"Action without meaning?"
Action Relationships as bottom-up unitization approach and its influence on the age-related associative memory deficit – behavioral and electrophysiological evidence

Dissertation
zur Erlangung des akademischen Grades eines
Doktors der Naturwissenschaften
der Fakultät HW
Bereich Empirische Humanwissenschaften
der Universität des Saarlandes

vorgelegt von

Véronique Huffer

aus Würzburg

Saarbrücken, 2022

Dekan:	Prof. Dr. Jörn Sparfeldt, Universität des Saarlandes
Berichterstatter*innen:	Prof. Dr. Axel Mecklinger, Universität des Saarlandes
	Prof. Dr. Jutta Kray, Universität des Saarlandes
Tag der Disputation:	22.07.2022

Für Mama und Papa

– meine Inspirationen fürs Leben

Abstract

Dual-process theories of recognition propose that two independent processes, familiarity and recollection, contribute to successful recognition memory. During the process of healthy aging, recollection is attenuated while familiarity is preserved, resulting in the age-related associative memory deficit, which is characterized by a greater age-related decline in associative memory as compared to item memory. Critically, associations are thought to require recollection whilst items can be recognized via familiarity. However, unitization represents one exception to this rule and describes the processing of integrating to-be-associated components into one single entity, enabling enhanced familiarity-based remembering of the associations. Thus, unitization provides a promising approach to alleviate the age-related associative memory deficit given that older adults could rely more on the intact familiarity process during associative recognition memory and thus, compensate the attenuated recollection. This dissertation had the goal to investigate the influence of bottom-up unitization induced by action relationships on the age-related associative memory deficit.

In an event-related potential (ERP) study with younger and older adults, we manipulated the presence of action relationships as a bottom-up unitization approach. Participants had to learn pictures consisting of semantically unrelated object pairs that were arranged in a way that an action could be imagined and thus unitized (e.g., a body lotion above a sports shoe so that body lotion could be poured into the sports shoe) or not (e.g., a punch below a towel so that the action of punching the towel could not be imagined). In a subsequent associative recognition memory test, participants had to distinguish between intact, recombined and new object pairs. We found the age-related associative memory deficit in that there were larger age-related differences for associative as compared to item memory. However, both age groups' associative memory performance benefitted from the presence of action relationships. Regarding the ERP results in the test phase, the late parietal old/new effect (i.e., intact vs. new)

was smaller in older age, reflecting the attenuated recollection process. Furthermore, there was an early associative familiarity effect (i.e., intact vs. recombined) for action-related intact object pairs in older adults only. For the late recollection time window, there was a significant larger difference between intact and recombined for action-related object pairs, regardless of age group, indicating associative memory processes for action-related intact object pairs. In sum, these results suggest that the observed associative memory benefit due to the presence of action relationships is a result of different mechanisms depending on the age group: While older adults seemed to rely more on familiarity for the association of intact action-related object pairs, younger adults show rather more reliance on recollection.

We found supporting evidence for this interpretation in an additional behavioral ABAC cued-recall study with younger adults, in which we investigated the representational characteristics of action-related object pairs. It is assumed that unitized representations (i.e., action-related object pairs), which should be familiarity-based remembered, are characterized by less flexibility as compared to non-unitized representations (i.e., action-unrelated object pairs). Therefore, the included components can be harder to decouple so that the learning of novel, but overlapping, associations is hindered. The participants had to learn and recall AB object pairs with and without action relationships. Afterwards, they were instructed to learn and remember AC object pairs corresponding to previously action-related and action-unrelated AB object pairs, respectively. Contrary to our expectations, we did not find more intrusions of previously action-related object pairs (i.e., AB+ object pairs) relative to action-unrelated object pairs (i.e., AB- object pairs), when the novel but overlapping associations (i.e., AC object pairs) had to be recalled. Furthermore, there was no difference in the memory performance for AC object pairs (i.e., hit rates) between both previous AB action relationship conditions. In conclusion, these results patterns did not support the assumption that the representations underlying action-related object pairs are characterized by enhanced familiarity-based remembering and less flexibility as expected for unitized representations.

To sum up, the experiments presented in this dissertation showed that younger and older adults' associative memory could benefit from the presence of action relationships as bottom-up unitization approach. However, the underlying mechanisms of this memory boost seem to differ between both age groups: Older adults seem to rely more on familiarity for the associations in action-related intact object pairs. The younger adults, instead, seem to rely more on recollection for associations instead of benefitting from enhanced familiarity-based remembering, which is also observed when underlying representations of action-related object pairs are investigated. Thus, the results suggest that the presence of action relationships acted as bottom-up unitization approach especially for older adults, who could not rely on recollection as younger adults.

Zusammenfassung

Zwei-Prozess Theorien der Rekognition nehmen an, dass zwei unabhängige Prozesse, Vertrautheit und Rekollektion, zu erfolgreichem Rekognitionsgdeächtnis beitragen. Der Prozess des gesunden Alterns ist durch eine Abnahme der Rekollektion charakterisiert, während der Vertrautheitsprozess intakt bleibt, wodurch das altersbedingten Assoziationsgedächtnisdefizit beobachtet werden kann. Dieses ist durch eine größere altersbedingte Abnahme im Assoziationsgedächtnis im Vergleich zum Itemgedächtnis gekennzeichnet. Entscheidend ist, dass angenommen wird, dass das Erinneren von Assoziationen Rekollektion erfordert, wohingegen einzelne Items basierend auf Vertrautheit erinnert werden können. Unitarisierung stellt allerdings eine Ausnahme dieser Regel dar und beschreibt den Prozess der Integration von zu assoziierenden Komponenten in eine einzelne Einheit. Dies ermöglicht ein verstärkt vertrautheitsbasiertes Erinnern der Assoziationen. Somit stellt Unitarisierung einen vielversprechenden Ansatz dar, um das altersbedingte Assoziationsgedächtnisdefizit zu minimieren, da sich ältere Erwachsene stärker auf den intakten Vertrautheitsprozess beim Erinnern an Assoziationen verlassen und somit die abgeschwächte Rekollektion kompensieren könnten. Ziel dieser Dissertation war es, den Einfluss von Handlungszusammenhängen als Bottom-up Unitarisierungsansatz auf das altersbedingte Assoziationsgedächtnisdefizit zu untersuchen.

In einer Studie mit ereigniskorrelierten Potentialen (EKP) mit jüngeren und älteren Probanden wurde die Anwesenheit eines Handlungszusammenhangs als Bottom-up Unitarisierungsansatz manipuliert. Die Teilnehmenden mussten Bilder semantisch unrelatierter Objektpaare lernen, die so angeordnet waren, dass man sich eine Handlung zwischen den beiden Objekten vorstellen konnte und diese unitarisiert werden konnten (z.B., eine Bodylotion über einem Turnschuh, sodass die Bodylotion in den Turnschuh gegossen werden könnte) oder nicht (z.B., ein Locher unter deinem Handtuch, sodass die Handlung des Lochens des

Handtuchs nicht vorgestellt werden konnte). In einem darauffolgenden assoziativem Rekognitionsgedächtnistest mussten die Teilnehmenden zwischen intakten, rekombinierten und neuen Objektpaaren differenzieren. Wir fanden das altersbedingte Assoziationsgedächtnisdefizit, welches sich in größeren altersbedingten Unterschieden im Assoziationsgedächtnis im Vergleich zum Itemgedächtnis zeigte. Allerdings profitierten beide Altersgruppen von der Anwesenheit der Handlungszusammenhänge in ihrer Assoziationsgedächtnisleistung. Die EKP-Ergebnisse der Testphase zeigten, dass der späte parietale alt/neu Effekt (intakt vs. Neu) für die älteren Teilnehmenden kleiner war und somit den beeinträchtigten Rekollektionsprozess widerspiegelte. Darüber hinaus fand sich ein früher assoziativer Vertrautheitseffekt (intakt vs. Rekombiniert) für die intakten Objektpaare mit Handlungszusammenhang in der Gruppe der älteren Teilnehmenden. Im späten Zeitfenster der Rekollektion fand sich ein signifikant größerer Unterschied zwischen intakten und rekombinierten Objektpaaren mit Handlungszusammenhang, welcher unabhängig von der Altersgruppe war und assoziative Gedächtnisprozesse für die intakten Objektpaare mit Handlungszusammenhang anzeigt. Zusammengefasst legen diese Ergebnisse nahe, dass der Gedächtnisvorteil im Assoziationsgedächtnis, welcher für die Objektpaare mit Handlungszusammenhang beobachtet wurde, je nach Altersgruppe auf unterschiedlichen zugrundeliegenden Mechanismen basierte: Die älteren Teilnehmenden scheinen sich verstärkt auf den Vertrautheitsprozess für die Assoziationen in intakten Objektpaaren mit Handlungszusammenhängen zu stützen, während die jüngeren Teilnehmenden sich eher auf Rekollektion für die Assoziationen stützen.

Stützende Evidenz für diese Interpretation fand sich in einer behavioralen ABAC cued-recall Studie mit jüngeren Probanden, in der wir Charakteristika der Repräsentationen von handlungsbezogenen Objektpaaren untersuchten. Es wird angenommen, dass unitarisierte Repräsentationen (d.h., Repräsentationen von handlungsbezogenen Objektpaaren), welche verstärkt vertrautheitsbasiert erinnert werden sollten, weniger flexibel sind als nicht unitarisierte Repräsentationen (d.h., Repräsentationen von Objektpaaren ohne Handlungszusammenhang). Das hat zur Folge, dass die enthaltenen Komponenten schwieriger entkoppelt und neu verknüpft werden können, wodurch das Lernen neuer Assoziationen, die mit den bestehenden Assoziationen überlappen, erschwert wird.

Die Teilnehmenden hatten die Aufgabe, zunächst AB Objektpaare mit und ohne Handlungszusammenhang zu lernen und abzurufen. Danach mussten AC Objektpaare gelernt und abgerufen werden, welche eine identische Komponente (das A-Objekt) zu den vorherigen Objektpaaren mit und ohne Handlungszusammenhang besaßen. Entgegen unseren Erwartungen fanden wir weder einen größeren Anteil an Intrusionen für zuvor handlungsbezogene Objektpaare (AB+) im Vergleich zu Objektpaaren ohne Handlungszusammenhänge (AB-) während der AC Testphase, noch einen signifikanten Unterschied zwischen den Handlungszusammenhangsbedingungen in der Gedächtnisleistung für die AC Objektpaare. Zusammengefasst sprachen die Ergebnisse nicht für eine geringere Flexibilität der zugrundeliegenden Repräsentationen von handlungsbezogenen Objektpaaren wie es für unitarisierte Repräsentationen erwartet wurde.

Abschließend lässt sich sagen, dass die in dieser Dissertation präsentierten Ergebnisse zeigten, dass junge und ältere Teilnehmende in ihrer Assoziationsgedächtnisleistung von der Anwesenheit von Handlungszusammenhängen als Bottom-up Unitarisierungsansatz profitieren konnten. Allerdings scheinen sich die zugrundeliegenden Prozesse dieses Gedächtnisvorteils zwischen den Altersgruppen zu unterscheiden: Die älteren Teilnehmenden scheinen sich verstärkt auf vertrautheitsbasiertes Erinnern der Assoziationen in handlungsbezogenen Objektpaaren zu stützen. Im Gegensatz dazu scheinen sich die jüngeren Teilnehmenden eher auf Rekollektion für die Assoziationen zu stützen, was auch zu beobachten ist, wenn die zugrundeliegenden Repräsentationen handlungsbezogener

Objektpaare untersucht werden. Somit legen die Ergebnisse nahe, dass die Anwesenheit von Handlungszusammenhängen besonders für die älteren Teilnehmenden, welche sich nicht in gleicher Art und Weise auf Rekollektion stützen können wie die jüngeren Teilnehmenden, als Bottom-up Unitarisierungsansatz gewirkt hat.

Acknowledgements

Doing a PhD and finishing the dissertation makes you realize how many people support you during this journey, without whom you would not have made it across the finish line.

First and foremost, I would like to thank my supervisor, Prof. Axel Mecklinger, for giving me the opportunity to do research in one of the most interesting research fields. Thank you for supporting me during the whole process from the conceptualization and conduction to the interpretation of my research ideas, for discussions that taught me how deep you can think about theories and for letting me grow professionally and personally. Thank you to Prof. Jutta Kray for your interest in this project and for reading and reviewing this dissertation. Furthermore, I would like to thank Prof. Hubert Zimmer for his constant interest in my research about action relationships and for always having a little bit of time to discuss the current status of my research. I would like to thank Dr. Regine Bader, for supporting me as a Post-doc during this time, always having an open door, teaching me some finesses of experimental designs and for exciting discussions.

Many thanks go to my current and former colleagues of the Experimental Neuropsychology Unit at Saarland University, for supporting me in my research, but not only for that. There were so many moments of laughing and joking, which brightened some stressful days and always served as little breaks from the research madness. In this context, I would also like to thank all my participants who took part in my experiments and my student assistants, who supported me during the data collection and the creation of stimulus materials. I would further like to thank the German Research Foundation for funding this work [grant number ME1588/10-1].

Julia Meßmer, thank you for being my "best buddy" during this whole process up to finish line with valuable comments on this dissertation. We started as colleagues, both fresh in the PhD game, and became friends sharing one office, having discussions between unitization and schema-based learning, enjoying moments of craziness, creativity and loud laughs. It was great to share our almost unitized “Kreative-Zimmer” with you and watching the sunset through the most beautiful office window while drinking a cup of fresh coffee.

I am grateful for my loving and caring friends who are always by my side and celebrate every achievement with me. They cheer me up since our school days (Corinna Jung, Nina Hänjes, Maike Herla and Jana Rippel) and are part of the journey since my time at Bamberg University (Katharina Weitz).

Lastly, I thank my family, who will always be my home no matter how far apart we live. Thank you, Fabienne, my little sister and brunette to my blonde, for always being by my side and picking up your phone no matter what time your big sister calls and needs a little break. Thank you, Léon, my little brother, for always being there and having some clearing advice when I overthink a little bit too much. And finally, thank you to my mother, Heidrun Omlor, and my father, Manfred Huffer, for your unconditional love and encouraging me my whole life to believe in myself and to reach for the stars. You taught me that there is not one right way but that every way you choose is the right one. Without you, I would not be where I am now.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

A+	Action-related object pairs
A-	Action-unrelated object pairs
AB+	AB object pairs with action relationship
AB-	AB object pairs without action relationship
AC+	AC object pairs corresponding to previously action-related AB object pairs
AC-	AC object pairs corresponding to previously action-unrelated AB object pairs
AC|AB	AC memory performance conditionalized by AB memory performance
ADH	associative deficit hypothesis
ANOVA	Analysis of variance
cm	Centimeter
EEG	Electroencephalography
e.g.	*exempli gratia* (for example)
ERP	Event-Related Potential
FCC	Forced-choice-corresponding
FCNC	Forced-choice non-corresponding
fMRI	functional Magnetic Resonance Imaging
i.e.	*id est* (that is)
ms	milliseconds
M	Mean
OA	Older adults
PD	Process Dissociation
PrC	Perirhinal Cortex
R/K	Remember/Know
ROC	Receiver operating characteristic
SD	Standard deviation
SEM	Standard error of the mean

vs.	versus
YA	Younger adults

List of publications

This dissertation is based on three studies including an aging rating study, an ERP aging study, and a behavioral study, which are described in chapters 6 – 8. The ERP aging study (chapter 7) was submitted in an international peer-reviewed journal and is currently in the revision process. I am the first author of the article and the other authors listed below contributed to the work. However, to facilitate reading I will consistently use "we" instead of "I" throughout this dissertation. The article is presented here in the form in which it was resubmitted for revision, apart from minor changes in formatting.

Chapter 7 – Experiment 1:

Huffer, V., Bader, R.,& Mecklinger, A. (under review). *Can the elderly take the action? – The influence of unitization induced by action relationships on the associative memory deficit* [Manuscript resubmitted for publication].

Introduction

"I'm always brushing my teeth with the left hand to keep my brain fit"

This is a sentence I got to hear very often from actually right-handed older adults when they came to the lab to participate in my studies. This sentence reflects the awareness of older adults that their memory and cognitive fitness are not as good as they were in their youth. In our society, people get older and older, and thus, concerns related to healthy aging are getting more and more relevant.

"I want to stay cognitively fit because my mum had severe dementia"

This quote represents the worries of some older adults when they come to our lab to participate in our memory experiments. Besides the normal side effects of healthy aging, neurodegenerative diseases like dementia, which are associated with older age, are a highly relevant topic for older adults. They worry a lot about their memory deficits and are willing to learn strategies and techniques to stop the progress of memory problems.

"I'm always trying new things and testing new technology so that I stay mentally fit"

This is a statement, which I was always happy to hear from participants coming to participate in my studies. This is because it means that they are open for my experiment, which is not natural, as the experience of being tested involves not only an electroencephalography (EEG) but also doing a memory experiment on the computer and coordinating the usage of special buttons.

Beyond the already mentioned, all these three examples of often heard statements have one thing in common: They show the motivation and willingness of older adults to learn and try new things, to stay cognitively fit and to train their abilities that are still intact.

When getting older, people have especially problems with remembering associations like the name to a person they meet in public. As these are highly important abilities, it becomes inevitable to find possible ways to help older adults improve their memory. Even though there are different approaches to achieve this goal, one perspective is my personal preference because it focus on the positive aspects of healthy aging: focusing on abilities that are still intact in older age. Nyberg et al. (2012) have proposed their “brain maintenance” hypothesis. Instead of re-organizing brain reserves as response to pathological changes, the authors emphasize that interventions and approaches should consider, which abilities are still available and encourage the usage of these.

In this thesis, I will follow this perspective by investigating a memory process (i.e., *familiarity*), which previous research suggests is still intact in older age (e.g., Friedman, 2013) and explore a possible approach (i.e., unitization) to encourage this process so that older adults' associative memory can benefit thereof.

I will start with an introduction in which I summarize previous research about the effects of healthy aging on episodic memory (Chapter 1). Afterwards, I will continue with presenting a process-oriented model providing an explanation for the age-related associative memory deficit (Chapter 2). Following this, there will be an introduction to the approach of unitization, its influence on the familiarity process and its usage in the scope of the age-related associative memory deficit (Chapter 3). Next, I will present the concept of action relationships, which will play a significant role in the unitization approach explored in this dissertation (Chapter 4). I will conclude the introduction by introducing my research questions (Chapter 5) and continue with reporting the conducted experiments (Chapter 6 – 8). Finally, the obtained results will be discussed (Chapter 9).

1 Memory and Aging

Not only neurodegenerative disorders, but also healthy aging impacts memory. This can be seen from self-reports about memory deficits, talked about by the majority of the older population. However, there are differential age-related changes of the memory depending on the type of memory which is affected. Remembering the name to a face is part of the declarative, episodic memory, which shows characteristic age-related changes, that will be introduced in the following.

1.1 Declarative Memory

Squire (1992) proposed that within the long-term memory, non-declarative and declarative memory can be distinguished. On the one side, non-declarative memory denotes a heterogeneous group of learning capacities referring to situations in which learning is expressed through performance instead of conscious access to memory content (e.g., classical conditioning, priming, habits and skill learning). These are supported by multiple brain systems (e.g., cerebellum, neocortex, striatum; Squire, 1992; Squire & Zola, 1996). On the other side, declarative memory, is characterized by speed and the ability of conscious recollection of memory contents, including the memory for words, scenes, faces and stories. Thus, it holds the capability of remembering events (e.g., meeting a friend in the supermarket) and facts (Squire, 1992). Declarative memory is supported by the hippocampal formation (i.e., hippocampal region and the entorhinal cortex including the adjacent perirhinal and parahippocampal cortices), the memory content is described as flexible and plasticity regarding declarative memory can occur rapidly (Squire, 1992; Squire & Zola, 1996). Within the declarative memory, semantic and episodic memory can be distinguished (Tulving, 1985). Semantic memory consists of abstract knowledge which is extracted from original learning episodes, whilst episodic memory represents not only knowledge about the world, but further encompasses acquisition and storage of knowledge about personal experiences and events including their temporal relations (Tulving, 2002). Tulving describes episodic memory as mentally “travelling back” in time and “re-experiencing” one’s own experiences from the past. Even though episodic and semantic memory bear similarities in knowledge acquisition and expression, both types of memory and their underlying brain systems can be dissociated (Tulving, 2002). While patients with hippocampal lesions show clear impairments of episodic memory (i.e., retrograde and anterograde amnesia), their semantic memory is still intact. On the other side, functional imaging data in healthy adults provide evidence for different activity patterns regarding episodic and semantic memory (see Tulving, 2002 for a discussion of the hemispheric encoding/retrieval asymmetry during encoding and retrieval of episodic memory).

Turning to episodic memory in more detail, successful episodic memory performance depends on the subject’s ability to retrieve knowledge about events that took place in a specific spatiotemporal context in their past. Richardson-Klavehn and Bjork (1988) propose that this knowledge can be accessed in three different tasks, namely free recall, cued recall and recognition. Albeit in all three measurements, people are asked to intentionally recall details about a specific learning episode in the past, the direct memory tests vary in several features. These include the number of cues given during the test phase, in the amount of information that has to be retrieved and the underlying retrieval strategies (Baddeley et al. 2020). Free recall requires the retrieval of information without any cues given so that a person’s skill of organizing information during encoding and selecting adequate strategies during retrieval are decisive for memory performance. During cued recall, a helping cue is given that restricts memory search to certain information and details. Thus, cued recall is assumed to be easier than free recall because the available cues serve as an environmental support for the search after information. Finally, recognition tests are the easiest form of direct episodic memory tests, because, instead of generating information, participants only have to decide whether a presented stimulus had been presented in the study phase or not. Thus, there is more environmental support compared to both, cued recall and free recall.

Recognition memory reflects the judgement whether an particular item or event has previously occurred (Mandler, 1980). Within recognition memory, item and associative recognition memory can be distinguished. For item recognition memory, the critical distinction is made between single items that occurred during study phase and items that are completely new. For associative recognition memory, instead, intact pairs (i.e., pairs with the same association as in the study phase) have to be discriminated from recombined pairs (i.e., pairs consisting of components that occurred during study phase but were combined with another partner; e.g., Ahmad & Hockley, 2014).

Both, recognition and (cued) recall memory, are considered declarative memory tasks. Note that it has been debated whether nondeclarative memory contributes to recognition memory. However, research on amnesic patients with selective impairment in declarative memory and intact nondeclarative memory shows no disproportional impairment of amnesic patients' recall memory performance as compared to recognition memory, indicating that recall and recognition are linked functions of declarative memory (Haist et al., 1992).

1.2 Effects of Aging on Episodic Memory

The process of healthy aging is associated with changes in the episodic memory (e.g., difficulties of remembering the name of a person) but the age-related changes differ depending on the way episodic memory is probed.

1.2.1 Recall vs. Recognition

Danckert and Craik (2013) conducted a series of behavioral memory experiments with younger and older adults to investigate age-related differences in recall and recognition memory. They tested the participants successively on the same word lists, always beginning with a free recall test, which was followed by a recognition test. The authors observed stronger age-related declines in free recall compared to recognition memory and that older adults are less able to recall recognized words compared to younger adults (see experiment 1). Furthermore, they found that recognition memory benefitted more from deep incidental encoding as recall, whereas recall was better when learned intentionally. Importantly, there were no age-related differences regarding recognition memory but still a clear decline in recall for older adults compared to younger adults (see results of experiment 2). In addition, even when intentional encoding strategies were more controlled by providing subjects with specific encoding strategies in order to minimize possible age-related differences regarding self-initiated intentional learning strategies, recall was characterized by a stronger age-related decline compared to recognition memory (see results in experiment 3). The authors discuss this result pattern in the context of the fact that free recall is characterized by a greater involvement of self-initiated processes to retrieve the information compared to recognition memory. Given that the process of healthy aging is associated with a decline and less efficiency of self-initiated processing (Craik, 1983) it is reasonable that recall is stronger attenuated in older age than recognition, which delivers more environmental support during retrieval. Critically, even though Danckert and Craik (2013) showed how the process of healthy aging impacts recall to a greater degree than recognition, the authors only investigated item recognition memory. However, particularly investigating age-related changes in recognition memory compared to recall requires a finer distinction between recognition memory types. While it is traditionally assumed that recall (free recall and cued recall) requires the retrieval of associations (i.e., associative memory like, for example, recalling a word pair or the partner, which was learned with a given word), recognition memory is characterized by recognizing single units of information (i.e., item memory) from the previous learning phase. However, different age-related changes regarding recall and recognition memory cannot be clearly connected to age-related differences in associative memory and item memory, respectively. Instead, there are multiple factors that might affect the age-related differences, like e.g., a greater demand of initiating memory search for free recall compared to recognition memory, which could be more difficult for older adults than younger adults, resulting in a stronger age-related decline of recall memory compared to recognition memory (Naveh-Benjamin, 2000). Thus, item and associative memory should be investigated with more comparable paradigms so that conclusions regarding age-related changes of both recognition memory types can be drawn. If done so, differential effects of older age on item and associative memory are observed, reflecting the age-related associative memory deficit, which will be introduced in the next section.

1.2.2 Age-related Associative Memory Deficit

Naveh-Benjamin (2000) postulates the associative deficit hypothesis (ADH), which extends the results about an age-related binding deficit found by Chalfonte & Johnson (1996). The hypothesis claims that older adults have especially difficulties in encoding and retrieving links between single units of information. This leads to a stronger decline in associative recognition compared to item recognition during the process of healthy aging. Hereby, older adults have especially difficulties in merging different aspects of an episode into a cohesive unit so that the associations between the aspects are hard to remember, even though the single components may be retained.

Naveh-Benjamin (2000) compared memory for item and associative information by using tasks that minimized retrieval differences and allowed attributing differences in item and associative memory performance on differential encoding processes. The participants had to learn unrelated word pairs and were tested both in an item and an associative recognition test afterwards (see experiment 2). For the item recognition memory test, they had to differentiate single words of previously learned word pairs from new single words. For the associative recognition memory test, they had to distinguish between intact word pairs (i.e., word pairs presented during study phase) and recombined word pairs (i.e., word pairs consisting of two presented words in a new combination). While younger adults performed better than older adults in both tasks, the age-related differences were significantly greater for associative than for item recognition memory. Furthermore, the older adults' associative memory did not benefit from intentional learning with equal performance under both, incidental and intentional encoding conditions. Younger adults, in contrast, could improve their associative memory when instructed to pay attention towards the word pairs during study phase (i.e., intentional encoding strategy) compared to incidental encoding instructions (i.e., incidental encoding for associations by focusing on single words). This leads to greater age-related differences in associative memory in the presence of intentional encoding instructions than incidental encoding instructions.

The ADH has been shown for several types of stimulus materials, as face-name pairs (Naveh-Benjamin et al., 2004) and face-face as well as face-location associations (Bastin & Van der Linden, 2005).

Given that there was evidence for the age-related associative memory deficit under incidental (Naveh-Benjamin, 2000) and intentional (Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2004) encoding instructions, the role of strategy utilization during encoding was investigated (Naveh-Benjamin et al., 2007, 2009). Naveh-Benjamin et al. (2007) investigated whether older adults could improve their associative memory performance when certain associative strategies are used during encoding and retrieval, suggesting a production deficit regarding the use of associative strategies (i.e., older adults are capable of using associative strategies but do not do so spontaneously; Craik & Byrd, 1982). Younger and older adults were instructed to learn word pairs, while encoding instructions where manipulated: One group of younger and older adults received only the instruction to learn the words and word pairs in preparation for upcoming recognition tests for components and associations. The second group was instructed to use an associative strategy during encoding which was forming a sentence including both words of the to-be-learned word pairs. The third group of younger and older adults had to use the same sentence strategy during encoding, but also had to rely on it during retrieval by trying to remember the sentence created during encoding to support associative recognition memory for the word pair. On the one hand, the results showed the age-related associative memory deficit when younger and older adults learned the word pairs under the simple intentional encoding instructions (i.e., instruction to learn word pairs for upcoming recognition tests). On the other hand, the older adults were able to improve their associative memory compared to the intentional encoding instruction condition (i.e., first encoding instruction condition), so that their associative memory deficit was not only reduced when an associative strategy was used during encoding (i.e., second encoding instruction condition) but almost eliminated when an associative strategy was applied during encoding and retrieval (i.e., third encoding instruction condition). This result pattern supports the assumption that the age-related associative memory deficit is partly mediated by a production deficit of applying appropriate strategies during encoding and retrieval, meaning that older adults do not engage as spontaneously as young adults in relational processing of components during encoding or retrieval.

Furthermore, Naveh-Benjamin et al. (2009) investigated the role of strategic processing during intentional and incidental encoding with regard to the associative memory deficit and found a more general memory decline instead of the specific associative memory deficit for older adults.

Taking together the results from Naveh-Benjamin et al. (2009) and Naveh-Benjamin (2000), some discrepancies regarding the age-related associative memory deficit under incidental encoding instructions is noticeable: the former study found evidence for an absence of the age-related associative memory deficit under incidental encoding instructions, while in the latter study the age-related associative memory deficit is present both under intentional and incidental encoding instructions. However, this can be explained by methodological differences regarding the encoding instructions. While instructing participants to focus on single components of the word pairs (i.e., incidental encoding instruction for associations; Naveh-Benjamin, 2000) might have led to a reduction of attentional resources during encoding, informing participants not at all about the upcoming memory tests (i.e., incidental encoding instruction; Naveh-Benjamin et al., 2009) was less attentional demanding, especially for older adults. Thus, older adults' might have shown the age-related associative memory deficit even under incidental encoding conditions due to increased attentional demands (Naveh-Benjamin, 2000).

Considering the role of attentional resources with regard to the ADH, Naveh-Benjamin et al. (2003) investigated whether younger adults in encoding conditions under divided attention show the same disproportional decrease in associative memory compared to item memory as reflected in the age-related associative memory deficit for older adults. However, younger adults with divided attention showed a general decrease in memory performance, which was similar for item and associative recognition memory. In conclusion, the age-related associative memory deficit does not seem to be mediated by a decline in attentional resources (see also Naveh-Benjamin et al., 2004, for similar results pattern for name-face associations).

Moreover, the ADH was contrasted with the contextual deficit hypothesis (e.g. Rabinowitz et al., 1982). A rich, distinctive encoding of an event is characterized by context reference. It is assumed that this integration of unique aspects of the item and its context represents controlled processing and requires attentional resources. The contextual deficit hypothesis states that older adults encode events and their contexts in a rather automatic fashion due to reduced processing resources, leading to a more general representation of the event and to reduced memory for perceptual-context attributes. In a series of behavioral experiments, Rabinowitz et al. (1982) found evidence for this contextual deficit hypothesis by comparing younger adults' and older adults' cued recall memory performance for word pairs. The critical manipulation referred to the presented retrieval cues during the test phase: either the cue was a context-specific, unique one (e.g., a self-generated unique retrieval cue) or the cue contained a more general relation to the target word (e.g., the name of the category to which the target word belongs). While younger and older adults showed similar memory performance when more general retrieval cues were used, which contained the core semantic meaning of the target words, older adults' memory performance was significantly decreased when retrieval cues with a specific relation to the context were presented. However, it might be possible, that the decreased memory performance arised from a poorer memory for the presented perceptual-context attribute (i.e., the retrieval cue), from a poorer memory for the target words themselves or from a poorer memory for the association between the perceptual-context attribute and the target word. This difficulty of disentangling was the reason for Naveh-Benjamin (2000) to create a test paradigm that allows to investigate the memory for perceptual-context attributes, target information and their associations separately. While older adults' recognition memory for words and fonts was as good as that of the younger adults, there were strong age differences in the recognition memory for the association between word and font. Given that older adults showed a differential age-related memory deficit for the associations, while their memory for the contextual details (i.e., the fonts) was as good as that of the younger adults, these results support rather the ADH instead of the contextual deficit hypothesis.

Finally, the ADH can be distinguished from the self-initiation/environmental support hypothesis, which assumes that encoding and retrieval tasks vary in their degree of demanding self-initiated operations (Craik, 1983). Hence, if self-initiated processing is reduced, as it is the case in older age, than older adults should show especially difficulties when the task requires such processing (e.g., free recall). Accordingly, the more environmental support is given, the more the memory performance could be improved despite of reduced and less efficient self-initiated processing and age-related differences in memory performance between younger and older adults should decrease. Naveh-Benjamin (2000) investigated the self-initiated/environmental support hypothesis as opposed to his formulated ADH by testing younger and older adults' memory for word pairs in free recall, cued recall and recognition memory tasks as those represent a continuum of environmental support and required self-initiated processes (see introduction of test paradigms in section about episodic memory above). The crucial condition in the comparison between ADH and self-initiated/environmental support hypothesis is the cued recall task. While the self-initiated/environmental support hypothesis would expect that older adults benefit from the environmental support given by the cues in the retrieval task, leading to smaller age-related differences compared to free recall, larger age-related differences in cued recall than free recall would support the ADH because the retrieval of a specific association is required. The author found largest age differences between younger and older adults for semantically unrelated word pairs in the cued recall task, followed by age differences in free recall and recognition task. Thus, these results are less consistent with the self-initiation/environmental support hypothesis and rather serve as additional support for the ADH.

Taking the described evidence together, there are multiple factors contributing to the age-related associative memory deficit. While reduced attentional resources and less efficient self-initiated processes, leading to stronger reliance on environmental support, contribute to the associative memory deficit, they cannot fully explain this specific deficit. Furthermore, they do not serve as an explanation model on a functional or process-oriented level. Thus, in the next chapter, a process-oriented perspective will be taken in by considering dual process theories of recognition and their role for the age-related associative memory deficit.

2 Dual Process Theories of Recognition and the Influence of Aging

The focus lies on recognition memory given that the age-related associative memory refers to recognition memory and, furthermore, recognition memory represents the appropriate paradigm to disentangle age-related differences in item and associative memory (e.g., Naveh-Benjamin, 2000)

In dual process theories of recognition, it is assumed that recognition memory performance relies on two distinct memory processes: familiarity and recollection. In his review, Yonelinas (2002) compares different dual-process models and presents the main characteristics of both memory processes, as well as how they can be measured. Both retrieval processes are functionally independent and differ regarding the type of information provided and also in their impact on recognition confidence. Based on signal detection theory, familiarity is described as a memory strength process, resulting in a feeling of "knowing" without the retrieval of details of the previous episode. It relates to a wide range of confidence regarding recognition decisions. Recollection, on the other hand, encompasses the retrieval of episodic details alike a threshold process. This process shows in high confidence ratings in recognition decisions. Regarding processing speed, familiarity is a faster process than recollection (e.g., Eichenbaum et al., 2007). Familiarity is also often described as a more automatic process, whilst recollection is a controlled process, including the effortful memory search process. There are various indices, which support the distinction between both processes of familiarity and recollection. I will present a selection with focus on behavioral and event-related potential (ERP) indices before the impact of healthy aging on these two processes will be discussed.

2.1 Behavioral Indices for Familiarity and Recollection

Measurement methods can be classified into two groups: *task-dissociation methods* and *process-estimation methods* (Yonelinas, 2002). *Task-dissociation methods* aim at isolating one of the two processes. Therefore, their focus lies on the behavioral performance in the implemented task or test condition itself. If there is a difference between performance in the decisive task or test condition, which enhance familiarity or recollection, and performance in a standard recognition test condition, which is assumed to rely on both familiarity and recollection, then conclusions about effects of the task or test condition on familiarity and recollection can be made. Task-dissociation methods include response-speed methods, recall/recognition methods, and item/associative recognition methods.

