50), 50 (39-58); easy, 35 (26-47), 32 (19-45), 43 (36-50). The equivalent values for adolescents were: difficult, 28 (16-49), 26 (16-46), 40 (21-56); easy, 28 (16-44), 27 (16-42), 37 (18-48).

5.2.3.5 Data analyses

All trials in which no response was given were discarded from behavioral analysis. In keeping with the analyses in Study 1, memory accuracy was defined as Pr (Snodgrass & Corwin, 1988) where Pr = p(target hit) – p(false alarm). For target/non-target discrimination (Pr_Source), p(false alarm) was the proportion of false alarms to non-targets. A target/new discrimination index (Pr_New) was also calculated, where p(false alarm) was the proportion of false alarms to new items. This index was used to compute response bias, defined as Br = p(new false alarm) / 1 – Pr_New (Snodgrass & Corwin, 1988).

ERP effects were explored in a series of analyses of mean amplitudes of ERPs to targets, non-targets, and new items from 9 electrodes (F3, FZ, F4, C3, CZ, C4, P3, PZ, P4). These electrodes were grouped into anterior/posterior (AP: frontal, central, parietal) and Laterality (left, midline, right) factors in all analyses. They were conducted separately for each of the successive time-windows, selected according to the epochs in which ERP old/new effects have been observed previously (e.g. Wilding et al., 2005) as well as to capture the differences between age groups that became evident from visually inspecting the waveforms. For both age groups, the early frontal and the parietal old/new effects were evaluated from 300 to 500 ms, respectively from 500 to 700 ms. Further analyses from 700 to 900 ms and 900 to 1200 ms were conducted to evaluate the prolonged parietal positivities in adolescents as well as the late posterior negativities and right-frontal effects in adults. To evaluate these latter old/new effects in adolescents, visual inspection of the ERPs suggested an additional analysis between 1200 and 1500 ms for this age group.

Behavioral and ERP data were analyzed using ANOVAs for repeated-measures including the factors Age (adults, adolescents), Difficulty (difficult, easy), and, except for the analyses of memory accuracy and response bias, the factor Item Type (IT; target, non-target, new). Effects that did not involve the IT factor are not reported. All analyses included Greenhouse-Geisser corrections for nonsphericity, and where necessary corrected p values are reported (Greenhouse & Geisser, 1959).

5.2.4 Results

5.2.4.1 Behavioral data

The mean values of Operation Span scores were 27.75 (*SD* = 7.28) for adults and 25.22 (*SD* = 6.25) for adolescents. A one-way ANOVA revealed no age differences in these scores (*p* = .26).

The probabilities of correct color discrimination judgments were statistically equivalent between the pink/red and the pink/green blocks for both adolescents (pink/red: *M* = .95, *SD* = .04; pink/green: *M* = .96, *SD* = .04) and adults (pink/red: *M* = .96, *SD* = .04; pink/green: *M* = .98, *SD* = .03), as assessed by separate ANOVAs for both age groups (*p* values > .11). These analyses were conducted to ensure that effects of the difficulty manipulation on behavioral and ERP data can be attributed to the ease of memory retrieval rather than to differences in perceptual discriminability. Therefore, the pattern obtained here suggests that these difficulty effects are unlikely to reflect differences in color discrimination.

Table 2 shows probabilities and RTs of correct responses to targets, non-targets, and new words in the difficult and easy conditions for both age groups. To analyze age differences in memory accuracy and response bias, Pr_Source, Pr_New, and Br were subjected to separate ANOVAs with the factors Age and Difficulty. The analyses of memory accuracy revealed that adults performed better than adolescents, as reflected in main effects of age for Pr_Source [F(1,36) = 6.54, *p* < .05] and Pr_New [F(1,36) = 4.08, *p* = .05]. Main effects of Difficulty [F(1,36) = 25.00, *p* < .001 and F(1,36) = 17.52, *p* < .001 for Pr_Source and Pr_New, respectively], indicated that, across age groups, memory accuracy was higher in the easy than in the difficult condition. The analysis of response bias revealed no significant effects (*p* values > .653).

For the RT data, an ANOVA with the factors Age, Difficulty, and IT revealed main effects of IT [F(2,72) = 100.43, *p* < .001] and Difficulty [F(1,36) = 8.33, *p* < .01] as well as an interaction between these two factors [F(2,72) = 6.05, *p* < .01]. Follow-up analyses revealed that new words yielded faster responses than targets and non-targets in both conditions (*p* values < .001). Target responses were faster than non-target responses in the easy ($p < .001$) but not in the difficult condition ($p = .12$). Compared to the difficult condition, the easy condition yielded faster responses to targets and new words (p values < .001) but not to non-targets ($p = .86$).

Table 2. Memory performance data of both age groups in both conditions

	Adults		Adolescents	
	Difficult	Easy	Difficult	Easy
p(correct)				
Targets	.81 (.11)	.87 (.09)	.73 (.12)	.81 (.11)
Non-Targets	.76 (.12)	.81 (.14)	.67 (.13)	.75 (.12)
New	.96 (.04)	.98 (.02)	.96 (.03)	.97 (.03)
Pr_Source	.57 (.19)	.68 (.19)	.40 (.18)	.57 (.21)
Pr_New	.77 (.13)	.84 (.10)	.69 (.12)	.79 (.12)
Br	.17 (.09)	.16 (.08)	.15 (.17)	.14 (.13)
RT (ms)				
Targets	906 (141)	860 (161)	937 (152)	889 (136)
Non-Targets	937 (145)	939 (200)	941 (170)	933 (117)
New	748 (107)	716 (109)	797 (158)	756 (118)

Note. Memory accuracy was calculated with regard to non-targets [Pr_Source = p(target hits) - p(non-target false alarms] and new items [Pr_New = p(target hits) - p(new item false alarms]. Response bias was calculated with regard to new items [Br = p(new item false alarms] / (1 - Pr_New)]. Reaction times are given for correct responses to new, non-target, and target items. Standard deviations of means are given in parentheses.

To summarize the behavioral data, consistent with the expectation, the likelihood to discriminate targets from non-targets and new words increased with decreasing task difficulty for both age groups and also improved with age in both difficulty conditions. No such differences were evident for response bias. In terms of RTs, there were no age differences in the processing of targets, non-targets, and new items. Both age groups responded faster in the easy than in the difficult condition to targets and new words but not to non-targets.

5.2.4.2 ERP data

Figures 8A and 8B show the ERPs from 9 selected recording sites in the difficult and the easy conditions for adolescents and adults, respectively. The figures show the ERPs elicited by correct judgments to target, non-target, and new words. Between 300 and 500 ms, both age groups showed more positive waveforms for old (targets and non-targets) relative to new words at frontal sites in both conditions. From 500 to 700 ms, adults showed more positive-going ERPs for targets relative to non-targets and new words at parietal sites. An additional positivity for non-targets was seen at frontal sites between 500 and 700 ms in the difficult condition. In adolescents, parietal positivities were present for both targets and non-targets and exhibited a prolonged temporal course. From 900 to 1200 ms, adults showed right-frontal old/new effects for targets, accompanied by greater negativities (LPN) for old relative to new words at parietal locations. In adolescents, these effects appeared to be delayed by about 300 ms.

Figures 9A and 9B shows the scalp distributions of the ERP old/new effects for targets and for non-targets in both conditions over 3 time-windows: 300-500 ms and 500-700 ms to capture the early frontal and the parietal old/new effects, in addition to 900-1200 ms for adults, respectively 1200-1500 ms for adolescents, to capture the late posterior negativities and right-frontal effects.

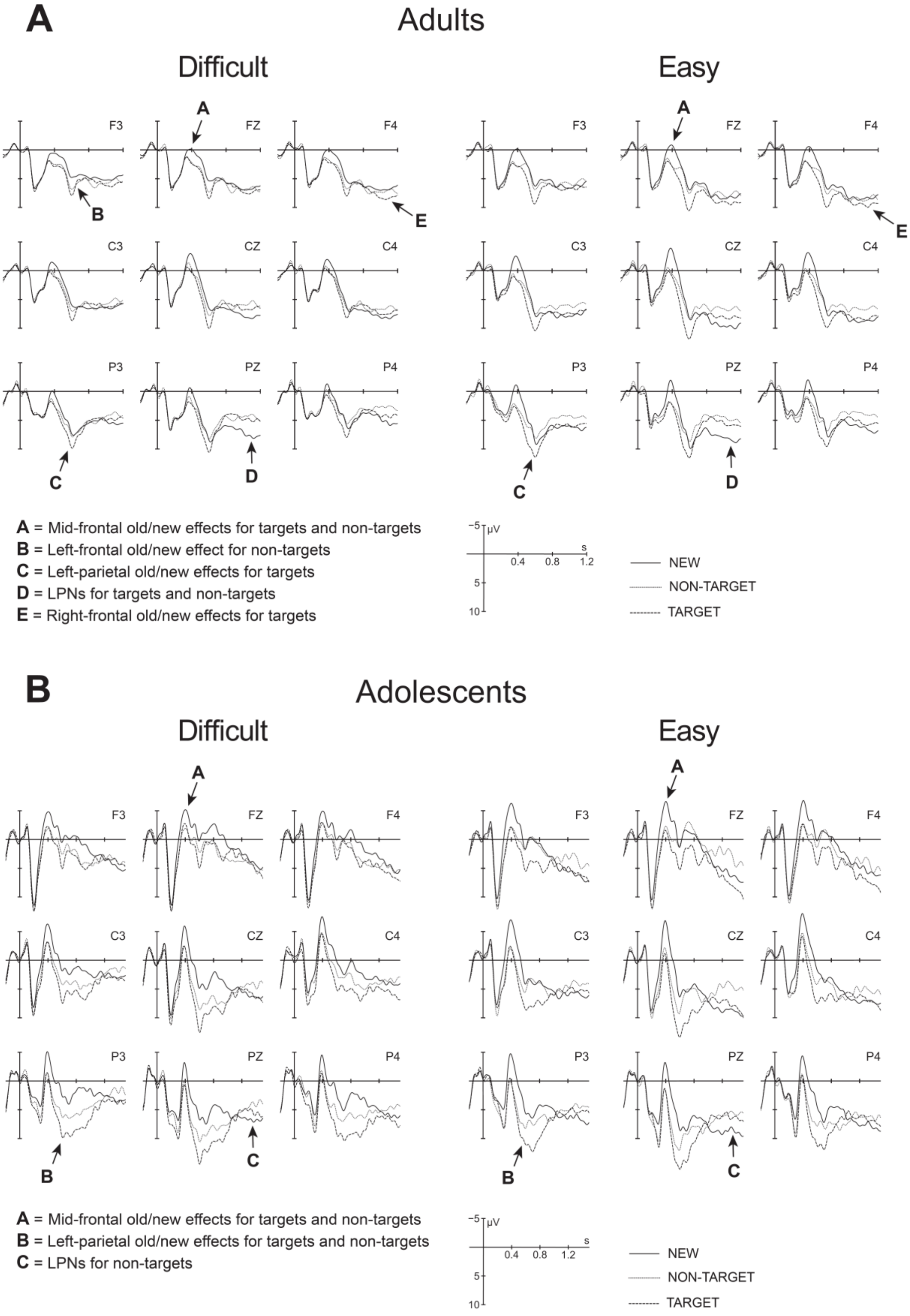

Figure 8. *Grand average ERPs elicited by correct judgments to targets, non-targets, and new words for* ***(A)*** *adults and* ***(B)*** *adolescents in both difficulty conditions. The ERPs are shown at nine electrodes (frontal: F3, Fz, F4; central: C3, Cz, C4; parietal: P3, Pz, P4). Note the different time scaling in both age groups. Arrows indicate the ERP effects identified in both age groups, and the letters (A-E in A; A-C in B) indicate the type of ERP effect along the time axis of processing.*

