

**THE EFFECTS OF AGING AND COGNITIVE STRATEGIES ON ASSOCIATIVE
MEMORY: NOT ALL ASSOCIATIONS ARE CREATED EQUAL**

Héloïse Drouin

A thesis submitted to the
Faculty of Graduate and Postdoctoral Studies
in partial fulfillment of the requirements for the
Doctorate in Philosophy degree in Clinical Psychology

School of Psychology
Faculty of Social Sciences
University of Ottawa

Acknowledgments

I would like to extend my sincere and deepest appreciation to the following individuals who were instrumental in my journey through the doctoral program. First and foremost, I would like to thank my supervisor, Dr. Patrick Davidson. Your genuine enthusiasm for research has been infectious! Thank you for your constant support, your time and dedication and for providing me with a skillful balance of independence and guidance. I also thank my committee members, Drs. Charles Collin, Sylvain Gagnon, and Vanessa Taler, for your time, feedback, and encouragement. A special thank you as well to Dr. Veronika Huta, who provided valuable feedback and suggestions on the statistical analyses of this dissertation.

I would also like to express my gratitude to members of the Neuropsychology Lab – in particular Annick Tanguay and Kylee Ramdeen who helped with data collection and scoring and who were always available for brainstorming sessions when I got stuck in my thinking. Of course, I would likely still be collecting data were it not for the « DreamTeam » consisting of Abdo Elnakouri, Kerri Adams, and Sofija Lavrinsek – a talented and devoted trio of volunteer research assistants. Thank you all for your dedication, enthusiasm, professionalism and reliability. A heartfelt thank you as well to all of the research participants who have generously volunteered their time for this project – you have taught me so much.

Je tiens à remercier aussi ma famille et mes amis, sans qui je n'aurais été en mesure de compléter le doctorat. Un gros merci à ma mère, Marie-Andrée Drouin et mon beau-père Pierre Shields, ainsi qu'à ma fratrie, Alycia, Chantal, Marie-Hélène, Isabelle et Simon, pour vos encouragements et soutien tout au long du programme. À mon père, Pierre St-Onge : j'ai fini! Merci à mes amis pour votre patience malgré mes moments d'absence et à Azar, sans qui je n'aurais jamais même osé appliquer au programme.

Abstract

Young adults often outperform older adults on tests of associative memory, however, the source of this age-related associative memory deficit is still under debate. There are two main non-mutually exclusive hypotheses: 1) impaired binding processes (i.e. creating and retrieving links between units of information) and; 2) impaired strategic processes (i.e. cognitive control processes that support encoding and retrieval). Although both components are thought to contribute uniquely and interact to support associative memory, they have rarely been studied together.

The primary goal of this dissertation is to further characterize associative memory deficits in healthy aging by measuring and controlling binding and strategic processes. Specifically, in this series of three experiments, we studied these two components concurrently by varying the level of demands on binding (i.e. comparing memory for different types of associations) and strategic processes (i.e. varying demands on self-initiated processes). A total N of 97 young adults and 94 older adults studied lists of object-pairs and object-location pairs under intentional encoding conditions. Demands on self-initiated processes were manipulated by increasing the number of foils at test (Experiment 1: 4 alternative forced-choice (AFC), vs. Experiment 2 & 3: 20AFC), and by providing strategy instructions in Experiment 3. We measured the production of strategies with trial-by-trial self-report. In all three experiments, we found that young adults outperformed older adults on object-object memory, but not on object-location memory. Older adults were just as proficient as young adults in generating strategies at study. This remained true even when demands on self-initiated processes increased. However, we found in all three experiments that young adults had greater strategy effectiveness (i.e. accuracy on pairs encoded with a strategy) on the object-object test. In contrast, performance on the object-location task was

found to be less related to strategies. Our findings suggest that not all associations are equally affected by aging and that even when strategy production is equivalent between age groups older adults can still be impaired on associative memory.

The secondary goal of this dissertation was to explore the contribution of individual variability in age, general cognitive functioning, meta-memory and executive functioning on object-object and object-location memory, strategy production, and strategy effectiveness. Our results highlight the important contribution of executive functioning over and above any effects of age in explaining age-related associative memory decline.

TABLE OF CONTENTS

Acknowledgments	ii
Abstract.....	iii
List of Figures.....	viii
List of Appendices.....	x
Contribution of Author	xi
CHAPTER 1 – GENERAL INTRODUCTION & LITERATURE REVIEW	1
General Introduction	2
Biological and cognitive changes in normal aging.....	3
Memory and aging: Not all types of memory are equally affected by aging	5
Age-related associative memory impairment: two main interdependent hypotheses	8
A closer look at binding: Memory for different types of associations	13
A closer look at the strategic component: strategies in associative memory	15
Strategies and between-domain associations.....	22
The impact of inter-individual variability on associative memory and strategies	22
Original Contributions of the Thesis.....	26
Data Checking and Screening Procedure	28
CHAPTER 2. EXPERIMENT 1.....	31
Objectives and Hypotheses	32
Method	32
Participants	32
Design.....	33
Materials	33
Procedure.....	37
Results.....	38
Discussion	45
CHAPTER 3: EXPERIMENT 2.....	48
Objectives and Hypotheses	49

Methods	49
Materials	50
Procedure	51
Results	51
Discussion	58
CHAPTER 4. EXPERIMENT 3	60
Objectives and Hypotheses	61
Method	61
Participants	61
Materials	62
Procedure	63
Results	64
Discussion	69
CHAPTER 5: THE IMPACT OF INTER-INDIVIDUAL VARIABILITY ON ASSOCIATIVE MEMORY PERFORMANCE AND STRATEGIC BEHAVIOUR	71
Method	72
Overview of measures	72
Results and Discussion	73
Correlational analyses	73
Hierarchical Regressions	77
CHAPTER 6: GENERAL DISCUSSION	92
Interpretation of Results in the Context of the Binding and Strategic Deficit Hypotheses of Age-related Associative Memory Deficits	97
Theoretical and Methodological Implications of the Research	99
Practical & Clinical implications	105
Potential Limitations, Strengths, and Future Directions	107
References	113
APPENDICES	133

List of Tables

- Table 1. Participant Demographic Information in Experiment 1
- Table 2. Participant Demographic Information in Experiment 2
- Table 3. Participant Demographic Information in Experiment 3
- Table 4. Zero-Order Correlations and Partial Correlations Controlling for Age among Outcomes and Predictors in Older Adults in Experiment 1
- Table 5. Zero-Order Correlations and Partial Correlations Controlling for Age among Outcomes and Predictors in Older Adults in Experiment 2
- Table 6. Zero-Order Correlations and Partial Correlations Controlling for Age among Outcomes and Predictors in Older Adults in Experiment 3
- Table 7. Hierarchical Regression Predicting Object-Object Memory from Age, the Experiment, Education, MoCA, MMQ (Feelings, Mistakes, and Strategies), Executive Functioning, Strategy Knowledge, and Mediator Production
- Table 8. Hierarchical Regression Predicting Object-Location Memory from Age, the Experiment, Education, MoCA, MMQ (Feelings, Mistakes, and Strategies), Executive Functioning, Strategy Knowledge, and Mediator Production
- Table 9. Hierarchical Regression Predicting Mediator Accuracy on Object-Object Memory from Age, the Experiment, Education, MoCA, MMQ (Feelings, Mistakes, and Strategies), Executive Functioning, and Strategy Knowledge

List of Figures

- Figure 1. Encoding trial for the object-object test in Experiment 1 and 2
- Figure 2. Test trial for the object-object test in Experiment 1
- Figure 3. Encoding trial for the object-location test in Experiment 1 and 2
- Figure 4. Test trial for the object-location test in Experiment 1
- Figure 5. Proportion of correctly recognized pairs by age group and type of association in Experiment 1
- Figure 6. Proportion of mediators reported by age group and type of association in Experiment 1
- Figure 7. Proportion of correct object-object recognition by age group and by type of strategy used at encoding (mediator vs. non-mediator) in Experiment 1
- Figure 8. Proportion of correct object-location recognition by age group and by type of strategy used at encoding (mediator vs. non-mediator) in Experiment 1
- Figure 9. Test trial for the object-object test in Experiment 2 and 3
- Figure 10. Test trial for the object-location test in Experiment 2 and 3
- Figure 11. Proportion of correctly recognized pairs by age group and type of association in Experiment 2
- Figure 12. Proportion of mediators reported by age group and type of association in Experiment 2
- Figure 13. Proportion of correct object-object recognition by age group and by type of strategy used at encoding (mediator vs. non-mediator) in Experiment 2
- Figure 14. Proportion of correct object-location recognition by age group and by type of strategy used at encoding (mediator vs. non-mediator) in Experiment 2
- Figure 15. Encoding trial for the object-object test in Experiment 3
- Figure 16. Encoding trial for the object-location test in Experiment 3
- Figure 17. Proportion of correctly recognized pairs by age group and type of association in Experiment 3
- Figure 18. Proportion of mediators reported by age group and type of association in Experiment 3
- Figure 19. Proportion of correct object-object recognition by age group and by type of strategy used at encoding (mediator vs. non-mediator) in Experiment 3