2.1.1 Response-speed Methods

The core assumption underlying response-speed methods is the finding that familiarity is faster than recollection (e.g., Eichenbaum et al., 2007) so that response speed can be used in order to disentangle familiarity and recollection. This can be achieved by comparing recognition memory performance of fast recognition responses (i.e., reflecting rather familiarity-based responses) with performance of slow recognition responses (i.e., reflecting responses with a greater contribution of recollection), i.e., the response-time method. Furthermore, familiarity and recollection can be disentangled with the response-deadline method. Here, in one condition subjects have to response within a certain time interval (i.e., speeded condition), while in the second condition the response is non-speeded (i.e., without deadline). Assuming that familiarity is faster, responses in the speeded condition should rely primarily on familiarity, whereas responses in the non-speeded condition should represent the contribution of both processes, familiarity and recollection. Finally, in the scope of response-speed methods, it is also possible to implement a speed-accuracy trade-off (SAT) method in which participants have to respond at variable intervals so that the increase of recognition memory performance can be observed as a function of processing time and retrieval speed in the different test conditions can be investigated.

2.1.2 Recall/Recognition Methods

In contrast to response-speed methods, recall/recognition methods focus on isolating the recollection process. Assuming that the search process during recall reflects the recollection process, comparing recall performance with recognition performance (i.e., reflecting recollection and familiarity) in a specific condition enables conclusions about the contribution of the recollection process to the condition. A potential limitation of the recall/recognition method is the fact that the two conditions within the comparison (i.e., recall and recognition) differ not only in the assumed contribution of recollection and familiarity, but also in some practical respects: while the test targets are presented in recognition tests so that subjects must give a yes/no response, they must produce the test targets themselves during recall. These different response requirements might lead to differences in the recruited recollection process. A possible solution for that limitation is the comparison between item and associative recognition tests instead of contrasting recognition with recall tests because in both recognition tests, item and associative, the test targets are presented and the subjects have to judge their previous occurrence.

2.1.3 Item/Associative Recognition Methods

During associative recognition the subjects have to retrieve qualitative information about the previous episode (i.e., the learned association between two items or an item and its context or feature) in order to give the correct response, whether the presented target appeared in the given constellation or not. During item recognition, on the other side, participants have to discriminate between studied and non-studied single items without the need of retrieving any association or qualitative information about the study episode. Thus, recollection should be especially useful for associative recognition. For item recognition, instead, familiarity should be sufficient because studied single items have a larger memory strength than unstudied single items. Therefore, associative recognition should require recollection whilst item recognition should involve both recollection and familiarity. An advantage of the comparison between item and associative recognition is the fact that the required responses are constant across the contrasted conditions because the test targets are presented in the item as well as associative recognition paradigm and the participants have to give an old/new judgement in both conditions.

Besides the above described task-dissociation methods, following the definition of task-dissociation methods by Yonelinas (2002), there is a further behavioral method that can be classified in a broader sense as a task-dissociation method: forced-choice paradigm.

2.1.4 Forced-choice Paradigm

A main characteristic of the forced-choice paradigm is the layout of the test display during the test phase. In contrast to a yes/no recognition paradigm, (i.e., presenting one trial after another and demanding an old/new judgement after each trial) in the forced-choice paradigm, the target is presented together with foils (i.e., the items with which the target item has to be compared). Depending on the degree of similarity between target and foils, the forced-choice-corresponding (FCC) condition is differentiated from the forced-choice non-corresponding (FCNC) condition (e.g., Bader et al., 2020; Migo et al., 2009). In the FCC condition, the foils have a high feature overlap with the target (e.g., an elephant as target and another elephant as foil). In the FCNC condition, instead, the foils presented together with the target have high feature overlap with other targets of the study phase (e.g., an elephant as target and a dog as foil that is similar to a dog that was studied as target). Migo et al. (2009) showed in their study that the FCC condition is accompanied by a higher contribution of familiarity to remembering while for the FCNC condition, recollection is needed. The reason for this result is the possibility to rely on the comparison between the familiarity signals of the target and the similar foil presented side by side in the FCC condition with higher familiarity for the target (Bader et al., 2020). Thus, the forced-choice-corresponding test format increases the diagnostic reliability of familiarity as compared to the yes/now recognition paradigm, in which a global familiarity criterion must be considered in each trial.

Beside these task-dissociation methods, Yonelinas (2002) describes *process-estimation methods* as another approach to estimate familiarity and recollection based on behavioral indices. *Process-estimation methods* focus on model equations that help to calculate parameter estimates for the contribution of familiarity and recollection to overall performance, based on behavioral measurements. Process-estimation methods include process-dissociation procedure, remember/know procedure, and the receiver operating characteristic (ROC) procedure, which I will outline briefly.

In the process-dissociation procedure (PD), two types of test conditions are applied, namely inclusion and exclusion test. These two test conditions differ in whether the old/new judgement is based on successful retrieval of qualitative information about the study phase or not (see Yonelinas, 2002, for further details about the method).

The remember/know procedure (R/K) reflects participants' capability of introspection as they have to report, whether they base their memory judgement on remembering (i.e., recollection of specific episodic details about the study phase) or on knowing (i.e., familiarity of the item without recollection). Referring to proportions of "remember" and "know" responses, estimates for recollection and familiarity, respectively, can be calculated.

Finally, in the ROC procedure, familiarity and recollection are estimated by plotting participants' hits and false alarms as a function of their response confidence. Participants have to rate the confidence of their yes/no recognition decisions. An old item is assumed to be recognized with "yes" either if it is recollected or its familiarity exceeds the subject's response criterion. A new item, instead, is assumed to be responded to "yes" (i.e., representing a false alarm) if familiarity of the new item exceeds the subject's response criterion. At the end, fitting the estimated equation to observed ROCs based on participants' responses provides estimations of recollection and familiarity.

Besides behavioral estimation methods for familiarity and recollection, another measurement that can be used, are ERPs.

2.2 Event-Related Potential (ERP) Correlates of Familiarity and Recollection

Familiarity and recollection can be assigned to two qualitatively distinct electrophysiological correlates depicted in old/new effects. ERPs are stimulus-locked to the onset of the items in the test phase. Old/new effects are characterized by more positive-going event-related potential (ERP) waveforms for correctly to responded old items when compared to correctly to responded new items (e.g., Rugg & Curran, 2007).

2.2.1 Familiarity

Familiarity is associated with the early mid-frontal old/new effect that appears about 300 to 500 ms post-stimulus (for a review, see Mecklinger, 2006; but see for an alternative veiw, Paller et al., 2007). Familiarity is assumed to reflect a global matching process between test items and memory traces derived from study phase. Thus, similarity between study and test items impacts the ERP correlate of familiarity in that way that for correctly identified studied items (i.e., hits) as well as for incorrectly as old identified similar lures (i.e., false alarms), ERP waveforms show a more positive-going relative to correctly rejected new items (i.e., correct rejections; Mecklinger, 2006). In line with the assumption that familiarity-based remembering reflects memory strength in sense of a signal detection process, the mid-frontal old/new effect varies monotonically with familiarity strength operationalized by response confidence in a modified remember/know paradigm (see for verbal stimuli, Woodruff et al., 2006 and for pictorial stimuli, Yu & Rugg, 2010). Furthermore, Mecklinger et al. (2011) showed that the mid-frontal old/new effect is observed when participants have to deliver fast responses (i.e., speeded response deadline). This result supports the assumption that familiarity is earlier available than recollection.

2.2.2 Recollection

Recollection is associated with the late parietal old/new effect, which comprises a phasic, positivity from around 400-800 ms post-stimulus with a left-sided posterior distribution (Rugg & Curran, 2007). In line with the idea, that recollection represents the retrieval of qualitative information and details about the study phase, Wilding and Rugg (1996) found an enhanced positive-going for correctly retrieved source memory when compared to correct rejections and correctly recognized old items without retrieving source information. Furthermore, the late parietal old/new effect is sensitive for the amount of retrieved information about the study episode as Vilberg et al. (2006) showed in their study that the late parietal old/new effect for remembering the associated partner of a picture pair (i.e., full recollection) is enhanced when compared to the late parietal old/new effect for remembering only any kind of detail of the study phase (i.e., partial recollection). Regarding associative recognition memory, Donaldson and Rugg (1998) found more positive-going ERPs with parietal maximum for same word pairs as compared to rearranged word pairs, which they interpret as reflecting recollection.

Considering the characterization of familiarity and recollection, a dissociation between these two processes is conceivable. There is a bunch of evidence supporting a double dissociation between familiarity and recollection when different materials and task formats are applied (e.g., Curran & Doyle, 2011; Opitz & Cornell, 2006; Woodruff et al., 2006; for reviews, see Friedman & Johnson, 2000; Mecklinger, 2000;Yonelinas et al., 2010).

In conclusion, the early mid-frontal old/new effect and late parietal old/new effect represent reliable neural correlates of familiarity and recollection, respectively, and can be considered independent estimates of these two processes. Familiarity and recollection are impacted differentially by the process of healthy aging, which is reflected in estimates of these two processes and will be described in the following section.

2.3 Impact of Healthy Aging on Familiarity and Recollection

When investigating the impact of healthy aging on familiarity and recollection as well as the corresponding estimates, the neuroanatomical correlates of these two processes and their contribution two item and associative memory should be considered.

2.3.1 Neuroanatomy of Familiarity and Recollection

Familiarity and recollection are supported by distinct neuroanatomical regions within the medial temporal lobe (MTL). While the hippocampus contributes to recollection, familiarity is supported by perirhinal cortex (PrC; e.g., Diana et al., 2007, see Eichenbaum et al., 2007; Rugg & Vilberg, 2013 for reviews). In their review, Rugg and Vilberg (2013), for example, argue for a content-independent network including the hippocampus, which is characterized by enhanced activity when manipulations target recollection and is sensitive to the amount of retrieved contextual information about the study episode. With regard to the perirhinal cortex and familiarity, Montaldi et al. (2006) present functional magnetic resonance imaging (fMRI) data that show that increasing familiarity strength as indicated by subjects' familiarity judgements leads to a decrease of activation in the PrC, while hippocampus was not sensitive to variations in familiarity strength.

The distinction between hippocampus contributing to recollection in associative memory, on the one hand, and PrC supporting familiarity in item recognition memory on the other hand is also supported by studies with lesion patients with hippocampal damage but no extended lesions including PrC, who show spared item recognition memory relative to recall and associative recognition memory, supposedly due to familiarity-based remembering (e.g., Holdstock et al., 2005).

2.3.2 Impact of Aging on Familiarity and Recollection

The process of healthy aging impacts familiarity and recollection differentially: While familiarity is relatively preserved, recollection shows a strong attenuation in older age (Koen & Yonelinas, 2016). Regarding recollection, this attenuation can be traced back to an the age-related atrophy of the hippocampus (Raz et al., 2005; Yonelinas et al., 2007). Regarding familiarity, the evidence about age-related changes in neuronal regions is more heterogeneous. In their study, Yonelinas et al. (2007) found a double dissociation between the hippocampus and entorhinal cortex contributing to recollection and familiarity, respectively, with larger age-related changes in hippocampus as compared to entorhinal cortex (see also Raz et al., 2005). Even though there is only little research about the impact of healthy aging on the perirhinal cortex, which contributes to familiarity (Eichenbaum et al., 2007), Duarte et al. (2010) investigated age-related changes in neuronal activity underlying familiarity and found no age-related atrophy in the perirhinal cortex, supporting the assumption of preserved familiarity in older age.

Besides age-related changes in neuronal regions, behavioral estimation methods (i.e., PD, ROC, R/K) converge on the pattern that familiarity is preserved in older age while recollection is attenuated (Koen & Yonelinas, 2014, 2016). Here, it is important that strict instructions are used in the R/K paradigm when investigating familiarity and recollection because otherwise older adults tend to interpret “remember” in a less strict way, giving “remember” instead of “know” responses to items that are highly familiar which then leads to unexpected age-related decrease in familiarity estimates (Koen & Yonelinas, 2016).

Finally, there is electrophysiological evidence supporting the pattern of a selective decline in recollection with preserved familiarity at the same time in older age: While the late parietal old/new effect (i.e., the putative correlate of recollection) shows age-related diminution, the early mid-frontal old/new effect (i.e., the correlate of familiarity) is characterized by smaller age-related changes (see for a review, Friedman, 2013). It is important to note that regarding the early mid-frontal old/new effect, the used stimulus materials play a critical role: reliable early mid-frontal old/new effects are found in older adults when using pictorial stimuli (Ally et al., 2008) as compared to verbal stimuli for which evidence is more heterogeneous (e.g., Duarte et al., 2006; Trott et al., 1999; Wang et al., 2012).

Now, putting all these presented findings together, the age-related associative memory deficit can be explained as follows: Given that recollection encompasses the retrieval of qualitative information (i.e., retrieving associations; Yonelinas et al., 2010) and that healthy aging is characterized by a decrease in recollection, which is supported by findings on the behavioral, neuroanatomical as well as on the electrophysiological level, older adults have a greater associative memory impairment relative to younger adults as compared to age-related differences in item memory. At the same time, the outlined evidence shows that familiarity, the second process contributing to successful recognition memory, is preserved in older age. Interestingly, in their fMRI study, Haskins et al. (2008) found an increased contribution of familiarity to associative recognition memory which cannot be explained by the above presented findings focusing on item recognition memory (Holdstock et al., 2005; Montaldi et al., 2006). The authors observed enhanced activation in PrC during encoding of word pairs as compounds when compared to sentence condition. Furthermore, they found a positive correlation between PrC activation during encoding and familiarity strength in the test phase. How can this be integrated with the findings presented above? The manipulation in Haskins et al. (2008) involved an unitization manipulation where the to-be-learned novel associations could be encoded as unitized representations, and thus can be treated as single entities or items. This then leads to increased activation in PrC during encoding as well as enhanced familiarity-based remembering during retrieval. Thus, there are possibilities that familiarity contributes to associative recognition memory. This provides a chance for older adults to bridge their associative memory deficit by providing an opportunity to rely on their intact familiarity process during retrieval of associations.

Recapitulating some behavioral evidence from studies investigating associative recognition memory in younger and older adults, higher false alarm rates are observed in older adults relative to younger adults, while there are no age-related differences in hit rates for novel associations (e.g., Naveh-Benjamin et al., 2009). This result pattern suggests that familiarity contributed to associative recognition memory but in this case older adults could not benefit from familiarity to improve their associative recognition memory. Thus, the question rises how the contribution of familiarity to associative recognition memory can be increased as compensation for older adults' attenuated recollection so that successful associative recognition memory can be supported by enhanced familiarity-based remembering instead of increasing false alarm rates resulting in the associative memory deficit. One very promising approach in this field is unitization, which will be discussed in the following chapter.

3 Unitization and Aging

Unitization represents an approach to increase the contribution of familiarity to associative recognition memory (e.g., Ahmad & Hockley, 2014; Bader et al., 2010; Diana et al., 2008; Quamme et al., 2007; Rhodes & Donaldson, 2007). Given that familiarity is preserved in older age, unitization serves as a possibility to minimize the age-related associative memory deficit by compensating for the attenuated recollection in older age (e.g., Ahmad et al., 2015; Bastin et al., 2013; Zheng et al., 2015).

3.1 Unitization and Unitized Representations

Unitization is defined as the process of creating a representation of previously separate items as a single unit (Graf & Schacter, 1989). The advantage of unitization is that reprocessing of some components leads to reactivation of the unitized representation as a whole, which facilitates subsequent processing of the established unit (Graf & Schacter, 1989). Graf & Schacter (1989) proposed two possible approaches to support unitization: perceptual mechanisms or meaning as the "glue". Referring to the former one, unitization can result from perceiving a coherence among the separate stimulus components due to perceptual characteristics (e.g., proximity). Regarding meaning, the second approach, connecting the stimulus components by creating a structure (i.e., a sentence) can support unitization as well. These two approaches map quite good onto the distinction of unitization strategies proposed by Tibon et al. (2014). Tibon et al. (2014) distinguish top-down from bottom-up unitization approaches. Top-down unitization approaches encompass explicit encoding instructions about the way the to-be-learned components have to be encoded (e.g., instructing participants to imagine the item in the color of the background, e.g., Diana et al., 2008). These encoding instructions have to be applied actively by the participants to support unitization. Bottom-up unitization approaches, instead, focus on stimulus materials as the basis for supporting unitization. While encoding instructions are the same in bottom-up conditions supporting unitization or not, features like perceptual or semantic properties of the to-be-learned materials are manipulated in order to encourage more or less unitization.

Referring to bottom-up unitization approaches, the modality of the to-be-associated components plays a role with regard to whether unitization is supported more or less. Mayes et al. (2007) propose that there are three possible types of associations in episodic memory: intra-item associations (i.e., unitized entities, as for example compound words), within-domain associations (i.e., associations between same or similar kinds of items, for example a glass and a bottle) and between-domain associations (i.e., associations between different kinds of items or modalities, for example a picture and a sound). While memory for intra-item associations and within-domain associations is assumed to rely on the PrC and familiarity, memory for between-domain associations is supported by hippocampus and recollection. Given that within-domain associations are familiarity-based remembered when the components are linked directly together during encoding, this model suggests that such associations can be unitized with higher probability than between-domain associations. Following this suggestion, Tibon et al. (2014) showed in their study that associative memory for unimodal picture-picture pairs (i.e., unitized within-domain associations) was supported by familiarity, while cross-modal picture-sound pairs (i.e., non-unitized between-domain associations) were retrieved with the help of recollection.

However, one common conceptual idea for all unitization approaches is formulated in the levels of unitization (LOU) framework by Parks and Yonelinas (2015). The levels of unitization framework comprises the idea that unitization approaches can be arranged on a continuum: on the lower end, there are conditions not supporting unitization of two components but instead both items are treated as separate components; on the higher end, there are conditions supporting unitization so that both components are entirely processed as a single entity. Following this continuum idea, unitization approaches differ regarding the degree to which components of associations are treated as a single unit or separate constituents. Corresponding to unitization as relative concept, it always depends on the comparison between both conditions (i.e., unitization vs. no unitization) whether one certain condition represents the high unitization condition or not. The idea of "levels" resembles another theoretical framework, which should be dissociated from the levels of unitization framework, namely the levels of processing framework (Craik & Lockhart, 1972). Craik and Lockhart (1972) propose that the deeper the processing, the greater is the degree of semantic and elaborative processing. If unitization would represent elaborative processing in the sense of deeper processing as compared to conditions not supporting unitization, then associative and item memory should benefit in a similar way from conditions in which associations are unitized. However, Parks and Yonelinas (2015) demonstrated that unitization is not just a form of elaborative processing by showing that conditions supporting unitization (i.e., on the higher end of the unitization continuum) improved selectively associative memory while item memory was hardly impacted. Furthermore, familiarity was increased in unitized conditions as compared to non-unitized conditions. Thus, unitization encompasses effects that go beyond effects of deep levels of processing.

An interesting question concerns the results from unitization, namely unitized representations and their characteristics especially in how far they differ from non-unitized representations. Henke (2010) postulates a model based on processing modes that delivers assumptions about characteristics of unitized representations. The model assumes that depending on the processing mode, specific brain regions are involved and distinct memory traces are generated. The processing modes are defined by three different variables: rapid vs. slow encoding (i.e., number of learning trials required for successful retrieval), associative vs.

single item encoding and flexible and compositional vs. rigid and unitized representations. Compositionality means that both the entire memory of an association and its individual components are mentally represented. These components are not unitized but are accessible individually or in relation to each other. This leads to flexible representations. Rapid encoding of flexible associations occurs during one single encoding trial and reflects the processing mode that relies on the hippocampus and neocortex, so that recollection-based memory is generated. The resulting representations are viewer-independent and flexible and represent the “classic” view of associative memory. Regarding hippocampal-independent encoding of associations, Henke (2010) suggests two possible ways. On the one side, associations can by slowly encoded over multiple learning trials resulting in rigid neocortical representations. On the other side, it is proposed that single or unitized items can be encoded rapidly during one single encounter by relying on parahippocamapl and neocortical regions. These unitized representations can be familiarity-based remembered but are characterized by rigidity given that the single components are not encoded independently as compared to rapid encoding of flexible associations via hippocampus.

To sum up, unitization is a concept that includes unitization approaches, which support that associations are more or less unitized, and processes that occur during encoding, resulting in unitized representations that are characterized by rigidity. The main idea of unitization is that it serves as a possibility to remember newly learned associations familiarity-based instead of being dependent on recollection-based retrieval what makes it an interesting approach to aging given that older adults could rely more on familiarity during associative recognition memory and compensating their attenuated recollection.

3.2 Unitization and Familiarity

As unitization supports the integration of the to-be-associated components into one single unit, it can enhance familiarity-based remembering during associative recognition memory (Yonelinas, 2002; Yonelinas et al., 2010) bypassing the claim that associations can only be remembered based on recollection as only items can be remembered based on familiarity. Firstly, there is behavioral evidence for increasing the contribution of familiarity to associative recognition when conditions are applied, which support unitization (e.g., Haskins et al., 2008; Jäger & Mecklinger, 2009; Yonelinas et al., 1999). For example, Yonelinas et al. (1999) used faces as stimuli and manipulated their orientation: the faces were either presented upside down or upright. While the upright presentation allowed to integrate external (i.e., hairs and shoulders) and internal features (i.e., mouth, eyes, and nose) into a whole unit (i.e., the face), the upside-down presentation hindered such an integration. The participants had to discriminate between intact faces (i.e., internal and external features in the same combination as in study phase) and recombined faces (i.e., internal features from one face of study phase were combined with external features from another face of study phase). The authors found that familiarity estimates were significantly higher and ROCs were curvilinear when faces were presented upright, whereas an upside-down presentation of faces resulted in linear ROCs and familiarity estimates near to zero. These results suggest that the contribution of familiarity was increased for associative recognition, but only, if the to-be-associated information (i.e., internal and external facial features) can be integrated into an entity (i.e., features are unitized; for similar results by observing increased familiarity estimtates for intra-item associations as compared to inter-item associations using face pairs, see Jäger & Mecklinger, 2009).

The increased contribution of familiarity to associative recognition was also found for pre-experimentally unitized compound words (Ahmad & Hockley, 2014) and for unitized item-background color associations (Diana et al., 2008).

Besides behavioral evidence, studies with lesion patients show that unitization can promote familiarity for associative recognition (e.g., Diana et al., 2010; Giovanello et al., 2006; Quamme et al., 2007). Quamme et al. (2007), for example, compared patients with temporal lobectomy (i.e., damage to hippocampus, perirhinal cortex, entorhinal cortex and parahippocampal cortex) and patients with cerebral hypoxia (i.e., relatively limited damage to hippocampus) with age-matched controls in an associative memory task. The participants had to learn unrelated word pairs by encoding the word pair with a sentence, in which every word could be filled into (i.e., non-unitization condition) or with a definition, which explained the new compound (i.e., unitization condition). In the test phase, intact word pairs had to be distinguished from recombined word pairs. The patients with temporal lobectomy showed impaired associative memory performance in both, the sentence and the compound condition as compared to healthy controls, whereas the hypoxia patients' associative memory benefitted from the compound condition (i.e., unitization) even though their performance was lower compared to healthy controls. This suggests that hypoxia patients could rely more on familiarity in the unitization condition (i.e., compound condition) given that their damage was limited to hippocampus and attenuated recollection only. The patients with temporal lobectomy could not benefit from the unitization condition by relying more on familiarity as both familiarity and recollection were impaired due to their damage.

Diana et al. (2010) found similar results for source memory in amnesic patients (i.e., patients with mild hypoxia), who had to learn associations between word and background color (red or green) by imaging either the color as a contextual detail (i.e., context detail condition: imaging interaction between the study item and dollar bill for background color green or stop sign for background color red) or as an item detail (i.e., item detail condition: imaging the study item in the color green or red). The patients' source memory benefitted from the item detail condition compared to the context detail condition. This result suggests that they could rely more on familiarity in the item detail condition, which supported unitization, as compared to the context detail condition, in which recollection is necessary for retrieving the contextual detail and was impaired due to the patients' recollection deficits (for similar results about associative memory benefit and increased contribution of familiarity to associative recognition for pre-experimentally unitized compound words relative to unrelated word pairs in amnesic patients, see Giovanello et al., 2006).

Furthermore, functional imaging studies have shown that there is enhanced activation in the PrC during encoding of unitized word pairs, which also predicts subsequent familiarity-based associative memory (Haskins et al., 2008). In addition, Diana et al. (2010) showed that, during retrieval, PrC is involved for remembering item details (i.e., unitization condition), whereas hippocampus plays a role for retrieval of context details (i.e., no unitization condition). These studies deliver evidence for enhanced involvement of PrC during encoding and retrieval of unitized associations, suggesting increased contribution of familiarity to associative recognition memory given that PrC is associated with familiarity-based processing.

Finally, there is a bunch of electrophysiological evidence supporting enhanced familiarity-based remembering in associative recognition when conditions supporting unitization are applied (e.g., Bader et al., 2010; Diana et al., 2011; Jäger et al., 2006; Rhodes & Donaldson, 2007, 2008). Starting with top-down unitization approaches, Bader et al. (2010) showed greater early old/new effects (350-500 ms post stimulus) for novel compound words out of pre-experimentally unrelated nouns, which were learned with a definition (i.e., unitization) as compared to word pairs encoded with a sentence including blank spaces for each word separately (i.e., no unitization). Furthermore, a qualitatively different late old/new effect was present for the sentence condition (i.e., non-unitized word pairs) only. This results pattern suggests enhanced familiarity-based remembering of newly unitized compound word pairs relative to non-unitized unrelated word pairs. Rhodes and Donaldson (2008b) used semantically related word pairs and implemented an interactive imagery strategy as top-down unitization approach by instructing participants to imagine an interaction between the two to-be-associated items. The authors observed a larger bilaterally frontal old/new effect (250-500 ms post stimulus) for semantically related word pairs encoded with interactive imagery strategy (i.e., unitized word pairs) as compared to item imagery strategy (i.e., non-unitized word pairs), suggests enhanced familiarity during associative recognition when word pairs are encoded under conditions supporting interactive integration of the components.

Turning to bottom-up unitization approaches, Rhodes & Donaldson (2007) focused on characteristics of the to-be-learned word pairs and manipulated the pre-experimentally existing association. The authors compared word pairs with an association (e.g., glow-worm), word pairs with an association and a semantic relationship (e.g., needle-thread) and word pairs with only a semantic relationship (e.g., fork-plate). The word pairs with association were rated as most reflecting a single unit and associative recognition memory was highest for these word pairs. Furthermore, the ERPs during retrieval showed the early bilateral frontal old/new effect for word pairs with association only, while the late left parietal old/new effect was observed for all three word pair conditions. These results suggest that improved associative memory performance was accompanied by enhanced reliance on familiarity when the word pairs were unitized. Another bottom-up unitization approach using semantic relationships was implemented by Tibon et al. (2014) using pictorial stimuli instead of word pairs. The authors manipulated semantic relationship between objects included in object pairs, which had to discriminated from recombined and new object pairs. For the ERP results, intact object pairs were compared to recombined object pairs to analyze processes related to associative memory, whereas intact/recombined object pairs were contrasted with new object pairs as indicator for item memory processes. For semantically related object pairs only, there was an early frontal associative familiarity effect, while the early frontal item familiarity effect was present for both semantic relationship conditions. Furthermore, the late parietal ERP effect representing associative recollection (i.e., intact vs. recombined) was present for both semantic relationship conditions, but with larger effects for semantically related object pairs. Thus, associative recognition memory of semantically related object pairs was supported by enhanced familiarity-based remembering for the included association (i.e., familiarity effect for contrast of intact vs. recombined object pairs) encouraging the assumption that semantic relationship served as an unitization approach, which leads to processing of semantically related object pairs in an unitized fashion.

Following the line of evidence presented above, it becomes clear that the contribution of familiarity to associative recognition memory can be increased when encoding manipulations are created that support unitization. Therefore, it is conceivable that unitization provides a possibility for older adults to rely more on their intact familiarity process during associative recognition memory and compensate their attenuated recollection, resulting in mitigating the age-related associative memory deficit. Naveh-Benjamin et al. (2003) already observed in their study that certain stimulus characteristics impact the age-related associative memory deficit. While older adults showed larger age-related deficits in associative memory compared to item memory (i.e., ADH) when word pairs were semantically unrelated, their associative memory performance was improved and approached younger adults' associative memory performance when word pairs were semantically related, probably due to unitization, providing an approach to reduce age-related associative memory deficit. Research of the last years has focused on investigating possible ways to enable older adults to improve their associative memory by compensating their attenuated recollection and relying more on familiarity due to unitization, which will be outlined in the following section.

3.3 Unitization and Age-related Associative Memory Deficit

Starting with the behavioral perspective, Bastin et al. (2013) implemented a top-down unitization approach and investigated whether this could reduce the age-related associative memory deficit in a source memory task. The participants were instructed to encode associations between a word and background color either by imaging the item in the same color as the background (i.e., item detail condition, unitization) or by imaging an interaction between the item and another object representing the color of the background (i.e., context detail condition, non-unitization). While older adults showed the aforementioned associative memory deficit in the context detail condition (i.e., significant worse source memory performance for background color as compared to younger adults), their source memory performance was not significantly decreased relative to younger adults in the item detail condition. Furthermore, the authors analyzed ROC curves in older adults and found increased familiarity estimates for item detail condition relative to context detail condition. These results suggest that older adults' source memory could benefit from unitization by relying more on familiarity during retrieval. Ahmad et al. (2015) found additional behavioral evidence by using compound words (i.e., unitized) and noncompound words (i.e., non-unitized) in a series of experiments. Older adults' age-related associative memory deficit was alleviated for compound words. Furthermore, when associative memory performance was tested with a two-alternative forced-choice recognition paradigm (i.e., a test paradigm enhancing reliance on familiarity during retrieval), younger and older adults' associative memory performance benefitted from the bottom-up unitization condition (i.e., compound words). These results suggest that older adults could improve their associative memory by increased reliance on familiarity for pre-experimentally unitized word pairs.

Expanding the scope of evidence to electrophysiological perspective, Zheng et al. (2015) investigated in their ERP study the underlying processes during retrieval of unitized word pairs. Younger and older adults had to learn compound words (i.e., unitized) and unrelated word pairs (i.e., non-unitized). During retrieval, there were smaller age-related differences for compound words as compared to unrelated word pairs, representing an alleviation of the age-related associative memory deficit. In addition, the authors observed the early frontal old/new effect for both age groups in the condition supporting unitization (i.e., compound words), which was also positively correlated with associative memory performance. Thus, older adults' improved associative memory was accompanied by increased reliance on familiarity-based remembering of unitized word pairs (see also for similar results in a source memory paradigm using associations between words and background color, Zheng et al., 2016).

Focusing more on bottom-up unitization, but with pictorial stimuli instead of word pairs, Bridger et al. (2017) conducted an ERP study with younger and older adults, which is from high relevance for the current dissertation. The participants had to learn associations between two objects, which were semantically unrelated. Therefore, the object pairs were arranged in a way that the positions from both objects to each other were plausible (e.g., a shirt above a boat) or implausible (e.g., a wolf above a telescope). It was assumed that object pairs with plausible arrangement would support unitization of both objects, providing an opportunity to rely more on familiarity during retrieval so that older adults' associative memory deficit could be alleviated. During test, the participants had to distinguish between intact, recombined, and new object pairs. Both age groups' associative memory performance benefitted from plausible arrangement compared to implausible condition. Contrary to the expectations, there was a similar memory benefit for item memory in both age groups, meaning that the memory benefit was not selective for associative memory and thus, the age-related associative memory deficit was not mitigated. Considering the ERP results, there was no interaction between old/new effects and plausibility condition. This means, that familiarity and recollection were not differentially affected by the way of arrangement of the object pairs. Thus, there was no enhanced familiarity-based remembering, which would have been indexed by increased early mid-frontal old/new effects, for plausible arranged object pairs as compared to implausible arranged object pairs. The authors discuss the possibility that, instead of supporting unitization, plausible arrangement of object pairs might have led to general increase of fluent processing of the object pairs, resulting in better item and associative memory for these object pairs.

Thus, the question rises, which bottom-up unitization approach might foster the unitization of two semantically unrelated objects more than the applied approach by Bridger et al. (2017). The concept of action relationships serves as a promising approach, which will be introduced in the next chapter.

4 Action Relationships as Bottom-up Unitization Approach

The concept of action relationships and how they can be built, has its origin in research about visual perception. Here, especially research with patients suffering deficits in visual perception was fruitful. In the next two sections, first, definition and creation of action relationships will be introduced, and secondly, advantages of pictorial stimuli instead of verbal stimuli in the scope of research about bottom-up unitization and age-related associative memory deficit will be discussed.

4.1 Action Relationships

Action relationships can be created between two single objects included in one object pair. Here, one object represents the "active member", that is typically moved in the action, while the other one object acts as the "passive member", that may be held during the action (Humphreys & Riddoch, 2007). Humphreys et al. (2006) investigated how far an action relationship can enable the perception of two single objects as one single unit. On the one hand, the two objects of an object pair could form a familiar visual unit, meaning that these two objects are often used together or have a high probability of co-occurrence in a particular spatial relationship. In the visual system, representations of object pairs with familiar and frequent collocations relative to each other are stored. Thus, in case of an activation of the same stored representation by an object pair, this kind of semantic relationship between the two objects is decisive for the perception of an object pair as a single perceptual unit.

On the other hand, the "affordance" of the objects is the crucial aspect for the action relationship. "Affordance" refers to the fact that objects have structural properties that afford a certain action so that this affordance can cue attention to both objects of an object pair leading to the perception of a single unit including these two objects. It is assumed that higher order representations are stored containing objects that are action-related due to joint action usage (e.g., scissors and tape). Furthermore, it is assumed that these representations and the included actions can be abstracted from the objects themselves as long as the structural properties are maintained that are needed for the conduction of a particular action (e.g., blades for a cutting action instead of scissors). This leads to some kind of generalization (Humphreys & Riddoch, 2007) based on common properties between the objects.

In order to examine, which of these two possible ways of creating action relationship is crucial in order to perceiving an object pair as one perceptual unit Humphreys et al. (2006) conducted a series of visual perception experiments with a patient diagnosed with Balint's syndrome. This neuropsychological disorder is characterized by deficits of visual perception including simultanagnosia leading to the inability in perceiving two objects at a time (i.e., in this case: visual extinction for the left-sided visual field after a bilateral parietal damage). In the conducted experiments, object pairs including one object in the left and one object in the right visual field were presented simultaneously. The logic behind these experiments is that if these object pairs are presented in a way that the patient's left-sided visual deficit is reduced and he can identify both objects, it suggests that the attention is cued to both objects and the object pair is perceived as one perceptual unit. Thus, object pairs including two objects were created with the presence of a semantic relationship (i.e., representing familiar visual units), an action relationship or both. The crucial manipulation for the current study was examined by comparing object pairs with a semantic and an action relationship (e.g. a wine bottle above a wine glass) with object pairs without semantic relationship but having an action relationship by maintaining the structural properties that are needed for the conduction of the action per se (e.g. a wine bottle above a bucket; see experiment 3 in Humphreys et al., 2006). The patient's performance of identifying the two objects did not differ significantly between both conditions, which means that the presence of a semantic relationship was not necessary for the perception of the object pair as one unit. Rather, the affordance of the objects for the action is decisive in order to cue the attention towards both objects of an object pair so that it is possible to create one perceptual unit by using action relationship between two objects despite the absence of semantic relationship. This provides a possible bottom-up unitization approach that was investigated in the present dissertation.

Moreover, creating perceptual units with pictorial materials by using action relationships within semantically unrelated object pairs did not only offer a bottom-up unitization approach due to the outlined evidence from visual perception, but also has the advantage that pictorial materials are used. Recent research has shown that the kind of materials, which is selected for the bottom-up unitization approach, has significant impact on the behavioral and ERP results regarding the age-related associative memory deficit. Here, the picture superiority effect in older age is essential and the associated benefits will be discussed in the next section.