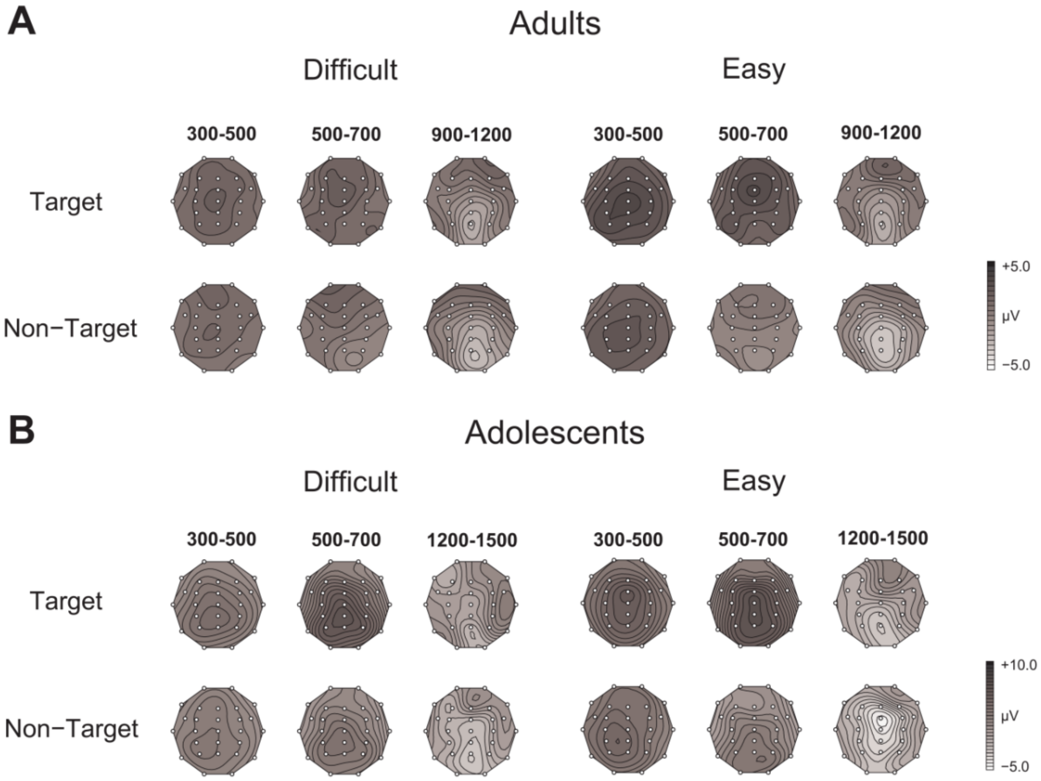

Figure 9. *Topographic maps showing the scalp distributions of the ERP old/new effects for targets and for non-targets for adults (A) and adolescents (B) in both difficulty conditions. All maps were computed on the basis of difference scores obtained by subtracting mean amplitudes of the ERPs elicited by new words from those elicited by targets and non-targets.* ***(A)*** *Data are shown for the 300-500, 500-700, and 900-1200 ms time-windows.* ***(B)*** *Data are shown for the 300-500, 500-700, and 1200-1500 ms time-windows.*

Analyses of age differences in ERP effects

For each of the 300-500, 500-700, 700-900, and 900-1200 ms time windows, an initial analysis incorporated data from both age groups (Age) and conditions (Difficulty), in addition to the factors of IT, AP, and Laterality. Each of the analyses revealed interactions between Age and IT [300-500 ms: F(2,72) = 5.38, $p < .01$; 500-700 ms: F(2,72) = 6.36, $p < .01$; 700-900 ms: F(2,72) = 10.51, $p < .001$; 900-1200 ms: F(2,72) = 3.25, $p < .05$]. The age-specific profiles of ERP effects were then established by separate analyses for each age group and time-window, in addition to the 1200-1500 ms interval for the adolescents. These analyses included the factors of Difficulty, IT, AP, and Laterality, and were followed-up with subsidiary paired contrasts of the ERPs to targets, non-targets and new items. An overview of the outcomes of these contrasts is provided by Tables 3 and 4 for adults and adolescents, respectively. The following description of the age-specific analyses is restricted to the highest-order interactions that were obtained in each case.

Adults

Between 300 and 500 ms, the initial ANOVA revealed a four-way interaction between Difficulty, IT, AP, and Laterality [F(8,152) = 2.28, $p < .05$]. Follow-up contrasts revealed robust early old/new effects for targets and non-targets across locations in both conditions. In the easy condition, the target old/new effect exhibited a maximum at CZ, as indicated by the three-way interaction. The target/non-target contrast revealed a widespread target positivity in the easy condition, while no significant differences were obtained in the difficult condition.

Between 500 and 700 ms, a Difficulty x IT interaction was obtained in the initial ANOVA [F(2,38) = 5.07, $p < .05$]. Subsidiary target/new contrasts revealed three-way interactions in both conditions, indicating that target positivities exhibited a mid-central (CZ) maximum and an additional left-parietal elevation at P3 (see Figure 8A). The non-target/new contrasts revealed no significant effects in the easy condition (*p* values >.38), whereas in the difficult condition a reliable non-target/new difference was found across frontal sites ($p < .05$). As reflected by the marginal three-way interaction, this effect was particularly pronounced at F3 (see Figure 8A). The target/non-target contrasts revealed an IT x AP interaction in the difficult condition, reflecting greater target positivities at parietal sites ($p < .05$). In the easy condition, this target/non-target effect was found across locations.

From 700 to 900 ms, a marginal four-way interaction between Difficulty, IT, AP, and Laterality [F(8,152) = 2.25, $p = .07$] was revealed in the initial ANOVA. No reliable ERP difference was obtained in any contrast (*p* values > .16).

For the 900-1200 ms time-window, the initial ANOVA revealed no interactions involving Difficulty and IT (*p* values > .16). Therefore, follow-up contrasts were collapsed across conditions. Both old/new contrasts revealed three-way interactions, reflecting reliable negativities for targets and non-targets with a maximum at PZ (*p* values < .01). These effects were accompanied by robust right-frontal old/new effects for targets at F4 (*p* < .05). The target/non-target contrast revealed greater negativities for non-targets across electrodes.

To summarize, early frontal old/new effects, the putative ERP correlate of familiarity, were present for targets and non-targets in both difficulty conditions. Conversely, left-parietal old/new effects, the ERP correlate of recollection, were elicited by targets only. Notably, no ERP correlates of non-target recollection were obtained in either condition, suggesting that adults pursued a target-selective retrieval strategy in both conditions. However, the results nevertheless suggest that the processing of non-targets was influenced by task difficulty, as evidenced by a selective non-target old/new effect between 500 and 700 ms with an unexpected frontal topography in the difficult condition. From 900 to 1200 ms, right-frontal old/new effects for targets reflecting post-retrieval monitoring were accompanied by mid-parietal LPNs for targets and non-targets, presumably reflecting the search for attribute conjunctions from the prior study phase.

Table 3. F values obtained in the paired contrasts between ERPs elicited by correct judgments to targets, non-targets, and new words for adults over the 300-500, 500-700, 700-900, and 900-1200 ms time-windows

Contrast	*df*	300-500		500-700		700-900		900-1200[a]
		Difficult	Easy	Difficult	Easy	Difficult	Easy	
Target vs. new								
IT	1,19	9.69**	50.13***	8.51**	18.22***	ns	ns	ns
IT x AP	2,38	ns	3.28•	ns	ns	ns	6.59*	14.65***
IT x LAT	2,38	ns	ns	ns	ns	ns	ns	3.78•
IT x AP x LAT	4,76	ns	3.87**	3.30*	3.49*	3.60*	4.94**	3.52*
Non-target vs. new								
IT	1,19	9.07**	21.55***	ns	ns	ns	ns	10.64**
IT x AP	2,38	ns	ns	8.14**	3.08•	4.97*	11.34**	14.02***
IT x LAT	2,38	ns	ns	4.8*	ns	3.55*	ns	9.20**
IT x AP x LAT	4,76	ns	ns	2.19•	ns	3.02*	ns	3.73*
Target vs. non-target								
IT	1,19	ns	10.60**	5.20*	33.18***	ns	ns	6.43*
IT x AP	2,38	ns	ns	5.69**	ns	ns	ns	ns
IT x LAT	2,38	ns	ns	ns	ns	ns	ns	ns
IT x AP x LAT	4,76	3.41*	ns	ns	ns	ns	ns	ns

Note. df = degrees of freedom, IT = item type, AP = anterior/posterior, LAT = laterality.

[a] All contrasts were collapsed across both difficulty conditions.

•p < .1, *p < .05, **p < .01, ***p < .001.

Adolescents

From 300 to 500 ms, the initial ANOVA revealed no interactions involving Difficulty and IT (*p* values > .19). The old/new contrasts collapsed across conditions revealed IT by Laterality interactions. These reflected the fact that the early old/new effects for targets and non-targets were larger across the midline compared to left and right hemisphere locations.