Figure 20. Proportion of correct object-location recognition by age group and by type of strategy used at encoding (mediator vs. non-mediator) in Experiment 3

List of Appendices

- Appendix A. Strategy descriptions
- Appendix B. Histograms of potentially skewed distributions in Experiment 1
- Appendix C. Proportion of pairs participants reported encoding by a given strategy in Experiment 1
- Appendix D. Proportion of correct paired-associate recognition performance as a function of the strategies participants reported producing at study in Experiment 1
- Appendix E. Histograms of potentially skewed distributions in Experiment 2
- Appendix F. Proportion of items that participants reported studying by a given strategy in Experiment 2
- Appendix G. Proportion of correct paired-associate recognition performance as a function of the strategies participants reported producing at study in Experiment 2
- Appendix H. Histograms of potentially skewed distributions Experiment 3
- Appendix I. Proportion of items that participants reported studying by a given strategy in Experiment 3
- Appendix J. Proportion of correct paired-associate recognition performance as a function of the strategies participants reported producing at study in Experiment 3

Contribution of Author

The experiments in this dissertation were conceived and elaborated by H elo ise Drouin, with the guidance and input of Dr. Patrick Davidson. In collaboration with Dr. Davidson, H elo ise Drouin selected the experimental stimuli, designed and programmed the memory tasks, conducted pilot testing, recruited and tested participants, scored and verified data, and analysed and interpreted results. Members of Dr. Davidson’s Lab of Cognitive Neuropsychology also helped with recruiting and testing participants, implementing data scoring procedures, and data scoring/verification. The results of this dissertation are currently being prepared for a journal article submission to *Psychology and Aging*, with Dr. Davidson as co-author.

CHAPTER 1 – GENERAL INTRODUCTION & LITERATURE REVIEW

General Introduction

Older adults coming into the Cognitive Neuropsychology Lab to participate in studies have often spontaneously commented on the state of their memory (e.g.: “I can remember every single word from a song I learned in kindergarten, but I can’t seem to remember what I had for dinner last night”) as well as the source of these subjectively identified memory changes (e.g. “Since I’ve hit 60, I’ve definitely noticed my memory is not what it used to be...but that’s to be expected!”). But what kind of memory changes *are* to be expected in normal aging? And what, if anything, can be done about these changes? In parallel to the aging of the population, in the last 30 years there has been a boom in research publications seeking to answer these very questions. Indeed, it has become increasingly important to better understand memory in the context of normal aging.

Although some types of memory are relatively spared by aging, one of the most consistent findings in the literature is that aging is associated with declines in episodic memory (see Verhaeghen, Marcoen, & Goosens 1993, Verhaeghen & Salthouse, 1997 for reviews). Episodic memory pertains to the capacity to remember specific personally-experienced episodes or events (Tulving, 1972), such as remembering what you ate for dinner last night. Episodic memory relies on the ability to generate, store, and retrieve associations between individual units of information such as between the “content” of an episode (i.e. what was of central interest to the observer; e.g. the meal that was consumed for dinner last night) and its “context” (i.e. sensory, spatial and temporal features of an “item” or “content”; e.g. the colour, odor and placement of the food on our plate, its taste on our palate, the time and location of dinner, who we were eating dinner with, etc.). This ability to bind and retrieve these associations between different components could indeed be considered to be the “glue” of episodic memory. It is

precisely this ability (i.e. associative memory) that is thought to be compromised in aging.

Although age differences favouring young adults in associative memory are well documented, the causes of this age-related deficit are still under debate.

Two predominant hypotheses propose that these declines originate from both impaired binding processes (i.e. creating and retrieving links between units of information) and strategic processes (i.e. cognitive control operations that support encoding and retrieval). This dissertation focuses on further characterizing associative memory deficits in aging by concurrently measuring/controlling binding and strategic processes. Identifying and measuring the effects of these factors on associative memory can help further delineate the source of the age-related deficit and help identify targets for memory rehabilitation. To provide the necessary context for the literature on age-related changes in associative memory, we first discuss the biological and cognitive changes that characterize healthy aging.

Biological and cognitive changes in normal aging

Normal aging is accompanied by both structural and functional brain changes. Structurally, normal aging is associated with a general reduction in brain volume (see Fjell and Walhovd, 2010; Hedman, van Haren, Schnack, Kahn, & Kulschoff Pol, 2012; Raz, 2000; Raz, 2005; and Raz & Kennedy, 2009 for reviews). This volumetric decrease is reflected in a loss of mass of both grey matter and white matter, with white matter volume and integrity being particularly vulnerable to aging (Gunning-Dixon & Raz, 2000; Raz, 2005). However, age-related atrophy does not affect all regions of the brain to the same degree. The medial temporal lobes (MTL) and the prefrontal cortex (PFC) are two regions that are particularly affected by aging, with the PFC showing the greatest decline (Raz, 2005; Raz, Rodrigue, Head, Kennedy, & Acker, 2004; Raz & Kennedy, 2009). There is ample evidence of age-related atrophy of the MTL and

PFC in both cross-sectional studies (e.g. Bartzokis, Beckson, Lu, Nuechterlein, Edwards, & Mintz, 2001; Jernigan et al., 2001) and longitudinal studies (Pfefferbaum, Sullivan, Rosenbloom, Mathalon, & Lim, 1998; Raz et al. 2005; Resnick, Pham, Kraut, Zonderman, & Davatzikos, 2003; Scahill et al., 2003) (for comprehensive reviews see Denis and Cabeza, 2008 and Raz, 2000).

Normal aging is also accompanied with functional brain changes, such as decreases of cerebral blood flow and metabolic activity (Dennis and Cabeza 2008), as well as a reduction in the integrity of neurotransmitter systems, such as dopamine (e.g. Bäckman, Lindenberger, Li, & Nyberg, 2010). Generally, the findings of functional imaging studies also suggest age-related changes in patterns of activation when completing a cognitive task. Broadly speaking, in comparison to young adults, older adults have shown both a reduction of activation in certain brain areas, often coupled with an increase in activation in other areas. For example, in processing of visual stimuli, older adults often show reduced activation of the occipital lobe, coupled with an increased activation of the PFC (posterior-anterior shift in aging-PASA; Davis, Dennis, Daselaar, Fleck & Cabeza, 2009; Grady et al. 1994). Similarly, in studies across several cognitive domains including memory, older adults tend to show a more bilateral pattern of activation in the PFC compared to young adults (Hemispheric Asymmetry Reduction in OLDER Adults-HAROLD; Cabeza, 2002). The PASA and the HAROLD patterns have been interpreted as representing a compensation mechanism in older adults. This interpretation is particularly compelling when this increased activation is accompanied by improved performance in older adults (Reuter-Lorenz et al. 2000, Reuter-Lorenz & Park, 2010). An alternative hypothesis is that these differential patterns of activation in aging reflect reduced efficiency in the use of neural resources (Baltes & Lindenberger, 1997; Logan, Sanders, Snyder, Morris & Buckner, 2002).

Normal aging is also associated with several cognitive changes (although some cognitive functions are preserved or even enhanced with aging, such as vocabulary). The cognitive domains showing the most age-related changes include attention, executive functioning, working memory, and long-term memory (e.g. Davidson & Winocur 2017, Drag & Bieliauskas, 2010). However, aging does not affect all types of memory equally. Rather, aging appears to differentially affect some types of memory, whereas others are relatively well preserved.

Memory and aging: Not all types of memory are equally affected by aging

Memory is not a unitary entity but rather is a broad term which refers to a wide range of cognitive abilities which enable us to acquire, store and retrieve information about ourselves and the world. Although it is generally accepted that memory is composed of multiple memory “systems” that treat various kinds of information, there remains no generally agreed upon classification of the different kinds of memory. Roediger, Marsh and Lee (2002) suggest that there are several dimensions that may be useful to broadly categorize different types of memory. One such dimension that is useful to consider when studying age-related memory changes are the processing requirements at encoding and at retrieval.