4.2 Picture Superiority Effect in Older Age

The picture superiority effect describes the phenomenon that items are easier remembered when presented as pictures compared to presentation as words (Nelson et al., 1976). The question of why this effect is discussed in the scope of two main hypotheses: the dual-coding hypothesis by Paivio (1991) and the sensory-semantic hypothesis by Nelson (1979). The dual-coding hypothesis posits that pictures can be represented by both image and verbal codes. This additivity increases the probability of remembering pictures compared to words, which are primarily represented by verbal codes only (Paivio, 1991; Paivio et al., 1968). The sensory-semantic hypothesis, on the other hand, assumes that the picture superiority effect goes back to unique visual information of pictures (i.e., sensory features) that allow the creation of visual representations that are more distinct than that associated with words, while semantic representations for pictures and words are identical (Nelson, 1979; Nelson et al., 1976). Mintzer & Snodgrass (1999) investigated the mechanisms underlying the picture superiority effect to distinguish between the dual-coding hypothesis and sensory-semantic hypothesis. Applying a form change paradigm (i.e., changing the form of the stimuli from study to test phase), they found the picture superiority effect presented in better memory for pictures than for words. Critically, they observed greater form change costs (i.e., contrasting memory performance from condition with same form in study and test phase with condition with changed form in study and test phase) for pictures compared to words (i.e., changing studied pictures into words in the test phase resulted in greater memory decrease compared to pictures in study and test phase than changing studied words into pictures in the test phase compared to words in study and test phase). This result supports the sensory-semantic hypothesis (also referred to as distinctiveness account) given that the distinct visual information that were present during study phase are not available in the test phase and thus cannot be used to retrieve the studied pictures. As the picture superiority effect was observed especially for recall of single items and item recognition memory, Hockley (2008) investigated the picture superiority effect in associative recognition memory. The author found higher hit rates for picture pairs compared to word pairs. He assumed that picture pairs are characterized by a deeper semantic and conceptual processing of the individual components and included associations.

Ally & Budson (2007) were interested in the neural correlates of the benefit from pictures for memory and examined the role of familiarity, recollection, and post-retrieval processes for the picture superiority effect in an item recognition paradigm. They replicated the pictorial superiority effect behaviorally by observing better memory performance for pictures compared to words. Regarding the neural correlates, the late parietal ERP index of recollection was shorter in duration and more localized for pictures compared to words, supporting the assumption that the distinct and unique memory representations of pictures enable faster recollection.

Expanding these findings of the picture superiority effect and the underlying neural mechanisms, Ally et al. (2008) compared younger and older adults' memory performance and ERP correlates in the same item recognition paradigm as in the study mentioned before from Ally & Budson (2007). Older adults benefitted from pictures as stimuli by showing a greater picture superiority effect than younger adults. Furthermore, for pictures, older adults seemed to rely on neural mechanisms in a similar manner to younger adults as the early frontal effect, late parietal effect, and late frontal effect did not differ between both age groups for pictures.

To sum up, memory performance benefits when stimuli are presented as pictures compared to words. This picture superiority effect can also boost memory in older adults. Furthermore, older adults can rely on the same neural mechanisms as younger adults when pictures are used as to-be-remembered stimulus materials. Given that we used pictorial materials in form of object pairs, we expected to find reliable old/new effects, especially the early familiarity effect, in both age groups consistent with evidence from Ally et al. (2008).

5 Research Questions

The main research question of this dissertation was to investigate, whether bottom-up unitization induced by action relationships can alleviate the age-related associative memory deficit and increase the reliance on familiarity during associative recognition. Therefore, younger and older adults had to learn semantically unrelated object pairs, which were presented in a way that an action relationship could be conducted or not. It was assumed, that action-related object pairs support unitization and increase the reliance on familiarity during associative recognition. This should be reflected in the ERP results by observing enhanced early old/new effect for action-related as compared to action-unrelated object pairs in both age groups. Thus, older adults should benefit from the presence of action relationships and be able to alleviate their age-related associative memory deficit by relying on familiarity and compensating their attenuated recollection. We will complement the old/new effect with additional contrasts including recombined object pairs in order to control for familiarity of the individual components of an association in intact pairs. The contrast between intact and recombined object pairs will reflect associative memory processes that controls for familiarity of the individual components of the object pairs given that these should be highly similar for old and recombined pairs (Kamp et al., 2016). Regarding item memory processes, recombined and new object pairs will be compared because the individual components of the recombined pairs should be more familiar than the components of the new object pairs, whereas the associations should be equally unfamiliar for both object pair types (Bridger et al., 2017; Tibon, Gronau, et al., 2014).

In a next step, the underlying representations of the object pairs were investigated with a behavioral experiment in younger adults. Here, the main research question was whether the underlying representations of the action-related object pairs show the same characteristic rigidity as unitized representations, suggesting that our implemented action relationships support unitization and the creation of unitized representations. Therefore, the influence of the representations underlying action-related object pairs on learning of novel but overlapping object pairs was investigated. Younger adults had to learn and recall action-related and action-unrelated object pairs before they had to study object pairs, which included only one component identical to first study phase. It was assumed that, if the representations underlying action-related object pairs represent unitized representations, they should be less flexible relative to representations underlying action-unrelated object pairs. This should be reflected in more intrusions of original associations for action-related object pairs relative to action-unrelated object pairs, when the novel but overlapping associations should be recalled.

6 Stimulus Materials and Rating Study

To investigate the research questions formulated in Chapter 5, semantically unrelated object pairs with and without action relationship were required. Therefore, object pairs without semantic relationship were constructed out of commonly known objects. Those were arranged in a way either representing an action relationship or not. In a second step, a rating study with both, a group of younger adults and a group of older adults was conducted to select the stimuli that are best recognizable and best matching with our experimental manipulation. To find an optimal set of stimulus materials, younger and older adults of similar age as the participants later tested in the EEG study were recruited to obtain representative rating results.

6.1 Introduction

The creation of semantically unrelated object pairs with and without action relationships was guided by the definition of *thematic relations* by Estes et al. (2011). *Thematic relations* are described by two key characteristics: *externality* and *complementarity*. *Externality* means that a thematic relation exists between different objects, concepts, people, or events instead of within, for example, objects. These links can constitute spatial, temporal, causal or functional relations. *Complementarity* describes the fact that thematically related things fulfill complementary roles within one scenario or event (e.g., anchor and sail). Thematic relations can be created by both *affordance* and *convention*. *Convention*, on the one hand, comprises a link between two things due to frequent co-occurrence (e.g., dinner plate and wine glass) but without a direct interaction between them. *Affordance*, on the other hand, describes the fact that certain features of things afford the conduction of a specific interaction between them (e.g., scissors have sharp blades to cut something; a piece of paper is thin enough to be cut), which results in an action relationship.

Critically, affordance included in the concept of complementarity aligns with the definition of action relationships by Humphreys et al. (2006) and thus, object pairs with an action relationship were created in this manner. All object pairs were semantically unrelated in that, all created object pairs consisted of objects that were not used together in the daily life so that they were not related in sense of convention. Referring to the definition of an action relationship that was introduced earlier, every object pair consisted of a tool and a target representing the active and passive member of the action, respectively (Humphreys & Riddoch, 2007). Furthermore, the applied objects were used in their usual function (e.g., a knife was used for the action of cutting something; a measuring cup was used for the action of pouring something into it). This fits with the idea that affordance is relevant for the creation of an action relationship (Humphreys et al., 2006) as the properties of both objects within one object pair can enable a certain action even though they are not usually used in this configuration, i.e., semantically unrelated (e.g., pouring body lotion into a measuring cup).

6.2 Methods

6.2.1 Sample

The sample consisted of 37 younger (YA) and 37 older adults (OA). All participants were right-handed as confirmed with positive values in the Edingburgh Handedness Inventory (Oldfield, 1971), native speaker of German and had normal or corrected-to-normal vision. Additionally, all participants reported not having any neurological or psychiatric disorders. One younger adult had to be excluded from statistical analyses due to a technical error during the experiment and one older adult had to be excluded because of inability of finishing the experiment. Thus, the final sample included 36 participants of each age group (YA: $M = 23.2$ years, range = 19 – 30 years, 28 female; OA: $M = 69.3$, range = 65 – 80 years, 23 female). The younger adults received 8€/hour or course credits and the older adults were equally paid with 8€/hour for their participation and additionally received financial compensation for the parking costs. All participants confirmed their willingness to participate and were debriefed after the experiment.

6.2.2 Stimulus Materials

The initial stimulus materials created for the the rating study consisted of 824 single objects of different semantic categories (e.g., hygiene articles, clothes, kitchen and food) that were gained from various internet resources. These 824 single objects were used to create 412 object pairs with an action relationship and without an action relationship, respectively. To achieve an optimal match of objects and the experimental condition *action relationship*, action-unrelated object pairs were created from action-related object pairs by switching positions of both objects. This enables the complete counterbalancing of single object assignment to action relationship conditions in the later EEG experiment (i.e., one proband sees a single object either in an action-related or action-unrelated object pair), avoiding confounds due to object-specific characteristics. The object pairs were presented with a height of 4 to 10 cm and width of 3 to 7 cm and both objects of an object pair were arranged with about 0.5 cm to each other. Furthermore, as the EEG experiment was conducted with right-handed participants, all action-related object pairs were constructed by positioning the tool in a way in which the action could be executed with the right hand. Thus, because of the small distance between both objects and the right-handedness the imagination of the presented action was facilitated for right-handed persons. An object pair without an action relationship was built in that way that the position of the two objects within an action-related object pair were switched (e.g., body lotion is positioned under the sport shoe so that the action of pouring the body lotion into the sports shoe is not possible, see Figure 6.1 for examples of action-related and action-unrelated object pairs).

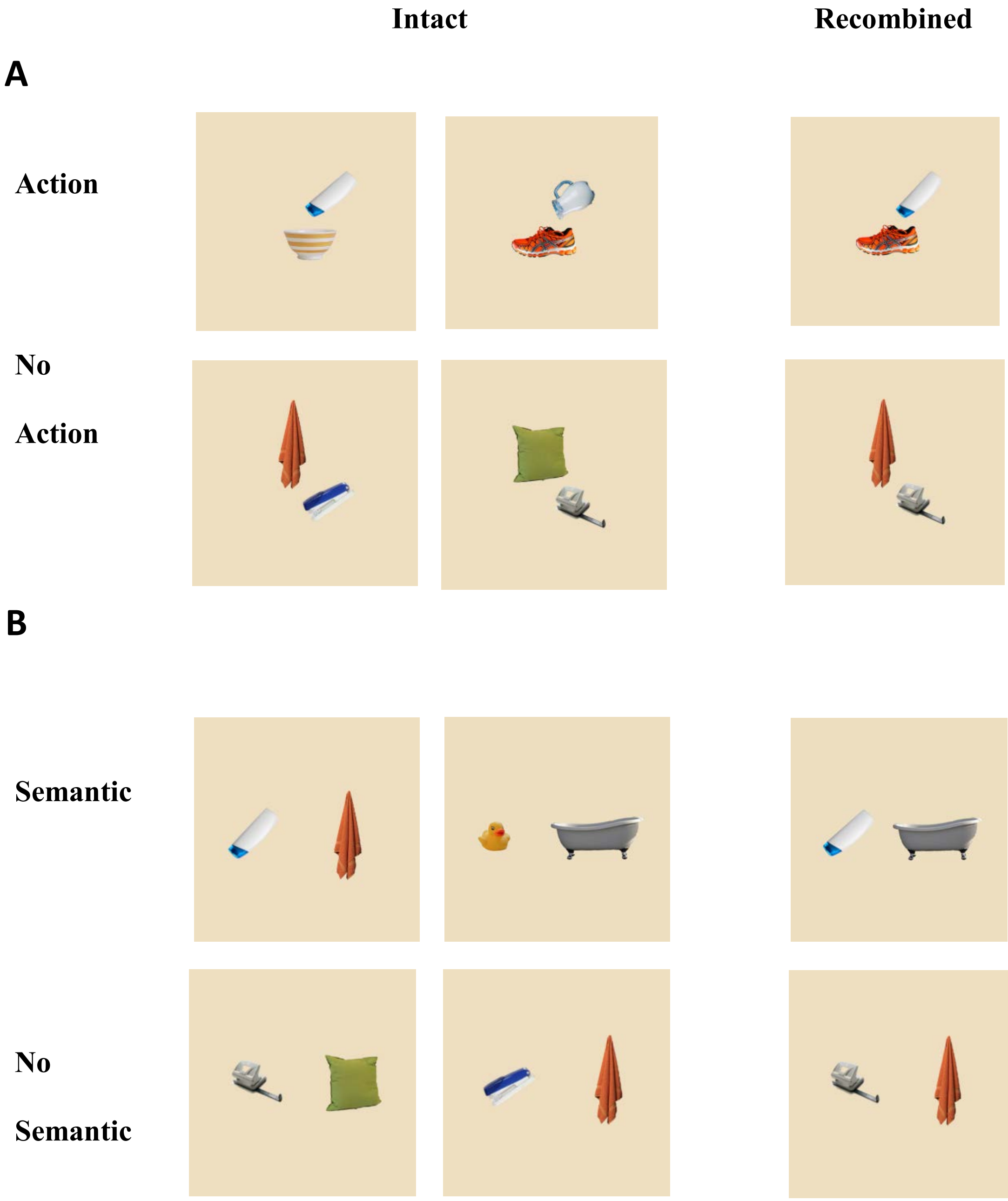
In addition to the 412 original intact object pairs of each action relationship condition 206 recombined object pairs were built for both action relationship conditions to be presented in the test phase. Recombined object pairs are required to make sure that participants cannot rely on item memory alone for recognition memory judgements but have to consider associative information. The creation principles of the recombined object pairs are presented in Figure 6.1. One recombined object pair was always formed on the basis of two original intact object pairs by maintaining the action relationship status between intact and recombined object pairs (i.e., two action-related intact object pairs were used to create an action-related recombined object pair, two action-unrelated intact object pairs were used to create an action-unrelated recombined object pair). In the rating study and the subsequent EEG experiment, only one out of two possible recombined pairs was used.

In sum, a total of 618 object pairs in each action relationship condition (i.e., in sum 1236 object pairs) were presented in the rating study. Besides the action relationship rating completed by a subsample of participants, the other subsample of participants had to rate the semantic relationship between the objects in an object pair to ensure that the selected stimuli are semantically unrelated. To create a plausible rating, an additional 412 semantically related object pairs were formed with the identical single objects that were included in the 412 semantically unrelated object pairs for the action relationship rating. Each object appeared once in a semantically related and once in a semantically unrelated object pair. Based on the 412 original semantically related object pairs, 206 semantically related recombined object pairs were created without changing the semantic relationship status between intact and recombined object pair (i.e., two semantically related intact object pairs were used to create a semantically related recombined object pair, two semantically unrelated intact object pairs were used to create a semantically unrelated recombined object pair, see Figure 6.1 for an example). In sum, there were 618 semantically related object pairs.

The younger and older adults were divided into two rating subsamples, respectively, so that one participant either rated object pairs regarding action relationship or semantic relationship. Twenty-four participants of each age group constituted the action relationship rating sample. The action relationship conditions were counterbalanced across participants, i.e., one participant rated a single object pair either with or without an action relationship, resulting in 12 participants' rating for each object pair in each action relationship condition. For the semantic relationship rating, the remaining 12 participants of each age group rated all semantically related and unrelated object pairs.

Figure 6.1

Examples for object pairs in both action relationship conditions as well as in both semantic relationship conditions



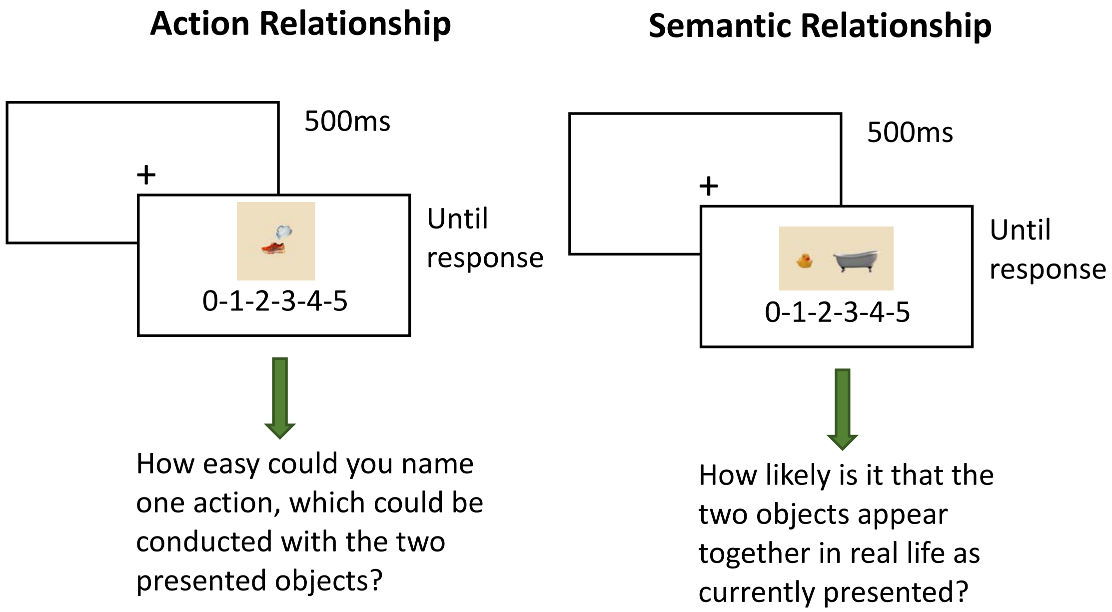
Note. **A**: Examples for action-related (i.e., body lotion above bowl; milk bottle about sports shoe) and action-unrelated (i.e., towel above stapler; pillow above punch) intact object pairs and the corresponding recombined object pairs (A+: body lotion about sports shoe; A-: towel above punch).
B: Examples for semantically related (i.e., body lotion and towel; squeaky duck and bathtub) and semantically unrelated (i.e., punch and pillow; stapler and towel) intact object pairs and the corresponding recombined object pairs (Sem+: body lotion and bathtub; Sem-: punch and towel).

6.2.3 Procedure

The rating study lasted about 1 to 1.5 hours and took place in a cabin, where a participant sat about 90 cm in front of a computer monitor with a resolution of 1920 x 1080 pixels. The rating study was programmed with E-Prime 2 software (Psychology Software Tools, Inc., Pittsburgh, PA). After having given their informed consent to the participation, the participants received a booklet in which all 824 single objects were depicted (three objects per page, arranged one below the other). The single objects were printed in the same size and orientation as in the actual experiment, which was conducted afterwards on the computer. The participants were instructed to go through the whole booklet and tell the instructor whenever they could not recognize an object. The instructor then told what the object was about. The aim of this procedure was twofold. On the one hand, we aimed to validate that each single object was recognizable and on the other hand, we wanted to reduce pre-experimental differences in familiarity for all objects. This procedure was also used in the EEG experiment. After the booklet, the actual rating experiment with the object pairs started. The trial procedure was identical for the rating of action relationship and semantic relationship despite of two aspects: the arrangement of the objects on the screen and the rating question. Figure 6.2 depicts the trial procedures for both rating tasks. The trial started with a fixation cross for 500 ms. After that, the object pair was presented until the participants gave their response.

Figure 6.2

Trial procedure for action relationship rating and semantic relationship rating



Action Relationship Rating. In the action relationship rating, the object pairs were arranged in a way that an action could be conducted or not (i.e., arrangement of the objects one above the other). The participants had to indicate, how easily they could name an action, which could be executed with the two presented objects even if they would not conduct that action in their daily lives (in German: "Wie leicht fällt es Ihnen, eine Handlung zu benennen, die mit den beiden dargestellten Objekten ausgeführt werden könnte?" 0 = not easy at all („gar nicht leicht") – 5 = very easy („sehr leicht")). To facilitate working on a computer especially for the older participants, a response box with only 6 large buttons, arranged in a line, was used for the rating judgement. The assignment of the buttons from 0 to 5 (ascendent or descendent) was counterbalanced across participants (0 = not easy at all, 5 = very easy). Each participant saw a single object either within an object pair with or without action relationship and the corresponding recombined object pair in the same action relationship condition. This assignment of the presentation of a single object in an action-related or action-unrelated object pair was counterbalanced across participants. Thus, 618 object pairs were rated by each participant and after half of the materials a self-paced break was included.

Semantic Relationship Rating. In the semantic relationship rating, the object pairs included two objects that were semantically related or not. The object pairs were arranged next to each other to avoid any additional action relationship. The presentation side of a single object within an object pair (i.e., whether the single object was presented on the left or right side) was counterbalanced across participants. The rating task was to indicate how likely it is that the two objects, as they are currently presented, appear together in real life (in German: "Wie wahrscheinlich ist es, dass diese beiden Objekte zusammen in der Umwelt so auftreten, wie sie hier dargestellt werden?" 0 = very unlikely ("sehr unwahrscheinlich") – 5 = very likely ("sehr wahrscheinlich")). The assignment of the buttons from 0 to 5 (ascending or descending) on the response box was again counterbalanced across participants (0 = very unlikely, 5 = very likely). The participants rated all semantically related and unrelated intact object pairs as well as the corresponding recombined object pairs with the same semantic relationship status. Thus, 1236 object pairs were rated by each participant and there were three self-paced breaks included.

After the rating (action relationship or semantic relationship), the participants were debriefed and compensated for their time.

6.2.4 Data Analysis & Stimulus Selection

First, we considered the recognizability of the single objects in the booklet. Each object that was not successfully recognized by at least 80 percentage of people in each age group was excluded from the stimulus materials. In a next step, we selected the 320 object pairs with an action relationship and their corresponding recombined object pairs (i.e., 160 recombined object pairs) that were selected best, i.e., for which participants gave high ratings concerning the question how easy it was to name an action. We decided to use this more conservative criterion of considering the action relationship rating in older adults to account for the assumption that they would be more rigid in judging an object pair as action-related when there is no kind of semantic relationship between both objects. After that, the corresponding action-unrelated intact and recombined object pairs were selected.

As a next step, the same object pairs with and without action relationship were selected for younger adults. After the selection of the object pairs, the rating of the intact and recombined object pairs was compared within each action relationship condition for younger and older adults, separately. Finally, the semantic relationship of the object pairs with and without action relationship was checked to ensure that all object pairs were semantically unrelated (i.e., all means ≤ 4) in both age groups. Furthermore, the rating for the intact and recombined object pairs with and without action relationship was contrasted between both age groups. Finally, regarding the semantic relationship, semantically unrelated intact object pairs were compared with semantically unrelated recombined object pairs for younger and older adults, respectively, and age-related comparisons were conducted for semantically unrelated intact and recombined object pairs, respectively. All analyses were conducted with the software R, version 3.6.1, and R studio (RStudio Team, 2019). For the t-tests, the package "stats" (R Core Team, 2019) was used and the effect size Hedges' g_s for the t-tests was calculated on the basis of the formula by Lakens (2013). By-item t-tests were calculated and data were averaged across participants within each age group. The alpha level was set to .05.

6.3 Results

6.3.1 Booklet

Each single object that was not successfully recognized by at least 80 percentage of both age groups, was excluded from the stimulus materials. Thus, 34 single objects had to be excluded, leading to the exclusion of a total of 64 object pairs (intact and their respective recombined object pairs included).

Action Relationship Rating. Table 6.1 shows the mean ratings for the action and semantic relationships of selected intact and recombined object pairs in both age groups.

Table 6.1

Mean ratings for action relationship as well as semantic relationship of selected intact and recombined pairs in both age groups

		Action Relationship		Semantic Relationship
		Action	No Action	
Younger adults				
	Intact	3.97 (0.65)	1.48 (0.79)	0.51 (0.52)
	Recombined	3.89 (0.69)	1.49 (0.79)	0.48 (0.60)
Older adults				
	Intact	3.80 (0.79)	1.64 (1.01)	0.65 (0.63)
	Recombined	3.70 (0.87)	1.58 (0.92)	0.58 (0.63)

Note. Standard deviations are given in parentheses.

Comparison between action-related and action-unrelated object pairs. In the first set of analyses, ratings of action-related object pairs were contrasted with ratings of action-unrelated object pairs for intact, and recombined pairs and for each age group, separately.

For the older adults, both the action-related intact object pairs were rated, $t(638) = 30.05$, $p < .001$, $g_s = 2.37$, and the action-related recombined object pairs, $t(318) = 21.14$, $p < .001$, $g_s = 2.36$, were rated significantly higher than action-unrelated intact and recombined object pairs, respectively.

Similarly, for the younger adults, the action-related intact pairs, $t(638) = 43.41$, $p < .001$, $g_s = 3.43$, and the action-related recombined object pairs, $t(318) = 28.98$, $p < .001$, $g_s = 3.22$, differed significantly from the action-unrelated intact and recombined object pairs, respectively, whereby object pairs with an action relationship were rated significantly higher than object pairs without an action relationship.

Comparison between intact and recombined object pairs. In a second set of analyses, ratings of intact and recombined pairs were compared across age groups, for action-related and action-unrelated pairs, separately.

For older adults, the action-related intact object pairs did not differ significantly from the action-related recombined object pairs, $t(478) = 1.23$, $p = .21$, $g_s = 0.12$. Additionally, the action-unrelated intact object pairs were not rated significantly lower than the action-related recombined object pairs, $t(478) = 0.63$, $p = .52$, $g_s = 0.06$.

For younger adults, there was no significant difference between action-related intact and recombined object pairs, $t(478) = 1.29$, $p = .19$, $g_s = 0.12$ and also not between action-unrelated intact and recombined object pairs, $t(478) = -0.03$, $p = .97$, $g_s = 0.01$.

To sum up, object pairs with action relationship (i.e., intact and recombined) were rated significantly higher compared to object pairs without action relationship (i.e., intact and recombined) in both age groups. Furthermore, for both age groups, the intact object pairs' rating did not differ significantly from the rating for the recombined object pairs in both action relationship conditions, ensuring that there is no confound due to difference in action relationship when it comes to the distinction between intact and recombined object pairs for action-related and action-unrelated object pairs, respectively.

Comparison between younger and older adults. In a third set of analyses, we were interested in whether there are age-related differences in the action relationship ratings.

For the action-related intact object pairs, there was a significant difference between younger and older adults, with higher action relationship ratings in younger adults, $t(638) =$

2.96, p = .003, g_s = 0.23. Regarding the action-related recombined object pairs, younger adults rated the object pairs significantly higher than older adults, t(318) = 2.09, p = .03, g_s = 0.24.

For the action-unrelated intact object pairs, there were age-related differences for the intact object pairs, t(638) = -2.19, p = .02, g_s = 0.17 with higher action relationship ratings in older adults. Regarding the action-unrelated recombined object pairs, younger adults' rating did not differ significantly from older adults' rating, t(318) = -0.97, p = .32, g_s = 0.10.

In sum, there were age-related differences in the ratings for both, object pairs with action relationship (i.e., intact and recombined) and action-unrelated intact object pairs with greater differences in the rating between action-related and action-unrelated object pairs for younger compared to older adults. Nevertheless, the analyses of the comparisons between action-related and action-unrelated object pairs within each age group show that the critical manipulation of the action relationship was confirmed in both age groups.

Semantic Rating. The goal of the following set of analyses was to ensure that the semantic relationship between the object pairs to-be-used in the EEG study was rated as equally low for intact and recombined pairs across both age groups. Consequently, only the semantically unrelated object pairs, containing object combinations used in the action-related and action-unrelated object pairs were used.

Comparison between intact and recombined object pairs. Similar to the action relationship ratings, ratings of intact object pairs were contrasted with ratings of recombined object pairs for each age group, separately.

For both age groups, there was no significant difference between the rating for semantically unrelated intact and recombined object pairs (OA: t(478) = 1.14, p = .25, g_s = 0.11; YA: t(478) = 0.54, p = .58, g_s = 0.05).

In sum, these results show that there were no significant differences regarding the semantic relationship for the semantically unrelated intact and recombined object pairs in both age groups.

Comparison between younger and older adults. In the last set of analyses, we were again interested in rating differences across age groups.

For the semantically unrelated intact object pairs, there was a significant age-related difference, $t(638) = -3.16$, $p = .001$, $g_s = 0.24$, representing slightly higher semantic relationship ratings in older adults compared to younger adults. Regarding the semantically unrelated recombined object pairs, there was no significant age-related difference, $t(318) = -1.50$, $p = .13$, $g_s = 0.16$.

To sum it up, there were age-related differences regarding semantic relationship of intact object pairs. However, the effect size is quite small and mean ratings show that in both age groups the semantically unrelated object pairs achieved rather low ratings in total.

6.4 Discussion

The goal of the rating study was to select the stimulus materials for the following EEG study, in which the influence of bottom-unitization on the age-related associative memory deficit is investigated. Therefore, semantically unrelated object pairs with or without an action relationship were created and rated by younger and older adults. Based on these ratings, the required 320 object pairs with and without action relationship were selected. Critically, those pairs were rated as being semantically unrelated. There were age-related differences regarding the action relationship rating (i.e., the difference between action-related and action-unrelated object pairs was greater for younger than older adults). However, these differences were quite small, as indicated by the effect sizes. Furthermore, the critical difference between experimental conditions to create a bottom-up unitization approach (i.e., action-related vs.

action-unrelated object pairs) was present in both age groups. Albeit small age-related differences in ratings, we decided to use the same stimulus materials for both age groups in the EEG experiment. The advantage of this approach is the high comparability of the experimental conditions in both age groups by avoiding confounding effects due to object characteristics.

In conclusion, we obtained semantically unrelated object pairs with and without action relationship, which were rated accordingly by both age groups and thus fulfilling the requirements to establish a bottom-up unitization approach, which was used in the following EEG study.

7 Experiment 1: Can the Elderly take the Action? – The Influence of Unitization induced by Action Relationships on the Associative Memory Deficit

7.1 Introduction

The process of healthy aging impacts different aspects of episodic memory in different ways, which is reflected in the associative memory deficit. According to the associative deficit hypothesis (ADH) proposed by Naveh-Benjamin (2000), the associative memory deficit is defined as the older adults' reduced ability of encoding and retrieving associations among separate components, while memory for each of the separate components is retained. This leads to stronger age-related differences in associative memory compared to item memory (Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003, 2004).

According to dual-process theories, recognition memory can be supported by two functionally distinct processes: familiarity and recollection (Andrew P. Yonelinas et al., 2010). Familiarity, a fast and automatic process, is described as a feeling of knowing without the retrieval of specific details, while recollection, a more effortful and deliberate process, includes the processing of relations (i.e., remembering when and where an item was encountered before) and associations (e.g. were item A and item B studied together?) as well as the retrieval of qualitative information from the prior study phase. These two processes play different roles in the successful recognition of items and associations, depending on the critical discriminations that have to be made in the respective task. While familiarity is sufficient for successful item recognition (i.e., discrimination between old and new items), recollection is necessary when more detailed distinctions have to be made. More specifically, in associative recognition tasks, when the discrimination between intact (i.e., pairs that were presented exactly in the same constellation during the study phase) and recombined pairs (i.e., pairs that consist of components that were presented in the study phase but with another partner) is required, all components of intact as well as recombined pairs possess a similar memory strength (familiarity) due to their prior exposure in the study phase. Therefore, recollection is necessary in order to retrieve the specific association so that intact pairs can be distinguished from recombined pairs. Healthy aging is associated with impaired recollection whereas familiarity is relatively unaffected (Friedman, 2013). Hence, dual-process theories of recognition memory can account for the age-related associative memory deficit with higher importance of recollection for associative compared to item memory tasks.

Familiarity and recollection can be mapped onto qualitatively distinct event-related potential (ERP) measures. In recognition memory tasks, ERP differences between waveforms elicited by correctly classified old and new pairs can be taken as correlate of general retrieval success (for a review, see Rugg & Curran, 2007). Familiarity is associated with an early mid-frontal old/new effect that appears between 300 to 500 ms post-stimulus, whereas recollection is reflected in a later (500 to 800 ms) and parietally distributed old/new effect (Mecklinger, 2000; for reviews, see Friedman & Johnson, 2000; Mecklinger, 2006; Mecklinger & Bader, 2020; Rugg & Curran, 2007; but see Paller et al., 2007, for an alternative view).

The pattern of relatively intact familiarity but attenuated recollection in older age is supported by behavioral (e.g. Koen & Yonelinas, 2016) and ERP evidence (Friedman, 2013; Scheuplein et al., 2014). In some studies, the early mid-frontal old/new effect was not observed in older adults despite successful familiarity-driven recognition memory (e.g., Duarte et al., 2006; Trott et al., 1999; Wang et al., 2012). However, the early mid-frontal old/new effect is consistently present in older adults when pictorial materials are employed as stimulus materials, for which detailed and distinctive memory representations can be formed. In an illustrative study, Ally et al. (2008) investigated the impact of aging on the so-called picture superiority effect. The picture superiority effect describes the phenomenon that items are more easily remembered when they are presented as pictures compared to words (Nelson et al., 1976). As pictures provide distinctive visual information and features, more unique memory representations can be created (Ally & Budson, 2007; Nelson et al., 1976). Ally et al. (2008) showed that older adults could benefit from this picture superiority effect given that they achieved similar memory performance to younger adults in a picture-picture study-test condition, while their memory in a word-word study-test condition was impaired. Furthermore, in the picture-picture study-test condition no age-related differences in the early mid-frontal old/new effect were observed, whereas in the word-word study-test condition the ERP familiarity effect was only present in younger adults. Hence, Ally et al. (2008) could show that for pictures, familiarity-driven memory in older age participants is accompanied by a mid-frontal old/new effect.

Several recent studies (e.g., Ahmad et al., 2015; Bastin et al., 2013; Bridger et al., 2017) that investigated the associative memory deficit in older adults explored environmental conditions that increase the contribution of familiarity to associative recognition in order to compensate for impaired recollection. In this context, unitization might be an efficient way of encoding to minimize the age-related associative memory deficit. Unitization is defined as the process of integrating previously separate stimulus components into a single unitized representation of the association (Graf & Schacter, 1989). When a pair is treated as a single item rather than as two separate items as a consequence of unitization, then familiarity should support associative recognition (Parks & Yonelinas, 2015).

According to Tibon et al. (2014), models of unitization can be categorized in bottom-up and top-down approaches. Top-down approaches represent active encoding strategies that have to be initiated by the participants themselves in order to encourage unitization (e.g., using fictional definitions, Bader et al., 2010 and using imagery instructions for word pairs, Rhodes & Donaldson, 2008). Conversely, in bottom-up approaches, the stimulus material per se induces a more or less unitized processing of the association without the necessity to actively adapt encoding strategies (Tibon, Gronau, et al., 2014). Bottom-up unitization can be implemented by manipulating different characteristics for the associations between the to-be-remembered components (e.g., Rhodes & Donaldson, 2007; Bridger et al., 2017). For example, Rhodes and Donaldson (2007) showed that the presence of an associative relationship between two words increased associative recognition performance and enhanced the reliance on familiarity (see Ahmad & Hockley, 2014 for similar results with pre-experimentally unitized compound word pairs).

Notably, several studies have shown that both top-down and bottom-up unitization strategies provide an opportunity to alleviate the age-related associative memory deficit, and are often accompanied by elevated familiarity in conditions supporting unitization. For instance, Bastin et al. (2013) report a reduction of the age-related associative memory deficit and higher familiarity estimates in a source memory task when older adults were instructed to encode the presented object in the color of the background. Ahmad et al. (2015) applied a bottom-up unitization approach by using pre-experimentally unitized compound word pairs. They showed a discrimination advantage for these unitized representations compared to noncompound word pairs, while younger and older adults relied more on familiarity for successful recognition of compound word pairs. Employing a bottom-up unitization approach with Chinese lexical materials, Zheng et al. (2015) showed a reduction of age-related differences in associative memory for compound words. Furthermore, older adults revealed the early mid-frontal old/new effect for compound words, suggesting that compound words were unitized and older adults were able to rely on associative familiarity when remembering these words. Thus, the aforementioned studies suggest that age-related deficits in associative memory cannot only be alleviated by actively adapting encoding instructions but instead can also be achieved by manipulating the stimulus material. Compared to top-down self-initiated processing, bottom-up unitization has the advantage of being less effortful. As self-initiated processing is also often more difficult and effortful for older adults, bottom-up unitization approaches are an ideal procedure for minimizing the age-related associative deficit (Old & Naveh-Benjamin, 2008).