For the 500-700 ms time-window, the initial ANOVA also revealed no Difficulty by IT interactions (*p* values > .48). Across both conditions, the target/new and the non-target/new contrasts revealed IT x AP interactions, indicating the parietal maxima of both old/new effects (see Figure 9B). For targets, the IT x Laterality interaction indicates additional midline maxima of the old/new effects. The target/non-target contrast revealed greater positivities for targets across sites.

From 700 to 900 ms, a Difficulty x IT x Laterality interaction was revealed [F(4,68) = 5.05, *p* < .01]. In the difficult condition, a parietally focused old/new effect was seen for targets, while for non-targets the effect exhibited a midline maximum, as indicated by the IT x AP and IT x Laterality interactions, respectively. In the easy condition, a target old/new effect was obtained across electrodes. The target/non-target contrasts revealed greater parietal positivities for targets in the difficult condition and a left hemisphere maximum of these positivities in the easy condition, as indicated by the IT x AP and IT x Laterality interactions, respectively.

Between 900 and 1200 ms, the ANOVA gave rise to a Difficulty x IT x AP interaction [F(4,68) = 3.50, *p* < .05]. While in the difficult condition robust old/new effects were obtained for targets and non-targets across locations, no significant ERP differences were observed in the easy condition.

From 1200 to 1500 ms, three-way interactions involving Difficulty and IT were found with AP [F(4,68) = 4.27, *p* < .05] and Laterality [F(4,68) = 3.03, *p* < .05]. The target/new contrasts revealed an IT x AP interaction in the easy condition, reflecting a marginal target negativity across parietal sites (*p* = .07), while the small positive-going old/new effect at frontal sites was not significant (*p* = .20). The non-target/new contrasts revealed a three-way interaction in the difficult condition and an IT x Laterality interaction in the easy condition, reflecting reliable non-target negativities at PZ and across the midline, respectively. The target/non-target contrast revealed an IT x AP interaction in the easy condition, reflecting greater non-target negativity at frontal sites.

In sum, adolescents showed early (300-500 ms) frontal old/new effects for targets and non-targets in both conditions which were highly similar to the effects observed in adults. However, the adolescents' ERPs differed from those in adults in all subsequent time-windows. In contrast to adults, adolescents showed parietal old/new effects for both targets and non-targets, confirming the hypothesis that adolescents would show no evidence of target-selective recollection even when task difficulty is low. Moreover, the time-courses of the positive-going old/new effects in adolescents exceeded those for adults by 500 ms in the difficult condition and by 200 ms for targets in the easy condition, suggesting a prolonged duration of recollective processing. Finally, as predicted, between 1200 and 1500 ms adolescents did not show right-frontal old/new effects. Likewise, LPNs were less consistently present in adolescents, as these effects were reliable for non-targets only.

Table 4. *F* values obtained in the paired contrasts between ERPs elicited by correct judgments to targets, non-targets, and new words for adolescents over the 300-500, 500-700, 700-900, 900-1200, and 1200-1500 ms time-windows

Contrast	*df*	300-500[a]	500-700[a]	700-900		900-1200		1200-1500	
				Difficult	Easy	Difficult	Easy	Difficult	Easy
Target vs. new									
IT	1,17	71.33***	31.95***	19.71***	14.23**	6.63*	ns	ns	ns
IT x AP	2,34	ns	10.16***	8.43**	ns	ns	ns	ns	4.76*
IT x LAT	2,34	7.63**	3.50*	ns	ns	ns	ns	ns	ns
IT x AP x LAT	4,68	ns	ns	ns	ns	ns	ns	ns	ns
Non-target vs. new									
IT	1,17	73.18***	16.35***	19.17***	ns	4.63*	ns	ns	6.56*
IT x AP	2,34	ns	5.13*	ns	ns	ns	ns	ns	ns
IT x LAT	2,34	8.47**	ns	3.46*	ns	ns	4.85*	ns	8.03**
IT x AP x LAT	4,68	ns	ns	ns	ns	ns	ns	3.06*	ns
Target vs. non-target									
IT	1,17	ns	16.21**	ns	9.98**	ns	ns	ns	3.83$^{\bullet}$
IT x AP	2,34	ns	ns	3.80$^{\bullet}$	ns	ns	ns	ns	5.60*
IT x LAT	2,34	ns	ns	ns	4.96*	ns	ns	ns	3.11$^{\bullet}$
IT x AP x LAT	4,68	ns	ns	ns	ns	ns	ns	ns	ns

Note. df = degrees of freedom, IT = item type, AP = anterior/posterior, LAT = laterality.

[a] All contrasts were collapsed across both difficulty conditions.

$^{\bullet}p < .1$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Influence of task difficulty on the early frontal old/new effects

Visual inspection of the ERPs in the 300-500 ms time-window suggested that, for both age groups, the early old/new effects were larger in the easy compared to the difficult condition (see Figure 8). Therefore, the amplitudes of these early effects were directly compared between conditions within both age groups. The analyses were performed on target and non-target old/new difference data obtained from Fz and Cz between 300 and 500 ms and included the factors of Difficulty, IT (target, non-target), and Electrode (Fz, Cz). Reliable, respectively marginal main effect of Difficulty were obtained for adults and adolescents [F(1,19) = 4.70, $p < .050$, and F(1,17) = 3.35, $p = .085$, respectively], confirming the greater amplitudes of early old/new effects in the easy condition.

Topographic analyses

These analyses were performed in order to explore for both age groups whether the early (300-500 ms) and consecutive (500-700 ms) ERP old/new effects, the putative correlates of familiarity and recollection, showed differed scalp distributions. Such differences would be expected if ERP activity in both intervals is associated with functionally different memory processes (recollection and familiarity). To avoid confounds with changes in overall amplitude with time, rescaled data were used for these analyses (McCarthy & Wood, 1985). They were conducted separately for target and non-target old/new difference data from the 9 electrodes indicated above, and included the factors of Difficulty, Time-window (300-500, 500-700 ms), and Electrode (9 levels). For adults, the analyses revealed Time-window by Electrode interactions for targets and non-targets [F(8,152) = 2.46, $p < .050$ and F(8,152) = 4.68, $p < .001$, respectively]. For targets, the interaction reflected the fact that old/new effects were broadly distributed between 300 and 500 ms, while additional left-parietal enhancements emerged between 500 and 700 ms. For non-targets, old/new effects were evident across electrodes from 300 to 500 ms, whereas these effects were focused to frontal sites from 500 to 700 ms. For adolescents, the analyses revealed marginal, respectively reliable Time-window by Electrode interactions for targets and non-targets [F(8,136) = 2.38, $p = .076$ and

F(8,152) = 4.00, *p* < .05, respectively]. In each case, these effects indicated a stronger parietal focus of the old/new effects in the second compared to the first interval, although this topographical change was somewhat less pronounced for targets.

Relationship between ERPs and WMC

The predictions regarding the relationship between the parietal ERP target/non-target diverge and WMC were tested via separate correlation analyses in both age groups for both conditions. These analyses were performed on the target/non-target difference amplitudes between 500 and 700 ms at parietal electrodes (P3, Pz, P4). For adults, significant positive correlations between these measures were obtained at P3 and PZ in the easy condition but not in the difficult condition (see Table 5). By contrast, no significant relationships were revealed for the adolescents (*p* values > .14). Figures 10 A and 10B illustrate this pattern of relationships at the P3 electrode. It shows that the ERP amplitude for targets relative to non-targets increased with Operation Span scores only for adults in the easy condition. Notably, all correlations for adolescents remained non-significant when two participants whose ERP difference amplitudes exceeded the group mean by more than 1.5 SDs were removed (p values > .56), suggesting that the absence of correlations cannot be attributed to the relatively large variability in the adolescents' ERP data (see Figure 10B).

Table 5. Pearson's R values relating ERP target/non-target difference amplitudes (target – non-target) at parietal electrode sites with operation span scores for both age groups in both conditions

	Adults		Adolescents	
Site	Difficult	Easy	Difficult	Easy
P3	.12	.49*	.31	.05
PZ	-.05	.54*	.28	.19
P4	-.01	.30	.35	.18

Note. All significance tests were two-tailed.

**p* < .05.

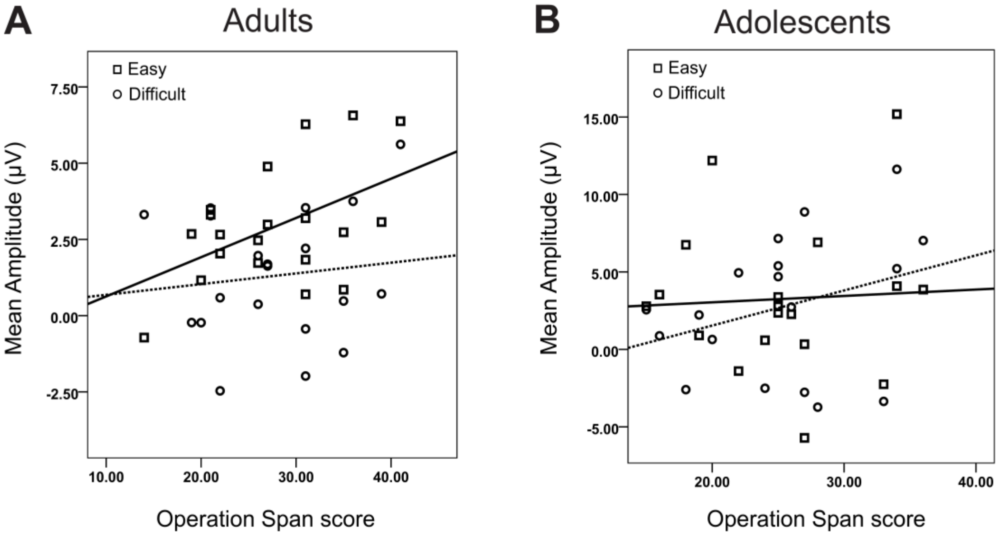

Figure 10. *Scatterplots showing the relationships between the Operation Span scores and the ERP target/non-target difference amplitudes (target – non-target) from 500 to 700 ms at P3 for **(A)** adults and **(B)** adolescents in both difficulty conditions.*

5.2.5 Discussion

The purpose of the present investigation was to examine the development of the ability to engage the kind of strategic processes which are necessary for selective retrieval processing, i.e., the prioritization of recollection of target information over non-target information. A further issue addressed here was the possibility of developmental differences between adolescents and adults in the degree to which their WMC was related to the ERP index of selective recollection. Behavioral results regarding memory performance will be discussed first, followed by the discussion of the ERP data.