At encoding, a broad distinction can be made between whether information is acquired intentionally or if it is acquired incidentally (i.e. in the absence of volition). Although both intentional and incidental encoding appears to be affected by age, intentional learning may be particularly affected (e.g. Old & Naveh-Benjamin, 2008). At retrieval, a distinction can be made by comparing two broad categories by which memory is tested: with a declarative/explicit memory test or a non-declarative/implicit memory test (Squire, 1992). Declarative memory is open to intentional retrieval and involves memory for facts and events. Non-declarative memory cannot be explicitly retrieved and is rather evaluated through performance. There is a general

consensus in the literature that age differences are larger in declarative memory tasks than in implicit memory tasks (Light & La Voie, 1993). In short, age-related memory impairments are largest under conditions involving volitional and effortful cognitive processes either at encoding and/or at retrieval.

Declarative memory can be further broken down into two main types of memory systems: semantic memory and episodic memory (Tulving, 1972). Semantic memory pertains to the memory of knowledge and facts (e.g. the colour of the sky, the capital of Canada) and episodic memory pertains to memory for specific events (e.g. remembering eating last night's dinner). Whereas semantic memory involves memory for the content of the information, episodic memory involves memory for the content *and* its spatial-temporal context. In other words, episodic memory is thought to rely on memory for associations between "items" and their "context" (i.e. associative memory). Although aging is associated with declines in episodic memory (Verhaeghen et al., 1993; Verhaeghen & Salthouse, 1997), semantic memory is less affected by age (Nyberg, Bäckman, Erngrung, Olofsson, & Nilsson, 1996).

Aging and associative memory deficits. A predominant hypothesis of age-related differences in associative memory is that older adults are impaired in associating or binding together different components/features of a given event. The first evidence of age-related differences favouring young adults in associative memory comes from the paired-associate learning literature. Several early studies have found that young adults outperform older adults on associative memory tests (e.g. Korchin & Basowitz, 1957; Ruch, 1934; Salthouse, Kausler & Sauls, 1988; see review by Kausler, 1994). These findings have led Kausler (1994) to conclude that paired-associate learning is highly sensitive to aging. Since these early findings, researchers have tested this hypothesis with different types of material such as source or context memory

paradigms, where participants are asked to associate an item (e.g. object) with a contextual feature (e.g. its colour, location, sequence in time, etc.). Young adults have also been found to generally have superior memory for source or context associations (see Spencer & Raz, 1995 for a review). In their meta-analysis, Spencer and Raz (1995) also found that older adults have a disproportionate impairment in memory for associations compared to memory for individual items or components. Building on these findings, Chalfonte and Johnson (1996) were the first to directly compare the performance of young and older adults on recognition of single features (e.g., memory for an object, a location, a colour), and bound features (e.g. association between an item and its location, or an item and its colour) within participants. Older adults had consistently lower recognition memory for location but not item or color. Older adults also consistently showed lower recognition memory for bound information, particularly under intentional encoding conditions. The authors concluded that older adults have both a feature deficit (i.e. at least for location information) and a binding deficit which both uniquely contribute to their episodic memory impairments (see also Mitchell & Johnson, 2009). Naveh-Benjamin (2000) further replicated and extended the binding deficit hypothesis by proposing the associative deficit hypothesis (ADH). The ADH suggests that older adults may not only be impaired in binding features with contextual information (e.g. association between an object and its location), but may also be impaired in creating and retrieving links between single units of information, including between same kinds of information (e.g. association between two words or objects). Naveh-Benjamin and colleagues have garnered significant evidence in support of this hypothesis (Bender, Naveh-Benjamin & Raz, 2010; Naveh-Benjamin 2000; Naveh-Benjamin, Guez, Kilb & Reedy, 2004; Naveh-Benjamin, Hussain, Guez & Bar-On, 2003, but see Benjamin, 2010 for an alternative hypothesis of age-related memory deficits). Specifically, in their 2008

meta-analysis, Old and Naveh-Benjamin found that the age-related effect for item-memory measures was of $d = 0.73$, CI [0.68, 0.78], whereas it was of $d = 0.92$, CI [0.87, 0.97] for associative memory measures. These results support the claim that older adults are disproportionately impaired on tests of associative memory compared to memory for individual units of information (i.e. item memory).

Age-related associative memory impairment: two main interdependent hypotheses

Age-related impairments in binding processes may only be half the story. Indeed, age-related associative memory impairments are also considered to originate from impairments in strategic processes (i.e. cognitive control operations that support encoding and retrieval). Both the binding and the strategic components have unique contributions and likely interact to support episodic memory (Shing, Werkle-Bergner, Li, & Lindenberger 2008; Shing et al., 2010; Simon & Spiers, 2003; Werkle-Bergner, Müller, Li, & Lindenberger 2006).

The binding component. The term “binding” encompasses mechanisms at encoding, storage and retrieval that bind together features of an event to create a cohesive episode (Zimmer, Mechlinger, & Lindenberger, 2006). Experientially, “binding provides the memorial experience that certain features belong together” (Chalfonte & Johnson, 1996 – p. 41). As described earlier, there is a significant amount of behavioural data to suggest that older adults have impaired binding processes. Lesion studies and neuroimaging studies in healthy brains inform us of the neural correlates of these binding processes. Based on a significant body of such research, there is a general consensus in the literature that medial temporal lobes are most responsible for binding processes (Cabeza, 2006; Cohen & Eichenbaum, 1994; Davachi & Wagner, 2002; Eichenbaum, 2000). For example, functional imaging studies tell us that

successful binding is positively correlated with the level of hippocampal activation (Davachi, 2006).

In aging, structural imaging studies have produced mixed results. Although some studies have found that hippocampal volume is positively correlated with associative memory (e.g. Driscoll, 2003; review by Raz, 2000), others have found that there is no strong evidence of a relationship between hippocampal volume and associative memory performance (e.g. see review by Van Petten, 2004). The results of functional imaging studies paint a clearer picture. The general trend is that older adults show reduced activity in the MTL's compared to young adults during encoding (e.g. Dennis et al., 2008; see review by Dennis & Cabeza, 2008) and at retrieval (Giovanello & Shacter, 2012). For example, in a study with young and older adults comparing item (objects or locations only) and associative memory (object-locations), young adults, but not older adults, showed greater activation in left anterior hippocampus at encoding of associative memory trials (Mitchell, Johnson, Raye, & D'Esposito, 2000).

The strategic component. In the broadest sense of the term, strategic behaviour can be defined as *the approach* taken by an individual to a given task (Rogers, Hertzog, & Fisk, 2000). Strategic behaviour can thus occur with or without volition (Rogers et al., 2000). The way in which strategic behaviour is operationalized and measured between studies varies from indirect indices of implicit strategic behaviour (e.g. measuring semantic categorization of word lists at recall, without participants' having consciously planned to categorize the words at encoding), to direct measurement of explicit, volitional behaviour (e.g. measuring strategies produced by participants at encoding for an intentional memory test). Given that age-related memory impairments are largest under conditions involving volitional and effortful cognitive processes, in this dissertation we focus on strategies involving explicit goal-oriented behaviour.

Specifically, goal-oriented strategies (i.e. referred to simply as “strategies” from this point on) can be defined as cognitive control operations depending on effortful, conscious processes that support the encoding and retrieval of discrete memory traces (Shing et al., 2010; Simon & Spiers, 2003). Strategies have been shown to improve memory for all types of information (Craik, 2002) in general, and for associative information, in particular (Richardson, 1998). Yet, strategies may be particularly important to successfully remember associative information. Indeed, successful encoding of associative information may be more effortful than encoding item information. Studies supporting this claim have replicated the age-related associative deficit in young adults under dual-task conditions (Castel & Craik, 2003; Hara & Naveh-Benjamin, 2015; Troyer, Craik, Winocur & Moscovitch, 1999; Troyer & Craik, 2000), suggesting that concurrent processing demands at encoding may selectively hurt associative memory, whereas item memory is less affected.

Associative memory may be particularly effortful when the information to be associated is unrelated. Indeed, compared to encoding semantically-related items, encoding unrelated pairs has been associated with increased brain activation in the PFC and MTL as well as with greater subjective ratings of difficulty (Leshikar, Gutchess, Hebrank, Sutton, & Park, 2010).