In a recent ERP study, Bridger et al. (2017) implemented bottom-up unitization using pictorial stimulus materials. Presenting pairs of two semantically unrelated objects, the critical manipulation concerned the plausibility of the spatial relation between the two objects. Object pairs that were positioned to each other in a spatially plausible way (e.g., a can opener over a schnitzel) – intended to induce unitization - were remembered better than object pairs arranged in a spatially implausible manner. From a memory perspective, this spatial plausibility effect was comparable for associative and item memory and, interestingly, the performance benefit for spatially plausible arrangements was greater for younger than older adults. In addition, the ERP effects in younger and older adults did not differ between spatially plausible and implausible object pairs, suggesting that there was no electrophysiological evidence for enhanced familiarity-based remembering for spatially plausible object pairs (i.e., in the unitization condition). It is thus conceivable that the spatial plausibility manipulation was too weak to support unitization encoding and familiarity-based recognition.

Therefore, it could be asked how conditions can be created that increase the probability of bottom-up unitization and familiarity-based recognition of unitized pairs in order to attenuate the age-related associative memory deficit. These unitization conditions should not only lead to a boost in associative memory in both age groups, but also to a greater benefit for older adults compared to younger adults; this is because increasing the contribution of familiarity for associations should compensate for older adults' impaired recollection, whereas for younger adults the benefit should be smaller because they can rely on their intact recollection in both conditions.

One possibility to improve unitization of two objects could be to induce an action relationship between these two objects (Humphreys et al., 2006). Empirical support for the importance of action relationships during visual perception comes from a series of studies on a patient with Balint's syndrome, which is characterized by a variety of visual perception deficits. Crucially, patients with Balint's syndrome are not able to perceive two objects simultaneously. In an illustrative study by Humphrey et al. (2006), object pairs with a semantic relationship, an action relationship or both were presented. The identification performance of the patient with Balint's syndrome was not only better for objects presented with an action relationship, but it was also better for action-related objects even when no semantic relationship existed, suggesting that the sole presence of an action relationship supports the perception of the object pair as a single unit. It is assumed that an action relationship between two objects can be created by familiar visual units (e.g., a corkscrew and a wine bottle) or by "affordance" of the objects themselves. "Affordance" means that objects have structural properties that afford a certain action. When presented together with another object, this affordance can cue attention to both objects of an object pair at a time leading to the perception of a single unit. In other words, the affordance of the objects for the action, and not the presence of a semantic relationship, is critical in order to enhance integration. Affordance cues the attention towards both objects of an object pair enabling a recovery of the patient's visual extinction (Humphreys et al., 2006).

In line with the reasoning by Humphreys and colleagues, we assume that action relationships between two objects without a semantic relationship can create a perceptual unit and encourage bottom-up unitization. The goal of the present study was to investigate whether bottom-up unitization through action relationships between two semantically unrelated objects fosters familiarity-based remembering and can reduce the age-related associative memory deficit. Therefore, object pairs including two semantically unrelated single objects were presented in a way that an action could be conducted or not. Assuming that the presence of an action relationship can support unitization, associative memory performance should be enhanced for action-related object pairs (i.e., unitized object pairs) compared to action-unrelated object pairs (i.e., not unitized object pairs). Furthermore, under the assumption that bottom-up unitization by action relationships boosts associative memory mainly by increasing familiarity, which as opposed to recollection is largely preserved in old age, we expect the age-related associative memory deficit to be attenuated for action-related object pairs compared to action-unrelated pairs. ERP measures were used to further index the contribution of familiarity and recollection to memory performance: Familiarity should be reflected in differences between ERPs elicited by correctly identified intact and new object pairs in the early time window, whereas recollection should be reflected in the same contrast in the late time window (Bridger et al., 2017; Tibon, Gronau, et al., 2014). Since the current study used pictorial stimuli in the form of object pairs, we expected comparable familiarity effects in older and younger adults. If the condition with action-related object pairs encourages unitization and if this leads to an enhanced reliance on familiarity, then the early familiarity effect (i.e., intact vs. new) should be larger for action-related object pairs compared to action-unrelated pairs (i.e., no unitization) in both age groups. In addition, given that recollection is attenuated in old age, the late parietal old/new effect should be attenuated in older adults compared to younger adults in both action relationship conditions, while the early familiarity effect should be preserved for action-related object pairs in older adults.

The ERP differences between correctly responded to intact and new object pairs serve as an index of general retrieval success and enable to establish a correspondence between the results of the current study and widely reported ERP recognition memory studies of this kind (see Friedman, 2013, for a review). A drawback of the general old/new contrast in associative memory studies is that in this comparison familiarity of the individual components of an association in intact pairs cannot be controlled for. Therefore, we will complement the index of general retrieval success with two additional contrasts including recombined object pairs: First, ERPs elicited by correctly identified intact and recombined object pairs will be compared as an index of associative memory processes that controls for familiarity of the individual components of the object pairs, as these should be highly similar for old and recombined pairs (Kamp et al., 2016). Second, differences between ERPs elicited by correctly responded to recombined and new object pairs will be considered as complementary measures of item memory processes because the individual components of the recombined pairs should be more familiar than the components of the new object pairs, whereas the associations should be equally unfamiliar for both object pair types (Bridger et al., 2017; Tibon, Gronau, et al., 2014).

7.2 Methods

7.2.1 Sample

Twenty-four younger adults (YA) were tested. To obtain the same sample size for older adults (OA), twenty-nine participants were invited to the first session (i.e., neuropsychological screening). After excluding older adults with severe cognitive deficits (see section about neuropsychological screening below), 24 OA were tested in the second session (i.e., EEG session). The YA were students from Saarland University. The OA were recruited from various internal databases and through an announcement in the daily newspaper. Data of one younger adult and five older adults was excluded from the analyses because of a technical error during the experiment (YA: n = 1) or due to an insufficient number of correctly responded to trials (i.e., less than eight) in one of the conditions for ERP averaging (OA: n=5). The final sample for behavioral and ERP data included 23 younger adults (17 females, M = 21 years, SD = 2.0 years, range = 18-25 years) and 19 older adults (14 females, M = 72.5 years, SD = 4.5 years, range = 66-81 years). All participants were German native speakers, right-handed as confirmed by positive values on the Edinburgh Handedness Inventory (Oldfield, 1971), had no known neurological problems and had normal or corrected-to-normal vision and no signs of color-blindness. Informed consent was required, and the younger adults received a payment of 8€/hour or course credit for their participation. The older adults received a payment of €8/hour plus parking fees. All participants were debriefed after the experiment. The experiment was approved by the ethics committee of the Faculty for Human and Business Sciences, Saarland University.

7.2.2 Neuropsychological Screening

After completing a screening on the telephone, in which general criteria such as age, native language, neurological and psychological diseases as well as visual problems were assessed, older adults were invited for a first session to conduct neuropsychological tests. This session lasted about 45 minutes and started with the neuropsychological test battery CERAD-Plus (Monsch, Thalmann, & Scheitter, 1997) that includes the following seven subtests: (1) verbal fluency, (2) Boston Naming Test, (3) Mini-Mental Status, (4) word-list memory (recall, recognition), (5) figural memory (copy and recall), (6) Trail-Making Test A and B and (7) phonemic fluency. Afterwards, an adapted version of the Wechsler Digit-Symbol Substitution Test (Wechsler, 2009) consisting of nine digit-symbol mappings and a total of 93 digits was administered. The session concluded with the Edinburgh Handedness Inventory (Oldfield, 1971). Twenty-nine older adults were tested and only those participants who showed no severe deficits in all subtests of the CERAD (i.e., min. -1.5 SD) were invited to the second session (n=24), in which the EEG experiment was conducted. Table 7.1 shows the demographic information as well as some neuropsychological data for the final sample that was included into all analyses. The two age groups did neither differ significantly regarding the years of education, $t(40) = 0.78$, $p = .43$, nor regarding their gender distribution, $\chi^2(1) = 0.00$, $p = .98$.

The older adults' performance in the Wechsler Digit-Symbol Substitution Test (M = 44.10, SD = 8.61), representing their perceptual speed of processing, corresponds to the normal range for this age group as indicated by results of previous studies (e.g. Ferdinand & Kray, 2013; Kray, Eber, & Karbach, 2008). The Mini-Mental State Examination (MMSE, Folstein, Folstein, & McHugh, 1975) is used as a short standardized test in order to investigate one's cognitive state and indicate severe cognitive impairments. All older adults had a normal MMSE score (M = 29.10, SD = 0.80, range = 28 - 30).

Table 7.1

Demographic information and neuropsychological data of the sample

	Younger adults	Older adults
N	23	19
Gender distribution (female/male)	17/ 6	14/ 5
Mean age (years)	21 (2.08)	72.52 (4.50)
Age range (years)	18-25	66-81
Education (years)	15.08 (1.97)	14.53 (2.63)
Neuropsychological data		
Mini-Mental State Examination		29.10 (0.80)
Digit-Symbol-Test		44.10 (8.61)

Note. Standard deviations are given in parentheses.

7.2.3 EEG Session

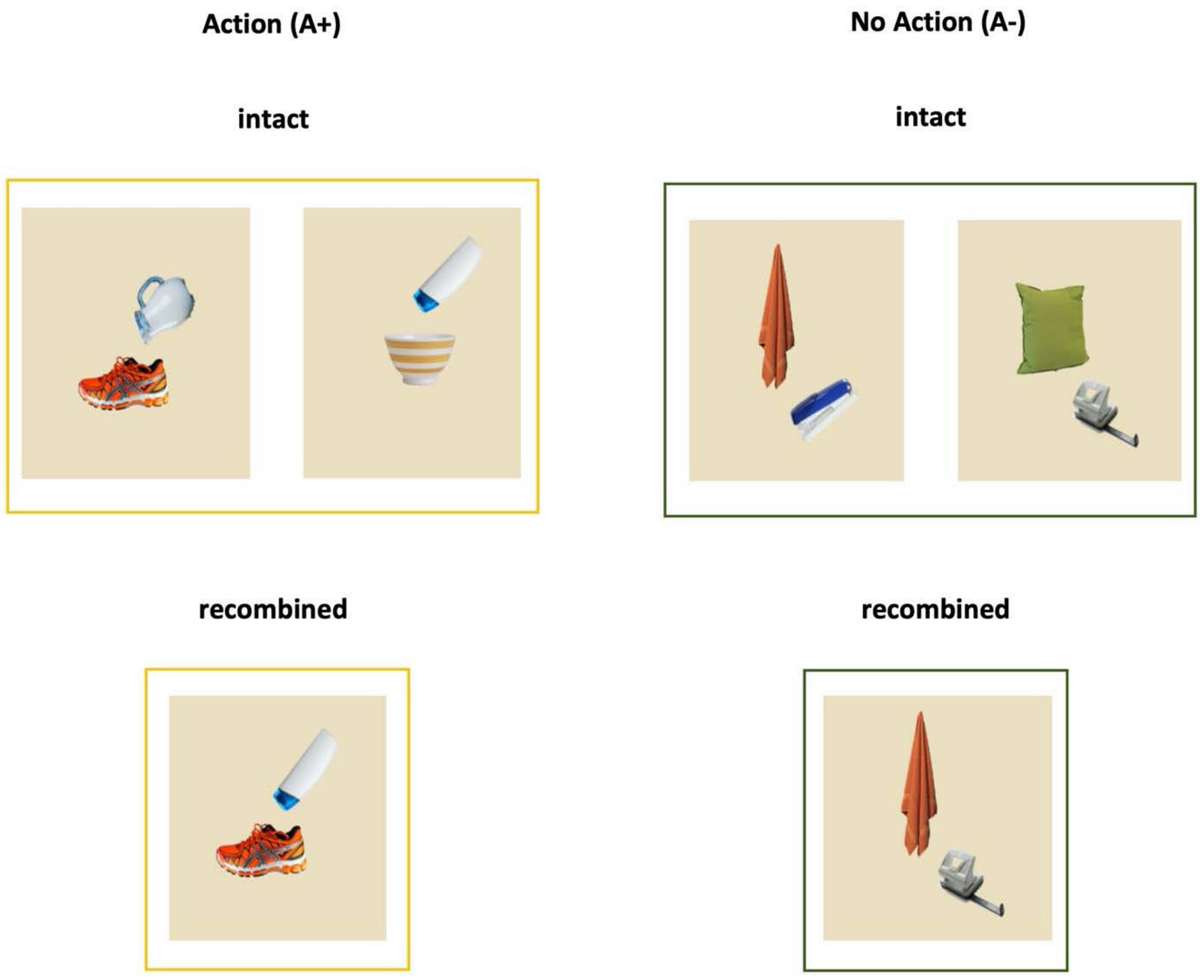
Stimulus Material. The stimulus material consisted of 640 single objects that were collected from various picture databases and internet sources and then edited with Photoshop CS6. These objects were used to build 320 object pairs without a semantic relationship. To evaluate the stimulus material, a rating study was conducted. For this purpose, 412 object pairs and their 206 corresponding recombined pairs were created by using 824 single objects. Every recombined pair was built on the basis of two intact pairs. All action-related object pairs included actions that could be conducted from a right-handed perspective. For the action-unrelated object pairs, the positions of the two objects were swapped so that the previous upper object was at the bottom and vice versa for the previous bottom object (see Figure 7.1 for examples of the object pairs). Size relations between the two objects building an object pair were approximately realistic. The object pairs had a height of 4 to 10 cm and a width of 3 to 7 cm. In order to facilitate the processing of the object pair as one unit, the distance between the two single objects of an object pair was 0.5 cm. The material was rated by 36 older (M = 69.36 years, range = 65 - 80) and 36 younger (M = 23.22 years, range = 19-30) adults, who did not participate in the EEG experiment. First, participants were familiarized with all single objects by presenting them in a booklet in the same size as their presentation shown later on the computer screen. Participants were instructed to indicate those objects they could not recognize. Afterwards, 24 subjects of each age group rated the action relationship of the object pairs by answering the question how easy it is to name one action that could be executed with the two presented objects (in German: "Wie leicht fällt es Ihnen, eine Handlung zu benennen, die mit den beiden dargestellten Objekten ausgeführt werden könnte?" 0 = not easy at all („gar nicht leicht") – 5 = very easy („sehr leicht")). Each object pair and the corresponding recombined pair were evaluated by half of the subjects in an arrangement with (A+) and by the other half without action relationship (A-). Furthermore, the same object pairs were rated with regard to their (associative) semantic relationship by 12 additional subjects of each age group, asking the participants to rate the likelihood of the two objects to appear together in real life as currently presented (in German: "Wie wahrscheinlich ist es, dass diese beiden Objekte zusammen in der Umwelt so auftreten, wie sie hier dargestellt werden?" 0 = very unlikely ("sehr unwahrscheinlich") – 5 = very likely ("sehr wahrscheinlich")). Participants saw all semantically unrelated pairs (intact and recombined) as well as 412 semantically related intact pairs and their 206 corresponding recombined pairs (the latter were not used in this study). The pictures of the two single objects contributing to each object pair were presented side by side to reduce the possibility of participants perceiving an action relationship because of a vertically presentation mode.

Prior to the selection of the object pairs with and without action relationship, only single objects that were recognized by at least 80 percent of the participants of both age groups were included into the material set. Then, the best 320 object pairs based on older adults' action relationship rating were chosen assuming that especially the older adults would be stricter in their rating of an action relationship for a pair of objects that is usually not used together. Afterwards, it was verified that these object pairs were not rated as highly semantically related (i.e., semantic relatedness <= 4). For younger adults, the same object pairs were selected, and Table 7.2 shows the total means regarding action relationship and semantic relationship for the intact and recombined pairs in both age groups. For both age groups, the rating of the action relationship did not differ significantly between the intact pairs and the recombined pairs, YA: A+: $t(478) = 1.29$, $p = .19$, $g_s = 0.12$, A-: $t(478) = -0.03$, $p = .97$, $g_s = 0.01$; OA: A+: $t(478) = 1.23$, $p = .21$, $g_s = 0.12$, A-: $t(478) = 0.64$, $p = .52$, $g_s = 0.06$. As expected, the object pairs with action relationship achieved significantly higher action ratings than the object pairs without action relationship, YA: intact: $t(638) = 43.41$, $p < .001$, $g_s = 3.43$, recombined: $t(318) = 28.98$, $p < .001$, $g_s = 3.22$; OA: intact: $t(638) = 30.06$, $p < .001$, $g_s = 2.37$, recombined: $t(318) = 21.14$, $p < .001$, $g_s = 2.36$. Although the rating differences between action-related and action-unrelated object pairs were larger for younger adults compared to older adults, the results show that the manipulation of the action relationships was effective in both age groups.

Study lists consisted of 240 object pairs (120 pairs with action relationship, 120 pairs without action relationship). Test lists consisted of 120 object pairs with action relationship and 120 object pairs without action relationship with 40 intact pairs, 40 recombined pairs and 40 new pairs (in each condition). Within the stimulus set, each object pair appeared once as a new and intact pair and twice as a recombined pair in each action condition. The assignment of the object pairs to the conditions was counterbalanced across subjects.

Figure 7.1

Examples of intact and recombined object pairs with and without action relationship



Note. One recombined object pair was always built on the basis of two intact object pairs.
A+ intact: A milk bottle above a sports shoe (left side), a body lotion above a bowl (right side),
A+ recombined: a body lotion above a sports shoe;
A- intact: A towel above a stapler (left side), a cushion above a punch (right side),
A- recombined: A towel above a punch.

Table 7.2

Means for action relationship as well as semantic relationship of selected intact and recombined pairs for both age groups

		Action Relationship		Semantic Relationship
		Action	No Action	
Younger adults				
	Intact	3.97 (0.65)	1.48 (0.79)	0.51 (0.52)
	Recombined	3.89 (0.69)	1.49 (0.79)	0.48 (0.60)
Older adults				
	Intact	3.80 (0.79)	1.64 (1.01)	0.65 (0.63)
	Recombined	3.70 (0.87)	1.58 (0.92)	0.58 (0.63)

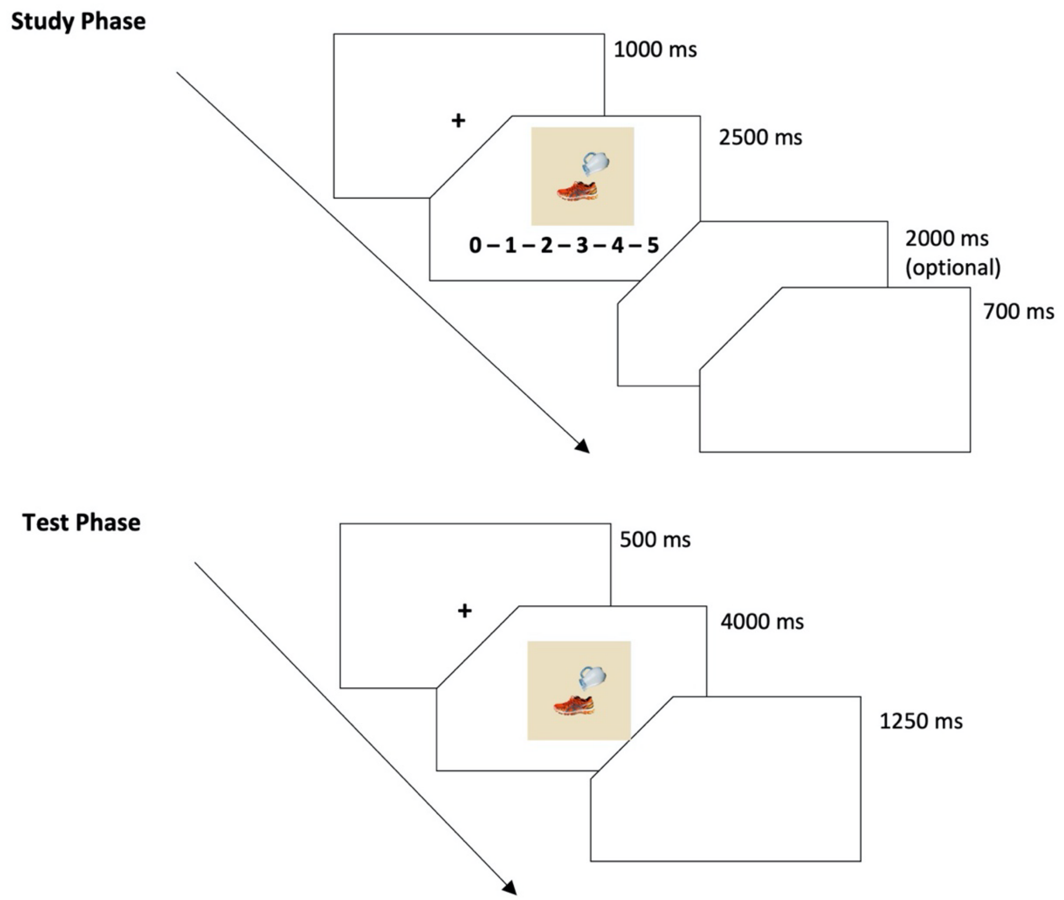
Note. Standard deviations are given in parentheses.

Procedure. The EEG session lasted about 3 hours. At the beginning, participants gave informed consent and filled out a questionnaire about general health aspects. The younger adults additionally completed the Edinburgh Handedness Inventory (Oldfield, 1971). During the following preparation of the EEG, participants were familiarized with all single objects used later in the experiment by looking through a booklet containing the single objects. Afterwards, subjects were seated comfortably in a sound- and electrically-shielded room with a distance of approximately 80 cm from a 19''-display monitor with a resolution of 1280 x 1024 pixels. The experiment was programmed and presented with E-Prime 2 software (Psychology Software Tools, Inc., Pittsburgh, PA). All object pairs were presented against a beige background with a size of 500 x 500 pixels.

Before the actual experiment started, a practice block including a study and a test phase was conducted. Therefore, 30 additional object pairs were used that were not selected for the actual experiment. The practice study phase consisted of 18 object pairs (nine pairs with action relationship, nine pairs without action relationship). The practice test phase included 18 object pairs, with half of them possessing an action relationship (three pairs per condition intact/recombined/new) and the other half possessing no action relationship (again three pairs per condition intact/recombined/new). The practice block followed the procedure from the actual experiment. The only exception was that feedback was provided after each trial, indicating whether the answer was correct or, if not, which answer would have been correct. The actual experiment was divided into four study-test cycles leading to 60 trials (30 object pairs with action relationship, 30 pairs without action relationship) per study block and test block, respectively. The order of the four blocks was randomized and the order of the trials within each block was pseudorandomized for each participant with the constraint that in the study phase, no more than three object pairs of the same action relationship were presented in a row and in the test phase, each combination of action relationship (A+ or A-) and status condition (intact, recombined or new) appeared not more than three times in a row. Each study and test block began with additional four stimulus examples in order to ensure that the subjects knew which task is relevant for the following part. During the study phase, participants had to judge how appropriate the arrangement was in order to conduct an action with the two presented objects (0 = not at all appropriate ("gar nicht richtig"), 5 = absolutely appropriate ("absolut richtig")) using a response box with six buttons. The assignment of the buttons to the response options was counterbalanced across subjects. Furthermore, they were instructed to memorize the presented object pairs for the next part of the experiment. A study trial started with a fixation cross for 1000 ms (randomly jittered between 975 and 1025 ms), and then the object pair was presented for 2500 ms. If no response was given during the presentation of the object pair, a blank screen was presented for 2000 ms during which participants were still able to provide their answers. A response finished the trial and led to a 700 ms blank screen concluding the study trial (see Figure 7.2). After half of the trials within each study block, there was a self-paced break, in which subjects read again the instructions of the encoding task. After each study phase, a paper-pencil filler task was conducted for that lasted approximately three minutes. Here, the subjects had to indicate whether given arithmetic equations were correct or incorrect. In the test phase, participants had to judge if the presented object pair was old, recombined or new by pressing one of three buttons. Response assignments were counterbalanced across participants. Each test trial started with a fixation cross presented for 500 ms (randomly jittered between 475 and 525 ms), which was replaced by the object pair shown for 4000 ms. Participants had to respond as accurately as possible while the object pair was presented on the screen. As soon as an answer was given, a blank screen for 1250 ms finished the trial (see Figure 7.2). After completing all four study-test blocks, the participants concluded the session with an unrelated active oddball task. This task is part of another study and will not be reported in this paper. At the end of the session, subjects filled out a follow-up survey, were debriefed and paid for their participation.

Figure 7.2

Trial procedure for the study and test phase



EEG Recording and Analysis. The EEG was recorded using BrainVision Recorder V1.02 (Brain Products) from 28 Ag/AgCl-electrodes embedded in an elastic cap according to the international 10-20 electrode 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, and A2) during the study and the test phase. Four additional electrodes were placed around the eyes (two electrodes above and below the right eye, two electrodes at the outer canthi of both eyes) to measure the vertical and horizontal Electrooculogramm (EOG). An electrode placed on the left mastoid (A1) served as online reference and AFz was used as ground electrode. Electrode impedances were kept below 5 kΩ. The EEG was amplified with a BrainAmp DC amplifier (Brain Products GmbH) from 0.016Hz to 250Hz and digitized at a sampling rate of 500Hz. For offline processing of the EEG data, BrainVision Analyzer 2.1 software (Brain Products GmbH) was used. Offline processing applied to EEG data was identical for both age groups. The data were filtered with a fourth order bandpass-filter at 0.1 – 30 Hz and a notch filter at 50 Hz. In order to identify and correct blinks and horizontal eye movements, the semi-automatic algorithm implemented in BrainVision Analyzer 2.1 was applied to the continuous EEG data (Ocular Correction ICA). After re-referencing to the left and right mastoid electrodes, the continuous EEG was divided into segments that started 200 ms before stimulus presentation and ended 2000 ms after stimulus onset. Baseline correction was applied using the 200 ms time interval pre-stimulus onset. Thereafter, averaging was conducted for each condition with a minimum of eight trials per condition. Even though this is a rather small number of trials for subject averages, this procedure is consistent with a variety of previous studies investigating memory-related ERPs (e.g., Höltje & Mecklinger, 2020; Kamp et al., 2018; Otten & Donchin, 2000; Trott et al., 1999). No further artifact rejection was applied in order to avoid loss of further trials and consequently exclusion of participants due to too small trial numbers for subject averages (see Trott et al., 1999 for a similar procedure). The mean trial numbers and ranges were: intact pairs with action relationship (YA: 33.3 (23-38), OA: 31.5 (22-37)), recombined pairs with action relationship (YA: 24.2 (11-38), OA: 16.7 (10-28)), new pairs with action relationship (YA: 31.8 (18-38), OA: 30.2 (18-37)), intact pairs without action relationship (YA: 27.5 (15-36), OA: 25.3 (8-37)), recombined pairs without relationship (YA: 22.7 (12-33), OA: 15.6 (9-23)), new pairs without relationship (YA: 32.9 (21-39), OA: 29.8 (15-37)). Grand averages were calculated for each condition and filtered with a second order low-pass filter at 12 Hz for illustration purposes only.

7.2.4 Analyses

All statistical analyses were conducted with R, version 3.6.1 and R studio (RStudio Team, 2019). The package "ez" (Lawrence, 2016) was used for the computation of mixed-model Analysis of Variance (ANOVA). In case of violation of sphericity, the Greenhouse-Geisser correction was applied, and uncorrected degrees of freedom are reported. The package "stats" (R Core Team, 2019) was used for computing *t*-tests for independent and dependent samples in order to disentangle significant interactions. The package "DescTools" (Signorell et al., 2020) was used to compute the effect size partial eta squared (η^2_p). The effect size Hedges' g for the between-subjects and within-subjects comparisons was conducted based on the formula by Lakens (2013). The alpha level was set to .05.

Behavioral Analyses

Study Phase. For the analysis of the judgement task during the study phase, the mean rating of the action relationship based on the given ratings during encoding was calculated for action-related and action-unrelated object pairs, respectively. These ratings were included in a mixed-model ANOVA with Age Group (young/old) as between-subjects factor and Action Relationship (A+/A-) as within-subjects factor.

Test Phase. To quantify associative memory performance, an associative memory index for each action relationship was calculated. In the equation for associative memory (1), the false alarm rate includes recombined object pairs mistakenly recognized as old relative to all recombined pairs with at least correct item memory (recombined pairs as recombined and recombined pairs as old). This false alarm rate is subtracted from the hit rate containing the proportion of object pairs correctly recognized as old (i.e., correct associative memory) relative to all intact object pairs with at least correct item memory (old object pairs as old and old object pairs as recombined).

$$PR - Association = \frac{old|\text{old}}{old|\text{old}+rec|\text{old}} - \frac{old|\text{rec}}{rec|\text{rec}+old|\text{rec}} \quad (1)$$

In addition, an item memory index was computed in order to establish a correspondence with other aging studies on memory. This allowed us to test whether the frequently reported associative memory deficit (i.e., larger age-related differences in associative than in item memory tasks) (Bastin et al 2013; Old & Naveh-Benjamin 2008) is also present in this study. The equation for item memory (2) consists of the difference between the hit rate including the proportion of object pairs with correct item memory (old object pairs as old, old object pairs as recombined, recombined object pairs as recombined, recombined object pairs as old) relative to all object pairs that could be known from the study phase (old and recombined object pairs). The corresponding false alarm rate comprises new object pairs that are mistakenly recognized as known on an item basis (new object pairs as old and new object pairs as recombined) relative to all new object pairs.

$$PR - Item = \frac{old|\text{old}+rec|\text{old}+rec|\text{rec}+old|\text{rec}}{\text{old+rec}} - \frac{old|\text{new}+rec|\text{new}}{\text{new}} \quad (2)$$

The indices were included in a 3-factorial mixed-model ANOVA with the between-subjects factor age group (young/old) and the two within-subjects factors action relationship (A+/A-) and memory type (item/associative). In addition, reaction times (RT) to correct responses were analyzed with a 3-factorial mixed-model ANOVA including the between-subjects factor age group (young/old) and the two within-subjects factors action relationship (A+/A-) and status (intact/recombined/new).

Electrophysiological Analyses

Here, we only report EEG data from the test phase. Analyses of the ERPs were limited to correct responses. Nine representative electrodes were selected: F3, Fz, F4 for frontal, C3, Cz, C4 for central, and P3, Pz, P4 for parietal scalp distribution of the ERP effects (see Bridger et al., 2017; Bridger & Mecklinger, 2012; Zheng et al., 2016, for similar configurations). For both age groups, an early and a late time window were analyzed, which are associated with familiarity and recollection, respectively. For younger adults, the early time window was set from 300 to 500 ms post-stimulus onset and the late time window was set from 500 to 700 ms post-stimulus onset. The selection of the time windows for older adults followed previous studies showing an age-related delay of the early familiarity effect by about 100 ms (Nessler et al., 2007; Wegesin et al., 2002). Therefore, the time window from 400 to 600 ms was selected for the early old/new effects in older adults. The time window for the late effects was adjusted accordingly (600 to 800 ms) to avoid overlapping time windows.

First, a global ANOVA was conducted separately for each time window including the between-subjects factor age group (young/old) and the within-subjects factors action relationship (A+/A-), retrieval category (intact/recombined/new), laterality (left/middle/right) and location (frontal/central/parietal). Further ANOVAs were conducted with pooled electrodes data, anticipating the lack of significant interactions between action relationship, retrieval category and laterality. In case of significant interactions, these were further unraveled by 2-factorial ANOVAs and pairwise *t*-tests so that for the investigation of old/new effect as well as associative and item memory contrasts the following critical comparisons were conducted for both action relationship conditions: intact vs. new object pairs (familiarity in early time window, recollection in late time window), intact vs. recombined object pairs (associative familiarity in early time window, associative recollection in late time window) and recombined vs. new object pairs (item familiarity in early time window, item recollection in late time window).

7.3 Results

7.3.1 Behavioral Results

Study Phase. Table 7.3 shows the mean ratings for action-related and action-unrelated object pairs within each age group**.** The mixed-model ANOVA of the mean ratings yielded a significant main effect of Action Relationship, $F(1,40) = 672.20, p < .001, \eta^2_p = 0.94$, indicating that, as expected, action-related object pairs were rated significantly higher than action-unrelated object pairs. Neither the main effect of age group nor the Age Group x Action Relationship interaction reached significance. Age differences were neither present in ratings of action-related object pairs, $t(40) = 0.98, p = .33, g_s = .30$, nor in ratings of action-unrelated object pairs, $t(40) = -1.74, p = .08, g_s = 0.53$.

Table 7.3

Mean ratings during the study phase for action-related and action-unrelated object pairs within each age group

	Action Relationship	
	Action	No Action
Younger adults	4.43 (0.34)	0.93 (0.50)
Older adults	4.31 (0.49)	1.27 (0.78)

Note. Standard deviations are given in parentheses.

Test Phase. Figure 7.3 shows the means for the two calculated performance measures. Table 7.4 includes the indices and RTs for the correct responses in the test phase.

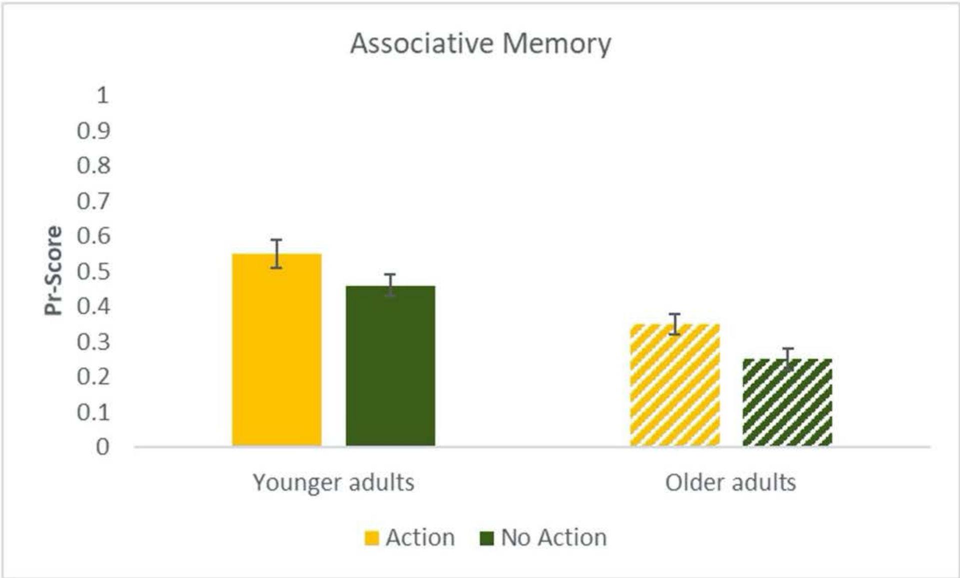
There were main effects of age group, $F(1,40) = 16.84, p < .001, \eta^2_p = 0.29$, action relationship, $F(1,40) = 28.90, p < .001, \eta^2_p = 0.41$, and memory type, $F(1,40) = 167.99, p < .001, \eta^2_p = 0.80$. In addition, an interaction between age group and memory type, $F(1,40) = 7.91, p = .007, \eta^2_p = 0.16$, was revealed. This interaction was dissolved by memory type specific analyses. There were age-related differences for both item, $t(40) = 2.10$, $p = .041$, $g_s = 0.63$, and associative memory, $t(40) = 4.98$, $p < .001$, $g_s = 1.23$, revealing better memory for younger adults than older adults with larger effect sizes for associative memory, indicating the frequently reported larger age-related difference in tests of associative memory than item memory (e.g. Naveh-Benjamin, 2000) None of the other interactions reached significance (*ps* > .25).