5.2.5.1 Behavioral results

As expected, participants in both age groups were better in discriminating targets from non-targets and new words in the easy compared to the difficult condition. Reduced task difficulty in the easy condition also accelerated the speed of memory judgments for targets and new words in both age groups. These data suggest that the difficult/easy manipulation resulted in relatively lower strategic control demands in the easy condition. Furthermore, consistent with the initial prediction, memory accuracy improved with age. This effect was of similar magnitude in both difficulty conditions and particularly pronounced for target/non-target discrimination. This finding contrasts with Study 1 where no age difference between adolescents and adults in source discrimination was found. This discrepancy between the two studies presumably reflects the low target/non-target distinctiveness and thus increased retrieval demands in the present study compared to Study 1, resulting in a higher likelihood for age differences in memory accuracy to be detected. This account receives support from the fact that overall source memory performance in the present study was lower than in Study 1. In order to elucidate the mechanisms that underlie the age-related improvement in source memory performance observed here, ERP effects associated with targets and non-targets were analyzed in both age groups.

5.2.5.2 ERP results

For adults, reliable left-parietal old/new effects were obtained for targets in both conditions while non-targets failed to elicit these effects in either condition. Similarly, late right-frontal effects were elicited by targets only, indicating that the adult participants engaged in the post-retrieval monitoring of information about targets but not non-targets. These results are consistent with the view that the adults adopted a target-selective retrieval strategy in the present paradigm and in turn inhibited the recollection of non-target information even when strategic control demands were high.

Notably, these results obtained for the adults are consistent with the view that the likelihood of discriminating targets from non-targets does not solely determine the conditions under which selective retrieval will occur (Herron & Wilding, 2005). It is noteworthy that, in contrast to the results obtained here, previous investigations in which color information was used for the target/non-target distinction have reported reliable parietal old/new effects for non-targets (Cycowicz et al., 2001; de Chasteleine et al., 2007; Wilding et al., 2005). These effect have been attributed to the high degree of source similarity when color information is used, possibly precluding the restriction of recollection to targets only (Wilding et al., 2005). Although color information was also used here, the present study differs from the experiments referenced above in that words in the current paradigm were encoded elaboratively, which in turn might have generated contextual details that facilitated source discrimination. Consistent with this account are the findings reported by Herron and Wilding (2005). In their study, targets and non-targets were encoded elaboratively and target accuracy was reduced in one condition with an increased study-test interval. Similarly to the present results, targets but not non-targets elicited left-parietal and right-frontal old/new effects in either condition. It therefore appears that selective retrieval can occur despite a close correspondence between different sources of information, for example when elaborative encoding provides a sufficient amount of discriminative contextual characteristics.

Despite the absence of ERP correlates of non-target recollection for adults, non-targets elicited an unexpected left-frontal old/new effect between 500 and 700 ms in the difficult condition, an effect that was not seen in the easy condition. A possible functional account of this effect could be derived, at least tentatively, from memory exclusion paradigms which have shown that retrieval difficulty influences ERP activity elicited by new items (Dzulkifli, Sharpe, & Wilding, 2004; Rosburg, Mecklinger, & Johansson, 2011). As mentioned in Chapter 1, differences between ERPs to new items across conditions with different retrieval demands have been taken as correlates of retrieval orientation, the mechanism which is thought to underlie the kind of selective retrieval processing investigated here (Dzulkifli & Wilding, 2005). More specifically, the operations indexed by ERP contrasts of this kind have been related to cue bias mechanisms which serve to specify and maintain relevant features of the test cue in order to optimize the cue – memory trace interaction (Mecklinger, 2010).

For example, Rosburg et al. (2011) demonstrated a left-frontal ERP difference between new test items when contrasted across two different target designations that differed in task difficulty. Critically, the amplitude of this effect was largest for participants with the highest relative task difficulty, as indexed by the difference in memory performance between the two conditions. These results were taken to indicate that the control processes which support the maintenance and specification of task-dependent cue features (Mecklinger, 2010) need to be engaged to a greater extent when retrieval demands increase (Rosburg et al., 2011). Therefore, although these latter data were obtained with a different operational definition of strategic retrieval, on the basis of the similarity to the present results regarding the influence of task difficulty on left-frontal ERP effects, they may account for the current non-target effect which might reflect the greater demands on cue specification processes in the difficult condition. This possibility would also be consistent with fMRI results which have been taken to reflect a specific implication of left VLPFC in cue specification processes (Dobbins et al., 2002).

Following these lines of reasoning, it was hypothesized that the amplitude of the frontal ERP non-target/new difference should be related to the availability of control resources as indexed by Operation Span scores. This hypothesis was confirmed, as a post-hoc correlation analysis revealed significant positive correlations between both measures at all three frontal electrodes (*R* values = .52, .46, and .45 for F3, Fz, and F4, respectively, p values < .05; see Figure 11). This outcome confirms the view that the frontal non-target effect in the difficult condition most likely reflects a capacity-limited control process, possibly the relatively stronger engagement in cue specification operations in the difficult compared to the easy condition.

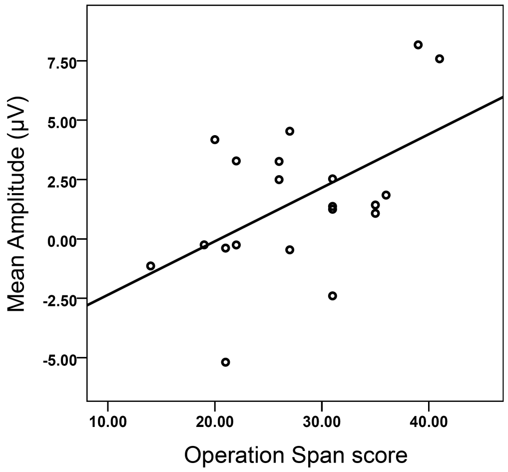

Figure 11. *Scatterplot showing the relationship between the Operation Span scores and the ERP non-target/new difference amplitude (non-target – new) between 500 and 700 ms at F3 for adults in the difficult condition.*

Notably, as evident from Figures 8A and 9A, the frontal positivities observed for non-targets in adults were also present for targets over the same time-window in both difficulty conditions. Similar frontally enhanced target positivities are also evident in the ERP data reported in other studies employing exclusion paradigms (Herron & Rugg, 2003a; Herron & Wilding, 2005), and one interesting possibility to explore in future research is whether this kind of frontal activity reflects the engagement of a prefrontal control mechanism that facilitates selective cue processing in order to discriminate targets from non-targets.

For adolescents, the present study revealed reliable parietal ERP old/new effects for targets as well as for non-targets across both conditions. This is consistent with the prediction that adolescents would recollect information associated with both, targets and non-targets, and in this way, show less evidence of target-selective retrieval as compared to adults. Importantly, adolescents showed ERP correlates of non-target recollection in the easy condition, while adults did so in neither of the two. As memory performance of adolescents in the easy condition was equal to that of adults in the difficult condition, the aforementioned result indicates that the age-related difference in strategic recollection uncovered here does not depend on the difficulty of the task and therefore supports the hypothesis of general immaturity in target-selective retrieval processing in young adolescents.

A noteworthy result in this regard is that both age groups showed similar early mid-frontal old/new effects for targets and non-targets reflecting familiarity-based remembering, as this observation sheds light on the processing stage at which maturation in strategic retrieval occurs. Support for a familiarity account of these effects stems from the fact that they were topographically distinct from the later parietal effects, and that they were larger in the easy compared to the difficult condition. This latter result is consistent with the view that the frontal old/new effect is related to familiarity strength (Woodruff et al., 2006). Therefore, because the age groups did not differ with regard to their early frontal effects, it can be concluded that the processes reflected by these effects were independent from the strategic operations that the adults employed with greater success to exert control over recollection. This conclusion is consistent with the evidence that recollection undergoes more developmental change during childhood and adolescence than does familiarity, as suggested by several behavioral studies where different materials and operational definitions of recollection and familiarity were used (Anooshian, 1999; Billingsley et al., 2002; Ghetti & Angelini, 2008; Ofen et al., 2007).

Further weight to the developmental difference in strategic recollection observed here was provided by the analysis of relationships between WMC and the parietal ERP target/non-target differences. For adults, positive correlations between these measures were observed in the easy but not in the difficult condition, in which WMC was instead correlated with the frontal non-target old/new effect (see above). In order to account for this somewhat unexpected pattern of relationships in terms of the hypothesized link between WMC and the control of recollection, the proposal that WMC reflects resources available for the inhibition of irrelevant information (Conway & Engle, 1994) is worth mentioning. As discussed in Chapter 1, on the basis of the latter proposal it has been suggested that the greater attenuation of non-target ERP old/new effects relative to target effects with increasing WMC reflects the active inhibition of task-irrelevant (non-target) information (Wilding & Herron, 2006; Elward & Wilding, 2010). This suggestion may also account for the current data from the easy condition. Conversely, in the difficult condition, it is conceivable that cognitive resources indexed in WMC needed to be allocated to a greater extent to the specification of task-relevant cue features, including the inhibition of task-irrelevant features. In this way, the present pattern of relationships suggests that task difficulty has influenced which particular aspects of strategic retrieval processing in adults were modulated by their resources for cognitive control.

By contrast, for adolescents no correlations between WMC and the critical ERP difference amplitudes were observed in either condition. This outcome raises the possibility that the adolescents were limited in their ability to allocate resources for cognitive control to strategic recollection. This hypothesis is consistent with behavioral data showing continued improvement in the ability to use basic working memory processes for higher-order control operations until late adolescence (Luciana et al., 2005; De Luca et al., 2003). It is also supported by neuroimaging findings suggesting that cognitive maturation involves a process of increased functional connectivity and integration among distributed local brain regions (Luna et al., 2001; Scherf et al., 2006). Therefore, though any inferences derived from a mere lack of relationship must remain preliminary, the potential significance of this outcome is that it may index age-related limitations in the efficiency of integration among distributed brain networks underlying strategic retrieval, involving prefrontal, temporal, and parietal cortical areas (Cabeza et al., 2008; Simons & Spiers, 2003).