In aging, age-related differences favouring young adults are largest under conditions with high demands on effortful, strategic processes. Indeed, age-related differences are largest in explicit, compared to implicit memory tasks, and in free recall compared to recognition tasks. Craik’s dual environmental support/self-initiated processes theory (1983, 1986) suggests that cognitive processing resources diminish with aging, which in turn leads to a reduction in self-initiated mental operations, such as implementing deep and elaborate encoding strategies. According to this account, age-related differences are decreased (and sometimes eliminated)

when older adults are provided with environmental support (e.g. with pre-existing semantic associations between items) thus reducing demands on self-initiated processes. This age-related reduction in self-initiated strategy use has also been identified as contributing to the age-related associative memory deficit (e.g. Naveh-Benjamin, Brav & Levy, 2007).

It is generally accepted that the prefrontal cortex is most responsible for the strategic component (e.g. Moscovitch, 1992, Moscovitch & Winocur 1995). More specifically, at encoding the PFC is thought to play a role in implementing strategies and organizing input to the MTL (Moscovitch, 1992), and more generally is considered to play a supervisory role over the function of other brain regions and the MTL (Miller & Cohen, 2001). Additional evidence supporting the importance of the PFC-mediated strategic component comes from the lesion literature. Patients with PFC lesions demonstrate less use of strategies during encoding than healthy aged-matched controls (Gershberg & Shimamura, 1995). However, patients with frontal lobe lesions can effectively use elaborative encoding strategies when they are instructed to do so (Gershberg & Shimamura, 1995), which suggests that the PFC are important for self-initiated encoding processes.

In aging, structural imaging studies tell us that prefrontal gray matter volumes are associated with more frequent strategy use in older adults (e.g. Kirchoff, Gordon & Head, 2014) and superior associative memory (Becker et al., 2015). In functional imaging studies, the most consistent finding across studies is that aging is associated with a reduction in activation in the left PFC at encoding (e.g. Addis, Giovanello, Vu & Shacter, 2014; Dennis et al., 2008; Nyberg et al. 2010, see review by Dennis & Cabeza, 2008) and at retrieval (Giovanello & Shacter, 2012). This pattern is most prevalent in intentional encoding paradigms, which underlines the strategic components to age-related episodic memory deficits (Dennis & Cabeza, 2008).

The interaction between binding and strategies. Although both the MTL and PFC make unique contributions to support associative memory, both components are also thought to interact and “work together” (e.g. Preston & Eichenbaum, 2013; Simon & Spiers 2003; Shing et al., 2010). Greater patterns of co-activation in these areas have been associated with better episodic memory (Kaplan et al., 2014; Shing, Brehmer, Heekeren, Bäckman & Lindenberger, 2016; Shott et al., 2013; Wagner et al., 1998).

In aging, structural imaging studies suggest that age-related changes in the PFC and MTL may be interdependent. Indeed, Raz et al., (2005) found a strong positive correlation between volumetric losses of the MTLs and PFC in older adults. In addition, results of some functional imaging studies have suggested that there may be diminished connectivity between the MTL and PFC. For example, a study by Grady et al., (1995) found a significant correlation between MTL and PFC in activity in young but not in older adults. Similarly, Gutchess et al., (2005) obtained a negative correlation between MTL and PFC activation in older, but not young adults, suggesting that older adults showing lower MTL activation showed higher PFC activation. The authors interpreted these results as indicating that older adults may compensate from diminished MTL activation by increasing demands on the PFC.

Taken together, these findings suggest there are two main components that both contribute uniquely and interact to support associative memory. Aging appears to impact the functioning of both components separately, and may also affect the functional connectivity between the two. Results of some studies suggest that older adults may compensate for lower activation in one brain area by increasing activation in another (e.g. Gutchess et al., 2005, see also the HAROLD compensation theory of aging; Cabeza, 2012). Another factor that may influence which areas of the brain are activated may be the type of association to be encoded.

A closer look at binding: Memory for different types of associations

There are two main types of associative memory tests. There are memory tests for within-domain associations (i.e. the association between two similar kinds of information, such as word-word or object-object pairs) and memory tests for between-domain associations (i.e. the association between two different kinds of information, such as object-location pairs). Some lesion and imaging research suggest that between-domain associations may tax binding more heavily (Borders, Aly, Parks & Yonelinas, 2017; Mayes et al., 2001; Vargha-Khadem, 1997, but see Turriziani, Fadda, Caltagirone & Carlesimo, 2004). For example, a study conducted with three hypoxic patients who had early and selective hippocampal damage found that although the patients had unimpaired recognition memory for pairs of words, non-words, and faces, they were impaired at recognition of object-location and face-voice associations (Vargha-Khadem, 1997). A series of experiments conducted by Mayes and colleagues (2001, 2004) with a patient with selective hippocampal damage obtained similar results. Indeed, this patient's recognition memory for associations between similar kinds of items was relatively intact (0.7 SDs below the mean of control participants), whereas her recognition memory for associations between different kinds of information was significantly impaired (2.9 SDs below the mean of control participants).

Mayes et al., (2007) interpret these results as supporting the domain-dichotomy theory of the MTL which posits that different MTL structures mediate different types of associative memory. Specifically, they suggest that within-domain associations are processed in closely adjacent neocortical brain regions (e.g. perirhinal cortex) whereas between-domain associations are processed in more distal neocortical regions. According to this theory, the hippocampus is considered to be uniquely important for encoding between-domain associations, for which

maximal memory-binding convergence is needed (Mayes, Montaldi, & Migo, 2007). Given that the hippocampus may be particularly vulnerable to age-related senescence, memory for between-domain associations may be particularly impacted by aging.

Although lesion studies predict larger age difference with between-domain associations, the results of the Old and Naveh-Benjamin meta-analysis (2008) suggest equivalently large effect sizes of the age-related associative memory deficit in studies measuring associative memory for between-domain associations (e.g. items and their temporal order or location) and for within-domain associations (e.g. word-word pairs). However, very few studies have directly compared memory for within- and between-domain associations in aging in a within-participant design. To my knowledge, the two exceptions are a study conducted by Bastin and Van der Linden (2006), and one by Troyer, D'Souza, Vandermorris, and Murphy (2011).

Bastin and Van der Linden (2006) compared young and older adult performance on recognition tests of face-face associations (within-domain association) and face-spatial location associations (between-domain association), in a within-participant design. Although they found no significant difference in performance for both types of associations, point-biserial correlations between the age groups and the scores on the tasks suggest that age differences on recognizing face-location associations were larger than for remembering face-face associations (correlation of .48 for the face-spatial location task and of .33 for the face-face task). Troyer et al., (2011) compared young and older adults on recognitions tests of word-word (within-domain) and face-name (between-domain) associations in a within-participant design. Similarly to Bastin and Van der Linden's (2006) between-domain associations yielded a larger age effect than did within-domain associations. In other words, there was a greater associative deficit on the face-name task than on the word-word task in older adults only.

Thus, the existing data do lend at least partial support to the domain dichotomy view of the MTL's: age-related differences may be greater in memory for between-domain associations compared to within-domain associations due to increased demands on binding processes for remembering the association between different kinds of information. However, as described above, successful episodic memory is likely supported by both binding and strategic processes. Thus, an important limitation of both these studies is that neither one attempted to control or measure strategic processes.

A closer look at the strategic component: strategies in associative memory

Strategies have an important impact on associative learning (Bower, 1970; Kirchoff, 2009; Richardson, 1998). Most effective for associative learning are strategies that link the information to be remembered in some way (i.e. mediators). Two highly effective mediators are sentence generation (i.e. creating a sentence that combines the two items to be encoded) and interactive imagery (i.e. creating a mental image in which both items are interacting) (Bower & Winzenz, 1970; Paivio & Yuille, 1967; Paivio, Yuille, & Smythe, 1966; Richardson, 1998). These mediators aid associative learning to a greater extent than do other strategies that do not involve creating an associative link (i.e. non-mediator strategies such as rote repetition) (Richardson, 1998; Yuille, 1973). The vast majority of the studies looking at the effect of mediators on associative learning have used paradigms with verbal paired associates.

Strategies, associative memory, and aging. Aging has been associated with a decrease in the ability to self-initiate mediator production when encoding associations (*strategy production deficit*; Kausler, 1994), whereas the basic ability to employ a mediator is purported to be unaffected by aging. According to this hypothesis, although older adults may be impaired at spontaneously generating mediators, they are successful at doing so when instructed. An

alternative hypothesis is that older adults are able to produce mediators, but that they affect memory less effectively than they do for young adults (*utilization deficit*; Dunlosky, Hertzog, & Powell-Moman, 2005). There are several different ways in which researchers have tested these hypotheses.