The analysis of RTs to correct responses yielded main effects of age group, $F(1,40) = 26.83$, $p < .001$, $\eta^2_p = 0.40$, action relationship, $F(1,40) = 42.49$, $p < .001$, $\eta^2_p = 0.51$, and status, $F(2,80) = 81.62$, $p < .001$, $\eta^2_p = 0.67$. Furthermore, interactions between age group and status, $F(2,80) = 5.77$, $p = .004$, $\eta^2_p = 0.12$, and between action relationship and status, $F(2,80) = 25.23$, $p < .001$, $\eta^2_p = 0.38$, were obtained. Concerning the Age Group x Status interaction, response times were faster for younger adults for intact, $t(40) = -4.63$, $p < .001$, $g_s = 1.31$, recombined, $t(40) = -5.50$, $p < .001$, $g_s = 1.64$, and new object pairs, $t(40) = -3.68$, $p < .001$, $g_s = 1.10$, with these age differences in response speed being largest for recombined object pairs. Following up the Action Relationship x Status interaction, comparisons between the action relationship conditions for each status condition revealed faster responses for action-related intact, $t(41) = -10.30$, $p < .001$, $g_{av} = 0.55$, and recombined pairs, $t(41) = -2.40$, $p = .020$, $g_{av} = 0.12$, compared to action-unrelated intact and recombined pairs, respectively. The corresponding effect sizes indicate that these differences were larger for intact than for recombined pairs. There was no significant difference between the action relationship conditions for the new object pairs, $t(41) = 1.10$, $p = .27$, $g_{av} = 0.06$.

Figure 7.3

Means of the Pr-Scores for Association and Item Memory, separated for Action Relationship Condition and Age Group

A



B

Note. **A** shows the mean of the PR-Score for Associative Memory, separated for Action Relationship condition and Age Group; **B** shows the Mean of the PR-Score for Item Memory, separated for Action Relationship condition and Age Group. Error bars show ±1 SME.

Table 7.4

PR-Scores and RTs to correct responses of the test phase

	Younger Adults		Older Adults	
	Action	No Action	Action	No Action
Pr-Score				
Item	0.74 (0.12)	0.69 (0.14)	0.67 (0.15)	0.59 (0.16)
Association	0.55 (0.19)	0.46 (0.17)	0.35 (0.12)	0.25 (0.13)
RT				
Intact	1357 (260)	1540 (282)	1753 (316)	1982 (339)
Recombined	1748 (270)	1821 (308)	2361 (423)	2408 (444)
New	1483 (255)	1473 (258)	1847 (370)	1808 (373)

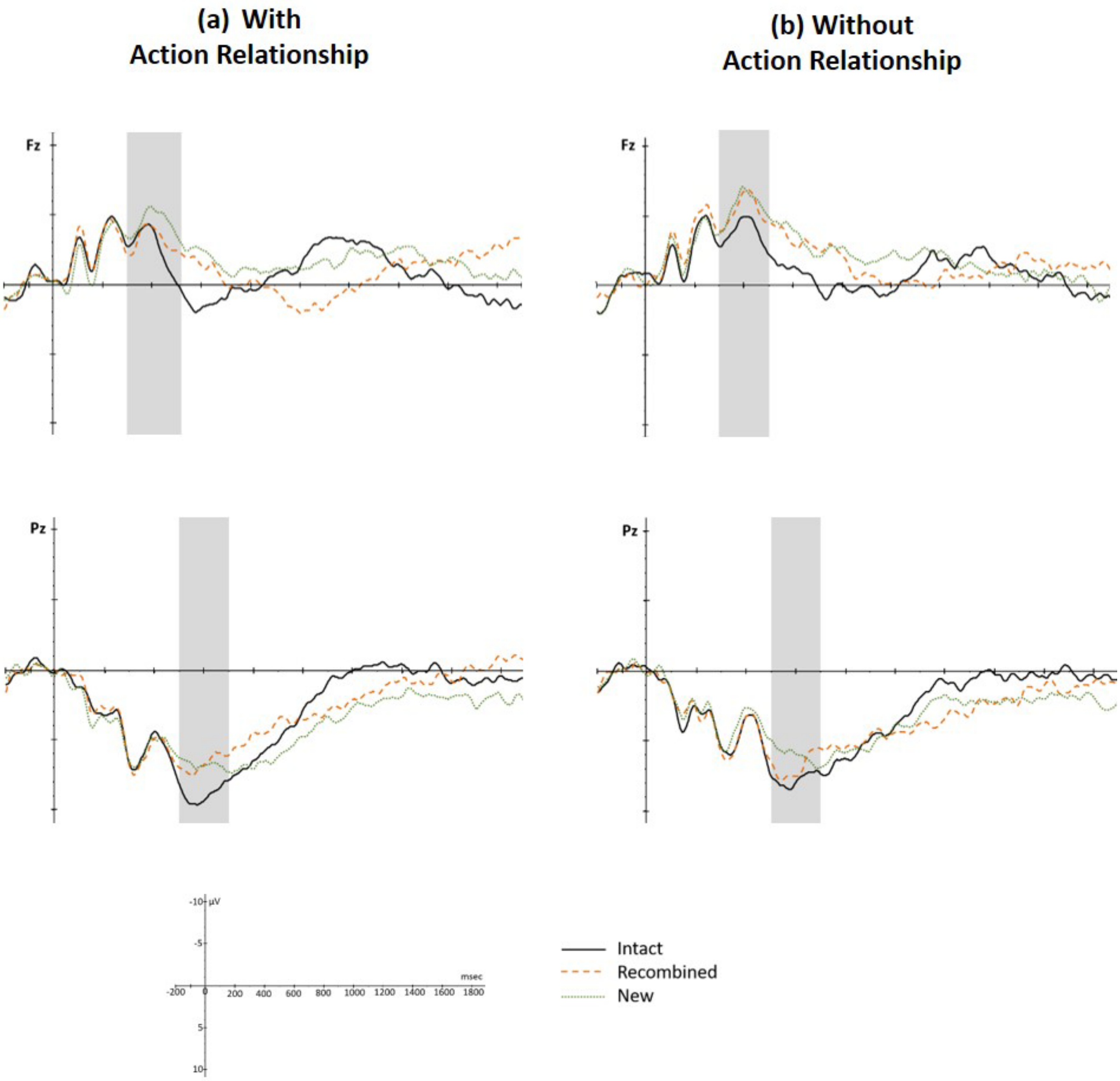
Note. Standard deviations are given in parentheses.

7.3.2 Electrophysiological Results

Figures 7.4 and 7.5 show the averaged ERP waveforms for correct responses to intact, recombined, and new object pairs in the condition with action relationship (Figure 7.4a/7.5a) and without action relationship (Figure 7.4b/7.5b) for younger adults and older adults respectively. Figure 7.6 presents the topographical maps for the early and late old/new effects in both age groups.

Figure 7.4

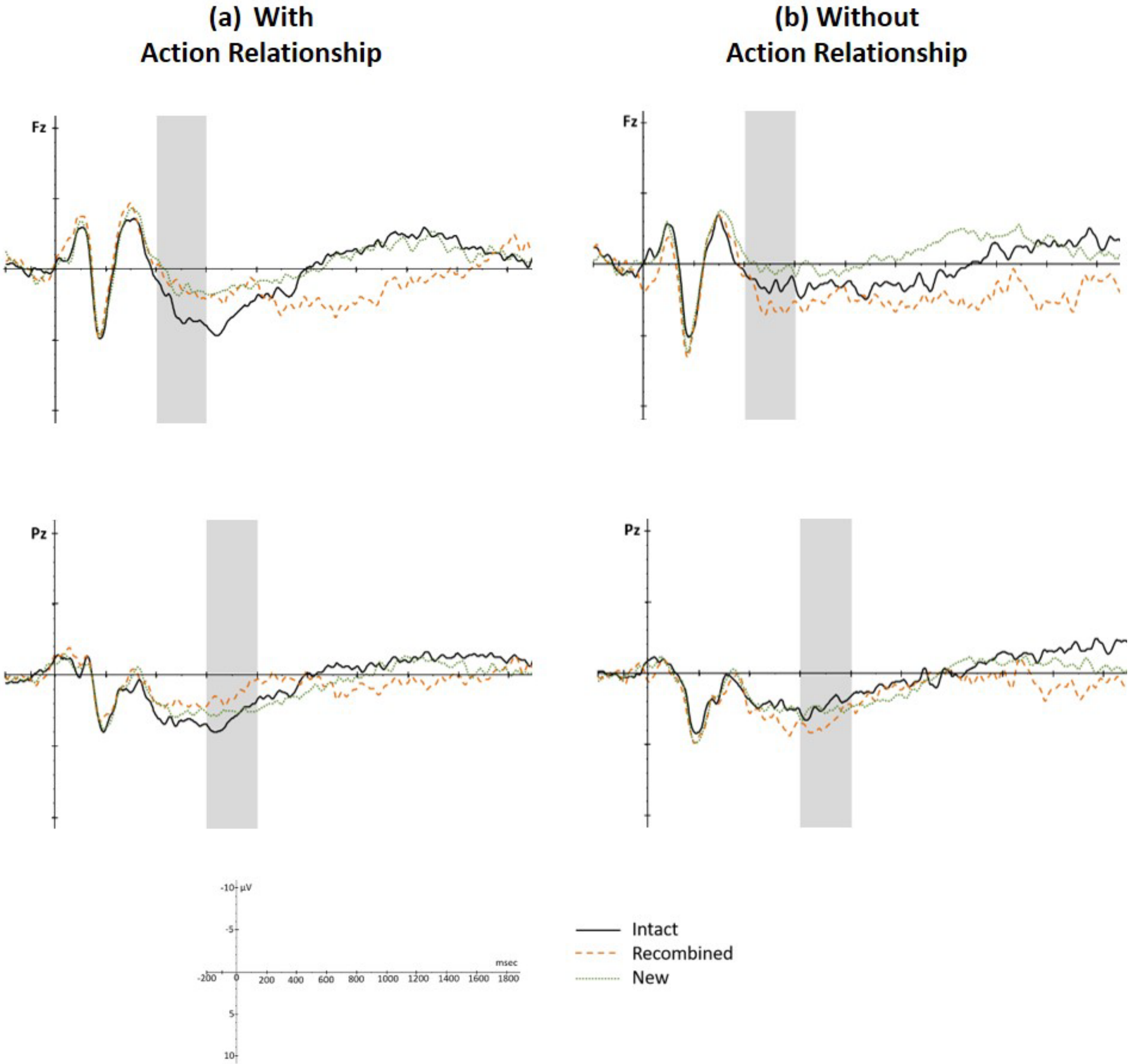
ERP waveforms associated with correct responses to intact, recombined and new object pairs for both Action Relationship conditions for Younger Adults



Note. (a) condition with action relationship and (b) condition without action relationship for Younger adults. Data are depicted at the Fz and Pz electrode.

Figure 7.5

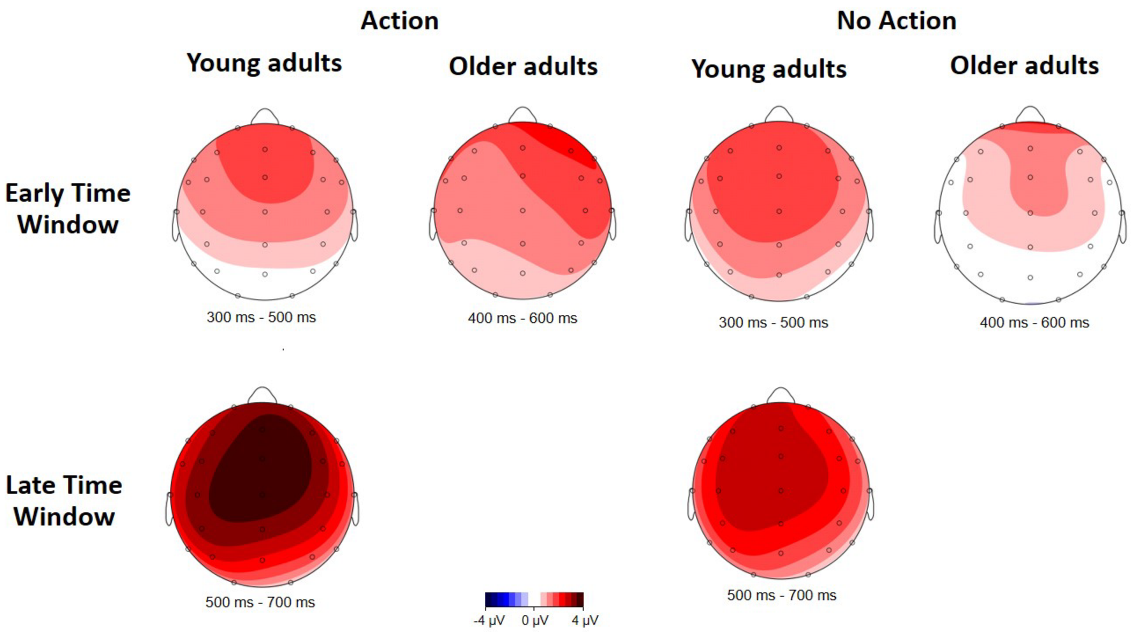
ERP waveforms associated with correct responses to intact, recombined and new object pairs for both Action Relationship conditions for Older Adults



Note. (a) condition with action relationship and (b) condition without action relationship for Older adults. Data are depicted at the Fz and Pz electrode.

Figure 7.6

Topographical maps for old/new effects for Younger and Older Adults



Note. Topographical maps for the early old/new effects are presented for both age groups, while the distribution of the late old/new effects is shown only for Younger adults, representing the results pattern of the analyses regarding the old/new effects.

Early Time Window (YA: 300-500 ms, OA: 400-600 ms)

As a first step, a global 5-factorial ANOVA with the between-subjects factor age group (young/old) and the within-subjects factors action relationship (A+/A-), retrieval category (intact/recombined/new), laterality (left/middle/right) and location (frontal/central/parietal) was conducted for the early time window. Table 7.5 provides an overview of the results of this ANOVA, depicting only the significant effects and interactions that include retrieval category or action relationship. There was an interaction between age group, action relationship, retrieval category and location in the early time window. As there were no significant interactions between action relationship, retrieval category and laterality (all *p*s >.27), all follow-up analyses were pooled across the laterality factor (i.e., frontally combining F3, Fz, F4).

Table 7.5

Outcomes of global ANOVA in each time window

	Early Time Window	Late Time Window
	(YA: 300-500 ms, OA: 400-600 ms)	(YA: 500-700 ms, OA: 600-800 ms)
ActionRel F(1,40)	14.09***	10.84**
ActionRel x Age (F(1,40)	8.36**	6.44*
ActionRel x Laterality F(2,80)	17.11 ***	4.95**
ActionRel x Location F(2,80)	-	17.32***
ActionRel x Laterality x Location F(4,160)	2.80*	2.87*
Retrieval Category F(2,80)	7.25**	18.52***
Retrieval Category x Age F(2,80)	-	5.09*
Retrieval Category x Location F(4,160)	7.47***	7.30***
Retrieval Category x Laterality x Age F(4,160)	-	4.05**
Retrieval Category x Laterality x Location F(8,320)	-	6.75***
Retrieval Category x ActionRel F(2,80)	-	5.13**
Age x ActionRel x Retrieval Category F(2,80)	5.64**	-
Age x ActionRel x Retrieval Category x Location F(4,160)	3.45 *	-

Note. Shown are only significant effects and interactions including the factors Status or Action Relationship in the global ANOVA in each time window.
ActionRel = Action Relationship.
* $p < .05$. ** $p < .01$. *** $p < .001$.

Old/New Effects. In order to investigate age-related old/new effects depending on the action relationship in the early time window, a 2 x 2 x 2 ANOVA with the between-subjects factor age group (young/old) and the within-subjects factors action relationship (A+/A-) and retrieval category (intact/new) was conducted for the pooled mean amplitudes at frontal electrodes in the early time window.

This analysis revealed main effects of age group, $F(1,40) = 11.58$, $p = .001$, $\eta^2_p = 0.22$, action relationship, $F(1,40) = 15.39$, $p < .001$, $\eta^2_p = 0.28$, and retrieval category, $F(1,40) = 29.64$, $p < .001$, $\eta^2_p = 0.42$. None of the interactions reached significance (all *ps* > .39). Thus, the waveforms were more positive-going for older than younger adults, and in the A+ than in the A- condition. Reliable ERP correlates of familiarity were present in both age groups and were not modulated by action relationship.

Contrast between Intact and Recombined Object Pairs. In order to investigate age-related differences regarding associative memory and their modulation by action relationship, a 2 x 2 x 2 ANOVA with the between-subjects factor age group (young/old) and the within-subjects factors action relationship (A+/A-) and retrieval category (intact/recombined) was conducted with the pooled frontal electrodes in the early time window.

There were main effects of age group, $F(1,40) = 11.57$, $p = .001$, $\eta^2_p = 0.22$, and action relationship, $F(1,40) = 6.37$, $p = .015$, $\eta^2_p = 0.13$. There were also significant interactions between age group and action relationship, $F(1,40) = 5.48$, $p = .024$, $\eta^2_p = 0.12$, and between age group, action relationship and retrieval category, $F(1,40) = 10.54$, $p = .002$, $\eta^2_p = 0.21$. Following-up the significant three-way interaction, 2-factorial ANOVAs were conducted to investigate differences between action relationship conditions for each age group.

For younger adults, there was a main effect of action relationship, $F(1,22) = 18.05$, $p < .001$, $\eta^2_p = 0.45$, reflecting the generally more positive-going waveforms in the A+ when compared to the A- condition. The interaction between action relationship and retrieval category did not reach significance (p = .16).

For older adults, there was a significant interaction between action relationship and retrieval category, $F(1,18) = 8.07$, $p = .01$, $\eta^2_p = 0.31$. In order to disentangle this interaction, follow-up contrasts between intact and recombined pairs were conducted for each action relationship condition. There was a significant difference between the action-related intact and recombined pairs, $t(18) = 2.66$, $p = .016$, $g_{av} = 0.25$. For the action-unrelated condition, the difference between intact and recombined pairs did not reach significance, $t(18) = -1.39$, $p = .18$, $g_{av} = 0.22$). In sum, for older adults, reliable ERP differences between intact and recombined object pairs (i.e., reflecting associative familiarity processes) are observable only for action-related object pairs, whereas for younger adults, action relationship and retrieval category did not interact.

Contrast between Recombined and New Object Pairs. In order to investigate age-related differences regarding item memory and their modulation by action relationship, a 2 x 2 x 2 ANOVA with between-subjects factor age group (young/old) and the within-subjects factors action relationship (A+/A-) and retrieval category (recombined/new) was conducted with the pooled frontal electrodes in the early time window.

There were main effects of age group, $F(1,40) = 12.63$, $p < .001$, $\eta^2_p = 0.24$, action relationship, $F(1,40) = 4.81$, $p = .034$, $\eta^2_p = 0.11$, and retrieval category, $F(1,40) = 7.39$, $p = .009$, $\eta^2_p = 0.16$. Also, there were significant interactions between age group and action relationship, $F(1,40) = 9.77$, $p = .003$, $\eta^2_p = 0.19$, and between age group, action relationship and retrieval category, $F(1,40) = 8.15$, $p = .007$, $\eta^2_p = 0.17$. Following-up the significant three-way interaction, 2-factorial ANOVAs were conducted in order to investigate differences between action relationship conditions for each age group.

For younger adults, there was a main effect of action relationship, $F(1,22) = 12.84$, $p = .002$, $\eta^2_p = 0.37$, again reflecting the generally more positive-going waveforms in the A+ condition. The interaction between action relationship and retrieval category did not reach significance ($p = .25$).

For older adults, there was a significant interaction between action relationship and retrieval category, $F(1,18) = 8.44$, $p = .009$, $\eta^2_p = 0.32$. Follow-up contrasts between recombined and new pairs revealed no significant difference for action-related pairs, $t(18) = 0.03$, $p = .97$, $g_{av} = 0.00$. However, for action-unrelated object pairs, ERPs were more positive for recombined than new pairs, $t(18) = 2.95$, $p = .009$, $g_{av} = 0.36$.

To sum up the results for the early time window, there were neither age-related differences nor differences between the action relationship conditions for the ERP correlate of familiarity (i.e., intact vs. new). Regarding the additional ERP contrast for associative familiarity (intact vs. recombined), effects were only found for action-related pairs in older adults. In contrast, no modulation of this contrast by action relationship was found in younger adults. For the ERP contrast relating to item familiarity (recombined vs. new), older but not younger adults showed a significant difference between recombined and new object pairs that was only found for action-unrelated object pairs.

Late Time Window (YA: 500-700 ms, OA: 600-800 ms)

As for the early time window, a global 5-factorial ANOVA with the between-subjects factor age group (young/old) and the within-subjects factors action relationship (A+/A-), retrieval category (intact/recombined/new), laterality (left/middle/right) and location (frontal/central/parietal) was conducted also for the late time window. Table 5 provides an overview of the results of this ANOVA, depicting only the significant effects and interactions that include retrieval category or action relationship. All two-way interactions between the four factors age group, action relationship, retrieval category and location were significant (all *ps*

<.016) so that the follow-up 3-factorial ANOVA was conducted for the parietal electrodes. Since there were no significant interactions including action relationship, status and laterality (all *ps* > .16), all follow-up analyses were pooled across the laterality factor (i.e., parietally combining P3, Pz, P4).

Old/New Effects. As in the early time window a 2 x 2 x 2 ANOVA with the between-subjects factor age group (young/old) and the within-subjects factors action relationship (A+/A-) and retrieval category (intact/new) was conducted in the late time window but with pooled parietal electrodes.

As in the early time window, there were main effects of age group, $F(1,40) = 7.94$, $p = .007$, $\eta^2_p = 0.16$, action relationship, $F(1,40) = 5.54$, $p = .024$, $\eta^2_p = 0.12$, and retrieval category, $F(1,40) = 19.38$, $p < .001$, $\eta^2_p = 0.33$. Notably, there was a significant interaction between age group and retrieval category, $F(1,40) = 11.76$, $p = .001$, $\eta^2_p = 0.23$. In order to disentangle this interaction, follow-up comparisons between both levels of the retrieval category factor (intact vs. new) were conducted for younger and older adults collapsed across action-related and action-unrelated pairs. For younger adults, there was a significant old/new effect, $t(22) = 5.04$, $p < .001$, $g_{av} = 0.42$, whereas for older adults the late old/new effect did not reach the significance level, $t(18) = 0.49$, $p = .63$, $g_{av} = 0.04$.

Contrast between Intact and Recombined Object Pairs. In order to investigate age-related differences regarding late associative memory processes and their modulation by action relationship, a 2 x 2 x 2 ANOVA with between-subjects factor age group (young/old) and the within-subjects factors action relationship (A+/A-) and retrieval category (intact/recombined) was conducted with the pooled parietal electrodes in the late time window.

There were main effects of age group, $F(1,40) = 9.21$, $p = .004$, $\eta^2_p = 0.19$, and retrieval category, $F(1,40) = 7.74$, $p = .008$, $\eta^2_p = 0.16$. Furthermore, there were significant interactions between age group and action relationship, $F(1,40) = 4.22$, $p = .046$, $\eta^2_p = 0.09$, and between action relationship and retrieval category, $F(1,40) = 13.39$, $p < .001$, $\eta^2_p = 0.25$.

In order to disentangle the latter interaction, intact and recombined pairs were directly contrasted in each action relationship condition collapsed across both age groups. There was a significant difference between action-related intact and recombined object pairs, $t(41) = 5.07$, $p < .001$, $g_{av} = 0.39$. For action-unrelated object pairs, intact pairs did not differ significantly from recombined pairs, $t(41) = 0.08$, $p = .94$, $g_{av} = 0.00$. The interaction between age group and action relationship reflects larger age-related differences for action-related object pairs, $t(40) = 3.50$, $p = .001$, $g_s = 1.06$, than for action-unrelated object pairs, $t(40) = 2.45$, $p = .01$, $g_s = 0.74$.

Contrast between Recombined and New Object Pairs. In order to investigate age-related differences regarding item memory processes and their modulation by action relationship, a 2 x 2 x 2 ANOVA with between-subjects factor age group (young/old) and the within-subjects factors action relationship (A+/A-) and retrieval category (recombined/new) was conducted with mean amplitudes at pooled parietal electrodes in the late time window as dependent variable.

This analysis revealed a main effect of age group, $F(1,40) = 5.55$, $p = .023$, $\eta^2_p = 0.12$, and significant interactions between age group and action relationship, $F(1,40) = 7.19$, $p = .011$, $\eta^2_p = 0.15$, and between action relationship and retrieval category, $F(1,40) = 5.65$, $p = .022$, $\eta^2_p = 0.12$. Contrasts between recombined and new pairs revealed a marginally significant difference (rec > new) for action-unrelated pairs, $t(41) = -1.95$, $p = .058$, $g_{av} = 0.17$, but no significant difference for action-related pairs, $t(41) = 1.26$, $p = .22$, $g_{av} = 0.09$. The interaction between age group and action relationship reflects age-related differences for action-related object pairs, $t(40) = 2.97$, $p = .004$, $g_s = 0.90$, whereas there were no age-related differences for action-unrelated object pairs, $t(40) = 1.71$, $p = .09$, $g_s = 0.74$.

To sum up, in the late time window, age-related differences were observed in the ERP correlate of recollection (i.e., the late parietal old/new effect) with smaller old/new effects in older adults than younger adults. For the ERP differences between intact and recombined object pairs, which are assumed to reflect associative memory processes, there were differences between the action relationship conditions regardless of age group, showing a significant difference between intact and recombined object pairs only for object pairs with action relationships (i.e., unitized object pairs). In contrast, regarding the ERP differences between recombined and new object pairs, presumably reflecting item memory processes, there were differences between the action relationship conditions regardless of age group, showing a marginally significant difference between recombined and new object pairs only for object pairs without action relationships (i.e., non-unitized object pairs).

7.4 Discussion

The goal of the present study was to investigate whether bottom-up unitization through action relationships between two semantically unrelated objects fosters familiarity-based remembering and can reduce the age-related associative memory deficit. Assuming that bottom-up unitization by action relations boosts associative memory mainly by increasing familiarity, which is relatively unaffected by age, we expected the associative memory deficit to be alleviated for action-related object pairs compared to action-unrelated object pairs. The behavioral results revealed main effects of age and action relationship on memory performance. As expected, and consistent with a large number of prior studies (e.g., Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003, 2004), we found an age-related associative memory deficit, i.e. larger age differences in measures of associative memory than item memory. Contrary to our prediction that bottom-up unitization by action relationships boosts associative memory, in particular in older adults (i.e., compensates for compromised recollection), the associative memory deficit in the elderly was not attenuated for action-related object pairs. Instead, both age groups showed a comparable memory boost for action-related object pairs. Interestingly, age-related differences between the ERP indices of memory processes suggest that the memory advantage for action-related object pairs in both age groups results from different underlying mechanisms.

7.4.1 Comparable Memory Boost in Younger and Older Adults

Contrary to our expectations we found a similar boost in memory performance for action-related object pairs in younger and older adults, as well as for both, associative and item memory. However, our behavioral measure of item memory is only an indirect measure as it was extracted from the associative memory task by pooling old and recombined responses. Therefore, the effect of action relationship on item memory should be interpreted with caution. Future studies which assess associative and item recognition in separate recognition tasks as has been done for example in Naveh-Benjamin (2000) should shed further light on this issue.

In order to explain that both age groups showed a comparable memory boost in associative memory performance, it is worth comparing our manipulation of action-relatedness with another action-related manipulation, the so-called subject-performed task (SPT) effect. The classical SPT includes an enactment component during encoding of object-action associations. Participants are instructed to conduct an action that is described in a phrase with and physically present external object. This leads to enhanced episodic memory performance (for reviews, see Engelkamp & Cohen, 1991; Nyberg et al., 2002). Investigating the crucial components for the enactment effect, Kormi-Nouri (2000) showed that neither physical movement nor the presence of a real object is necessary for the enactment effect because the increase in memory performance was similar for the classical SPT (i.e., real movement and real object) and for visual imagination of both the action and the object. Furthermore, Zhao et al. (2016) showed that the SPT improved associative memory performance and enhanced familiarity-based remembering of the associations between action and object. This is consistent with the view that the components of an action can be unitized by enactment. As unitization is considered as one potential mechanism for the observed enhanced familiarity-based remembering of the action-related associations in the SPT, unitization and enactment are not mutually exclusive explanations for the action effect observed in our study. Rather, enactment can be seen as another encoding manipulation that fosters the creation of unitized representations that support familiarity-based remembering. Recent brain imaging studies suggest that such representations enable a bypassing of hippocampal encoding while learning new associations (see for a review, Gilboa & Marlatte, 2017). Thus, these two circumstances (i.e., enactment and unitization) expand conditions supporting encoding of new associations without hippocampal involvement (see Sharon et al., 2011; van Kesteren et al., 2012). Thus, it is conceivable that the applied action relationships in the current study enabled unitization similar to enactment because objects in each action-related object pair in the current study are arranged in a manner to convey an action that can easily be imagined (i.e., constructed for right-handed persons and positioned close to each other, see Figure 2).

If enactment is the driving factor of the action effect on associative memory in the current study, it might be less surprising that we did not find this effect to be moderated by age. Research about the effects of encoding enactment in healthy aging has found that older and younger adults showed a similar memory benefit from an SPT manipulation (e.g., Silva et al., 2015) but that different mechanisms contribute to this effect in both age groups. For example, Mangels and Heinberg (2006) investigated whether the associative memory deficit in older adults can be reduced by enactment. Compared to verbal encoding, enactment improved memory performance for episodic associations, even when object-action associations were semantically unrelated. Interestingly, however, both age groups benefitted similarly from the enactment. To account for these results, Mangels and Heinberg (2006) proposed that there are multiple routes to successful associative retrieval. On the one hand, enactment can facilitate conscious recollection, which may be especially beneficial for younger adults but a rather unlikely route for older adults for which recollection is attenuated. On the other hand, older adults' associative memory benefits from enactment because familiarity is preserved for the unitized object action relation. In line with Mangels and Heinberg (2006), we assume that in the current study both age groups use different routes to successful associative retrieval: Older adults seem to rely more on associative familiarity, whereas younger adults rely more on recollection. This will be discussed in more detail below.

7.4.2 ERP Results in the Early Time Window

Familiarity Effect (intact vs. new). No significant age-related differences were obtained for the frontal old/new effect, the ERP correlate of familiarity, suggesting that both younger and older adults relied on familiarity during successful recognition. This result is in line with aging studies showing that familiarity and its ERP correlate is mostly preserved in old age (Friedman, 2013; Koen & Yonelinas, 2016; Scheuplein et al., 2014). In addition, by showing a topographically similar early old/new effect in both age groups, our study adds to the increasing number of memory studies revealing that a reliable ERP correlate of familiarity can be obtained with perceptually rich pictorial stimuli for which detailed and distinctive memory representations can be created (e.g., Ally et al., 2008; Scheuplein et al., 2014). Unexpectedly, there were no differences in the frontal old/new effect for object pairs with and without action relationships. At first glance, this challenges the idea that action-related object pairs are unitized and enhance familiarity-based remembering. However, as outlined before, in the comparison between intact and new object pairs familiarity of the individual components cannot be completely controlled for (Kamp et al., 2016), and thus, additional contrasts including recombined object pairs were considered as complementary ERP measures for associative and item memory processes that control for confounding factors (Bridger et al., 2017). Referring to these contrasts, differences between action relationship conditions were observed, suggesting that the implemented unitization approach differentially influenced early memory processes. These observations will be discussed in the following.

Associative and Item Familiarity (intact vs. recombined & recombined vs. new). Whereas younger adults showed no significant differences between action-related and action-unrelated object pairs in terms of associative and item memory processes, older adults revealed an early associative familiarity effect (i.e., intact vs. recombined) that was present for action-related object pairs only, i.e., in the condition assumed to support unitization and to enhance familiarity-based remembering. This result supports the view that older adults indeed benefitted from the bottom-up unitization via enhanced familiarity-based remembering of the action-related intact object pairs. However, for action-unrelated object pairs, older adults showed a significant difference between recombined and new object pairs with recombined pairs being more positive-going than new object pairs. It should be noted that an interpretation of this effect in terms of item familiarity might not be straightforward because only recombined but not intact object pairs seem to be processed differentially depending on the action relationship. In addition, we would have expected to observe item familiarity (i.e., recombined vs. new) also for action-related object pairs. Notably, the frontal positivity to action-unrelated recombined pairs bears similarities with the P3a, an ERP component that is assumed to reflect a stimulus driven attention mechanism to salient and rare events (Polich, 2007). Fonken et al. (2020) describe the fronto-centrally distributed P3a as an electrophysiological manifestation of involuntarily attentional shifts to distractors and infrequent stimuli. Given that, for older adults, correctly recognized recombined action-unrelated object pairs are the most difficult to process (i.e., showing the smallest proportion of correct responses), it is possible that these object pairs are perceived as a category of salient events presented with low frequency by older adults and give rise to a frontally distributed P3a that overlaps with memory-related effects in this time interval.

Of note, in all analyses, we found a main effect of action relationship, representing generally more positive-going waveforms for action-related compared to action-unrelated object pairs. This might represent an N400 effect for action-unrelated compared to action-related pairs, suggesting a similar processing of actions conveyed by pictures and linguistic stimuli (for a review, see Amoruso et al., 2013). Thus, it seems that in the current study, the depicted action-related object pairs were integrated and processed more easily than the object pairs without action relationships.

Unlike Bridger et al. (2017), the current revealed significant interactions between action relationship and retrieval category in older adults. As expected, we found enhanced associative familiarity-based remembering (i.e., intact vs. recombined) for action-related intact object pairs in older adults. This suggests that the implemented unitization approach (i.e., object pairs with action relationships) may have been more effective than the plausibility manipulation employed by Bridger et al. (2017). However, regarding the contrast between recombined and new object pairs in older adults, the findings were unexpected and cannot be interpreted unambiguously in terms of item familiarity. Given that these interactions were only observed in older adults, younger adults' associative memory boost for action-related pairs seems to be less reliant on enhanced associative familiarity for the unitized associations (i.e., action-related intact object pairs). Thus, the question arises in which way action relationship improved younger adults' associative memory. Therefore, recollection-related processes and their possible contribution to the memory boost in younger adults will be discussed next.

7.4.3 ERP Results in the Late Time Window

Recollection Effect (intact vs. new). The analyses of the parietal old/new effect (i.e., the ERP correlate of recollection) revealed the frequently reported general attenuation of recollective processing in older age (e.g., Friedman, 2013; Scheuplein et al., 2014). Thus, the correspondence between the results of the analysis of the typical old/new effects in the current study and similar ERP recognition memory studies emphasizes the importance of analyzing the old/new effects as index for general retrieval success. However, even if the ERP index of recollection did not differ between the action relationship conditions, a closer look at the complementary contrasts including recombined object pairs revealed differences between the action relationship conditions.