In addition to the differences in recollective processing discussed so far, the present study revealed further age-related differences in the ERP correlates of strategic retrieval, including those of post-retrieval processing. First, although the age groups did not differ in processing speed as indexed by RTs, adolescents showed temporally prolonged parietal old/new effects compared to adults, presumably reflecting a longer duration of recollective processing. Given that these prolonged effects were especially pronounced in the difficult condition, they may be an indication of the greater retrieval effort exerted by adolescents. This would agree with the proposal that greater effort to perform a cognitive task correlates with the recruitment of a given neural circuitry for a longer period (Luna et al., 2010).

Moreover, whereas adults showed reliable right-frontal old/new effects for targets in both conditions, for adolescents these effects were not significant in either condition. As this effect has been suggested to reflect post-retrieval monitoring processes supported by right dorsolateral prefrontal regions (Hayama et al., 2008; Hayama & Rugg, 2009), the lack of this correlate in adolescents is consistent with the results reported in Study 1 and agrees with the evidence for ongoing functional specialization within prefrontal regions during adolescence (Durston et al., 2006).

Finally, the LPN occurred in adults over mid-parietal sites for targets and non-targets in both conditions, whereas for adolescents late negativities were less consistently present, as these effects were statistically reliable only for non-targets. The functional significance of the LPN is a matter of continuing debate (Herron, 2007). As outlined in Chapter 1, Johansson and Mecklinger (2003) proposed that the LPN observed in source memory tasks reflects the search for attribute conjunctions from prior study episodes, a process that is not contingent upon successful retrieval. This latter account accommodates the current findings, given that the LPN for adults was elicited by targets and non-targets and by this dissociable from the left-parietal and right-frontal old/new effects which were present for targets only.

In order to account for the late non-target negativities in adolescents, one possibility is that these effects are functionally linked to action monitoring, if it is assumed that non-targets in these participants will engender greater response conflict than either targets or new words. This latter view would be supported by the finding of longer RTs for non-targets than for new words and for non-targets compared to targets in the easy condition. A further aspect of the negative-going non-target/new effects in adolescents is that the effect in the easy condition lacked to posterior distribution usually seen for the LPN (see Figure 8b). This data point is consistent with the findings reported by Cycowicz et al. (2003) who proposed maturation in the refinement of activity underlying source retrieval in order to account for the more frontal distribution of the LPN in adolescents. It is important to note, however, that a precise account of age-related changes in the LPN will depend on future investigations of these changes according to stimulus as well as response-related factors.

5.2.5.3 Conclusions

To summarize, the current study revealed three main findings that substantiate and expand upon earlier findings regarding the maturation of strategic memory retrieval. First, the present ERP data show a developmental difference between young adults and adolescents in selective recollection. This difference suggests that the ability to focus recollection on one kind of task-relevant information in order to make a binary source judgment continues to mature throughout adolescence. Second, the age-related pattern of correlations evident in the individual data suggests that adults but not adolescents efficiently used their capacity for cognitive control for strategic recollection. Finally, adults compared to adolescents showed a temporally and topographically more refined pattern of ERP effects, including the right-frontal old/new effect and the LPN. This confirms previously reported data of maturation in post-retrieval control processes (see Study 1) and suggests that a further aspect of maturation in strategic recollection may be a refinement in the temporal course of retrieval processing, possibly reflecting decreased cognitive effort.

These results fit well with the developmental framework outlined above (see section 2.1), suggesting ongoing and protracted functional maturation of specific neurocognitive control networks (Best & Miller, 2010; Luna et al., 2010) and strategic memory functions (Shing et al., 2008) during adolescence. Most notably however, the present results extend the latter line of evidence by uncovering the neural correlates of adolescent cognitive maturation in the domain of episodic memory retrieval.

6. General Discussion

The global aim of the two studies reported in the present thesis was to investigate the developmental course of episodic memory retrieval during childhood and adolescence, with a particular focus on the development of strategic retrieval processes. This purpose was licensed on the basis of previously reported evidence that such strategic processes are less efficient in late childhood than in adulthood, leaving open the question regarding their maturational course during adolescence. To this end, ERP correlates of item and source memory retrieval were compared between 7-8-year-old children, 13-14-year-old adolescents and young adults, with these ages being selected in order to cover specific age periods in the developmental course of cognitive control.

Different operational definitions of strategic memory retrieval were used in both studies. Study 1 focused on retrieval of temporal context information associated with non-target items in a continuous recognition memory task, following the view that this task is especially sensitive to developmental change in strategic retrieval processing during childhood (Czernochowski et al., 2009). Conversely, Study 2 investigated age differences in the ability to implement a selective retrieval strategy, in line with the notion that retrieval processing of this kind puts particularly high demands on cognitive control resources and should therefore be especially sensitive to developmental change during adolescence (Wilding & Herron, 2006).

The work presented here was based on a developmental framework according to which adolescence represents a developmental period which is crucial for maturation in the ability to control episodic retrieval. This framework is based on evidence from developmental cognitive neuroscience and assumes ongoing maturation in cognitive control functions throughout adolescence, with high-demand control functions not reaching maturity before late adolescence (Olson & Luciana, 2008). A hallmark of this maturation is the functional specialization of distributed networks which subserve specific core cognitive functions, such as inhibitory control and WM, along with greater localization and integration within these networks (Luna et al., 2010). One interest guiding the present work was to investigate whether and how these putative changes in cognitive control map onto developmental differences in source memory retrieval.

The following two subsections include a summary of the main findings of both studies as well as a discussion of the theoretical implications of these findings. The chapter then discusses a number of methodological and conceptual caveats of the studies together with possible directions for future research, before finally a general conclusion is drawn.

6.1 Summary of main findings

Study 1 investigated age differences between children, adolescents, and adults in the ERP and behavioral correlates of item and source memory. The analyses carried out suggested independent patterns of developmental change in item and source memory. Behavioral performance showed a linear improvement on the task assumed to index item memory. For the ERP correlate of recollection in the item memory task, no age differences were observed. Nonetheless, adults showed a more differentiated pattern of retrieval processing in the item memory task compared to children and adolescents. This was attested to by the presence of ERP correlates of familiarity and monitoring processes in the adult group only. In the source memory task, ERP correlates of non-target retrieval showed an increasing refinement with age. Children showed relatively immature source memory performance and no ERP effects of non-target recollection. With adolescence, adult-like source discrimination abilities and electrophysiological activity of non-target retrieval emerged, but the latter, however, lacked the topographical refinement seen in adults and showed no effects indicative of post-retrieval monitoring processes.

These latter results indicate that while the transition into adolescence is marked by the emergence of a network that allows for strategic retrieval, additional functional specialization of this network occurs during the transition into adulthood. Study 2 aimed at providing a stronger base of evidence for these changes during adolescence, given that in Study 1 no difference in behavior and only subtle divergences in the ERP correlate of source recollection were observed between adolescents and adults. Thus, Study 2 was designed to investigate whether adolescents would differ from adults in the ability to implement a strategy by which recollection of information about targets is prioritized over non-targets, following the view that retrieval processing of this kind should improve along with maturation in cognitive control functions. A further aim was to determine whether these possible age differences would be influenced by varying task difficulty. To this end, participants completed a memory exclusion task under two conditions that put different demands on strategic control, following the assumption that target-selective memory retrieval should be facilitated by low task demands.

Memory accuracy improved with age and also increased with decreasing control demands in both age groups. Examination of parietal ERP old/new effects revealed that adults showed correlates of recollection for targets in both difficulty conditions, whereas in adolescents these effects were present for targets and non-targets in both conditions. This pattern of ERP effects suggests that the adults implemented a strategy to prioritize recollection of information about targets over non-targets with greater success than adolescents regardless of control demands. Conversely, similar ERP correlates of familiarity for targets and non-targets were obtained for both age groups. Whilst this result stands in contrast to the outcome of Study 1, it allows for the conclusion that in Study 2 age differences in retrieval processing were greater for recollection than for familiarity.

Further analyses in Study 2 revealed an unexpected frontally focused old/new effect for non-targets in the difficult condition for adults. On the basis of the finding that the amplitude of this effect was correlated positively with WMC, discussion of this effect resulted in the hypothesis that it could reflect the engagement of control processes which serve to specify task-relevant cue features. In the easy condition, WMC was positively correlated with the parietal target/non-target ERP difference amplitude for adults. This pattern of relationships suggests an association between the degree of engagement in strategic retrieval processing and the availability of resources for cognitive control, although the exact processes to which these resources were allocated appear to have differed across difficulty conditions. One possibility is that these resources were deployed in the service of inhibition of irrelevant information during retrieval processing. Notably, for adolescents, no such correlation between WMC and ERP effects were observed. This outcome adds to the observed age differences in strategic recollection and may indicate a less efficient use of cognitive control resources for strategic memory retrieval.

In line with the outcomes of Study 1, Study 2 revealed ERP correlates of post-retrieval monitoring for adults only. Likewise, while adults showed LPNs for targets and non-targets, for the adolescents, late negativities were present for non-targets only, which raises the possibility that these effects reflect the enhanced monitoring demands for non-target items. A final age-related difference in Study 2 was a longer duration of parietal old/new effects in adolescents compared to adults. This prolonged activity was especially pronounced in the difficult condition and could be a reflection of greater retrieval effort exerted by adolescents.

6.2 Theoretical implications

This section is concerned with the theoretical implications associated with the results summarized above. First, the findings will be discussed in light of general aspects regarding the implementation of different retrieval strategies for completing source memory tasks. The section then addresses the developmental implications of the findings, including their discussion in light of several models on the neurocognitive development of episodic memory and cognitive control.

6.2.1 Retrieval strategies in source memory tasks

Studies 1 and 2 provide evidence that depending on the type of task, different retrieval strategies can be adopted when completing source memory tasks. Examination of ERP old/new effects in Study 1 suggested that the adults engaged in retrieval of information about non-targets, although the relatively small amplitude of the parietal non-target effect is indicative of the possibility that there was some variability either within or across participants with respect to the retrieval strategy adopted (Wilding et al., 2005). Conversely, the pattern of parietal old/new effects for targets and non-targets in Study 2 suggests that a target-selective retrieval strategy was adopted and that correct non-target judgments were not accompanied by recollection of corresponding source information.