Assessing age-related strategic deficits in associative memory tasks. One way that researchers have attempted to measure the role of strategies in age-related differences in associative memory has been to compare performance of young and older adults under intentional and incidental learning conditions. In intentional learning conditions, participants are informed about the upcoming memory test, whereas they are not in incidental learning conditions. To ensure that participants are still processing the information in incidental learning conditions, participants are asked to make some kind of rating about the material to be encoded, or are told that their memory will be tested for one component of the information only (e.g. item only and not its location), to then have their memory tested for both components. In their 2008 meta-analysis, Old and Naveh-Benjamin found that the effect size of the age-related associative deficit was larger in studies using intentional encoding conditions ($d=1.19$, CI [1.08, 1.29]) compared to the effect size of studies using incidental encoding conditions ($d = 0.73$, CI [0.63, 0.83]). The assumption made is that intentional encoding conditions alert participants about the possibility of using strategies in preparation for the upcoming memory test. Old and Naveh-Benjamin argued that intentional encoding conditions increase the age-related associative deficit because young adults are more likely than older adults to implement self-initiated encoding strategies. However, there are significant limitations to this type of strategy assessment. First, although there are attempts to manipulate participants' attention by having them complete some kind of information processing task, it remains difficult to know what participants are actually

paying attention to during incidental encoding. Second, and most importantly, since strategies are neither directly controlled nor measured, it is not possible to know whether participants in either condition are actually using strategies.

Another standard (and much better) method to assess the role of strategies in associative memory is to compare the performance of groups informed to use effective strategies to groups that are uninformed. If age differences occur in groups that are uninformed to use strategies but are minimized in groups that are informed, this is evidence for a strategy production deficit as it supports the idea that older adults do not engage in elaborative processing spontaneously. If young adults improve more than older adults after receiving strategy instructions, this may suggest that young adults have more attentional resources available to take greater advantage of effective encoding strategies than do older adults (Craik 1986). Finally, if both age groups improve to a similar degree, this would point to deficits related to other strategic factors (e.g. strategy utilization deficit, or strategic processes at retrieval) and/or to non-strategic factors (e.g. binding). However, this method may be insufficient by itself to properly assess strategic factors (Dunlosky & Hertzog, 1998).

Dunlosky and Hertzog (1998) have proposed a method to assess item-by-item self-report of strategies used by participants. These strategy reports can either be collected concurrently (i.e. after each pair studied, participants report the strategy that they used to encode it), or retrospectively (i.e. participants report the strategy they used to encode each pair after the memory test is completed – participants are shown each encoding trial again as a cue). This is a more accurate and rich way of measuring strategies because even when participants are instructed to use a strategy, it cannot be assumed that the instructed strategy was produced. More importantly, if compliance differs across age groups, this could lead to incorrect conclusions

regarding age differences in strategy production (Dunlosky & Hertzog, 1998). Indeed, studies that have adopted this strategy report method tell us that compliance is far from perfect (e.g. across two studies: young adult compliance ranged from 60% to 68%, whereas older adult compliance ranged between 58% to 71%; Dunlosky & Hertzog, 1998; Kuhlmann & Touron, 2012). Another reason why this method provides a more accurate and rich measure of strategies is that individuals often use more than one strategy across a set of items (e.g. they may adaptively switch strategies if they conclude that a previous strategy has been ineffective). This method thus allows for a fine-grained analysis of how strategies are distributed across items. Finally, assessing strategies in this way also provides information about the effectiveness of different types of strategies.

Is the performance of older adults' constrained by a strategy production deficit?

Studies that have compared the number of mediators produced by young and older adults, either measured item-by-item, or in a (much less precise) general strategy questionnaire have led to mixed results. On the one hand, several studies have found that young adults do report producing more mediators than older adults. This pattern has been found in studies using a trial-by-trial strategy report (Froger, Bouazzaoui, Isingrini, & Tacconnat, 2012; Hulicka & Grossman, 1967), and in a study using an open-ended strategy questionnaire on overall strategy use (Naveh-Benjamin, et al., 2007). For example, in the study conducted by Hulicka and Grossman (1967), young adults produced mediators on 68% of word pairs, whereas older adults produced mediators on 36% of word pairs. On the other hand, strategy reports in other studies have failed to find a significant age-related difference in the number of mediators produced either with trial-by-trial reporting methodologies (Ariel, Price, & Hertzog, 2015; Kuhlman & Touron, 2012), or

in open-ended strategy questionnaires on overall strategy use (Brehmer, Shing, Heekeren, Lindenberger & Bäckman 2016; Shing, et al., 2016).

A clearer picture emerges in studies that have also controlled strategies. Several studies have also found that under strategy instructions, older adults improved more than young adults (Canestrari, 1963; Dunlosky & Hertzog, 2001; Froger et al., 2012; Hulicka & Grossman, 1967; Naveh-Benjamin et al., 2007; Treat, Poon & Fozard, 1981; Treat and Reese, 1976). However, the most impressive results supporting the strategy production deficit hypothesis are those obtained by Naveh-Benjamin and colleagues (2007). Under intentional learning conditions (no strategy instructions provided), corrected recognition scores (proportion hits – proportion false alarms) of word pairs for young adults were .73 and were .29 for older adults (a .44 difference). In this uninstructed condition, 100% of young adults reported using mediators in an open-ended strategy questionnaire, whereas only 11% of older adults did. Under instructions to use mediators at encoding (i.e. sentence generation), corrected recognition scores were .70 for young adults and .47 for older adults (a .23 difference). Finally, under instructions to use mediators at encoding *and* at retrieval, corrected recognition scores were .76 for young adults and .70 for older adults (a .06 difference). With instructions to use mediators at encoding and retrieval, the age-related difference in performance was no longer significant. In the strategy instructed conditions, 90% of both young and older adults reported using mediators. Whereas young adults appear to use mediators spontaneously, older adults may use them mostly when explicitly instructed to do so.

The results of more recent studies suggest that *some* but not all older adults improve under strategy instructions. Frankenmolen et al., (2016) found that only the older adults with a higher IQ improved more than young adults (approximately achieving the performance level of young adults), whereas older adults with lower IQ's did not. Similarly, older adults with high

fluid intelligence have been shown to improve their performance more than young adults when using effective strategies (Ariel et al., 2015). These results suggest that there are other factors that may interact with age to moderate the effectiveness of older adults' strategy use.

Is the performance of older adults' constrained by a strategy utilization deficit? There are several other findings that indicate that even when they are provided with strategies, young adults either improve more than older adults do (Shing et al., 2008) or both age groups improve to a similar degree (Ariel et al., 2015 [older adults with lower fluid intelligence]; Dunlosky & Hertzog, 1998; Hineault, Lemaire & Touron, 2016; Naveh-Benjamin, Craik, Guez & Kreuger, 2005). This pattern of results supports the strategy utilization deficit, such that despite adequate strategy production, older adults may be impaired in using these strategies effectively. The findings of the study by Naveh-Benjamin et al., (2005) bring further support to this hypothesis. Using a dual-task paradigm, Naveh-Benjamin and colleagues measured attentional costs of strategy implementation in young and older adults. Although both young and older adults' performance benefitted to a similar degree from strategy instructions, it did so at much greater attentional cost to older adults, as assessed by decreased dual-task performance. In contrast, pair relatedness selectively helped older adults at no additional attentional cost. Similarly, in a study conducted by Shing et al., (2008), young and older adults improved to a similar degree, but only with semantically-related paired-associates. With unrelated paired-associates, young adults improved their performance to a greater degree than older adults did.

In addition to a strategy utilization deficit, there may be non-strategic factors that contribute to age-related associative memory decline. Indeed, Shing and colleagues (2008) found that even after several sessions of practice implementing mediators, the age-related deficit persisted (i.e. that is that both young and older adults continued to improve to the same degree,

thus maintaining the difference in performance). They have concluded that older adults' deficits in associative memory may reflect not only lower levels of strategic functioning but also an additional impairment in binding.