Associative and Item Memory Processes (intact vs. recombined & recombined vs. new). Interestingly, associative (i.e., intact vs. recombined) and item (i.e., recombined vs. new) memory processes in the late time window were not modulated by age. The associative memory contrast revealed clear evidence for recollection for action-related object pairs (independent of age group). In the item memory contrast (i.e., recombined vs. new), a marginal significant recombined > new effect was obtained for action-unrelated object pairs (independent of age group). Duarte et al. (2006) found an ERP correlate of recollection only in high performing older adults. Given that older adults of the current sample were very well screened, it is conceivable that memory performance in our sample of older adults was similar to that in Duarte et al. (2006). However, comparing the high performing older adults' memory performance (Old-high: accuracy source correct: .70, Duarte et al., 2006) with the older adults' associative memory performance for action-related object pairs in the current study (PR-Score Associative Memory: Action: .35), it is clear that our older adults performed lower, even though both memory indices are not completely comparable. Thus, it is unlikely that, in the current study, older adults showed recollection processes similar to the high-performing older adults in Duarte et al. (2006). We have no explanation for these putative recollection processes in older adults. In light of the frequently reported general attenuation of recollective processing and its ERP correlate in older adults, it is rather unlikely that older adults did not show the standard recollection effect in the intact vs. new contrast, while an ERP correlate of associative recollection (intact vs recombined) was observed.

In the late time window, an age-related decline of recollection (i.e., intact vs. new) independent of the action relationship condition was detected. In addition, differences between action-related and action-unrelated object pairs were shown for associative (i.e., intact vs. recombined) and item (i.e., recombined vs. new) memory processes, independent of age group. In order to be able to interpret associative and item recollection processes depending on action relationship and the influence of healthy aging, we would have expected clear interactions with age group. Nevertheless, the fact that older adults showed an attenuated ERP correlate of recollection for intact vs. new pairs and that younger adults showed no ERP evidence for enhanced familiarity (neither associative nor item familiarity) for action-related intact pairs, supports the view that both age groups relied on different underlying mechanisms for their associative memory boost by action relationships. While young adults may have more strongly relied on recollective processing (due to the absence of enhanced familiarity for action-related intact object pairs), older adults seemed to have depended more on familiarity (due to the general attenuation of recollection).

With respect to the multiple route account of the action-relation effect (Mangels & Heinberg, 2006), our results provide electrophysiological evidence for the view that there are multiple routes to successful associative retrieval (i.e., reliance on recollection for younger adults and on familiarity for older adults). While younger adults show no associative familiarity for action-related object pairs and rely on recollection for associations, older adults seem to be able to rely on enhanced familiarity-based remembering for the associations.

7.4.4 Caveats and Conclusions

Even though our study unveiled a couple of age-specific mechanisms underlying successful associative recognition, there are some limitations. It could be argued that during the study phase a dual task situation was created because participants were explicitly instructed to learn the object pairs and had to judge the appropriateness of the arrangements at the same time. This could have been difficult, especially for older adults. However, the memory differences between younger and older adults were within the normal range of age-related changes and only a few older adults had to be excluded due to too poor memory performance (n=5). Additionally, given that participants had to judge the fit of the arrangement during encoding, it could be criticized that attention was directed to the unitization manipulation (i.e., action relationship) and can therefore not be considered to be a purely bottom-up unitization manipulation. However, drawing participants' attention to the action relationships has likely increased the probability of unitization, which can also be seen as a strength of the current design.

In sum, the current study showed that associative memory in both age groups can be improved by creating action relationships between two semantically unrelated objects as a bottom-up unitization approach. Even though associative memory performance in both age groups benefitted from the presence of an action relationship, the corresponding ERP indices for familiarity and recollection differed qualitatively, suggesting age-related differences regarding the underlying mechanism: The combined behavioral and ERP findings are consistent with the view that younger adults rely generally more on recollection during associative recognition judgements. Conversely, older adults, seem to rely on associative familiarity, which is evidenced by an early frontal associative familiarity effect for action-related object pairs and indirectly supported by an attenuation of the ERP correlate of recollection. Thus, they seem to take advantage of the environmental support, delivered by the "automatically" (Craik, 1983) executed encoding due to the presence of action relationships, so that the object pairs are unitized and less self-initiated processing during encoding is needed. The current study showed that younger and older adults could increase their associative memory performance by a bottom-up unitization approach with action relationships. Enhanced familiarity-based remembering of action-related intact object pairs was particularly evident in older adults, suggesting that they benefitted from this bottom-up unitization approach, even in encoding situations in which they cannot profit from semantic relationships.

8 Experiment 2: The more Unitization, the less Flexibility? – Investigating Characteristics of Unitized Representations built on Action-related Object Pairs

The following behavioral experiment focused on the representational characteristics of unitized representations, and how these representations impact the learning of novel associations, which overlap with the unitized representations.

8.1 Introduction

Referring back to the processing modes model on associative memory by Henke (2010), there are two processes by which new associations can be encoded rapidly, i.e., during one single encoding trial. Either the encoding of the associations is supported by the hippocampus, resulting in recollection-based memory and flexible underlying representations, or encoding is supported by extra-hippocampal regions (i.e., the perirhinal cortex), generating familiarity-based memories with rigid unitized representations. A related question is whether these differences in flexibility of learned associations (i.e., AB pairs) impacts the learning of new associations, which are related to previously learned associations (i.e., AC pairs), after the representations of AB pairs were created (i.e., formation of novel, overlapping representations). More precisely, can the elements of associations, which had been retrieved via recollection be more easily manipulated and decoupled from each other as compared to the elements within familiarity-based representations?

A suitable experimental paradigm to test this research question is the ABAC paradigm, which is often applied to explore transfer or interference effects (e.g., Postman, 1962). In this paradigm, first, an association between two stimuli, A and B is learned, and then, a new association between A and C is learned. This allows to investigate possible interference effects of the previously formed AB association on learning of new AC association.

Ozubko et al. (2017) implemented the ABAC paradigm to investigate the effects of recollection- and familiarity-based associations on the learning of subsequent associations. Assuming that recollection-based memory is more flexible whereas familiarity-based memory is characterized by rigidity (Henke, 2010), the former one should benefit the acquisition of related, novel information more than the latter one. This is because the rigidity of familiarity-based memory, as compared to the flexibility of recollection-based memory, should impede successful encoding of AC associations. Thus, higher AB intrusion rates (i.e., falsely remembering the B-partner instead of the C-partner) and lower AC hit rates should be observed when AC associations have to be retrieved.

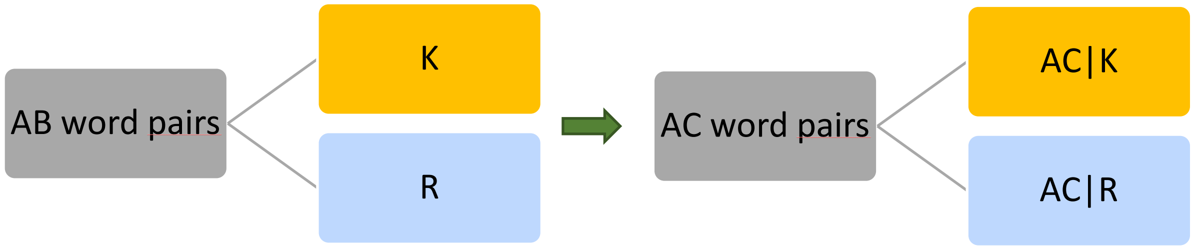
Investigating these assumptions, Ozubko et al. (2017) implemented a series of behavioral experiments including cued recall as well as recognition memory tests. At first glance, it might seem a little bit odd to investigate familiarity-based memory with a cued recall paradigm, given that familiarity is described as an automatic process (e.g., Yonelinas, 2002), whereas cued recall requires remembering of the partner corresponding to the presented cue, i.e., retrieving a contextual detail (i.e., recollection). However, there is evidence for the impact of familiarity in cued recall paradigms (e.g., Brainerd & Reyna, 2010; Lindsay & Kelley, 1996). Lindsay & Kelley (1996), for example, combined a word completion task (i.e., as a form of cued recall) with R/K judgements and observed that for trials, in which the completion was easy (e.g., due to only few missing letters), participants judged their responses as “know”, indicating that their memory was based on familiarity.

Ozubko et al. (2017) similarly combined the cued recall paradigm and R/K judgements within the ABAC paradigm (see Ozubko et al., 2017, experiment 1). Participants had to encode word pairs (i.e., AB word pairs) and retrieve the B-partners in the AB test phase, cued with the A-word by indicating whether they remembered the B-partner via recollection (i.e., "Remember" response), familiarity ("Know" response) or guessing. Afterwards, a second study phase with AC word pairs followed, in which the same A-word was combined with a new partner. In the final test phase, the C-partners had to be retrieved, cued by the A-word.

This procedure allowed the authors to sort the AC word pairs depending on whether during the AB test, the corresponding AB word pair had been remembered based on familiarity or recollection (see Figure 8.1 for classification of the word pairs). Their study provided two important results: there were more hits (i.e., correctly recalled C-partners during AC test) for the AC pairs, for which the corresponding AB pairs had been remembered based on recollection as compared to those for which the corresponding AB pairs had been remembered based on familiarity. Furthermore, there was a tendency for more AB intrusions in the AC test phase, when the corresponding AB word pair had been remembered based on familiarity as compared to when the AB word pair had been remembered based on recollection. This results pattern, in addition to the results of their other two experiments using cued recall and recognition memory tests (see Ozubko et al., 2017, experiment 2 and 3), suggests that the elements of the associations, which had been retrieved via recollection can (i.e., AB word pairs with "Remember" response) can be more easily manipulated and decoupled from each other as compared to the elements within familiarity-based representations (i.e., AB word pairs with "Know" response). This can be interpreted in that the familiarity-based representations (i.e., AB word pairs with "Know" response) were less flexible so that later learning of novel, but related associations (i.e., AC|K word pairs) was impaired as compared to recollection-based representations.

Figure 8.1

Classification of AB and AC word pairs in experiments by Ozubko et al. (2017)

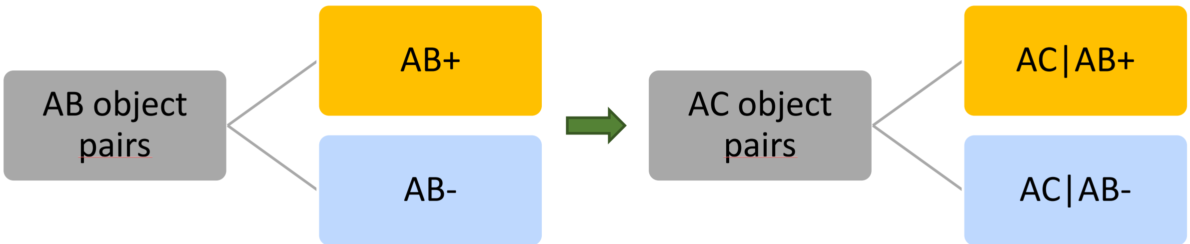


Note. The letter "K" indicates a "Know" response and the letter "R" indicates a "Remember" response in the R/K paradigm during AB test phase.

Based on these results, the goal of our study was to investigate whether action-related object pairs formed rigid unitized representations and thus influence the learning of novel, overlapping associations. As already outlined before, we assumed that the presence of an action relationship supports unitization of the object pair, whilst this is not the case for object pairs without an action relationship. As so, the resulting representations of action-related object pairs should be unitized and less flexible than the representations based on action-unrelated object pairs. We applied a procedure similar to Ozubko et al. (2017) by using the ABAC cued recall paradigm with AB and AC object pairs (see Figure 8.2 for classification of our object pairs in accordance with the classification by Ozubko et al., 2017).

Figure 8.2

Classification of our object pairs in accordance with the classification of word pairs by Ozubko et al. (2017)



Note. AB+ represents the action-related object pairs, AB- includes the action-unrelated object pairs.

If action-related AB object pairs form unitized representations and are familiarity-based remembered, they should be less flexible and this should lead to more AB intrusions in the AC test phase as compared to action-unrelated AB object pairs (i.e., non-unitized, recollection-based remembered and more flexible). Furthermore, the hit rate for AC object pairs corresponding to action-unrelated AB object pairs should be higher than the hit rate for AC object pairs corresponding to action-related AB object pairs due to more flexibility of representations of action-unrelated AB object pairs (i.e., non-unitized).

8.2 Methods

8.2.1 Sample

The sample included 40 younger adults (*M* = 22.8 years, range = 18 – 30 years, 8 male). One participant had to be excluded due to low memory performance in the AB test phase (i.e., zero hits for action-unrelated object pairs in AB test phase) so that the final sample for the analyses consisted of 39 younger adults (*M* = 22.9 years, range = 18-30 years, 8 male). All participants were German native speakers, right-handed as confirmed by positive values on the Edinburgh Handedness Inventory (Oldfield, 1971), had normal or corrected-to-normal vision and reported not having color blindness. Participants gave their informed consent and received a payment of 10€/hour or course credit for their participation. All participants were debriefed after the experiment.

8.2.2 Stimulus Materials

The stimulus materials consisted of 64 AB object pairs with (AB+) and without action relationship (AB-) and 64 corresponding AC object pairs for each action relationship condition. All stimulus materials of AB and AC pairs were taken from the stimulus materials in the EEG study (see Chapter 7): The AB object pairs consisted of the intact object pairs with and without action relationships, the AC object pairs included recombined object pairs. The action-unrelated object pairs included the same single objects as action-related object pairs but the positions of the objects were swapped. For the AC object pairs, A-objects were paired with a new C partner (see Figure 8.3 for examples)[1]. The selection of the action-related AB object pairs was guided by the older adults' action relationship ratings (see Chapter 6), whereby we used a subset of the best rated object pairs that had been used in the EEG experiment (see Chapter 7). To counterbalance whether the A-object (i.e., cue in test phases) in the AC phase is a tool or a target, for half of the AB object pairs, we used the tool as A-object in the AC object pair, whereas for the other half, the target was included in the AC pair.

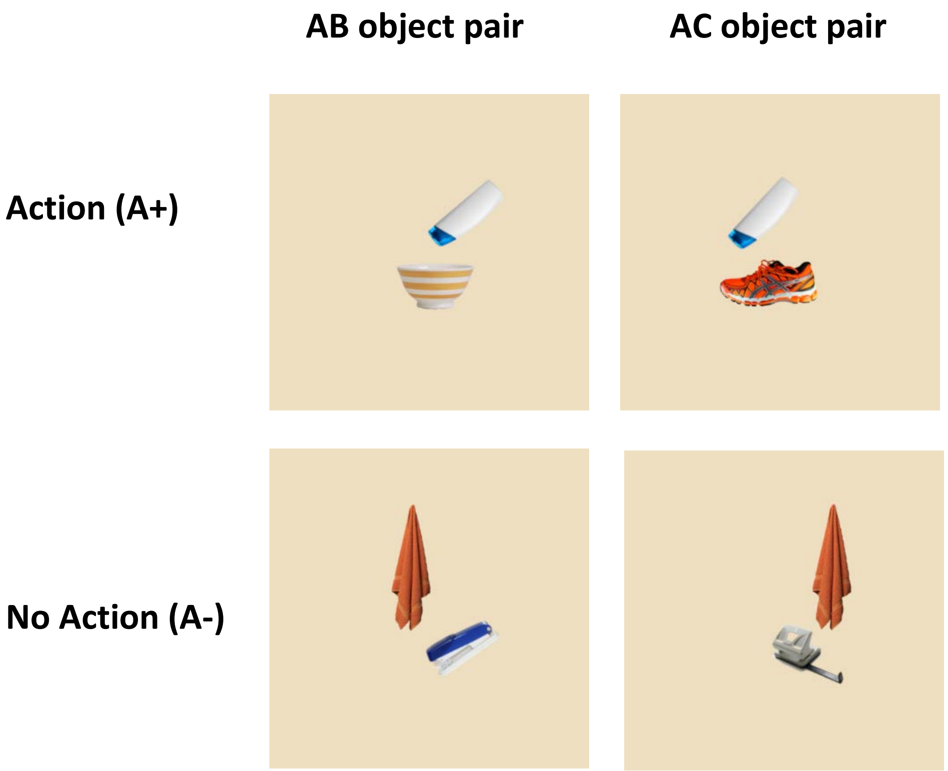
As the AC phase should not support familiarity-based remembering, AC object pairs should not include any action relationship (neither for previously action-related nor action-unrelated AB object pairs) so that there is no unitization manipulation in the AC phase. Therefore, the AC object pairs were edited with Photoshop CS6 in that when tools are A-objects, they were moved slightly to the left side and when the targets were A-objects, they were moved slightly to the right side. By applying these changes in position, the conduction of actions initiated by the tool can no longer be imagined. This change in position was applied equally for previously action-related and action-unrelated object pairs to have a shifting of the A-object in both action relationship conditions (see Figure 8.3 for examples of the position shifting between AB and AC object pairs). Table 8.1 gives an overview of the total rating means for the action relationship rating conducted in the rating study (see Chapter 6) of the selected AB object pairs. For both age groups, the action-related AB object pairs have significantly higher ratings than action-unrelated AB object pairs (YA: $t(126) = 30.28$, $p < .001$, $g_s = 5.39$;OA: $t(126) = 20.48$, $p < .001$, $g_s = 3.60$). Furthermore, there were no age-related differences regarding the rating (AB+: $t(126) = 0.27$, $p = .78$, $g_s = 0.05$; AB-: $t(126) = -1.39$, p

[1] Note that the AC pairs were taken from the pool of recombined pairs. However, only one out of two intact object pairs being combined to the recombined pair was shown in the AB phase so that the C object has never been presented before.

= .16, g_s = 0.24). Thus, our unitization manipulation (i.e., manipulation of action relationship) was effective in both, younger and older adults.

Figure 8.3

Examples for AB object pairs in both action relationship conditions as well as AC object pairs with the position shifting of the A-object between AB and AC object pairs



Note. For the action-related AB+ object pair (i.e., body lotion and bowl), the tool (i.e., body lotion) represents the A-object and its position is shifted slightly to the left in the corresponding AC object pair (i.e., body lotion and sports shoe). The same kind of position shift was conducted for action-unrelated AB- object pairs, in which the tool was selected as the A-object. For the action-unrelated AB- object pair (i.e., towel and stapler), the target (i.e., towel) represents the A-object and its position is shifted slightly to the right in the corresponding AC object pair (i.e., towel and punch). The same kind of position shift was conducted for action-related AB+ object pairs, in which the target was selected as the A-object.

Table 8.1

Mean ratings of object pairs with and without action relationship representing AB object pairs for both age groups

	Action Relationship	
	Action	No Action
Younger adults	4.10 (0.46)	1.38 (0.54)
Older adults	4.07 (0.57)	1.55 (0.80)

Note. Standard deviations are given in parentheses.

AB study lists consisted of 64 AB object pairs (32 AB+ object pairs with action relationship, 32 AB- object pairs without action relationship). AB test lists included the corresponding 64 A-objects as cues (32 A-objects belonging to action-related AB+ object pairs, 32 A-objects belonging to action-unrelated AB- object pairs). The AC study lists consisted of 64 object pairs (32 AC object pairs corresponding to previously action-related AB object pairs, 32 AC object pairs corresponding to previously action-unrelated AB object pairs). For half of the AC object pairs of each previous action relationship condition, respectively, the A-object was a tool and for the other half, it was a target. Figure 8.4 gives an overview about the distribution of the stimulus materials in each experiment phase. The assignment of the AB object pairs to action relationship conditions was counterbalanced across subjects.

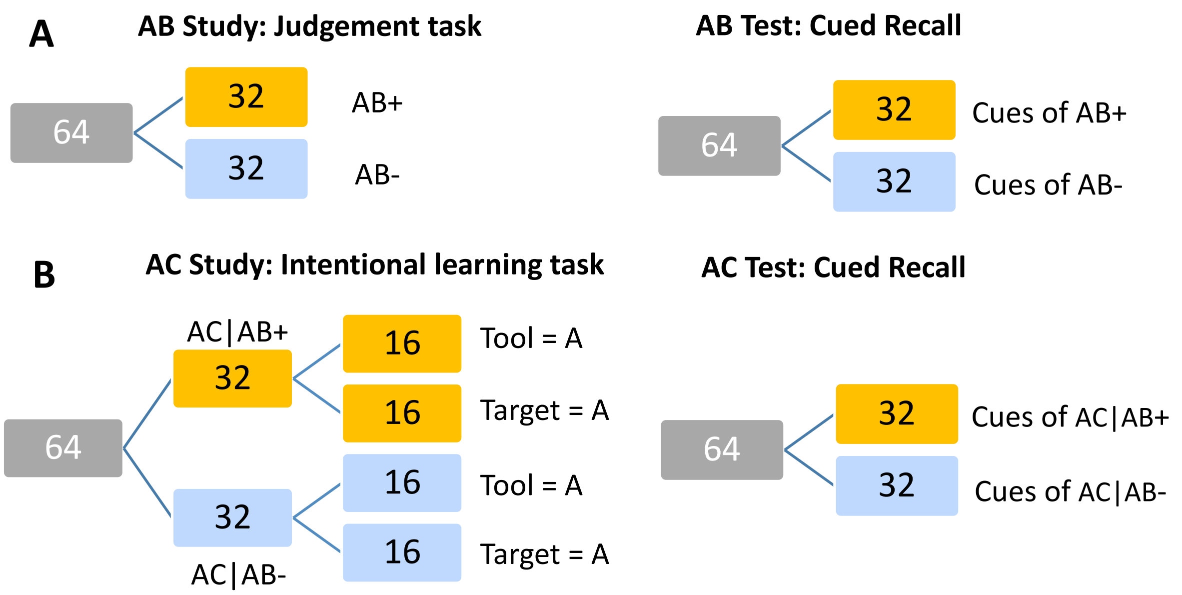
8.2.3 Procedure

The experiment lasted about 1.5 hours. At the beginning, participants gave their informed consent and completed the Edinburgh Handedness Inventory (Oldfield, 1971). Afterwards, participants were familiarized with all single objects used later in the experiment by looking through a booklet containing the single objects and their naming. Providing the naming of all objects in the booklet should help to articulate the objects later in the cued recall tasks. After the familiarization phase, subjects were seated comfortably in front of a computer monitor with a resolution of 1920 x 1080 pixels (viewing distance approximately 90cm). The experiment was programmed and presented with E-Prime (Psychology Software Tools, Inc., Pittsburgh, PA). All object pairs and single objects (i.e., A-objects as cues in the test phases) were presented against a beige background with a size of 500 x 500 pixels.

The experiment was divided into two ABAC-cycles, each including AB-study, AB-test, AC-study and AC-test. After both cycles, a total of 64 AB object pairs and 64 AC object pairs was encoded and tested. The order of the two cycles was counterbalanced across participants. The trial order within each cycle was pseudorandomized with the following constraints: In the AB study phase, no more than three object pairs of the same action relationship condition were presented in a row. In the AC study phase, each combination of previous action relationship of the AB object pair (AB+ or AB-) and designated A-object (tool or target) appeared not more than three times in a row. For the test phases (AB and AC), no more than three cues belonging to the same (previous) action relationship condition (A+ or A-) were presented in a row.

Figure 8.4

Overview about stimulus materials distribution for each experiment phase



Note. **A**: overview about the distribution of the stimulus materials in AB study and AB test phase; **B:** overview about the distribution of the stimulus materials in AC study and AC test phase. The figure represents the stimulus materials for both cycles.

AB Study Phase. The trial procedures for study and test phases can be seen from Figure 8.5. At the beginning of the AB study phase, four object pairs were presented as examples in order to explain the encoding task. A trial started with a fixation cross for 1000 ms, which was followed by an object pair presented for 2500 ms. After the object pair, a response screen appeared for 2000 ms during which subjects had to judge how appropriate the arrangement was in order to conduct an action with the two presented objects (0 = not appropriate at all ("gar nicht richtig"), 5 = absolutely appropriate ("absolut richtig")). The participants were also instructed to study the presented object pairs for a later memory test. The trial was finished with a blank screen for 700 ms. After the AB study phase, a paper-pencil filler task in which participants had to solve simple calculations was conducted (approximately 3 minutes).

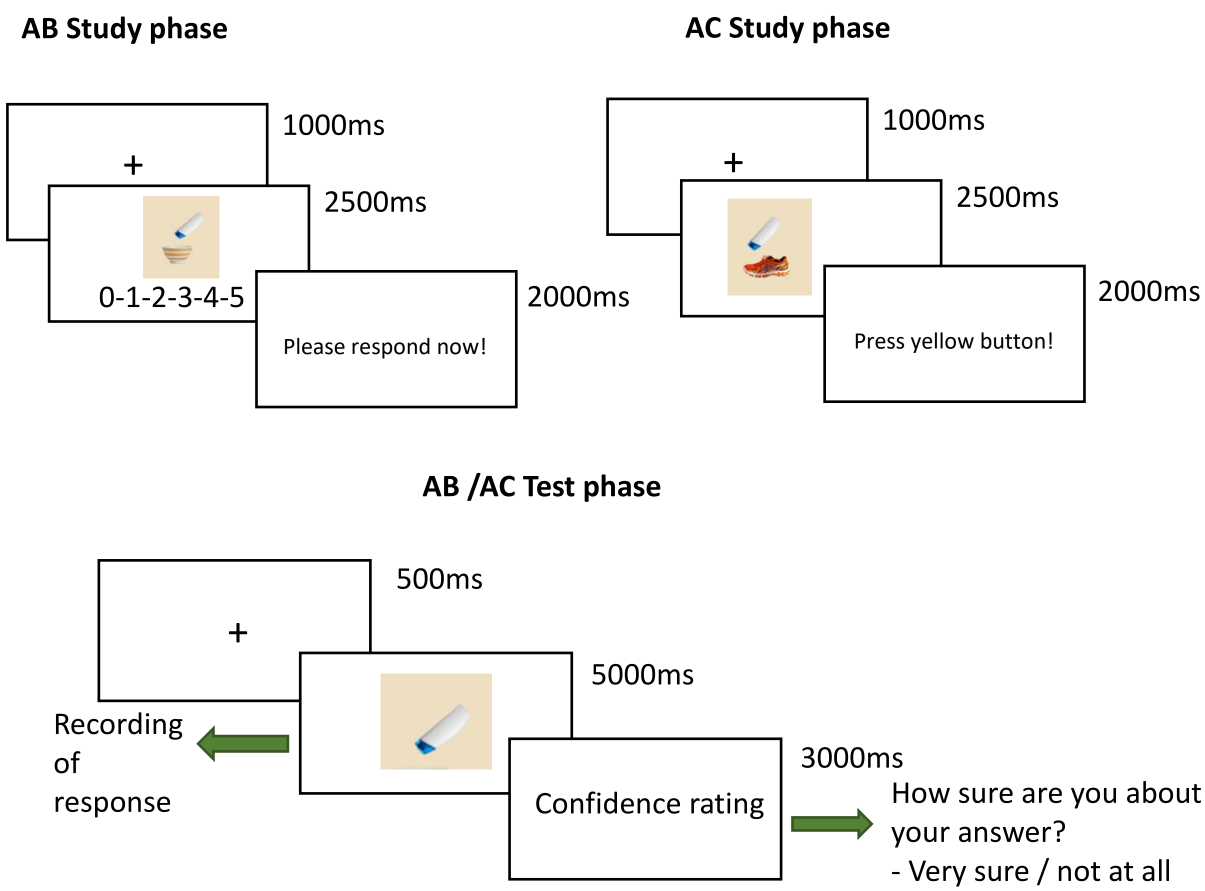
AB Test Phase. Afterwards, the AB test phase with the cued recall paradigm started. Participants were instructed to respond to the cue (the A-object) by saying aloud the corresponding B-object. To provoke familiarity-based remembering, they were told to name the first object that comes into their mind without thinking for too long. Furthermore, they were encouraged to guess if they do not remember the partner. The trial started with a fixation cross for 500 ms, followed by the cue (i.e., the A-object) for 5000 ms. During this time period, participants had to recall and name the studied B-partner. The responses were recorded with a microphone, which was positioned in front of the participants. After the response, there was a confidence rating in which they should index how sure they are with their recalled response ("How sure are you about your answer?" – "not at all"/"very sure"; German: "Wie sicher sind Sie sich bei Ihrer Antwort?" – "gar nicht sicher"/"sehr sicher"). The AB test trial concluded with a blank screen for 1000 ms. After the AB test phase, participants had about 3 minutes to solve a Sudoku task. The Sudoku task should help participants to distinguish between an AB block and an AC block to be able to differentiate between the C-partner from the B-partner, depending on the test phase.

AC Study Phase. The AC study phase also started with four object pairs as examples. The participants were instructed to learn the AC object pairs for a later memory test. There was no further encoding task. However, to require a similar active response from subjects as during AB study phase, they had to press a yellow button when the AC object pair was presented. The trial procedure of AC study phase was very similar to the trial procedure of AB study phase. After presenting a fixation cross for 1000 ms, the AC object pair was displayed for 2500 ms followed by a blank screen with the invitation to press the yellow button for 2000 ms. The trial ended with a blank screen for 700 ms. Before the AC test phase, mathematical equations again served as filler task for about three minutes.

AC Test Phase. The trial procedure for the AC test phase was identical to the trial procedure of the AB test phase. Participants were instructed to remember the C-partner of the previous AC study phase and to response with the object that came first into their mind. Furthermore, they were encouraged to guess if they are insecure and to name any object even if they do not remember in which phase it was presented. After completing both cycles, subjects were debriefed and paid for their participation.

Figure 8.5

Trial procedures for AB study and AC study phases, as well as for both test phases



8.2.4 Statistical Analyses

For the analyses of memory performances, the recorded responses of both, AB and AC test phases were manually transcribed trial. Afterwards, the responses were coded regarding their correctness. In addition to the correct label, which had been introduced during the familiarization phase, synonyms were accepted if suitable. After, accuracy rates were calculated for AB and AC test phase, respectively. Secondly, intrusion rates for the AC test phase were calculated by computing the percentages of AB intrusions in the AC test phase. Finally, memory performance in AC test phase was put into perspective to the memory performance in AB test phase by computing percentage of AC hits and AB intrusions, respectively, with only the amount of correct AB hits from AB test phase as denominator. Thus, only object pairs with correct memory in AB test phase were considered in AC test phase. Reason for conditionalizing AC memory performance by AB memory performance was that we wanted to avoid a bias due to testing effects (Karpicke & Roediger, 2008) and better memory performance for action-related AB+ object pairs compared to action-unrelated AB- object pairs in the AB test phase, as we found in the EEG study (see Chapter 7). This would result in more possible intrusions for the pairs with action relationships (i.e., AB+), compared to the pairs without an action relationship (i.e., AB-).

Statistical analyses were conducted with R, version 3.6.1 and R-Studio (RStudio Team, 2019). For paired-samples t-tests, the package "stats" (R Core Team, 2019) was used. The ANOVA was computed with the package "ez" (Lawrence, 2016) and effect size was estimated by partial eta squared (η^2_p) using the package "DescTools" (Signorell et al., 2020). For the paired-samples t-tests, effect sizes were estimated with Hedge's g_{av} on basis of formula by Lakens (2013). Alpha level was set on .05.

AB memory performance (i.e., hit rates) and unconditionalized AC memory performance (i.e., AC hit rates), as well as unconditionalized AB intrusion rates (i.e., AB intrusion rates) was compared between both action relationship conditions by using paired-samples t-tests. Furthermore, a two-factorial ANOVA with the within-subjects factors test phase (AB/AC) and action relationship (A+/A-) and hit rates as dependent variable was calculated in order to investigate whether there are proactive interference effects from the action relationship condition of AB object pairs on AC memory performance. Finally, conditionalized AC memory performance (i.e., AC|AB hit rates) as well as conditionalized AB intrusion rates (i.e., AC|AB intrusion rates) was compared between both action relationship conditions by computing paired-samples t-tests.

8.3 Results

Table 8.2 gives an overview about the descriptive statistics of AB hit rates, AC hit rates, AB intrusion rates and conditionalized AC memory performance (i.e., AC|AB hits and AC|AB intrusions). Figure 8.6 shows the probability for hits and intrusions in both test phases for both unconditionalized and conditionalized AC memory performance.

Table 8.2

Descriptive statistics for AB hit rates, AC hit rates, AB intrusion rates and conditionalized AC memory performance in both action relationship conditions for both test phases

	Action Relationship	
	Action	No Action
AB Hits	0.40 (0.16)	0.22 (0.14)
AC Hits	0.31 (0.14)	0.33 (0.19)
AB Intrusions	0.11 (0.09)	0.05 (0.07)
AC|AB Hits	0.36 (0.20)	0.34 (0.22)
AC|AB Intrusions	0.22 (0.16)	0.21 (0.23)

Note. Standard deviations are given in parentheses. AC|AB Hits represent the AC memory performance with correct memory of the AB object pairs in the AB test, only. AC|AB intrusions represent the AB intrusions of AB object pairs with correct memory in AB test, only.

Figure 8.6

Memory performance in AB and AC test phase for both unconditionalized and conditionalized AC memory performance

Note. **A**: Memory performance in the AB test phase for action-related and action-unrelated object pairs; **B:** Un-conditionalized memory performance in AC test phase (left side), conditionalized memory performance in AC test phase (right side);
C: Comparison of memory performance between AB and AC test phase; Error bars indicate ± 1 SEM of mean difference.

8.3.1 AB Memory Performance

There was a significant difference between AB hits for action-related and action-unrelated object pairs, $t(38) = 7.49$, $p < .001$, $g_{av} = 1.17$, with significantly higher hit rates for action-related AB object pairs (see Figure 8.6A). This result represents the memory benefit by the presence of action relationships.

8.3.2 AC Memory Performance

For the unconditionalized AC hit rates, there is no significant difference for AC hits between AC object pairs corresponding to previously action-related AB object pairs (AC+) and AC object pairs corresponding to previously action-unrelated AB object pairs (AC-), $t(38) = 0.63$, $p = .27$ (one-sided), $g_{av} = 0.05$ (see Figure 8.6B). For the unconditionalized AB intrusion rates in AC test phase, there was a significant difference between AB intrusions corresponding to previously action-related AB object pairs and AB intrusions corresponding to previously action-unrelated AB object pairs, $t(38) = 5.73$, $p < .001$ (one-sided), $g_{av} = 0.57$. Thus, there were more AB intrusions when the AB object pair was action-related as compared to action-unrelated AB object pairs when memory performance in the AB test phase is not taken into account.

8.3.3 Proactive Interference

For the unconditionalized hit rates in AB and AC test phase, depending on the action relationship condition, the two factorial ANOVA with the within-subjects factors test phase (AB/AC) and action relationship (A+/A-) showed a main effect for action relationship, $F(1,38) = 20.37$, $p < .001$, $\eta^2_p = 0.35$. Furthermore, there was a significant interaction between test phase and action relationship, $F(1,38) = 75.89$, $p < .001$, $\eta^2_p = 0.67$. Dissolving this interaction, comparisons between AB and AC test phase were computed for each action relationship condition separately. For the action-related object pairs (i.e., AB+ vs. AC+), there was a significant difference between AB and AC test phase, $t(38) = 3.36$, $p = .001$, $g_{av} = 0.51$, with higher hit rates in AB test phase as compared to AC test phase. For the action-unrelated object pairs (i.e., AB- vs. AC-), the reversed pattern with higher hit rates in AC test phase than in AB test phase is observed, $t(38) = -3.92$, $p <.001$, $g_{av} = 0.63$. Thus, while memory performance in AC test phase got worse for action-related object pairs, there was a benefit for action-unrelated object pairs (see Figure 8.6C).

8.3.4 AC|AB Memory Performance

For the conditionalized AC|AB hit rates, there is no significant difference between both action relationship conditions, $t(38) = -0.63$, $p = .73$ (one-sided), $g_{av} = 0.09$. Instead of higher hit rates for AC|AB- relative to AC|AB+, as expected, there is a numerical trend in the opposite direction (see Table 8.2 and Figure 8.6B). For the conditionalized AC|AB intrusion rates, there was no significant difference between AB+ and AB- object pairs, $t(38) = 0.19$, $p = .43$ (one-sided), $g_{av} = 0.03$. Thus, there were not more intrusions for previously action-related AB object pairs as compared to previously action-unrelated AB object pairs (see Figure 8.6B).