One question to be addressed in this context concerns the factors that influence which retrieval strategy is most beneficial for performance in a given source memory paradigm. It has been argued that a strategy which relies on assessing whether or not it is possible to recollect information about one class of information is beneficial for making binary source judgments, because a failure in recollection can be used as a basis for accurate judgments (Wilding & Herron, 2006). In fact, the idea of evaluating only those characteristics that are maximally diagnostic for the relevant judgment is central to the cognitive framework of source monitoring presented in Chapter 1 (Johnson et al., 1993). Supporting evidence comes from ERP data showing that focusing retrieval on only one form of episodic content can benefit memory judgments, presumably because the quality of information recovered is greater than when information from multiple sources is being monitored (Bridger, Elward, Herron, & Wilding, 2009). Selective retrieval strategies of this kind have been proposed to be abandoned only in cases when the targeted class of memory is insufficiently available (Herron & Rugg, 2003b) or when encoding conditions are not sufficiently elaborative (Herron & Wilding, 2005). In addition, selective retrieval processing has been assumed to rely on individual resources available for cognitive inhibitory control (Elward & Wilding, 2010).

Consistent with this latter view are the adult ERP data reported in Study 2, which suggest greater engagement in strategic retrieval processing for participants with high WMC. Also in line with this view are the age-related findings in Study 2, if it is assumed that the ERP effects of non-target recollection observed in adolescents are related to their lower resources to exert control over recollection compared to adults. It is important to note, however, that this latter interpretation runs counter to the observation that the age groups did not differ in WMC as indexed by Operation Span scores. This absence of age differences can be accommodated, however, with findings that behavioral performance in basic WM maintenance tasks may be relatively mature in early adolescence, whereas the networks that support higher-order WM control processes continue to develop through adolescence (Finn, Sheridan, Kam, Hinshaw, & D’Esposito, 2010; Luciana et al., 2005). Together, these findings provide therefore support for a link between selective episodic retrieval and resources available for cognitive control which potentially serve to facilitate the inhibition of non-target information.

From an alternative viewpoint, however, it is also the case that in Study 1 adults showed ERP evidence of non-target recollection although task difficulty in that study was relatively low (Pr_Source = .84), indicating that relatively high amounts of cognitive resources should have been available during this task. Moreover, the data from Study 1 as well as previous findings (Czernochowski et al., 2009, 2005) show that poorer source discriminations in children are not associated with ERP effects of non-target retrieval. These data points challenge the proposal that low resource availability and/or high task demands necessarily results in retrieval of non-target information.

The data discussed here instead stresses that, at least in some situations, a less selective retrieval strategy (i.e., recovery of non-target information) can benefit task performance and is more likely to be engaged by individuals with greater amounts of cognitive resources than by individuals with fewer resources. An interesting issue to explore is under which conditions this beneficial aspect of reduced selectivity in retrieval processing is most likely to be observed. One possibility is that the degree of relevance or irrelevance of information associated with contexts defined as “non-target” differs across task situations. For example, in the Czernochowski et al. (2005) study, the beneficial effect of non-target retrieval was primarily evident when the perceptual similarity between test cues and studied non-target information was high. In such circumstances, it is conceivable that non-target information is activated relatively more automatically by the cue, and as a result, this information becomes relevant for source discrimination.

In the case of the continuous recognition paradigm employed in Study 1, Schnider (2003) has argued that poor performance in this task primarily results from a failure to adjust memory representations evoked by non-targets according to whether they relate to ongoing reality or not. From a source memory perspective, however, it is possible that retrieval of context information associated with non-targets is an adaptive strategy for completing this task, because knowledge about this context may support later target judgments. This might come about because of the particular characteristics of this paradigm where source judgments are made on the same items presented in successive order, and by this, targets and non-targets can only be distinguished on the basis of temporal context. One possible implication that follows from this line of reasoning is that, as non-targets were relatively more relevant for task performance in Study 1 than in Study 2, the paradigms used in both studies differ in the extent to which a target-selective retrieval strategy is useful.

Speculation along these lines raises several interesting issues to explore in future research, such as whether the mechanisms supporting a less selective strategy differ from those underlying selective retrieval. An additional question is whether attempts to retrieve multiple episodic contents as opposed to selective strategies may be beneficial for source judgments that do not reduce to binary discriminations. In most memory exclusion tasks, the to-be-discriminated items are associated with only one of two contexts. A strategy that relies on determining whether a particular type of information can be retrieved or not, therefore, might be especially appropriate for completing this type of task. What is less clear, however, is whether strategies of the latter kind are also applied in tasks in which old items are associated with at least two classes of contextual information and judgments query information about each of these classes. One might rather assume that judgments of this kind benefit from attempts to monitor multiple contents of a memory trace simultaneously, and that disadvantages may result from focusing retrieval on only one source.

6.2.2 Developmental changes in episodic memory retrieval

6.2.2.1 ERP evidence for different developmental trajectories of item and source memory

Starting from the assumption that cognitive development reflects the interplay between different mechanisms that follow distinct lifespan gradients (Craik & Bialystok, 2006), one question guiding contemporary research on memory development is whether changes in performance across the lifespan can be modeled as changes in the processes and/or the neural systems that underlie episodic memory (Brehmer, Li, Müller, von Oertzen, & Lindenberger, 2007; Werkle-Bergner, Müller, Li, & Lindenberger, 2006). For example, it has been argued that, at least in childhood, the associative functions of the MTL contribute to a greater extent than the strategic functions of the PFC to improvements in source memory (de Haan et al., 2006). Conversely, others have emphasized that changes in source monitoring throughout childhood are primarily related to prefrontal development (Ruffman et al., 2001; Sluzenki, Newcombe, & Ottinger, 2004). In behavioral studies, children have been shown to improve in their ability to resist misleading questions about remembered events (Roebers & Schneider, 2005) or to suppress irrelevant information from WM (Lechuga, Moreno, Pelegrina, Gomez-Ariza, & Bajo, 2006). While these findings presumably reflect changes in frontal functions, however, they do not address the issue of how these changes relate to those in MTL functions.

As described in Chapter 2, Shing et al. (2008) introduced a comprehensive model which can accommodate these differing positions. The model portrays memory development as the interaction between the strategic component (i.e., cognitive control operations that organize memories at encoding and retrieval) and the associative component (i.e., binding mechanisms and automatic retrieval processes) which have been associated with the memory functions of the PFC and the hippocampus, respectively (Moscovitch, 1992; see Chapter 1). The model makes distinct assumptions about the lifespan trajectories of each of these components, following the view that their relative contributions to memory performance change across development (Shing & Lindenberger, 2011). While associative processes are thought to be relatively mature by middle childhood and to decline in old age, the strategic component is assumed to emerge with adolescence only and to decline in old age as well.

One line of support for divergent developmental trajectories of PFC and MTL memory functions comes from investigations of the neural correlates of successful memory encoding (Ofen et al., 2007), although this approach has not been frequently applied to child memory research (Werkle-Bergner et al., 2006). A further step towards approaching memory development from a two-component perspective is to compare neural indices of item and source memory retrieval between age groups (Cycowicz, 2000). As described in Chapter 1, source recollection is thought to involve cognitive control processes and therefore relies heavily on the strategic component (Simons & Spiers, 2003). Conversely, item recognition can be conceived as an operationalization of the associative component which according to Moscovitch (1992) includes recollective processes that occur when a retrieval cue automatically triggers stored episodic contents.

Source memory has long been assumed to follow a longer developmental course than item memory (e.g. Cycowicz et al., 2001). Consistent with this view are previous ERP memory studies which have revealed relative maturity in item recollection but immaturity in strategic retrieval processing in children compared to adults (e.g. Czernochowski et al., 2009; de Chastelaine et al., 2007). However, because no data on strategic retrieval processing in adolescents has been provided to date, the characteristics of maturation in these processes beyond childhood have remained relatively underspecified. The present work made an effort to overcome this limitation by comparing ERP correlates of item and source memory retrieval across three age groups that were selected to cover two distinct developmental periods during childhood and adolescence. By this, the present work aimed to model the way in which item and source memory evolve in greater detail as has been possible in the majority of previous developmental ERP studies.

Consistent with the view that the processes that rely on the associative component are mature by middle childhood was the finding of similar ERP correlates of recollection in the item memory task across age groups in Study 1. This suggests relative stability in processes that serve to recover contextual information in response to a proximal retrieval cue. In addition, from a broader perspective one might also consider the similarity in the ERP correlates of generic novelty processing across age groups consistent with this model. This would correspond to several proposals according to which memory development begins with processes that are mediated by the hippocampus and primarily reflect novelty detection (de Haan et al., 2006; Richmond & Nelson, 2007, 2008).

The most important contribution of the present studies comes from the comparisons between ERP correlates of source memory retrieval across age groups. The outcomes of these comparisons converge to suggest that the strategic retrieval processes investigated here mature only after or during late adolescence. In Study 1, this was shown by less refined ERP correlates non-target retrieval in adolescents compared to adults, including the absence of neural correlates of post-retrieval monitoring. In Study 2, strategic maturation was indexed by a pattern of ERP effects which suggests a smaller degree of selectivity in retrieval processing in adolescents compared to adults. In this way, on the basis of two independent operational definitions of strategic retrieval processing, the studies presented here point to a relatively late emergence of the strategic component in episodic memory retrieval.

From the perspective of a lifespan framework (Shing et al., 2008), one interesting aspect of the outcomes from Study 2 is that they are similar to the pattern that is evident in the decline of strategic retrieval processing in elderly individuals. Two ERP source memory studies with older adults have used a slightly modified version of the exclusion task in which old items served as targets while non-targets were provided by new items that were repeated during the test phase (Dwyan, Segalowitz, & Arsenault, 2002; Dwyan, Segalowitz, & Webster, 1998). In these studies, amplitudes of ERP old/new effects for targets and non-targets were found to be more similar to each other in older adults compared to young adults. This was attributed to failed inhibitory control in response to non-target events in older adults (Dwyan et al., 1998). Although the limits of inhibitory control as an explanatory model for age-related cognitive decline have been noted by some authors (e.g. Kramer, Humphrey, Larish, Logan, & Strayer, 1994), the ERP data discussed here can be accommodated within a framework which posits relatively late maturation and senescent declines in strategic memory functions.

Taken together, the findings reported in this thesis make a novel contribution to the evidence for changes in the mechanisms that underlie episodic memory across development. The divergence in the developmental patterns of item and source memory lends further support to a framework which assumes that memory abilities in childhood are primarily supported by associative functions, while adolescence is marked by the emerging strategic component and its interaction with associative processes (Shing & Lindenberger, 2011). Most notably, and in contrast to previous evidence which is primarily based on manipulations of encoding demands (Brehmer et al., 2007; Shing et al., 2008), the present work advances the two-component perspective to age differences in episodic retrieval processing. Further research is needed to provide additional insights into possible developmental changes in the interaction between encoding and retrieval operations and to determine at which point during adolescence the strategic retrieval processes examined here mature.