Taken together, these results suggest that a strategy production deficit may play a role in constraining older adults' associative memory performance, but that this is easily remediated by providing them with strategy instructions. However, although older adults may benefit from strategies to the same degree as young adults, it may be at greater attentional cost (Naveh-Benjamin et al., 2005). In addition, both individual differences (e.g. IQ, fluid intelligence) and the degree of pre-existing associations in the pairs to be encoded, may impact older adult's effective strategy use. Yet, even under conditions where older adults were able to improve their performance more so than young adults, there still remained a significant difference in performance between young and older adults (with the exception of Naveh-Benjamin et al., 2007). This points to what is likely a combination of an age-related reduction in effective strategy utilization, and to non-strategic factors such as the binding component. However, most of what we know about aging, strategies and associative memory has used verbal-paired associates (i.e. within-domain associations). There are significantly less data available on age-related strategic deficits on different types of associations. If between-domain associations do indeed place heavier demands on MTL-mediated binding processes, then we might also expect heavier demands on strategic processes (i.e. as a sort of compensatory mechanism). If this hypothesis holds, then we might expect that age-related strategic deficits (i.e. either at the production or utilization level) be larger when encoding between-domain associations than when encoding within-domain associations.

Strategies and between-domain associations

To my knowledge, the only two studies to date that have controlled strategies and measured strategy production with item-by-item report in between-domain associations were conducted by Kuhlmann and Touron (2012 and 2016). Older adults showed impaired word-location, word-font, and word-voice memory, but interestingly, there was no evidence of a strategy production or utilization deficit. However, because there was no comparison of within- and between-domain associations in the same study (i.e. within-participant design), the data do not tell us whether one type of association is more sensitive to the effects of aging and/or to age-related strategic deficits. In addition, these studies used only two location sources, such that a multitude of words were paired with one of two locations, text-type, or source (i.e. many-to-two mapping of words to location, text-type, or source). Because age differences may be smaller when associating a new item (e.g. word) with an already learned one (e.g. one of the two locations, text-type, or source) (Old & Naveh-Benjamin, 2008), it is possible that these conditions may have made it easier for older adults to generate and use strategies, thereby potentially precluding any discernible age-related differences associative memory and/or strategic behaviour.

The impact of inter-individual variability on associative memory and strategies

Increasingly, researchers of cognitive aging go beyond describing age-related group differences in performance to identify and measure individual differences that may mediate and/or moderate any effects of age. This approach will certainly provide a more accurate and complete picture of memory in aging, particularly as variability in episodic memory may in fact increase with age (Lindenberger, 2014; Lindenberger & Ghisletta, 2009; Morse, 1993; Wilson, 2002). Longitudinal studies of age-related structural brain changes also suggest significant

individual variability in the degree of age-related volume losses (Lindenberger, 2014) with the MTL and PFC showing particularly large inter-individual variability (Raz et al., 2005). Inter-individual differences within the older adult age group are also important to consider in the context of memory training. Indeed, the results of several studies suggest that older adults vary significantly in their ability to improve their associative memory performance when provided with strategy instructions or training (Ariel, Price, Hertzog, 2015; Fandakova, Shing, & Lindenberger, 2012; Frankenmolen et al., 2016). Three factors that are considered to influence associative memory and strategic behaviour are individual differences in executive functioning, meta-memory and general cognitive abilities.

Executive functioning. Executive Functioning (EF) refers to a set of PFC-mediated cognitive abilities required to guide effortful and goal-oriented behaviour (Banich, 2009), such as intentionally learning associations. Lesion studies, as well as structural and functional imaging studies with healthy older adults illustrate the importance of the PFC for strategic processes. Indeed, patients with PFC lesions generate less elaborative encoding strategies during intentional encoding than healthy aged-matched controls (Gershberg & Shimamura, 1995; Alexander et al. 2009). In healthy aging, PFC grey matter volume has been associated with strategy use (Kirchoff, Gordon & Head, 2012), and age-related reductions of activation in the left PFC have been found to be most prevalent in conditions with high demands on strategic processes (i.e. intentional encoding conditions) (Dennis & Cabeza, 2008). In addition to its association with objective measures of strategy, EF has also been found to be associated with self-reported strategy use. Bouazzaoui et al. (2010) found that 82% of age-related variance in self-reported internal strategy use in everyday life (e.g. forming visual images) was accounted for by EF.

EF may be particularly important for associative memory, and may be even more predictive of associative memory performance than age itself. Glisky, Rubin and Davidson, (2001) found an associative memory deficit only in older adults with low EF, whereas older adults with high EF were found to perform just as well as young adults. The link between EF and episodic memory is thought to be mediated by strategic processes (Moscovitch & Winocur, 2002). This hypothesis has been supported in item memory studies (e.g. word list learning) (Angel, Fay, Bouazzaoui, & Insingrini, 2010; Bryan, Luczcz, & Pointer, 1999; Bunce, 2003; Souchay & Insigrini, 2004; Tacconat, Clarys, Vanneste, Bouazzaoui & Insingrini, 2007) and associative memory studies (Glisky et al., 2001; Tacconat et al., 2006). For example, Glisky et al., (2001) were able to significantly reduce the associative memory deficit in low-EF older adults by providing them with an implicit encoding strategy. Although these findings provide some evidence suggesting that strategic processes mediate the effects of executive functioning on associative memory, none of these studies have directly measured explicit, volitional, goal-oriented strategies produced and used by their participants.

Meta-memory. Meta-memory includes beliefs about cognition, knowledge about cognitive processes, and processes geared towards monitoring cognition (see review by Hertzog & Dunlosky, 2004). Beliefs about cognition include implicit theories about learning (e.g. belief that memory is malleable or not), as well as beliefs about one's own memory abilities (Hertzog & Dunlosky, 2004). Likely informed by negative cultural ageist stereotypes, many older adults hold inaccurate beliefs about their memory abilities (Hertzog & Hultsch, 2000). This underestimation of one's own memory may have important repercussions on memory performance. Indeed as highlighted by Troyer and Rich (2002), poor appraisal of one's own memory can contribute to reduce one's sense of self-efficacy towards it (e.g. believing that one

holds little control over what they are able to learn and retain). Lower memory self-efficacy in turn may lead to a reduction in the use of learning strategies, thus potentially reducing memory performance (Hutchens et al., 2013; Lachman & Andreoletti, 2006; Lachman, Weaver, Bandura, & Elliot, 1995, but see Hertzog, McGuire, Horhota, & Jopp, 2010). Another aspect of meta-cognition that may play an important role in mediating memory performance concerns knowledge about cognitive processes. In the context of memory, an important aspect of this knowledge pertains to effective and ineffective strategies for learning and memory, including the conditions under which a given strategy may be more or less effective (Hertzog & Dunlosky, 2004). Generally however, no clear age-related difference has emerged in strategy knowledge between young and older adults (e.g. Bender & Raz, 2012; Hertzog & Hultsch, 2000). Although it may not be an important factor to explain age-related difference in associative memory, individual differences in strategy knowledge have been associated with associative memory performance (e.g. Bender & Raz, 2012). For example, Bender and Raz (2012) found that greater endorsement of effective encoding strategies (i.e. mediators such as integrative imagery) was associated with greater hits and fewer false alarms on a test of associative memory. In addition, they found that greater endorsement of less effective encoding strategies (i.e. non-mediators such as rote repetition) was associated with fewer hits on the associative memory task.

General cognitive abilities. In healthy adults, general cognitive abilities are thought to mitigate age-related cognitive decline (Stern, 2009). Indeed, greater cognitive abilities have been associated with greater strategy production and strategy efficacy in older adults (Barrulli, Rakitin, Lemaire, & Stern, 2013). As described earlier, several studies have found that older adults with better cognitive abilities show greater improvement on associative memory tasks after practice or strategy instructions compared to older adults with lower cognitive abilities

(Ariel, Price & Hertzog, 2015; Fandakova, Shing & Lindenberger, 2012; Frankenmolen et al., 2016).

In sum, the existing evidence suggests that inter-individual variability in EF, meta-memory, and general cognitive abilities may all influence associative memory, strategy production, and strategy effectiveness. However, there have been no studies that have looked at the effect of these variables together, and whether memory for different types of associations is differentially associated with individual variations in these variables.

Original Contributions of the Thesis

Binding and strategic processes are probably both important (and may be interdependent) to support associative memory. Age-related changes in the integrity of both of these components and their interactions may contribute to age-related deficits in associative memory. One way to measure the role of these components is to vary the demands on these systems. Between-domain associations may place heavier demands on binding than do within-domain associations.

However, between- and within-domain associations have rarely been examined in the same study. In addition, in the few studies that have made this comparison, strategies have not been controlled or assessed. Yet we know from the within-domain association literature that strategies can affect performance and can drive at least part of the age-related associative deficit.

Thus the primary objectives of the following studies aim to:

- 1) Conduct a close comparison between within-domain (i.e. object-object) and between-domain (i.e. object-locations) associations to help answer whether within-domain associations are less hurt by aging than between-domain associations are.