To sum up, in the AB test phase, there was a memory benefit due to the presence of action relationships. Regarding memory performance in the AC test phase, there were not significantly higher AC hit rates for previously action-unrelated object pairs as compared to previously action-related object pairs (neither without nor with conditionalizing AC memory performance). For the AB intrusions in the AC test phase, there were significant more AB intrusions for previously action-related AB object pairs, but when conditionalizing AB intrusions by AB memory performance, this difference disappeared. Finally, comparing memory performance in the AB and AC test phase, action-related object pairs showed higher hit rates in AB test while action-unrelated object pairs had higher hit rates in AC test, which can be interpreted as more proactive interference for action-related AB object pairs.

8.4 Discussion

The goal of the present study was to investigate whether action-related object pairs form unitized representations characterized by rigidity and hereby influence the learning of novel, overlapping representations. To address this research question, we used the ABAC cued recall paradigm (Ozubko et al., 2017). In the AB-phase of this experiment, the participants learned and remembered novel object pairs that either had an action relationship or not. In the AC-phase, the B-partner was exchanged for an unpresented object and no further experimental manipulation was implemented. Participants were instructed to merely learn the novel object pairs.

First, we found a memory benefit for action-related object pairs compared to action-unrelated object pairs, replicating the memory benefit due to the presence of action relationships, which we found in the EEG study (see Chapter 7), with a cued-recall paradigm. Regarding the influence of the representations of action-related object pairs on learning of novel, overlapping representations, we did not find the expected results pattern. Instead of higher hit rates for the novel, overlapping object pairs without action relationship, which would have indicated that the representations of action-unrelated object pairs are more flexible, the memory performance for the new to-be-learned object pairs did not differ between both action relationship conditions. Furthermore, there were more intrusions of previously action-related object pairs as compared to action-unrelated object pairs in the AC test phase, but when the intrusions were conditionalized by AB memory performance due to possible memory strength influences, the were no more intrusions of previously action-related object pairs. This suggests that the representations of action-related object pairs are not less flexible than the representations of action-unrelated object pairs. Finally, we found a crossover interaction between memory performance in both test phases and action relationship condition by observing better memory performance for action-related object pairs in AB test phase than AC test phase, while memory performance for action-unrelated object pairs is worse in AB test phase as relative to AC test phase.

8.4.1 AB Memory Benefit and AB Intrusions

Starting with the memory performance in the AB test phase, we found a memory benefit for action-related object pairs. Thus, our applied unitization manipulation (i.e., action relationships) could not only improve associative memory in an associative recognition memory paradigm (see Chapter 7), but also in a cued recall paradigm.

However, memory performance in the AB test phase was important to enable us to interpret AB intrusions in the AC test phase (see results for AB intrusions without conditionalizing to AB memory performance, Figure 8.6B) as the result of underlying unitized representations in the action-related condition which are familiarity-based and less flexible as proposed by (Henke, 2010). Without conditionalizing, more AB intrusions for previously action-related object pairs could result from higher memory strength due to deeper processing (Craik & Lockhart, 1972), prohibiting conclusions about representational characteristics. However, when conditionalizing AB intrusions by AB hit rates, there are no longer more AB intrusions of previously action-related object pairs, contradicting our assumption of less flexibility of these unitized representations, resulting in more AB intrusions in the AC test phase.

Ozubko et al. (2017) addressed the possible issue of memory strength on the AB intrusions in a recognition memory paradigm with a confidence rating (see experiment 3 in Ozubko et al., 2017). They observed the same results pattern as in their cued recall paradigms, in that that there were higher AB intrusion rates for previously familiarity-based remembered representations as compared to recollection-based remembered representations. This difference in AB intrusions did not depend on memory strength, meaning that the kind of underlying representation (i.e., familiarity-based vs. recollection-based) was the critical force behind the effects. Future research with a different experimental paradigm like, for example, an associative recognition paradigm is needed to further explore the impact of action relationships as unitization approach on the learning of novel but overlapping object pairs and to disentangle the influence of memory strength and possibly unitized representations.

However, one methodological difference between our intrusions and the intrusion results found in the results by Ozubko et al. (2017) refers to their counting method. The authors also counted false responses during AB test phase as intrusion if the same false response was given during AC test phase. These are instances for which no stable representation was built during AB study phase, leading to recall of false response during AB cued recall, which results in creation of a familiarity-based representation including an incorrect association. This was not done for the present study. This approach can be seen problematic because different pairs and representations are summarized, which do not represent the same (i.e., representations including correctly recalled AB word pairs and representations including incorrectly recalled AB word pairs). Thus, differences in counting method might be one possible reason why our results diverge from the expected pattern. However, our counting can be seen as a more suitable approach to count AB intrusions (i.e., only considering correct B partners in AC test phase) as it does not mix several types of representations.

8.4.2 Similar Memory Performance for AC Object Pairs corresponding to both Action Relationship Conditions

Besides the AB intrusions in AC test phase, we analyzed AC hits and expected higher AC hit rates for previously action-unrelated object pairs as compared to previously action-related object pairs, assuming more flexibility of the non-unitized and recollection-based representations so that these associations can be more easily decoupled as compared to unitized and familiarity-based representations. Instead, we found no significant difference between both action relationship conditions of the corresponding AB object pairs. At first glance, this contradicts the results of AC hits found by Ozubko et al. (2017), who observed higher AC hit rates for recollection-based word pairs relative to familiarity-based word pairs (see experiment 1), which they interpreted as indicating more flexibility of recollection-based representations. However, there is an important difference between their study and our study regarding stimuli and design. Ozubko et al. (2017) used word pairs with and without semantic relationship. There was not only a manipulation of the semantic relationship between the AB word pairs, but also between the AC word pairs. Thus, the participants might have benefitted from the presence of semantic relationships during AC study phase, leading to a memory boost for semantically related AC word pairs as compared to semantically unrelated AC word pairs. Thus, during AC test phase, enhanced familiarity-based remembering might have occurred for semantically related AC word pairs, which might have influenced the AC hit rates besides the characteristics of the underlying representations of the previous AB word pairs (see for an example showing possible influence of semantic relationships between word pairs on associative memory, Rhodes & Donaldson, 2007). This interpretation is conceivable, but, given that the authors do not report any results in dependence of semantic relationship, it is difficult to interpret their memory performance difference for AC hits in sense of flexibility or rigidity of representations based on AB word pairs. Moreover, considering the stimulus examples given by the authors, it seems possible that the semantic relationship changed between AB and AC word pairs at least for some word pairs. If this was the case, changing the semantic relationship status between AB and AC word pairs might have influenced memory performance during AC test phase. In our study, instead, we removed action relationships (i.e., our unitization approach) for the AC study phase so that no additional unitization effects could influence the memory performance in the AC test phase. The fact that there was no significant difference between both action relationship conditions for the unconditionalized AC hit rates suggests that we avoided successfully a second unitization effect (i.e., memory benefit) with our AC object pairs.

Looking at the memory performance in AC test phase in our study, there is an interesting pattern observed, when comparing with the AB test phase, which will be discussed in the next section.

8.4.3 Differential Memory Performance for both Test Phases depending on Action Relationship

Comparing memory performance in AB and AC test phase, we found an interaction between test phase and action relationship condition (i.e., unitization manipulation) with better memory performance for action-related object pairs in AB test phase as compared to AC test phase, while for action-unrelated object pairs the results pattern was reversed (i.e., worse memory performance in AB test than in AC test). Whilst Ozubko et al. (2017) observed better memory performance in AB test than in AC test, which the authors interpret as reflecting proactive interference, our analyses showed that the presence of action relationships impacts the difference in memory performance between both test phases. For action-related object pairs, there was better memory performance during AB test as compared to AC test. For action-unrelated object pairs, instead, we observed better memory performance in AC test as compared to AB test. It seems that there is an effect of proactive interference for the action-related object pairs. Considering research about proactive interference, it stands out that in most cases the memory performance in the first test phase is not used for analyzing effects of proactive interference. Instead, memory performance in second test phase is analyzed with regard to correct retrieval and intrusions from previous study phases (e.g., De Beni & Palladino, 2004; Jacobs et al., 1990; Jacoby et al., 2010; Lustig et al., 2001; Shimamura et al., 1995). However, Kane and Engle (2000) took memory performance in the first test phase into account. Participants had to learn lists with single words and their memory was tested after each list with a free recall paradigm. The authors calculated a relative proactive interference effect by subtracting baseline memory performance from memory performance in the second list and conditionalizing that difference on baseline memory performance. They found increasing relative proactive interference effects, the more lists had to be learned and discuss their results in the context of interindividual differences regarding working memory span. Even though it is conceivable to interpret our results regarding proactive interference for the action-related object pairs, the question remains, how the reversed effect for action-unrelated object pairs can be interpreted. Thus, we consider another explanation for the differential results pattern between AB and AC phase for action-related and action-unrelated object pairs. When comparing both phases about the presence of action relationships, it becomes clear that the context, in which the object pairs are encoded and retrieved, differs between both test phases. That means, in AB test phase, the presence of action relationships in the action-related object pairs could suppress memory for action-unrelated object pairs, which is also reflected in the observed memory benefit for action-related object pairs. In the AC phase, instead, the object pairs do not differ regarding the presence of action relationships. Thus, the absence of action relationships in this phase enables memory performance for AC object pairs corresponding to previously action-unrelated object pairs (AC-) to approach memory performance for AC object pairs corresponding to previously action-related object pairs (AC+), which is reflected in the fact that there is no more memory benefit for AC+ object pairs as compared to AC- object pairs.

8.4.4 Limitations and Future Directions

There are some limitations of the study that should be considered. As discussed earlier, the memory benefit due to presence of action relationships in AB test phase makes the interpretation of the memory performance in AC test phase including AC hits and AB intrusions difficult. It is interesting that we found this memory benefit with our unitization approach in a cued recall paradigm, which is not the typical paradigm in order to investigate familiarity-based memory. We addressed this issue of memory benefit for action-related object pairs by conditionalizing the AC memory performance (i.e., AC hits and AB intrusions) by AB memory performance. However, it would be beneficial to conduct follow-up studies, in which the memory performance in AB test is equalized so that the memory benefit from action relationships is minimized. It is conceivable that participants applied some kind of strategy during the AC test phase by remembering the previously learned action relationship with the presented cue (due to better memory for action-related object pairs), which then leads to rejection of this AB intrusion. Thus, in future studies, dummy AC object pairs (i.e., AC object pairs that won't be included in the analyses) with and without action relationship could be included in the AC study phase. In this way, remembering action relationships would not serve as cue during AC test phase to reject an AB intrusion. Another possibility could be trying to equalize memory performance in AB test phase by presenting action-unrelated AB object pairs more frequently than action-related object pairs so that memory performance for action-unrelated object pairs approach memory performance for action-related object pairs. Finally, the used cued recall test paradigm, especially in AC test, could be replaced by a test paradigm that enhances reliance on familiarity during retrieval in younger adults. Here, the forced-choice corresponding paradigm would be one possible approach, which supports familiarity-based remembering (see for example, Bader et al., 2020). Applying this test paradigm to our study, participants would be presented with the A-object as cue and had to select between B and C partner so that the probability of intrusions (i.e., selection B-partner more often than C-partner for action-related object pairs as compared to action-unrelated object pairs) is increased given that the B-partner is a component of the familiarity-based representation of the AB+ object pair.

Furthermore, changing the modality between study and test phase might play a role for the results. While participants studied the object pairs as picture pairs during study phases (i.e., visual modality), they had to recall the partner during cued recall by naming the to-be-remembered object (i.e., verbal modality). Yonelinas (2002) argues that changing modality between study and test phase, i.e., reducing perceptual match between study and test phase, can lead to decrease of familiarity, whereas recollection is unaffected. Thus, differences between processing at encoding and retrieval due to different presentation modes might have influenced the retrieval processes (Parks & Yonelinas, 2015). Following this line, contribution of familiarity to retrieval in the current experiment might have been attenuated due to reduced perceptual matching between study (i.e., visual presentation of object pairs) and test phase (i.e., visual presentation of cue and verbal naming of the to-be-remembered partner). Moreover, there is ERP evidence for the influence of perceptual match between study and test phase on the early old/new effect (i.e., the correlate of familiarity) by showing that the early old/new effect is larger when study and test phase match (i.e., picture pairs in study and test phase) as compared to non-matching modality (i.e., word pairs in study and picture pairs in test phase or vice versa; Ally & Budson, 2007; Curran & Doyle, 2011). Thus, future research with test paradigms that enable a perceptually match between study and test phases, as a recognition memory paradigm or the already outlined forced-choice corresponding paradigm is necessary.

8.4.5 Conclusion

In conclusion, we found a memory benefit induced by our unitization approach, i.e., the action relationships in a cued recall paradigm. Furthermore, there were proactive interference effects of action relationships, which can also be discussed against the background of context effects depending on the presence of action relationships: the presence of action relationships in action-related object pairs might suppress memory benefit for action-unrelated object pairs (i.e., AB+ hit rates > AB- hit rates), while the absence of action relationships allows memory performance for previously action-unrelated object pairs (i.e, AC-) to approach memory performance for previously action-related object pairs (i.e., AC+). In contrast to our expectations, we found no increased intrusions for action-related object pairs as compared to action-unrelated object pairs. Thus, based on these results, we cannot conclude that our action-related object pairs are less flexible in sense of familiarity-based, unitized representations. It remains the question, whether our action-related object pairs are unitized or rather more deeply processed in sense of levels of processing. However, given that younger adults can rely on intact recollection and cued recall might not be the optimal test paradigm to answer this question, further research with another test paradigm enhancing reliance on familiarity might be fruitful.

9 General Discussion

9.1 Summary of Results

9.1.1 Experiment 1: The Impact of Bottom-up Unitization induced by Action Relationships on the Age-related Associative Memory Deficit

In our ERP study with younger and older adults, we manipulated the presence of action relationships as bottom-up unitization approach. In a subsequent associative recognition memory test with intact, recombined and new object pairs, we found the age-related associative memory deficit in that there were larger age-related differences for associative as compared to item memory. However, both age groups' associative memory performance benefitted from the presence of action relationships. Regarding the ERP results, there was the classic early old/new effect (i.e., intact vs. new), representing familiarity, in both action relationship conditions for both, younger and older adults. The late parietal old/new effect (i.e., intact vs. new) was smaller in older age, reflecting the attenuated recollection process. Having a closer look at the ERP contrasts for associative and item memory processes, respectively, there was an early associative familiarity effect (i.e., intact vs. recombined) for action-related object pairs in older adults only. Furthermore, the correlate for the early item familiarity effect (i.e., recombined vs. new) was only present in older adults for action-unrelated object pairs. For the late recollection time window, there was a significant larger difference between intact and recombined for action-related object pairs, regardless of age group, indicating associative memory processes for action-related intact object pairs. In addition, for action-unrelated object pairs, there was a significant larger difference between recombined and new object pairs, indicating item memory processes, regardless of age group. In sum, these results suggest that the observed associative memory benefit by the presence of action relationships lied on different mechanisms depending on age group: While older adults seemed to rely more on familiarity for the association of intact action-related object pairs, younger adults show rather more reliance on recollection.

9.1.2 Experiment 2: The representational Characteristics underlying action-related Object Pairs

In our behavioral ABAC cued-recall study with younger adults, the participants had to learn and recall AB object pairs with and without action relationships. Afterwards, they were instructed to learn and remember AC object pairs corresponding to previously action-related and action-unrelated AB object pairs, respectively. Contrary to our expectations, we did not find more intrusions of previously action-related object pairs (i.e., AB+ object pairs) relative to action-unrelated object pairs (i.e., AB- object pairs), when the novel but overlapping associations (i.e., AC object pairs) had to be recalled. Furthermore, there was no difference in the memory performance for AC object pairs (i.e., hit rates) between both previous AB action relationship conditions. When comparing memory performance between AB and AC test phase, there was a crossover interaction. On the one side, for action-related object pairs, memory performance was better in AB test as compared to AC test (i.e., AB+ > AC+), indicating proactive interference effects of the AB object pairs with action relationships. On the other side, for action-unrelated object pairs, there was an increase in memory performance from AB test to AC test (i.e., AB- < AC-), suggesting that the absence of action relationships in the AC phase allowed the memory performance for AC object pairs corresponding to previously action-unrelated AB object pairs (i.e., AC-) to approach memory performance for previously action-related AB object pairs (i.e., AC+). In sum, these results patterns did not support the assumption that the representations underlying action-related object pairs are characterized by less flexibility as expected for unitized representations.

9.2 Alleviation of the Age-related Associative Memory Deficit by Action Relationships as Bottom-up Unitization Approach?

The main goal of this dissertation was to investigate, whether the age-related associative memory deficit can be alleviated by bottom-up unitization induced by action relationships. Therefore, semantically unrelated object pairs with action relationships served as condition supporting bottom-up unitization. Behaviorally, we found greater age-related differences for associative memory as compared to item memory, replicating the often described age-related associative memory deficit (e.g., Naveh-Benjamin et al., 2003; Scheuplein et al., 2014). However, contrary to our hypotheses, no interaction between age, action relationship and memory type (i.e., item vs. associative memory) was present, which would have indicated an alleviation of the age-related associative memory deficit by the presence of action relationships. This means, there was no selective greater memory benefit for older adults' associative memory for action-related object pairs as compared to younger adults. Instead, the memory benefit was neither selective for associative memory nor greater for older adults relative to younger adults.

Critically, there was also no interaction between action relationship condition and memory type (i.e., item vs. associative memory), independent of age, which we would have expected as a typical pattern indicating differential unitization in both action relationship conditions. Here, we would have expected greater memory benefit for associative memory as compared to item memory in the condition supporting unitization (i.e., object pairs with action relationships), which is what differentiates unitization from levels of processing (Parks & Yonelinas, 2015). Regarding the item memory benefit due to action relationships, it is important to mention that we did not measure item memory in a "pure" sense by means of a separate item memory test, in which the occurrence of single objects in the study phase has to be judged, as it has been done in previous research (e.g., Naveh-Benjamin, 2000). Instead, we estimated item memory based on memory performance in the associative recognition paradigm by calculating an indirect measurement of item memory. Thus, our approach only provides an item memory estimation which is probably not as optimal as using a separate item memory test.

Addressing the similar memory boost in associative memory for both age groups, the parallels between the effects in our condition with action-related object pairs and the enactment effect (see Nyberg et al., 2002, for a review) are very interesting. The enactment effect describes the phenomenon of better memory performance in the subject-performance-task (SPT), in which participants are instructed to conduct an actual action with two to-be-associated objects, (e.g., Nilsson & Craik, 1990) than in a control condition in which participants have to learn the associations only verbally. The reason, why the enactment effect is fruitful for the discussion of our results, is that Kormi-Nouri (2000) showed in his study that no physical conduction of the actual action between the to-be-associated objects is necessary for the enactment effect, but the imagination of the action is sufficient. Thus, it is conceivable that younger and older adults in our study have imagined performing the action in the action-related object pairs given that we created these objects with action relationships in a way that the imagination of the action was facilitated (i.e., positioning of the tool for right-handed people, small distance between both objects).

To draw a bow between unitization and enactment, Zhao et al. (2016) found in their study enhanced familiarity-based remembering of associations learned in the SPT and discuss unitization as the underlying process, which might be induced by enactment and resulting in increased reliance on familiarity during associative recognition.

Following this line, Mangels and Heinberg (2006) found a similar associative memory boost for younger and older adults in the SPT task relative to verbal task, suggesting a similar enactment effect for both age groups. They interpret this result with the idea that there are multiple routes to successful associative memory, and younger and older adults differ regarding the memory process, on which they rely most during successful retrieval. While older adults might rely more on familiarity, due to their attenuated recollection, younger adults show more reliance on their intact recollection.

Our results deliver now support for this assumption on the electrophysiological level. We did not only find intact familiarity (i.e., early old/new effect) for both age groups, but older adults showed a selective early familiarity effect for the associations of intact action-related object pairs. This emphasizes the relevance of the additional ERP contrasts including the recombined object pairs given that they provide an opportunity to control for familiarity of single components within the object pairs and to look at associative (i.e., intact vs. recombined) and item (i.e., recombined vs. new) memory processes in more detail (see for example, Bridger et al., 2017). Considering the contrast between intact and recombined object pairs, it is possible to control for the familiarity of single components included in object pairs given that for both types of object pairs (i.e., intact and recombined object pairs) the single objects were presented during study phase. The difference between these two types of object pairs refers to the included association: the association of intact object pairs is identical to the association presented during study, and thus should be more familiar as compared to recombined object pairs, which include new associations relative to study phase. Thus, with the contrast between intact and recombined object pairs, processes regarding actual associative memory can be investigated. Here, for older adults, we found enhanced familiarity for associations in intact action-related object pairs relative to action-unrelated object pairs. Turning to younger adults, there was no enhancement of familiarity-based remembering of action-related object pairs. Instead, we found recollection for the associations in intact object pairs with action relationship regardless of age group. Given that the younger adults' associative memory benefitted from the presence of action relationships as well, we conclude that they seem to rely more on recollection for the associations in intact action-related object pairs.

Further support for the assumption that younger adults rely on recollection for action-related object pairs is delivered by our second experiment. Contrary to our expectations, we did not find more intrusions for previously action-related object pairs as compared to action-unrelated object pairs, when novel but overlapping associations had to be recalled. Thus, the results suggest no enhanced reliance on familiarity-based remembering for the action-related (i.e., unitized) object pairs. Even though this result was unexpected, as we assumed that the presence of action relationships should enable the formation of unitized representations, it is conceivable that younger adults relied more on recollection because they have no recollection deficit instead of relying more on familiarity and thus, are able to retrieve contextual details as, for example, the concrete association. One supporting aspect for this assumption is the fact that in the cued recall paradigm, even if there is evidence for familiarity-based remembering during cued recall (e.g., Brainerd & Reyna, 2010; Lindsay & Kelley, 1996), recollection can easily contribute to successful recall, when this process is still intact as it is the case for younger adults. Considering ERP evidence about unitization and familiarity-based remembering, Rhodes and Donaldson (2007), for example, found for their younger adults the late parietal old/new effect (i.e., the correlate of recollection) even in the unitization condition (i.e., word pairs including associations), which was characterized by enhanced reliance on familiarity (i.e., early old/new effect). Furthermore, instead of relying on familiarity, younger adults could use a recall-to-reject strategy of recollection-based remembering during the AC test phase (Rotello & Heit, 2000). The recall-to-reject process describes the phenomenon that the corresponding old item is recalled when a similar foil is presented in a recognition paradigm, leading to the rejection of the similar foil (Rotello & Heit, 2000). If we transfer this idea to our cued recall paradigm, it is possible that the participants remembered that the familiarity-based incoming

B-partner (i.e., reactivated AB object pair as similar foil for the AC object pair) was learned during the previous AB study phase instead of the current AC study phase and thus, reject this B-intrusion and recall the C-partner. However, the question arises, whether the presence of action relationships supports bottom-up unitization and the creation of unitized representations, which will be discussed in the next section.

9.3 Creation of Unitized Representations by Action Relationships?

Regarding the representational characteristics of object pairs with action relationships, the results pattern of our ABAC cued recall experiment with younger adults did not support the assumption that the created underlying representations are characterized by less flexibility than the representations based on action-unrelated object pairs as it would have been expected for unitized representations (Henke, 2010). In combination with the evidence from our EEG study, in which younger adults showed no enhanced reliance on familiarity for the intact action-related object pairs, it seems as if the younger adults relied more on recollection and thus, the question rise, whether the presence of action relationships supported the bottom-up unitization and resulted in the creation of unitized representations.

Regarding this lack of an indication of unitization in younger adults, the complexity of our stimuli used in both, the EEG experiment and the ABAC cued recall experiment, might be an interesting aspect to consider. Parks and Yonelinas (2015) discuss the role of the complexity of stimuli for the probability of unitization. The authors assume that it is easier to build a “new object” (i.e., high end of unitization continuum) in sense of a coherent concept when stimuli are simple (like, for example, unrelated word pairs can be unitized as a new coherent concept) as compared to complex stimuli. Reason for that is that complex stimuli demand more attention during processing. Thus, the attempt to combine them into one concept might either fail because the new concept is not ecologically valid (e.g., unitizing two different faces into one entity) or the high attentional demand of unitizing both components might attenuate the benefit by unitization. Our object pairs with action relationships represent rather complex materials for which the combination of both components into one unit might be more demanding as compared to word pairs. Thus, this complexity might have reduced the probability of unitization of the action-related object pairs. However, our results suggest that the presence of action relationships supported bottom-up unitization especially in older adults, even though our object pairs might be more complex for two reasons: Firstly, we found enhanced familiarity-based remembering of the associations in intact action-related object pairs for older adults – the sample group that could not rely on recollection as younger adults. Secondly, if our object pairs would have been too complex to support unitization due to increased attentional demands, the older adults' associative memory should not have benefitted from the presence of action relationships given that attentional resources are reduced in older age (Craik & Byrd, 1982). Thus, our bottom-up unitization approach by using action relationships seems to work for older adults by providing an opportunity to rely more on familiarity, while younger adults rely more on their intact recollection.

9.4 Limitations and Future Directions

Following the discussion of the results in this thesis, there are some open questions, which represent potential for further research about the alleviation of the age-related associative memory deficit by bottom-up unitization.

9.4.1 Multiple Routes to Associative Memory

Our main preliminary conclusion that there are multiple routes to associative memory (i.e., familiarity and recollection) and that the associative memory boost relies on different mechanisms for younger and older adults, respectively, offers room for further research.

In a follow-up study, which is currently planned, I want to investigate older adults' greater reliance on familiarity for the associations, while younger adults rely more on recollection, by implementing a test paradigm that encourages the use of familiarity. This is achieved with a speeded and non-speeded response condition, in which intact and recombined object pairs of both action relationship conditions have to be recognized (i.e., recognition memory paradigm). In the speeded condition (i.e., response deadline during recognition) the use of familiarity is encouraged, whereas the non-speeded condition allows use of recollection (e.g., Diana et al., 2008; Mecklinger et al., 2011) due to their differential temporal characteristics. If younger adults can use associative familiarity for intact action-related object pairs when they cannot rely on recollection anymore (i.e., speeded condition), then the memory performance between action-related and action-unrelated object pairs in the speeded condition should be similar for younger and older adults. If younger adults, instead, need to rely on recollection for associations of intact action-related object pairs and cannot take advantage of the early familiarity effect, as older adults seem to do in our ERP study (Experiment 2), then the difference of the memory performance between speeded and non-speeded response condition should be larger for younger adults than for older adults. This results pattern should be observable because younger adults should benefit from their recollection for action-related object pairs (i.e., non-speeded condition), whereas older adults should rely more on familiarity in both conditions (i.e., speeded and non-speeded) due to reduced recollection so that their memory performance would not benefit in a similar way as younger adults in the non-speeded condition. In a second step, ERP measurements can be included to estimate the contribution of familiarity and recollection. Scheuplein et al. (2014) combined such a response deadline paradigm with ERPs in younger and older adults. They investigated item recognition memory by using single colored object drawings during encoding. At test, participants had to distinguish between old and new object drawings, while their response time was limited or not. The authors found the early familiarity effect in the speeded condition, suggesting increased contribution of familiarity to item recognition memory in this condition. Furthermore, they found this early familiarity in both age groups for the speeded condition, while recollection (i.e., late parietal old/new effect) was absent for older adults. Applying such a paradigm to the above outlined response deadline paradigm, we would expect the early associative familiarity effect (i.e., intact vs. recombined) for intact action-related object pairs in the speeded condition for both age groups, if younger adults can rely on associative familiarity in a similar way as older adults, when the use of their intact recollection is limited. However, if younger adults need to rely on recollection for intact action-related object pairs, the early associative familiarity effect for intact action-related object pairs should be observed in the speeded condition for older adults only. For younger adults, instead, there should be greater associative recollection for intact action-related object pairs in the non-speeded condition as compared to older adults, who should show an attenuation of their recollection.

Another approach to investigate age-related differences regarding the memory processes underlying the associative memory benefit by action relationships can be explored by implementing a six-scale confidence rating during associative recognition memory test with intact and recombined object pairs of both action relationship conditions so that ROC curves can be calculated to estimate the contribution of familiarity and recollection (see for example, Yonelinas et al., 2010).

Extending the scope of bottom-up unitization approaches and their possibility to reduce the age-related associative memory deficit, another characteristic of the materials can be manipulated, besides action relationships, which is the semantic relationship. Instead of object pairs with and without action relationships, object pairs with semantic relationships could support unitization as compared to semantically unrelated object pairs. Tibon et al. (2014) implemented semantic relationships as bottom-up unitization approach in their study with object pairs and found in their ERP results increased contribution of familiarity (i.e., intact vs. recombined) to associative recognition of semantically related object pairs. This study was conducted in younger adults only, so that the potential of semantic relationships as bottom-up unitization approach to alleviate the age-related associative memory deficit is unknown. However, semantic relationships are a bottom-up unitization approach which is very promising to alleviate the age-related associative memory deficit, given that there is a shift to semantic memory including more reliance on prior knowledge in older age (Ofen & Shing, 2013). This suggests that especially older adults might benefit from the presence of semantic relationships for their associative memory because they could rely on pre-experimentally associations. Furthermore, unitization of familiar items (like, for example, semantically related object pairs) is assumed to happen rather automatic during encoding because processing of the to-be-unitized components is guided by preexisting representations that are activated (Graf & Schacter, 1989). Delhaye et al. (2018) tried to fill this research gap by testing associative recognition memory of semantically related and semantically unrelated object pairs in younger and older adults. Here, the authors found, contrary to expectations, that older adults did not benefit from the presence of semantic relationships. They assume that older adults show "misrecollection" indicated by increased false alarms to semantically related recombined object pairs, which hinders benefit for the associative recognition memory. However, both studies (Delhaye et al., 2018; Tibon, Gronau, et al., 2014) used recombined object pairs in the recognition memory test for which the semantic relationship of the original object pairs during the study phase was not maintained (i.e., previously semantically related object pairs were combined to semantically unrelated object pairs and vice versa for previously semantically unrelated object pairs). Thus, the change of the semantic relationship in the recombined object pairs during test phase can serve as cue to reject them as recombined object pairs instead of measuring memory for the actual associations (i.e., remembering the fact that, for example, a milk bottle was encoded with a semantically related partner and is recognized during test phase as recombined object pair because it is presented with a semantically unrelated object). In an

ERP aging study, which is currently undergoing, we aim to close this gap by exploring the impact of semantic relationships between object pairs as bottom-up unitization approach on the age-related associative memory deficit by maintaining the semantic relationship between study and test phase for all object pairs conditions. Preliminary results indicate that older adults' associative memory can benefit from the presence of semantic relationships between object pairs.

Finally, future research should focus on the brain regions underlying familiarity and recollection, respectively, to investigate their contribution to associative recognition memory for unitized relative to non-unitized associations in younger and older adults. Here, we would expect enhanced activation in the perirhinal cortex (i.e., the brain region associated with familiarity-based remembering) for unitized object pairs (e.g., Haskins et al., 2008). Furthermore, this increased activation in the perirhinal cortex should be present especially for older adults given that they rely on familiarity for the associations. For younger adults, additional increased activation in the hippocampus should be observed as they can use their intact recollection to remember associations, while older adults' hippocampus should show less activation in combination with their attenuated recollection (e.g., Raz et al., 2005). Following this neuroanatomical perspective, the role of consolidation for unitized object pairs and possible age-related differences can be explored. Referring to the complementary learning systems theory (CLS theory; Norman & Reilly, 2003), unitization should lead to perirhinal representations of the associations, which need time to be integrated in the neocortex without the involvement of hippocampus. Thus, consolidation can lead to improvement of associative memory when the associations are tested one day later (i.e., after consolidation). In contrast, representations based on the hippocampus are integrated rapidly so that additional time for consolidation does not affect memory for associations. Assuming that our action-related object pairs are unitized, they should be represented in the perirhinal cortex and associative memory should benefit from consolidation. This benefit should be observed for younger and older adults in a similar way, if both age groups rely on familiarity for the associations. However, if younger adults rely more on recollection for the associations in the action-related object pairs, and thus on hippocampal representations of the associations, their associative memory performance should not benefit significantly from consolidation.

9.4.2 Representational Characteristics of Unitized Representations by Action Relationships

Continuing the previous section about future research in the field of bottom-up unitization as possibility to alleviate the age-related associative memory deficit, there are open questions regarding the underlying representations of object pairs with action relationships.

As already outlined in the discussion of the results of experiment 3, our applied cued-recall paradigm might have reduced the contribution of familiarity to remembering of unitized representations (i.e., action-related object pairs). Naveh-Benjamin et al. (2003) discuss the advantage of associative recognition paradigms as compared to cued recall paradigm given that for cued recall not only the association has to be retrieved, but also the to-be-recalled item per se. Thus, item availability of the partner might play an additional role when associative memory should be measured. Thus, an investigation of the underlying representations of action-related object pairs with a recognition paradigm might be fruitful. Here, the forced-choice corresponding paradigm (FCC) seems to be a good choice given that in this test paradigm the reliance on familiarity is increased. Bader et al. (2020) found neurocognitive evidence for the FCC paradigm by showing that in this paradigm familiarity is more diagnostic when the intact pair has to be distinguished from the recombined pair within the same screen as compared to when each pair is presented sequentially like in the classic recognition paradigm. Thus, we would implement the FCC paradigm in a follow-up study from our ABAC experiment (experiment 2) as AC test phase, in which participants had to distinguish between previous AB object pairs and corresponding AC object pairs (i.e., corresponding object pairs). Assuming that previously action-related AB object pairs are unitized and the resulting representations are less flexible and familiarity-based remembered, we would expect more intrusions (i.e., selection of previous AB object pair instead of the AC object pair during AC test phase) as compared to previously action-unrelated AB object pairs (i.e., non-unitized).

Another aspect for future research refers to the limitation of our indirect measurement of item memory in our experiment 1. Here, the testing of item memory in an independent item recognition paradigm for single objects that were included in previously action-related and action-unrelated object pairs would help to disentangle the interpretation of the observed associative memory benefit as memory benefit due to unitization or to deeper levels of processing. If the associative memory benefit by the presence of action relationships is greater than the item memory benefit for single objects, which were included in previously action-related object pairs, then the results would suggest that action relationships served as a bottom-up unitization approach (Parks & Yonelinas, 2015). Furthermore, if item memory for components of action-related object pairs is lower than for action-unrelated object pairs, this would support the assumption that action-related object pairs were unitized (see for such a results pattern with compound word pairs, Ahmad & Hockley, 2014).

Moreover, the unitization of action-related object pairs can be analyzed by adapting a similar procedure as reversing order of components within word pairs as index for the creation of an unit (e.g., Bader et al., 2014). Bader et al. (2014) showed in their study that reversing order of word pairs in test phase that were encoded in the definition condition (i.e., unitization condition) leads to greater memory performance decline as compared to word pairs with reversed order encoded in the sentence condition (i.e., non-unitization condition). Adapting this approach, we could present the object pairs side by side in the test phase, so that no action relationships are present and the created units are being separated. If associative memory performance for previously action-related object pairs decreases more (in comparison to presenting the object pairs with action relationship in test phase) than for previously action-unrelated object pairs (in comparison to presenting the object pairs without relationship in test phase), then the results would suggest an unitization of action-related object pairs. The unit of the action-related object pairs would be destroyed by the side-by-side presentation and no enhanced familiarity-based remembering of the unitized representation might be possible. For the action-unrelated object pairs, instead, the change of the constellation to side-by-side presentation should have less detrimental effects on associative memory because these object pairs are assumed to be encoded hippocampal-based and more flexible. Finally, looking at the representations underlying action-related and action-unrelated object pairs, age differences regarding the cohesiveness of episodic representations can be explored. Naveh-Benjamin (2000) assumed that for younger adults, the new unit is qualitatively different from the representations of the separate components so that the episodic representation is cohesive and “compounded”. For older adults, in contrast, the episodic representations seem to be more fragmented and “blended”, meaning that the association as well as the separate components are represented, respectively. Thus, age-related differences in memory for single components of unitized representations could shed light into the question, whether the episodic representations differ regarding cohesiveness.