6.2.2.2 Neural correlates of maturation in strategic retrieval during adolescence

One important aspect of the current ERP findings is that they provide information about maturation in the networks that allow for the cognitive control of episodic memory retrieval. As noted in Chapter 2, several researchers have emphasized non-linear changes in cognitive control, since large improvements can be observed during middle childhood (Paus, 2005) followed by more gradual change through adolescence (Best & Miller, 2010). The current pattern of age differences in strategic retrieval processing, which suggest strong changes in childhood and ongoing maturation through adolescence, are largely consistent with this protracted developmental change in cognitive control.

Consensus has not been reached, however, on the characteristics of change in the functional neural correlates of cognitive control during adolescence. As Luna et al. (2010) have noted, one difficulty that surrounds the development of falsifiable models of neural development is the fact that the nature of age differences in functional activity can differ across paradigms, depending on the brain regions recruited. On the one hand, for example, functional brain maturation has often been characterized as a shift from diffuse to more local patterns of activity (Durston et al., 2006). This concept of ‘focalization’ is largely derived from developmental neuroimaging studies using fMRI, reporting either larger spatial extents of activation, a greater magnitude of regional activity, and/or a larger number of activated regions in children relative to adults (e.g. Casey et al., 2002; Velanova et al., 2008).

On the other hand, it has been noted that, to date, no clear and testable definition of ‘diffuse’ or ‘focal’ activity has been introduced (Brown, Petersen, & Schlaggar, 2006). In addition, neural maturation has also been associated with age-related *increases* of brain activation, for example when adults have been found to recruit DLPFC for a visuospatial WM task to a greater extent than children (Scherf et al., 2006). According to Luna et al. (2010), findings such as these emphasize the view that with increasing age, the set of regions that are incorporated into task-specific circuitries is extended, resulting in a functionally integrated but locally specialized network in adulthood. Therefore, because both increased and decreased activity can reflect immaturity in children and adolescents, it is important to characterize age differences in neural activation against an adult control group for which clear hypotheses can be made depending upon the particular task demands.

Of course, the difficulties in identifying a consistent concept of neural maturation for fMRI data also apply to the interpretation of ERP data which does not allow strong inferences about the generation of activity within specific brain regions. Nonetheless, one can still relate the current ERP findings to the notion of refinement and integration within cognitive control networks during adolescence. For example, one possibility is that the more widespread distribution of the non-target ERP old/new effect in adolescents compared to adults in Study 1, reflects a greater reliance on task-general frontal systems due to less computational abilities in task-specific local circuitries. Similarly, Dwyan et al. (2002) observed greater frontal ERP activity in older compared to younger adults, which was taken to reflect stronger reliance on controlled processing throughout source retrieval. A further possible indication of neural refinement is the greater systematic relationship between the degree of strategic retrieval processing and cognitive control resources for adults than adolescents in Study 2, possibly reflecting greater integration among prefrontal and temporal regions involved in strategic retrieval.

Finally, perhaps the clearest evidence for functional specialization here comes from the fact that, in both studies, right-frontal ERP correlates of post-retrieval monitoring could be reliably observed for adults but not for adolescents. A noteworthy observation is that, for adults, the distribution of the right-frontal effect varied across studies. Figures 6B and 9A indicate that the effect was more widespread in Study 1 than in Study 2 where the effect was restricted to frontal electrodes. One way to explain this divergence is via recourse to a framework put forward by Fletcher and Henson (2001) who proposed that anterior PFC is associated with higher-order memory control processes, such as the selection of task-specific processes or goals. Such processes may have been engaged to a greater extent in Study 2 than in Study 1, as in Study 2 a high-demanding selective retrieval strategy was maintained throughout the task. In this way, distinct prefrontal regions might have been engaged across studies for adults, consistent with the view that the processes reflected by the right-frontal ERP effect vary across task demands (Cruse & Wilding, 2009).

The lack of right-frontal ERP activity in adolescents, therefore, is a likely indication of immaturity in functional refinement within local prefrontal control circuitries, such as right dorsolateral PFC (Hayama et al., 2009; Hayama & Rugg, 2009), and/or their integration with more distributed networks associated with source retrieval. This interpretation is in line with evidence that dorsolateral PFC is among the last regions to mature, as indexed by the prolonged regional time-course of synaptic pruning (Gogtay et al., 2004; Sowell et al., 2001). Thus, while the ERP findings for adolescents discussed here are consistent with the characteristics of functional neurocognitive maturation outlined above, they serve as an indication of such maturation in the domain of episodic memory retrieval.

6.2.2.3 Lack of early frontal ERP old/new effects in children – evidence for a change in familiarity-based remembering?

The final possible implication addressed here refers to the observed age differences in the ERP correlate of familiarity. While in Study 1 this effect was obtained for adults only, similar early mid-frontal old/new effects were obtained for adolescents and adults in Study 2. The lack of ERP evidence for familiarity in school-aged children has attracted attention in developmental memory research (Friedman et al., 2010; Mecklinger et al., 2011), because such findings are difficult to reconcile with several models which state that the development of recognition memory predominantly results from changes in recollection rather than familiarity (e.g. Ghetti & Angelini, 2008). For example, Anooshian (1999) employed the process dissociation procedure to estimate the contribution of both processes to recognition performance in 4-year-olds and adults. Results showed no age difference for familiarity estimates but a reliable age-related increase in recollection, which was argued to be consistent with other studies showing greater developmental change in explicit vs. implicit memory processes throughout childhood (e.g. Billingsley et al., 2002).

Conversely, Brainerd, Holliday, and Reyna (2004) used the *conjoint recognition procedure* which allows analysis of the different phenomenologies associated with recollection and familiarity in terms of fuzzy-trace theory (Brainerd, Reyna, & Mojardin, 1999). According to this model, recollection is produced by retrieval of an items' exact surface form (*verbatim traces*) whereas familiarity reflects retrieval of the semantic relations and meanings that items instantiate (*gist traces*). While the exact characteristics of this procedure are not critical for present purposes, the study revealed that correct recognition in 7-year-olds was predominantly based on familiarity, whereas most of the correct responses in 11 and 14-year-olds were based on recollection. This pattern was described as a shift from vague familiarity in childhood to vivid recollection in adolescence, in line with the notion that memory for verbatim traces changes more with age than memory for gist traces (Brainerd et al., 2004).

These studies, using careful and empirically well-supported experimental manipulations, provide evidence for dissociable developmental courses of recollection and familiarity, as indicated by the relatively greater developmental stability in familiarity-based remembering. An analogous ERP finding was recently reported by Mecklinger et al. (2011) who showed comparable early mid-frontal old/new effects in children and adults in an experimental condition that was designed to maximize the relative contribution of familiarity to recognition. There remains the question, however, as to why children typically do not show ERP indices of familiarity in paradigms that were not designed to specifically tap familiarity-based remembering, and at this point only preliminary hypotheses regarding this issue can be formulated.

One possibility is that, at least when no explicit retrieval instructions are provided, children are less likely than adults to rely on conceptual similarity for recognition judgments. Preliminary support for this possibility comes from a study of false memory with 5-, 8-, and 11-year-old children (Dewhurst & Robinson, 2004). At encoding, participants heard words that allowed both semantic and phonological (i.e.

rhyme) associations. At test, 5-year-olds were more likely to falsely recall words that were phonologically associated to studied words than to recall semantic associations, whereas 11-year-olds showed the opposite pattern, i.e., the number of intrusions was highest for semantically associated words. This pattern has been taken to reflect a developmental shift from phonological/perceptual to semantic processes that support episodic memory (Dewhurst & Robinson, 2004).

Thus, in light of several proposals linking the mid-frontal ERP old/new effect to the facilitated access to semantic representations activated by the cue (Meyer, Mecklinger, & Friederici, 2007; Nessler et al., 2001), the lack of this effect in children in standard item memory tasks could serve as an indication that they are less likely to assess the global cue-target similarity on a conceptual level in these circumstances. By this argument, the greater perceptual detail provided by the pictures used in Study 1 may have encouraged children and adolescents to rely predominantly on recollection. Conversely, the use of word stimuli in Study 2 may have facilitated the assessment of semantic similarity, resulting in reliable mid-frontal ERP effects for adolescents.

An alternative possibility, however, was recently considered by Friedman et al. (2010) who emphasized a change in the general flexibility of memory retrieval with age. This hypothesis was formulated on the basis of their finding that children used familiarity-based processes to a lesser extent than adolescents and young adults and also showed a stricter response criterion compared to the two older groups (Friedman et al., 2010). This could indicate that children judge events as old only when they can be certain about this judgment, for example when a sufficient amount of contextual information is available. In turn, children may have difficulties in monitoring subtle differences in response uncertainty and relative familiarity, so that less familiar items are not incorporated into their memory decisions. This argument would not necessarily assume a developmental change in familiarity per se, but rather improvements in the ability to incorporate familiarity signals into the memory decision.

Following this line of reasoning, it is worth mentioning that the mid-frontal effect for adults in Study 1 was followed by a right-frontal old/new effect, which may indicate that low response uncertainty was accommodated by the engagement of post-retrieval control operations. One possibility licensed by this observation is that accurate memory decisions benefit from processes that serve to monitor various levels of familiarity in the service of task demands (see also Czernochowski et al., 2004). Consistent with this argument are fMRI data showing that monitoring the relative familiarity of picture items in a judgment of frequency task is associated with activity in right-dorsolateral PFC regions, suggesting that familiarity-monitoring depends on prefrontal control processes (Dobbins, Simons, & Schacter, 2004). These processes undergo profound development from childhood to adolescence, which may explain the presence of familiarity effects for adolescents but not for children (Friedman et al., 2010; see also Study 2), although the reasons why this was not the case in Study 1 also need to be addressed. Hence, at the current state of knowledge, it is difficult to draw definitive conclusions on the neural correlates of familiarity-based remembering in children.