- 2) Measure and control strategies to:
 - a. See whether the strategies that are known to be effective in word-word tasks are also effective with an object-object and an object-location task;
 - b. Test the strategy production and utilization deficit hypotheses with both within- and between-domain associations;
 - c. Test whether larger demands on binding lead to larger demands on strategic processes (i.e. are age-related difference in strategies larger in the between-domain association condition than in the within-domain association condition).

In older adults, above and beyond any effects of age, inter-individual variations in cognitive and non-cognitive factors may also impact associative memory and/or strategic processes. Thus, the secondary objectives of the following studies aim to:

- 3) Test whether individual variations in age, education, cognitive functioning, meta-memory and EF correlate with, and predict object-object and object-location memory;
- 4) Test whether individual variations in age, education, cognitive functioning, meta-memory, and EF correlate with, and predict strategy production and utilization (i.e. strategy effectiveness) on both tests;
- 5) Test whether any correlations between these individual differences, associative memory, and strategy production/utilization remain after controlling for age. Test whether these individual differences have any predictive power on associative memory and strategy production/utilization above and beyond any effects of age.

Data checking and screening procedure

All data were re-scored and data entry was double-checked. The relevant memory and strategy data were extracted from the E-Prime data files and copy-pasted into excel spreadsheets. Formulas to compute total counts of strategies and strategy accuracy rates were developed and double-checked. In addition, all data were re-pasted into excel into a separate “mirror” spreadsheet. These “mirror” spreadsheets were then subtracted from the original spreadsheets, and any discrepancies were flagged. This procedure helped to identify a few cases in which the wrong data had been copied.

The data were screened according to the procedure outlined by Tabachnick and Fidell (2007). First, univariate descriptive statistics including z-scores were inspected to identify out-of-range values, implausible means and standard deviations, as well as univariate outliers. In Experiment 1, the data of one young adult were excluded because of a score above 34 on the CES-D. In addition, two other univariate outliers were identified: one was an outlier on age ($z = 4.81$, participant age = 34); the other was an outlier on CES-D ($z = 3.33$, score = 33). Since these outliers were not on independent variables, they were both included in the analyses, untransformed. In Experiment 2, the data of four participants were excluded from further analyses because of a score above 34 on the CES-D. In addition, a univariate outlier was identified on object-object accuracy ($z = 3.31$, older adult score of 100% accuracy). We decided to run the analyses with and without the outlier to evaluate its influence on the distribution (details provided in the results section of Experiment 3). In Experiment 3, no data were excluded, and no univariate outliers were identified.

Second, the amount and distribution of missing data were evaluated. In Experiment 1, there were no variables with more than 5% of data missing. There were two older adults with

strategy report data missing because of a programming error. For these data, we used group mean substitution to estimate the missing data. In Experiments 2 and 3, there were no variables with more than 5% of data missing. No action was taken to replace these data.

Third, pairwise plots and histograms were inspected to check for nonlinearity and heteroscedasticity. To evaluate skew and kurtosis, we used a z-test by dividing skew or kurtosis by its standard error (Kim et al. 2013). If the result was greater than ± 1.96 , we concluded that there may be an issue with non-normality. To evaluate for heteroscedasticity, we used the F-Max test (i.e. ratio of the largest cell variance to the smallest). Using these methods, no issues of heteroscedasticity were identified in any of the three experiments. However, several distributions were flagged as being potentially skewed (and one distribution in Experiment 2 was also flagged as potentially being kurtotic). Given that repeated-measure ANOVA's are robust to mild to moderate violations of normality (Matt, 2016) we decided to uniformly apply parametric analysis, and in cases where skew was more severe, we followed-up with a post-hoc non-parametric test. The one distribution that was flagged as being kurtotic in Experiment 2 was the one on which an outlier had been identified. Running this analysis without this outlier reduced issues with kurtosis.

Fourth, data were screened for multivariate outliers using the Mahalanobis distance statistic. In Experiment 1, one multivariate outlier was identified (MAH distance of 25.18). We decided to run analyses with and without this outlier to determine whether these data were having an undue impact. Since the analysis yielded very similar results without this outlier, we decided to conserve these data. No multivariate outliers were identified in Experiments 2 and 3.

Finally, we evaluated variables for multicollinearity. We ran bivariate correlations between all independent variables and flagged any correlations higher than .90. Unsurprisingly,

we found multicollinearity between the number of mediators participants reported and the number of non-mediator strategies participants reported. Accordingly, we decided to analyze only the number of mediators participants reported.

CHAPTER 2. EXPERIMENT 1

Objectives and hypotheses

Our first objective in Experiment 1 was to test whether any age-related differences in associative memory would interact with the type of associative task (i.e. within-domain, or between-domain associations). We expected young adults to outperform older adults on both tasks, and we expected the age difference to be larger in the between-domain association task (i.e. object-location memory) than the within-domain association task (i.e. object-object memory). Our second objective was to measure strategies to see whether the mediators that have been shown to be effective in verbal paired-associate paradigms are also effective with object-object and object-location pairs. We also aimed to test the strategy production deficit hypothesis and the strategy utilization deficit hypothesis with both types of associative tasks. We expected that mediators would improve memory for both types of associations, that young adults would produce more mediators than older adults on both tasks, and that young adults would achieve greater accuracy on both tasks for mediated pairs compared to older adults.

Method

Participants

Thirty-four undergraduate students from the University of Ottawa (age range = 17-34), and thirty-two community dwelling older adults (age range = 61-81) participated in this experiment. Older adults were recruited through an advertisement published in the local newspaper and by word-of-mouth. Demographic information is presented in Table 1. Additional data from one young adult was excluded because of a score on the Center of Epidemiologic Studies Depression Scale (CES-D: Radloff, 1977) suggesting the presence of moderate to severe depressive symptoms (≥ 34). Undergraduate students received partial credit towards their introductory psychology course, and older adults received 25\$. Participants were exempt of any

current psychiatric or neurological illness. Participants did not have any significant cognitive impairment, as measured by the Montreal Cognitive Assessment (MOCA; Nasreddine et al., 2005). A cut-off score of 22 was used (Rosetti, Lacritz, Cullum, & Weiner, 2011), as the original cut-off score of 26 has been suggested to be too stringent. Since the effect size for the interaction between age and type of association (object-object vs. object-location) is not yet known, a medium effect size of 0.25 was selected. Based on this chosen effect size, our calculated a priori sample size was of 25 per group ($N=50$) to obtain 80% power (G*Power 3: Faul, Erdfelder, Lang & Buchner, 2007).

Table 1
Participant Demographic Information Experiment 1

	<i>n</i>	Age		CES-D		PSQI		Education Years		MOCA	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Young	34	20.06	2.93	11.38	7.36	6.53	2.69	13.53	1.26	--	--
Older	32	70.44	5.58	5.84	4.00	5.42	3.34	16.25	2.63	27.94	1.61

Design

Age (young vs. older) and test order were between-participants variables; type of association to be encoded (object-object vs. object-location) was manipulated within participants.

Materials

Memory Tests. Encoding stimuli were four lists of 15 unrelated object pairs. Objects were semantically unrelated familiar concrete objects (e.g. animals, food, vehicles, household items, sports equipment, etc.) from a standardized set of pictures (POPORO; Kovalenko, Chaumon, & Busch, 2012). Based on pilot testing results, three lists of 15 object pairs were used for the study phase of the object-object test (total of 45 object pairs), and one list of 15 object pairs was used for the study phase of the object-location pairs test. Each list of object pairs was

used in both the object-object and the object-location tests, creating four different combinations. In addition, the order of presentation of tests was counterbalanced, yielding a total of eight conditions. An additional two lists of four object pairs were used as practice trials for each test, as well as two lists of 8 object pairs that served as buffer items to control for primacy and recency effects. Object pairs were presented in various configurations on 5x5 grids (see Figure 1 for an example of a study trial for the object-object test, and Figure 2 for an example of a study trial for the object-location test).

The test phase of both tests used a four-alternative forced-choice method (i.e. 4AFC). On both tests, the three foils were previously studied objects or locations from other object-object pairs or object-location pairs (see Figure 3 for an example of a test trial for the object-object test, and Figure 4 for an example of a test trial for the object-location test).