There are further open questions, which will only be sketched shortly. The focus of this dissertation were the processes during retrieval, but what about the processes during encoding of unitized associations? Here, for example, Kamp et al. (2018) found evidence for age-related differences in activity during encoding of unitized and non-unitized associations, which affects subsequent associative memory. While younger adults were able to use a proactive encoding strategy, older adults showed no differential encoding processes depending on the unitization condition. Thus, encoding activity of our object pairs with action relationships could be explored. Moreover, integration processes as indexed by the N400 (see for a review, Kutas & Federmeier, 2011) can be considered with our pictorial materials (see for N400 in context of processing actions, Amoruso et al., 2013) and possible age-related changes in the integration processes (see for a review about age-related differences in N400, Joyal et al., 2020) as being relevant for memory encoding.

9.5 Conclusions

The research goal of this dissertation was to investigate the impact of action relationships as bottom-up unitization approach on the age-related associative memory deficit. We could show that older adults benefit from the presence of action relationships within semantically unrelated object pairs for their associative memory without the possibility of being able to rely on pre-existing semantic knowledge. Furthermore, for older adults, we extended the scope of bottom-up unitization approaches with more perceptual stimuli instead of word pairs, as Parks and Yonelinas (2015) have suggested. We used object pairs with and without action relationships, which represent perceptual rich and complex materials. Also, these object pairs represent a very interesting kind of materials given that parallels to the enactment effect can be drawn, which is observed in the subject-performed-task. We found electrophysiological evidence for the assumption of multiple routes to associative memory proposed by Mangels and Heinberg (2006). Our ERP results suggest that older adults rely more on associative familiarity of intact action-related object pairs, while younger adults' associative memory benefit lies more on recollection for the association.

The results of this dissertation emphasize the importance of investigating bottom-up unitization approaches in the scope of age-related associative memory deficit because older adults cannot rely on recollection so that demands on their intact familiarity processes increase when unitized associations have to be retrieved. In conclusion, the effects of the unitization approach on familiarity-based remembering are probably clearer observable as compared to when only younger adults are investigated, who can use their intact recollection and are not depended on enhanced familiarity-based remembering.

To bring us back to the beginning of this whole story, a bottom-up unitization approach with action relationships within object pairs can be seen as an approach in the sense of the brain maintenance by Nyberg et al. (2012) as we focus on maintaining the functions that still work in older age (i.e., familiarity) instead of re-organizing functions in response on the age-related brain pathology (i.e., attenuated recollection).

References

Ahmad, F. N., Fernandes, M., & Hockley, W. E. (2015). Improving associative memory in older adults with unitization. *Aging, Neuropsychology, and Cognition*, *22*(4), 452–472. https://doi.org/10.1080/13825585.2014.980216

Ahmad, F. N., & Hockley, W. E. (2014). The role of familiarity in associative recognition of unitized compound word pairs. *Quarterly Journal of Experimental Psychology*, *67*(12), 2301–2324. https://doi.org/10.1080/17470218.2014.923007

Ally, B. A., & Budson, A. E. (2007). The worth of pictures: Using high density event-related potentials to understand the memorial power of pictures and the dynamics of recognition memory. *NeuroImage*, *35*(1), 378–395. https://doi.org/10.1016/j.neuroimage.2006.11.023

Ally, B. A., Waring, J. D., Beth, E. H., McKeever, J. D., Milberg, W. P., & Budson, A. E. (2008). Aging memory for pictures: Using high-density event-related potentials to understand the effect of aging on the picture superiority effect. *Neuropsychologia*, *46*(2), 679–689. https://doi.org/10.1016/j.neuropsychologia.2007.09.011

Amoruso, L., Gelormini, C., Aboitiz, F., Alvarez González, M., Manes, F., Cardona, J. F., & Ibanez, A. (2013). N400 ERPs for actions: building meaning in context. *Frontiers in Human Neuroscience*, *7*(FEB), 1–16. https://doi.org/10.3389/fnhum.2013.00057

Baddeley, A., Eysenck, M.W., & Anderson, M.C. (2020). *Memory* (3rd ed.). Routledge.

Bader, R., Mecklinger, A., Hoppstädter, M., & Meyer, P. (2010). Recognition memory for one-trial-unitized word pairs: Evidence from event-related potentials. *NeuroImage*, *50*(2), 772–781. https://doi.org/10.1016/j.neuroimage.2009.12.100

Bader, R., Mecklinger, A., & Meyer, P. (2020). Usefulness of familiarity signals during recognition depends on test format: Neurocognitive evidence for a core assumption of the CLS framework. *Neuropsychologia*, *148*(April), 107659.

https://doi.org/10.1016/j.neuropsychologia.2020.107659

Bader, R., Opitz, B., Reith, W., & Mecklinger, A. (2014). Is a novel conceptual unit more than the sum of its parts?: FMRI evidence from an associative recognition memory study. *Neuropsychologia*, *61*(1), 123–134. https://doi.org/10.1016/j.neuropsychologia.2014.06.006

Bastin, C., Diana, R. A., Simon, J., Collette, F., Yonelinas, A. P., & Salmon, E. (2013). Associative memory in aging: The effect of unitization on source memory. *Psychology and Aging*, *28*(1), 275–283. https://doi.org/10.1037/a0031566

Bastin, C., & Van der Linden, M. (2005). The Effects of Aging on the Recognition of Different Types of Associations. *Experimental Aging Research*, *32*(1), 61–77. https://doi.org/10.1080/03610730500326291

Brainerd, C. J., & Reyna, V. F. (2010). Recollective and nonrecollective recall. *Journal of Memory and Language*, *63*(3), 425–445. https://doi.org/10.1016/j.jml.2010.05.002

Bridger, E. K., Kursawe, A. L., Bader, R., Tibon, R., Gronau, N., Levy, D. A., & Mecklinger, A. (2017). Age effects on associative memory for novel picture pairings. *Brain Research*, *1664*, 102–115. https://doi.org/10.1016/j.brainres.2017.03.031

Bridger, E. K., & Mecklinger, A. (2012). Electrophysiologically Dissociating Episodic Preretrieval Processing. *Journal of Cognitive Neuroscience*, *24*(6), 1476–1491. https://doi.org/10.1162/jocn_a_00152

Chalfonte, B. L., & Johnson, M. K. (1996). Feature memory and binding in young and older adults. *Memory & Cognition*, *24*(4), 403–416. https://doi.org/10.3758/BF03200930

Craik, F. I. M. (1983). On the transfer of information from temporary to permanent memory. *Philosophical Transactions of the Royal Society of London. B, Biological Sciences*, *302*(1110), 341–359. https://doi.org/10.1098/rstb.1983.0059

Craik, Fergus I. M., & Byrd, M. (1982). Aging and Cognitive Deficits. In *Aging and*

Cognitive Processes (pp. 191–211). Springer US. https://doi.org/10.1007/978-1-4684-4178-9_11

Craik, Fergus I.M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, *11*, 671–684. https://doi.org/10.4324/9781315440446

Curran, T., & Doyle, J. (2011). Picture superiority doubly dissociates the ERP correlates of recollection and familiarity. *Journal of Cognitive Neuroscience*, *23*(5), 1247–1262. https://doi.org/10.1162/jocn.2010.21464

Danckert, S. L., & Craik, F. I. M. (2013). Does aging affect recall more than recognition memory? *Psychology and Aging*, *28*(4), 902–909. https://doi.org/10.1037/a0033263

De Beni, R., & Palladino, P. (2004). Decline in working memory updating through ageing: Intrusion error analyses. *Memory*, *12*(1), 75–89. https://doi.org/10.1080/09658210244000568

Delhaye, E., Tibon, R., Gronau, N., Levy, D. A., & Bastin, C. (2018). Misrecollection prevents older adults from benefitting from semantic relatedness of the memoranda in associative memory. *Aging, Neuropsychology, and Cognition*, *25*(5), 634–654. https://doi.org/10.1080/13825585.2017.1358351

Diana, R. A., Van Den Boom, W., Yonelinas, A. P., & Ranganath, C. (2011). ERP correlates of source memory: Unitized source information increases familiarity-based retrieval. *Brain Research*, *1367*, 278–286. https://doi.org/10.1016/j.brainres.2010.10.030

Diana, R. A., Yonelinas, A. P., & Ranganath, C. (2007). Imaging recollection and familiarity in the medial temporal lobe: a three-component model. *Trends in Cognitive Sciences*, *11*(9), 379–386. https://doi.org/10.1016/j.tics.2007.08.001

Diana, R. A., Yonelinas, A. P., & Ranganath, C. (2008). The effects of unitization on familiarity-based source memory: Testing a behavioral prediction derived from neuroimaging data. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(4), 730–740. https://doi.org/10.1037/0278-7393.34.4.730

Diana, R. A., Yonelinas, A. P., & Ranganath, C. (2010). Medial Temporal Lobe Activity during Source Retrieval Reflects Information Type, not Memory Strength. *Journal of Cognitive Neuroscience*, *22*(8), 1808–1818. https://doi.org/10.1162/jocn.2009.21335

Donaldson, D. I., & Rugg, M. D. (1998). Recognition memory for new associations: Electrophysiological evidence for the role of recollection. *Neuropsychologia*, *36*(5), 377–395. https://doi.org/10.1016/S0028-3932(97)00143-7

Duarte, A., Graham, K. S., & Henson, R. N. (2010). Age-related changes in neural activity associated with familiarity, recollection and false recognition. *Neurobiology of Aging*, *31*(10), 1814–1830. https://doi.org/10.1016/j.neurobiolaging.2008.09.014

Duarte, A., Ranganath, C., Trujillo, C., & Knight, R. T. (2006). Intact Recollection Memory in High-performing Older Adults: ERP and Behavioral Evidence. *Journal of Cognitive Neuroscience*, *18*(1), 33–47. https://doi.org/10.1162/089892906775249988

Eichenbaum, H., Yonelinas, A. P., & Ranganath, C. (2007). The Medial Temporal Lobe and Recognition Memory. *Annual Review of Neuroscience*, *30*(1), 123–152. https://doi.org/10.1146/annurev.neuro.30.051606.094328

Engelkamp, J., & Cohen, R. L. (1991). Current issues in memory of action events. *Psychological Research*, *53*(3), 175–182. https://doi.org/10.1007/BF00941384

Estes, Z., Golonka, S., & Jones, L. L. (2011). Thematic Thinking. The Apprehension and Consequences of Thematic Relations. In *Psychology of Learning and Motivation - Advances in Research and Theory* (Vol. 54). https://doi.org/10.1016/B978-0-12-385527-5.00008-5

Ferdinand, N. K., & Kray, J. (2013). Age-related changes in processing positive and negative feedback: Is there a positivity effect for older adults? *Biological Psychology*, *94*(2), 235–

241. https://doi.org/10.1016/j.biopsycho.2013.07.006

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). “Mini-Mental State” - A practical state method for grading the cognitive state of patients for the clinician. *Journal l of Psychiatric Research*, *12*, 189–198.

Fonken, Y. M., Kam, J. W. Y., & Knight, R. T. (2020). A differential role for human hippocampus in novelty and contextual processing: Implications for P300. *Psychophysiology*, *57*(7), 1–13. https://doi.org/10.1111/psyp.13400

Friedman, D. (2013). The Cognitive Aging of Episodic Memory: A View Based on the Event-Related Brain Potential. *Frontiers in Behavioral Neuroscience*, *7*(AUG), 1–15. https://doi.org/10.3389/fnbeh.2013.00111

Friedman, D., & Johnson, R. (2000). Event-related potential (ERP) studies of memory encoding and retrieval: A selective review. *Microscopy Research and Technique*, *51*(1), 6–28. https://doi.org/10.1002/1097-0029(20001001)51:1<6::AID-JEMT2>3.0.CO;2-R

Gilboa, A., & Marlatte, H. (2017). Neurobiology of Schemas and Schema-Mediated Memory. *Trends in Cognitive Sciences*, *21*(8), 618–631. https://doi.org/10.1016/j.tics.2017.04.013

Giovanello, K. S., Keane, M. M., & Verfaellie, M. (2006). The contribution of familiarity to associative memory in amnesia. *Neuropsychologia*, *44*(10), 1859–1865. https://doi.org/10.1016/j.neuropsychologia.2006.03.004

Graf, P., & Schacter, D. L. (1989). Unitization and Grouping Mediate Dissociations in Memory for New Associations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *15*(5), 930–940. https://doi.org/10.1037/0278-7393.15.5.930

Haist, F., Shimamura, A. P., & Squire, L. R. (1992). On the Relationship Between Recall and Recognition Memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*(4), 691–702. https://doi.org/10.1037/0278-7393.18.4.691

Haskins, A. L., Yonelinas, A. P., Quamme, J. R., & Ranganath, C. (2008). Perirhinal Cortex

Supports Encoding and Familiarity-Based Recognition of Novel Associations. *Neuron*, *59*(4), 554–560. https://doi.org/10.1016/j.neuron.2008.07.035

Henke, K. (2010). A model for memory systems based on processing modes rather than consciousness. *Nature Reviews Neuroscience*, *11*(7), 523–532. https://doi.org/10.1038/nrn2850

Hockley, W. E. (2008). The picture superiority effect in associative recognition. *Memory and Cognition*, *36*(7), 1351–1359. https://doi.org/10.3758/MC.36.7.1351

Holdstock, J. S., Mayes, A. R., Gong, Q. Y., Roberts, N., & Kapur, N. (2005). Item recognition is less impaired than recall and associative recognition in a patient with selective hippocampal damage. *Hippocampus*, *15*(2), 203–215. https://doi.org/10.1002/hipo.20046

Höltje, G., & Mecklinger, A. (2020). Feedback timing modulates interactions between feedback processing and memory encoding: Evidence from event-related potentials. *Cognitive, Affective and Behavioral Neuroscience*, *20*(2), 250–264. https://doi.org/10.3758/s13415-019-00765-5

Humphreys, G. W., & Riddoch, M. J. (2007). How to Define an Object: Evidence from the Effects of Action on Perception and Attention. *Mind & Language*, *22*(5), 534–547. https://doi.org/10.1111/j.1468-0017.2007.00319.x

Humphreys, G. W., Riddoch, M. J., & Fortt, H. (2006). Action relations, semantic relations, and familiarity of spatial position in Balint's syndrome: Crossover effects on perceptual report and on localization. *Cognitive, Affective and Behavioral Neuroscience*, *6*(3), 236–245. https://doi.org/10.3758/CABN.6.3.236

Jacobs, D., Tröster, A. I., Butters, N., Salmon, D. P., & Cermak, L. S. (1990). Intrusion errors on the visual reproduction test of the wechsler memory scale and the wechsler memory scale - revised: An analysis of demented and amnesic patients. *Clinical*

Neuropsychologist, *4*(2), 177–191. https://doi.org/10.1080/13854049008401510

Jacoby, L. L., Wahlheim, C. N., Rhodes, M. G., Daniels, K. A., & Rogers, C. S. (2010). Learning to diminish the effects of proactive interference: Reducing false memory for young and older adults. *Memory and Cognition*, *38*(6), 820–829. https://doi.org/10.3758/MC.38.6.820

Jäger, T., & Mecklinger, A. (2009). Familiarity supports associative recognition memory for face stimuli that can be unitised: Evidence from receiver operating characteristics. *European Journal of Cognitive Psychology*, *21*(1), 35–60. https://doi.org/10.1080/09541440802003140

Jäger, T., Mecklinger, A., & Kipp, K. H. H. (2006). Intra- and Inter-Item Associations Doubly Dissociate the Electrophysiological Correlates of Familiarity and Recollection. *Neuron*, *52*(3), 535–545. https://doi.org/10.1016/j.neuron.2006.09.013

Joyal, M., Groleau, C., Bouchard, C., Wilson, M. A., & Fecteau, S. (2020). Semantic Processing in Healthy Aging and Alzheimer's Disease: A Systematic Review of the N400 Differences. *Brain Sciences*, *10*(11), 770. https://doi.org/10.3390/brainsci10110770

Kamp, S. M., Bader, R., & Mecklinger, A. (2016). The effect of unitizing word pairs on recollection versus familiarity-based retrieval-further evidence from ERPs. *Advances in Cognitive Psychology*, *12*(4), 168–177. https://doi.org/10.5709/acp-0196-2

Kamp, S. M., Bader, R., & Mecklinger, A. (2018). Unitization of word pairs in young and older adults: Encoding mechanisms and retrieval outcomes. *Psychology and Aging*, *33*(3), 497–511. https://doi.org/10.1037/pag0000256

Kane, M. J., & Engle, R. W. (2000). Working-memory capacity, proactive interference, and divided attention: Limits on long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*(2), 336–358.

https://doi.org/10.1037/0278-7393.26.2.336

Karpicke, J. D., & Roediger, H. L. I. (2008). The Critical Importance of Retrieval for Learning. *Science*, *319*(5865), 966–968. https://doi.org/10.1126/science.1152408

Koen, J. D., & Yonelinas, A. P. (2014). The Effects of Healthy Aging, Amnestic Mild Cognitive Impairment, and Alzheimer's Disease on Recollection and Familiarity: A Meta-Analytic Review. *Neuropsychology Review*, *24*(3), 332–354. https://doi.org/10.1007/s11065-014-9266-5

Koen, J. D., & Yonelinas, A. P. (2016). Recollection, not familiarity, decreases in healthy ageing: Converging evidence from four estimation methods. *Memory*, *24*(1), 75–88. https://doi.org/10.1080/09658211.2014.985590

Kormi-Nouri, R. (2000). The Role of Movement and Object in Action Memory: A Comparative Study between Blind, Blindfolded and Sighted Subjects. *Scandinavian Journal of Psychology*, *41*(1), 71–76. https://doi.org/10.1111/1467-9450.00173

Kray, J., Eber, J., & Karbach, J. (2008). Verbal self-instructions in task switching: A compensatory tool for action-control deficits in childhood and old age? *Developmental Science*, *11*(2), 223–236. https://doi.org/10.1111/j.1467-7687.2008.00673.x

Kutas, M., & Federmeier, K. D. (2011). Thirty Years and Counting: Finding Meaning in the N400 Component of the Event-Related Brain Potential (ERP). *Annual Review of Psychology*, *62*(1), 621–647. https://doi.org/10.1146/annurev.psych.093008.131123

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, *4*(NOV), 1–12. https://doi.org/10.3389/fpsyg.2013.00863

Lindsay, D. S., & Kelley, C. M. (1996). Creating Illusions of Familiarity in a Cued Recall Remember/Know Paradigm. *Journal of Memory and Language*, *35*(2), 197–211. https://doi.org/10.1006/jmla.1996.0011

Lustig, C., May, C. P., & Hasher, L. (2001). Working memory span and the role of proactive interference. *Journal of Experimental Psychology: General*, *130*(2), 199–207. https://doi.org/10.1037/0096-3445.130.2.199

Mandler, G. (1980). Recognizing: The judgment of previous occurrence. *Psychological Review*, *87*(3), 252–271. https://doi.org/10.1037/0033-295X.87.3.252

Mangels, J. A., & Heinberg, A. (2006). Improved Episodic Integration Through Enactment: Implications for Aging. *The Journal of General Psychology*, *133*(1), 37–65. https://doi.org/10.3200/GENP.133.1.37-65

Mayes, A., Montaldi, D., & Migo, E. (2007). Associative memory and the medial temporal lobes. *Trends in Cognitive Sciences*, *11*(3), 126–135. https://doi.org/10.1016/j.tics.2006.12.003

Mecklinger, A. (2000). Interfacing mind and brain: A neurocognitive model of recognition memory. *Psychophysiology*, *37*(5), 565–582. https://doi.org/10.1017/S0048577200992230

Mecklinger, A. (2006). Electrophysiological Measures of Familiarity Memory. *Clinical EEG and Neuroscience*, *37*(4), 292–299. https://doi.org/10.1177/155005940603700406

Mecklinger, A., Brunnemann, N., & Kipp, K. (2011). Two processes for recognition memory in children of early school age: An event-related potential study. *Journal of Cognitive Neuroscience*, *23*(2), 435–446. https://doi.org/10.1162/jocn.2010.21455

Migo, E., Montaldi, D., Norman, K. A., Quamme, J., & Mayes, A. (2009). The contribution of familiarity to recognition memory is a function of test format when using similar foils. *Quarterly Journal of Experimental Psychology*, *62*(6), 1198–1215. https://doi.org/10.1080/17470210802391599

Mintzer, M. Z., & Snodgrass, J. G. (1999). The picture superiority effect: Support for the distinctiveness model. *American Journal of Psychology*, *112*(1), 113–146.

https://doi.org/10.2307/1423627

Montaldi, D., Spencer, T. J., Roberts, N., & Mayes, A. R. (2006). The neural system that mediates familiarity memory. *Hippocampus*, *16*(5), 504–520. https://doi.org/10.1002/hipo.20178

Naveh-Benjamin, M. (2000). Adult age differences in memory performance: Tests of an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*(5), 1170–1187. https://doi.org/10.1037/0278-7393.26.5.1170

Naveh-Benjamin, M., Brav, T. K., & Levy, O. (2007). The associative memory deficit of older adults: The role of strategy utilization. *Psychology and Aging*, *22*(1), 202–208. https://doi.org/10.1037/0882-7974.22.1.202

Naveh-Benjamin, M., Guez, J., Kilb, A., & Reedy, S. (2004). The associative memory deficit of older adults: Further support using face-name associations. *Psychology and Aging*, *19*(3), 541–546. https://doi.org/10.1037/0882-7974.19.3.541

Naveh-Benjamin, M., Hussain, Z., Guez, J., & Bar-On, M. (2003). Adult age differences in episodic memory: Further support for an associative-deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*(5), 826–837. https://doi.org/10.1037/0278-7393.29.5.826

Naveh-Benjamin, M., Shing, Y. L., Kilb, A., Werkle-Bergner, M., Lindenberger, U., & Li, S. C. (2009). Adult age differences in memory for name-face associations: The effects of intentional and incidental learning. *Memory*, *17*(2), 220–232. https://doi.org/10.1080/09658210802222183

Nelson, D. L., Reed, V. S., & Walling, J. R. (1976). Pictorial superiority effect. *Journal of Experimental Psychology. Human Learning and Memory*, *2*(5), 523–528. https://doi.org/10.1037/0278-7393.2.5.523

Nelson, D. L., Cermak, L., & Craik, F. (1979). Remembering pictures and words: Appearance, significance and name. *Levels of processing in human memory*, 45-76.

Nessler, D., Friedman, D., Johnson, R., & Bersick, M. (2007). Does repetition engender the same retrieval processes in young and older adults? *NeuroReport*, *18*(17), 1837–1840. https://doi.org/10.1097/WNR.0b013e3282f16d9f

Nilsson, L.-G., & Craik, F. I. M. (1990). Additive and interactive effects in memory for subject-performed tasks. *European Journal of Cognitive Psychology*, *2*(4), 305–324. https://doi.org/10.1080/09541449008406210

Norman, K. A., & Reilly, R. C. O. (2003). Modeling Hippocampal and neocortical contributions to recognition memory: A complementary Learning System Approach. *Psychological Review*, *110*(4), 611–646.

Nyberg, L., Lövdén, M., Riklund, K., Lindenberger, U., & Bäckman, L. (2012). Memory aging and brain maintenance. *Trends in Cognitive Sciences*, *16*(5), 292–305. https://doi.org/10.1016/j.tics.2012.04.005

Nyberg, L., Persson, J., & Nilsson, L.-G. (2002). Individual differences in memory enhancement by encoding enactment: relationships to adult age and biological factors. *Neuroscience & Biobehavioral Reviews*, *26*(7), 835–839. https://doi.org/10.1016/S0149-7634(02)00074-X

Ofen, N., & Shing, Y. L. (2013). From perception to memory: Changes in memory systems across the lifespan. *Neuroscience & Biobehavioral Reviews*, *37*(9), 2258–2267. https://doi.org/10.1016/j.neubiorev.2013.04.006

Old, S. R., & Naveh-Benjamin, M. (2008). Differential Effects of Age on Item and Associative Measures of Memory: A Meta-Analysis. *Psychology and Aging*, *23*(1), 104–118. https://doi.org/10.1037/0882-7974.23.1.104

Oldfield, R. C. (1971). The Assessment and Analysis of Handedness: The Edinburgh

Inventory. *Neuropsychologia*, *9*, 97–113.

Opitz, B., & Cornell, S. (2006). Contribution of familiarity and recollection to associative recognition memory: Insights from event-related potentials. *Journal of Cognitive Neuroscience*, *18*(9), 1595–1605. https://doi.org/10.1162/jocn.2006.18.9.1595

Otten, L. J., & Donchin, E. (2000). Relationship between P300 amplitude and subsequent recall for distinctive events: Dependence on type of distinctiveness attribute. *Psychophysiology*, *37*(5), 644–661. https://doi.org/10.1017/S004857720098171X

Ozubko, J. D., Moscovitch, M., & Winocur, G. (2017). The influence of recollection and familiarity in the formation and updating of associative representations. *Learning and Memory*, *24*(7), 298–309. https://doi.org/10.1101/lm.045005.117

Paivio, A. (1991). Canadian Journal of Psychology. *Canadian Journal Of Psychology*, *45*(3), 255–287. http://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,url,cookie,uid&an=1992-07881-001&db=psyh&scope=site&site=ehost

Paivio, A., Rogers, T. B., & Smythe, P. C. (1968). Why are pictures easier to recall than words? *Psychonomic Science*, *11*(4), 137–138. https://doi.org/10.3758/BF03331011

Paller, K. A., Voss, J. L., & Boehm, S. G. (2007). Validating neural correlates of familiarity. *Trends in Cognitive Sciences*, *11*(6), 243–250. https://doi.org/10.1016/j.tics.2007.04.002

Parks, C. M., & Yonelinas, A. P. (2015). The importance of unitization for familiarity-based learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *41*(3), 881–903. https://doi.org/10.1037/xlm0000068

Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology*, *118*(10), 2128–2148. https://doi.org/10.1016/j.clinph.2007.04.019

Postman, L. (1962). Transfer of training as a function of experimental paradigm and degree of first-list learning. *Journal of Verbal Learning and Verbal Behavior*, *1*(2), 109–118.

https://doi.org/10.1016/S0022-5371(62)80007-3

Quamme, J. R., Yonelinas, A. P., & Norman, K. A. (2007). Effect of unitization on associative recognition in amnesia. *Hippocampus*, *17*(3), 192–200. https://doi.org/10.1002/hipo.20257

Rabinowitz, J. C., Craik, F. I. M., & Ackerman, B. P. (1982). A processing resource account of age differences in recall. *Canadian Journal of Psychology/Revue Canadienne de Psychologie*, *36*(2), 325–344. https://doi.org/10.1037/h0080643

Raz, N., Lindenberger, U., Rodrigue, K. M., Kennedy, K. M., Head, D., Williamson, A., Dahle, C., Gerstorf, D., & Acker, J. D. (2005). Regional brain changes in aging healthy adults: General trends, individual differences and modifiers. *Cerebral Cortex*, *15*(11), 1676–1689. https://doi.org/10.1093/cercor/bhi044

Rhodes, S. M., & Donaldson, D. I. (2007). Electrophysiological evidence for the influence of unitization on the processes engaged during episodic retrieval: Enhancing familiarity based remembering. *Neuropsychologia*, *45*(2), 412–424. https://doi.org/10.1016/j.neuropsychologia.2006.06.022

Rhodes, S. M., & Donaldson, D. I. (2008a). Electrophysiological evidence for the effect of interactive imagery on episodic memory: Encouraging familiarity for non-unitized stimuli during associative recognition. *NeuroImage*, *39*(2), 873–884. https://doi.org/10.1016/j.neuroimage.2007.08.041

Rhodes, S. M., & Donaldson, D. I. (2008b). Electrophysiological evidence for the effect of interactive imagery on episodic memory: Encouraging familiarity for non-unitized stimuli during associative recognition. *NeuroImage*, *39*(2), 873–884. https://doi.org/10.1016/j.neuroimage.2007.08.041

Richardson-Klavehn, A., & Bjork, R. A. (1988). Measures Of Memory. *Annual Review of Psychology*, *39*(1), 475–543. https://doi.org/10.1146/annurev.psych.39.1.475

Rotello, C. M., & Heit, E. (2000). Associative recognition: A case of recall-to-reject processing. *Memory & Cognition*, *28*(6), 907–922. https://doi.org/10.3758/BF03209339

Rugg, M. D., & Curran, T. (2007). Event-related potentials and recognition memory. *Trends in Cognitive Sciences*, *11*(6), 251–257. https://doi.org/10.1016/j.tics.2007.04.004

Rugg, M. D., & Vilberg, K. L. (2013). Brain networks underlying episodic memory retrieval. *Current Opinion in Neurobiology*, *23*(2), 255–260. https://doi.org/10.1016/j.conb.2012.11.005

Scheuplein, A.-L., Bridger, E. K., & Mecklinger, A. (2014). Is faster better? Effects of response deadline on ERP correlates of recognition memory in younger and older adults. *Brain Research*, *1582*, 139–153. https://doi.org/10.1016/j.brainres.2014.07.025

Sharon, T., Moscovitch, M., & Gilboa, A. (2011). Rapid neocortical acquisition of long-term arbitrary associations independent of the hippocampus. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(3), 1146–1151. https://doi.org/10.1073/pnas.1005238108

Shimamura, A. P., Jurica, P. J., Mange&, J. A., Gershberg, F. B., & Knight, R. T. (1995). Susceptibility to Memory Interference Effects following Frontal Lobe Damage: Findings from Tests of Paired-Associate Learning. *Jounal of Cognitive Neuroscience*, *7*(2), 144–152.

Silva, A. R., Pinho, M. S., Souchay, C., & Moulin, C. J. A. (2015). Evaluating the subject-performed task effect in healthy older adults: relationship with neuropsychological tests. *Socioaffective Neuroscience & Psychology*, *5*(1), 24068. https://doi.org/10.3402/snp.v5.24068

Squire, L. R. (1992). Declarative and Nondeclarative Memory: Multiple Brain Systems Supporting Learning and Memory. *Journal of Cognitive Neuroscience*, *4*(3), 232–243. https://doi.org/10.1162/jocn.1992.4.3.232

Squire, L. R., & Zola, S. M. (1996). Structure and function of declarative and nondeclarative memory systems. *Proceedings of the National Academy of Sciences of the United States of America*, *93*(24), 13515–13522. https://doi.org/10.1073/pnas.93.24.13515

Tibon, R., Ben-Zvi, S., & Levy, D. A. (2014). Associative Recognition Processes Are Modulated by Modality Relations. *Journal of Cognitive Neuroscience*, *26*(8), 1785–1796. https://doi.org/10.1162/jocn_a_00586

Tibon, R., Gronau, N., Scheuplein, A.-L., Mecklinger, A., & Levy, D. A. (2014). Associative recognition processes are modulated by the semantic unitizability of memoranda. *Brain and Cognition*, *92*, 19–31. https://doi.org/10.1016/j.bandc.2014.09.009

Trott, C. T., Friedman, D., Ritter, W., Fabiani, M., & Snodgrass, J. G. (1999). Episodic priming and memory for temporal source: Event-related potentials reveal age-related differences in prefrontal functioning. *Psychology and Aging*, *14*(3), 390–413. https://doi.org/10.1037/0882-7974.14.3.390

Tulving, E. (1985). How many memory systems are there? *American Psychologist*, *40*(4), 385–398. https://doi.org/10.1037/0003-066X.40.4.385

Tulving, E. (2002). EPISODIC MEMORY : From Mind to Brain. *Annual Review of Psychology*, *53*(1), 1–25.

van Kesteren, M. T. R., Ruiter, D. J., Fernández, G., & Henson, R. N. (2012). How schema and novelty augment memory formation. *Trends in Neurosciences*, *35*(4), 211–219. https://doi.org/10.1016/j.tins.2012.02.001

Vilberg, K. L., Moosavi, R. F., & Rugg, M. D. (2006). The relationship between electrophysiological correlates of recollection and amount of information retrieved. *Brain Research*, *1122*(1), 161–170. https://doi.org/10.1016/j.brainres.2006.09.023

Wang, T. H., de Chastelaine, M., Minton, B., & Rugg, M. D. (2012). Effects of age on the neural correlates of familiarity as indexed by ERPs. *Journal of Cognitive Neuroscience*, *24*(5), 1055–1068. https://doi.org/10.1162/jocn_a_00129

Wegesin, D. J., Friedman, D., Varughese, N., & Stern, Y. (2002). Age-related changes in source memory retrieval: An ERP replication and extension. *Cognitive Brain Research*, *13*(3), 323–338. https://doi.org/10.1016/S0926-6410(01)00126-4

Wilding, E. L., & Rugg, M. D. (1996). An event-related potential study of recognition memory with and without retrieval of source. *Brain*, *119*(3), 889–905. https://doi.org/10.1093/brain/119.3.889

Wolk, D. A., Sen, N. M., Chong, H., Riis, J. L., McGinnis, S. M., Holcomb, P. J., & Daffner, K. R. (2009). ERP correlates of item recognition memory: Effects of age and performance. *Brain Research*, *1250*, 218–231. https://doi.org/10.1016/j.brainres.2008.11.014

Woodruff, C. C., Hayama, H. R., & Rugg, M. D. (2006). Electrophysiological dissociation of the neural correlates of recollection and familiarity. *Brain Research*, *1100*(1), 125–135. https://doi.org/10.1016/j.brainres.2006.05.019

Yonelinas, A. P., Kroll, N. E. A., Dobbins, I. G., & Soltani, M. (1999). Recognition memory for faces: When familiarity supports associative recognition judgments. *Psychonomic Bulletin and Review*, *6*(4), 654–661. https://doi.org/10.3758/BF03212975

Yonelinas, Andrew P. (2002). The nature of recollection and familiarity: A review of 30 years of research. *Journal of Memory and Language*, *46*(3), 441–517. https://doi.org/10.1006/jmla.2002.2864

Yonelinas, Andrew P., Aly, M., Wang, W. C., & Koen, J. D. (2010). Recollection and familiarity: Examining controversial assumptions and new directions. *Hippocampus*, *20*(11), 1178–1194. https://doi.org/10.1002/hipo.20864

Yonelinas, Andrew P., Widaman, K., Mungas, D., Reed, B., Weiner, M. W., & Chui, H. C. (2007). Memory in the aging brain: Doubly dissociating the contribution of the hippocampus and entorhinal cortex. *Hippocampus*, *17*(11), 1134–1140. https://doi.org/10.1002/hipo.20341

Yu, S. S., & Rugg, M. D. (2010). Dissociation of the electrophysiological correlates of familiarity strength and item repetition. *Brain Research*, *1320*, 74–84. https://doi.org/10.1016/j.brainres.2009.12.071

Zhao, M.-F., Zimmer, H. D., Zhou, X., & Fu, X. (2016). Enactment supports unitisation of action components and enhances the contribution of familiarity to associative recognition. *Journal of Cognitive Psychology*, *28*(8), 932–947. https://doi.org/10.1080/20445911.2016.1229321

Zheng, Z., Li, J., Xiao, F., Broster, L. S., & Jiang, Y. (2015). Electrophysiological evidence for the effects of unitization on associative recognition memory in older adults. *Neurobiology of Learning and Memory*, *121*, 59–71. https://doi.org/10.1016/j.nlm.2015.03.006

Zheng, Z., Li, J., Xiao, F., Ren, W., & He, R. (2016). Unitization improves source memory in older adults: An event-related potential study. *Neuropsychologia*, *89*, 232–244. https://doi.org/10.1016/j.neuropsychologia.2016.06.025