6.3 Assorted caveats and open issues

As is the case with all cross-sectional developmental investigation, the age-related factors investigated in this thesis are possibly confounded with other variables such as cohort, personal characteristics, pre-experimental experience or socio-economic status. This last point might especially be a concern when children and adolescents from various social backgrounds are compared to university students. An additional concern is raised by the issue as to whether equivalent processes are assessed across age groups when the same task is used across the present range of ability levels.

In future investigations, using longitudinal or microgenetic (i.e. short-term longitudinal) designs in addition to cross-sectional comparisons might help to overcome some of these confounds. Such approaches may also provide data on issues that the experiments presented here can only address to a limited extent, such as the rate of developmental change in a given age period, the breadth of change (i.e. the range of domains to which children can apply newly acquired retrieval strategies), the interindividual variability in change, and the conditions and cognitive processes through which children acquire new mnemonic skills (Miller, 2007). In addition, it might be useful to employ flexible experimental paradigms by adapting encoding times, stimuli set size or the amount of discriminative characteristics to children's and adolescents' memory proficiency. This would not only ensure that participants engage in similar processing when completing the task, it may also allow the investigation of memory development across a wider age range, including early childhood.

A further possible caveat is related to the use of ERPs in the present studies. Although the conclusions drawn here are in line with the assumption that age differences in neural processing are the cause of differences in performance, it is important to note that all inferences from ERP data are generally correlational in nature (Otten & Rugg, 2005). This argument applies all the more to the interpretation of children's and adolescents' ERPs which have been argued to be even less correlated with task performance than those of adults (DeBoer et al., 2005). By this, it is important to keep in mind that the observed age differences in ERP activity do not necessarily reflect a difference in the processes of interest (i.e. recollection and post-retrieval control) but may also index changes in processes that occur downstream, or be incidental to them.

While the present studies focused on age differences in retrieval processing, it is important to note that improvements also occur in encoding processes throughout childhood and adolescence, especially in the ability to apply appropriate encoding strategies (Schneider & Pressley, 1997; Shing et al., 2008). It must be acknowledged, therefore, that some of the age differences found here may have come about because of less efficient encoding operations in children and adolescents. For example, adolescents may have difficulties in applying elaborative imagery strategies that were required in Study 2. This may have led to less distinctive memory representations associated with targets and non-targets, and as a result, greater difficulties in implementing a target-selective retrieval strategy (Herron & Wilding, 2005). Future studies could increase the degree of experimental control during memory encoding or compare encoding-related ERP effects across age groups.

At several points throughout this thesis, it has been speculated that inhibition may be the process which underlies target-selective retrieval processing in exclusion tasks. It should be noted, however, that the principal support for this view to date comes from two data points which show correlations between the ERP index of target-selective retrieval and WMC (Elward & Wilding, 2010; Study 2). These correlations, however, could also be explained in terms of maintenance processes, reflecting the possibility that high-WMC participants have greater capacities to maintain recollected target information in WM. This ambiguity is related to the limitation of inhibitory models mentioned in Chapter 1, as they allow only indirect inferences on inhibitory processes. Thus, as inhibitory models lack the parsimony of non-inhibitory models which explain selective retrieval simply by assuming greater activation of targets, there is a need to further validate the view that inhibition can account for the attenuation of non-target ERP old/new effects relative to target effects. For example, one could assess whether non-targets are less likely to be recalled than targets after the recognition test phase. In addition, it might be revealing to investigate associations between ERP indices of strategic retrieval and those obtained in paradigms used to measure retrieval inhibition.

A further conceptual limitation arises from that fact that although item and source memory are considered functionally distinct, this distinction is not pure, and both forms of memory are functionally related during encoding and retrieval. It is therefore likely to be a considerable oversimplification to assume that structural changes in the MTL and the PFC map onto functional changes in item and source memory in a mutually exclusive way. Moreover, although PFC matures relatively late, MTL structures, including the hippocampus, functionally reorganize throughout childhood (Gogtay et al., 2006), as do the interconnections between these regions. In addition, successful memory retrieval depends on attentional functions supported by the PPC which is also subject to development (Gogtay et al., 2004). Each of these aspects of brain maturation may have separable effects on the development of both item and source memory which remain to be investigated.

Support for the view that item memory does not solely depend on processes that mature during childhood comes from the observation that item memory performance in Study 1 linearly increased with age until adulthood. The reasons for this improvement cannot be precisely identified on the basis of the present data. One possibility is that greater flexibility in the interchangeable use of recollection and familiarity and the development of post-retrieval control have contributed to this change. Another hypothesis might focus on improvements in binding mechanisms that serve to associate features of a memory trace at encoding and retrieval (Zimmer, Mecklinger, & Lindenberger, 2006). For example, one study found age-related improvements between 4 and 6 years of age in a recognition memory task that required the binding of different features of picture items, but no improvements in recognizing single item features (Sluzenski, Newcombe, & Kovacs, 2006). This suggests different developmental courses for associative vs. single-item aspects of recognition memory and allows for the possibility that greater efficiency in associating item features has contributed to better item memory performance with age in Study 1.

The final issues addressed here arise from the observed differences in strategic memory retrieval and may provide interesting starting points for future research. One issue concerns the robustness of the developmental effects discussed here. Research has shown that intervention through providing instructions to use appropriate strategies during encoding and retrieval can enhance memory performance in children and adolescents (Brehmer et al., 2007; Shing et al., 2008). Similarly, data from studies with older adults indicates that training that focuses on strategic retrieval results in better source memory performance (Bissig & Lustig, 2007; Jennings & Jacoby, 2003). Relevant to this issue is the concept of *developmental plasticity* which describes the capacity for change in the possible range of cognitive performance depending upon strategy instruction and strategy practice (Lövdén, Bäckman, Lindenberger, Schaefer, & Schmiedek, 2010). In future studies, assessing age differences in the efficiency of cognitive intervention may provide additional insights into the limits and potentials for strategic retrieval at different stages of development (Shing & Lindenberger, 2011).

A further issue is concerned with the use of ERP old/new effects for investigating strategic retrieval processing. An important caveat for contrasts of this kind is that they index retrieval success and therefore provide no information about the processes that act prior to successful retrieval such as cue specification (see

Figure 1). In this way, the findings from Study 2 provide only an indirect indication of age-related change in target-specific retrieval orientation. The most obvious avenue to overcoming this problem is to compare ERP contrasts involving new items from different retrieval conditions across age groups (Rugg & Wilding, 2000). ERP contrasts of this kind are typically made across task conditions in which qualitatively different kinds of information have to be retrieved (e.g. information associated with two different kinds of study tasks: Bridger et al., 2009; Dzulkifli & Wilding; information studied as either words or pictures: Herron & Rugg, 2003a). As the current designs did not include manipulations of the type of information to be retrieved, they are not optimally suited for investigating neural correlates of retrieval orientation. In future studies, this approach would allow determination of whether the effects found here extend to age differences in retrieval cue processing.

Finally, there is a pressing need to track the ontogeny of strategic retrieval processes across wider age ranges, including late adolescence, as it is still unclear at which point during development these processes mature. In addition, it might be useful to address how different retrieval processes are related developmentally. For example, one possibility is that maturation in post-retrieval control promotes changes in the ability to implement selective retrieval strategies. Potentially longitudinal designs could show that change in one process is followed by change in another process, suggesting a possible causal relation between both kinds of change. Likewise, one might look for correlations between neural correlates of strategic retrieval and independent assessments of cognitive control, such as to determine, for example, whether changes in selective recollection are related to improvements in tasks that require inhibition.

6.4 General conclusion

Episodic memory abilities improve during childhood and adolescence. The findings presented here supports models which emphasize that the mechanisms underlying this improvement develop at different rates. In particular, the current data highlight a prolonged developmental course of retrieval processes that are mediated by strategic control processes and enable individuals to identify the source of their memories. This assertion follows from the comparisons of the neural correlates of successful item and source memory retrieval across children, adolescents, and adults. These comparisons have identified a critical transitional stage in the maturation of strategic retrieval processes in early adolescence. Whilst the network that allows for strategic retrieval emerges with adolescence, further refinements in this network occur throughout adolescence. A necessary endeavor for future research is to extend the work begun here to further ways of investigation on the development of strategic episodic memory retrieval as proposed above.

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List of Figures

List of Tables

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Acknowledgements

I officially started this PhD project in April 2008, and I consider the three years at the Neuropsychology Unit at Saarland University for me to be a crucial learning period. The work presented here is the result of a process in which many persons were involved, both professionally and personally, and all of them have significantly contributed to providing new insights into the development of episodic memory retrieval which constitute my PhD project. I am indebted, of course, to all these people for their long-lasting support and encouragement which was invaluable for the successful completion of this work.

I am definitely grateful to Prof. Dr. Axel Mecklinger for accepting me to work in his team, for providing excellent working conditions, and for very fruitful discussions. These discussions were challenging and helpful at the same time, as they always led me to direct my attention to the relevant aspects of the data and by this significantly contributed to my learning process. I also greatly appreciated his respect to my ideas and his patience in reading and commenting on my manuscripts.

Secondly, and very much relatedly, I want to thank Dr. Kerstin Kipp for her permanent support to my work, her excellent practical ideas in planning the experiments presented here, and finally for accepting me to work in the DFG-funded research project on memory development, both as PhD student and post-doctoral researcher. I also very much appreciated here patience during the time in which I was engaged in writing the thesis and was not fully available for the project.

Moreover, I am indebted to Dr. Emma Bridger for very fruitful discussions on my data and here bright ideas for its interpretation. Emma always made very thoughtful and profound comments on my manuscripts. This was especially the case regarding the discussion of the present thesis, which significantly contributed to constraining and streamlining it.

I also want to thank Prof. Dr. Edward Wilding from Cardiff University, not only for his acceptance to examine my thesis, but also for his articles on the neural correlates on memory control which definitely contributed to constraining the interpretation of the findings presented here.

There were several further people who contributed to my work. Included in these is Dr. Theo Jäger, whom I would like to thank for his effort in organizing all the interesting courses within the GradUS program as well as the IRTG project, in addition to his help regarding the administrative matters surrounding the dissertation. Moreover, I am grateful to Dr. Bertram Opitz who made a very helpful contribution to this thesis in providing me with a script that allowed me to perform the repetition lag analysis reported in Study 1. I also want to thank all research assistants who were involved in data collection, including, Michael Kursawe, Matthias Krämer, Jens Berens, Florian Beier, and Jérôme Rimpel.

A final special thank goes to my partner Nicole with whom I began my PhD project and who always provided enormous helpful support to me in every respect.

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