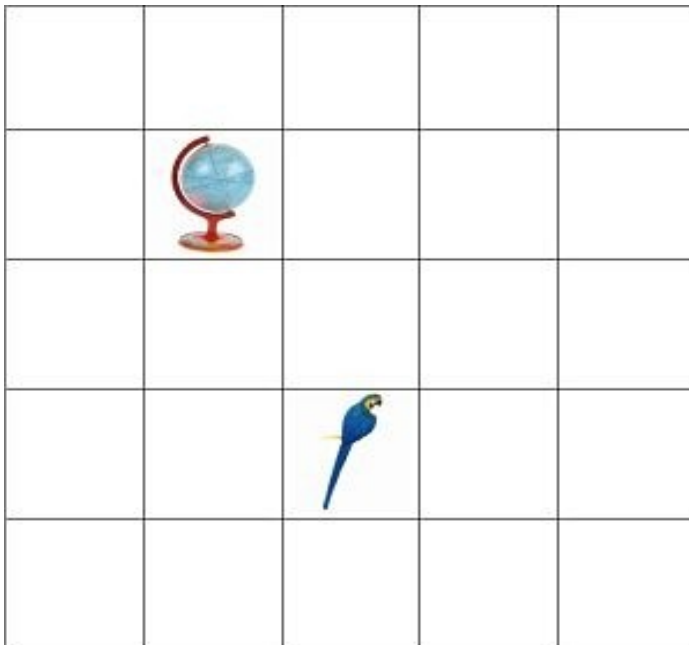


Figure 1. Encoding trial for the object-object test in Experiments 1 and 2.

Note. Configuration rules were as follows: no objects were presented in the corner or middle grid spaces, there were no fewer than one and no more than two grid spaces between objects, each grid space was occupied by an object a proportional number of times during the encoding phase (3-4 times), and object pairs were never presented on the same row or column.

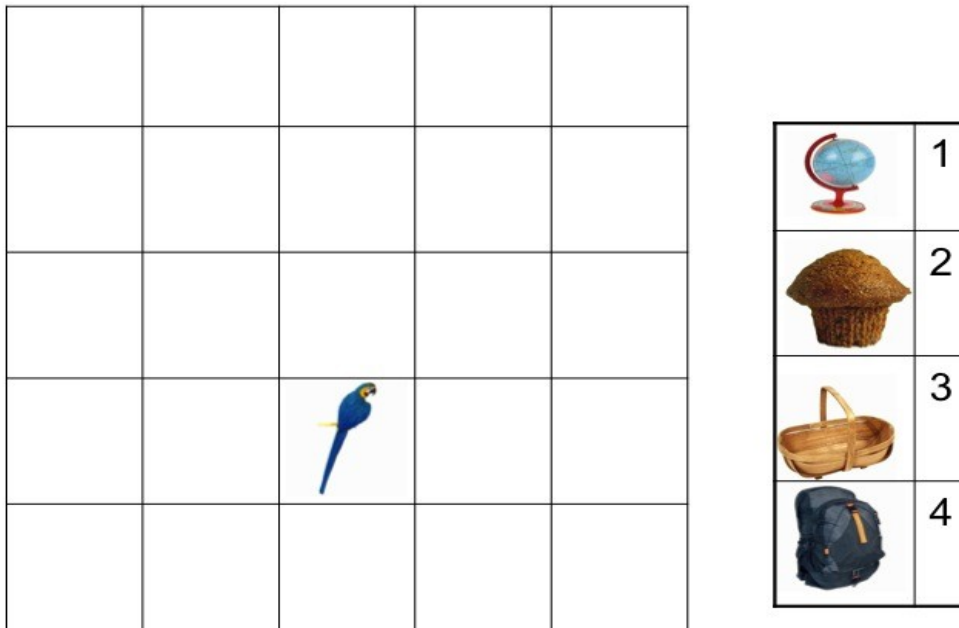


Figure 2. Test trial for the object-object test in Experiment 1.
Note. All foils were previously studied objects.

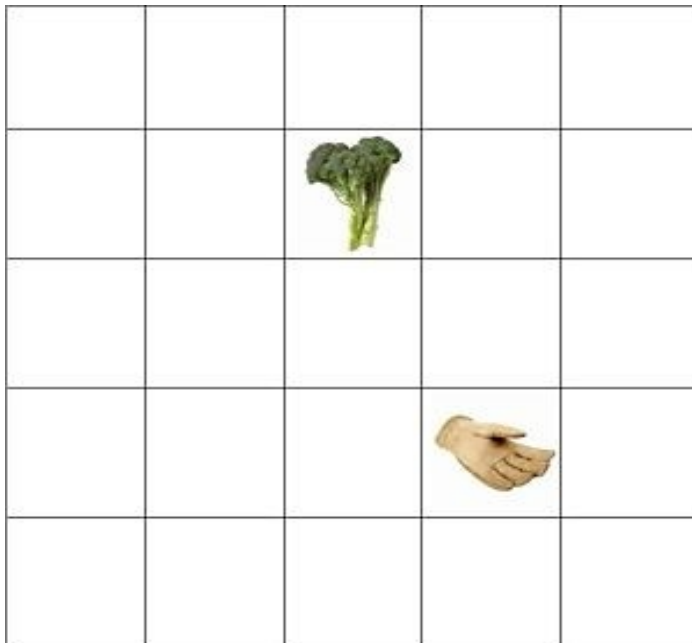


Figure 3. Encoding trial for the object-location test in Experiments 1 and 2.
Note. Configuration rules were as follows: no objects were presented in the corner or middle grid spaces; no fewer than one and no more than two grid spaces between objects; each grid space was occupied by an object a proportional number of times during the encoding phase (1-2 times); and object pairs were never presented on the same row or column.

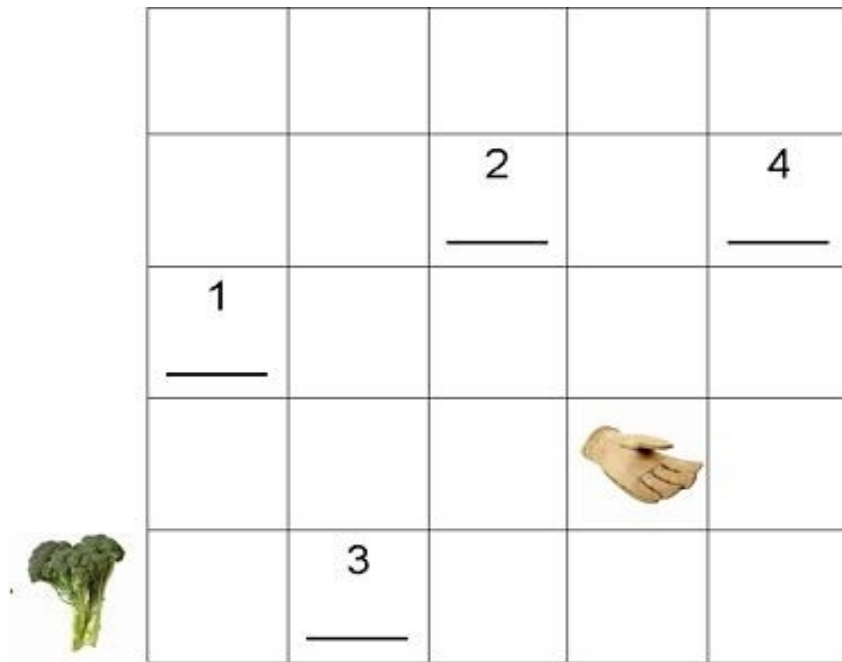


Figure 4. Test trial for the object-location test in Experiment 1.

Executive functioning. We used a series of tests grouped according to the results of two factor analyses (Glisky et al. 1995), with the exception of one test (Mental Arithmetic) that was later found to not load onto the executive functioning factor in young adults (Glisky & Kong, 2008). The included tests were the Wisconsin Card Sorting Test (WCST), the Verbal Fluency Test (FAS test), the Backward Digit Span from the Wechsler Adult Intelligence Scale IV (WAIS-IV), and the Mental Control test.

Other measures. Participants completed measures of mood (CES-D), sleep quality (Pittsburg Sleep Quality Inventory: PSQI), a general demographic questionnaire, and a health screening questionnaire. These measures were used for data screening purposes and to help interpret the data. In addition, they completed the Multifactorial Memory Questionnaire (MMQ: Troyer & Rich, 2002), and the Personal Encoding Preference Questionnaire (PEP: Hertzog & Dunlosky, 2004).

Procedure

Participants chose the time of day for testing and were tested individually. After signing the informed consent form, participants were asked to complete the demographic questionnaire, the health questionnaire, the PSQI and the CES-D. In addition, older adults completed the MoCA. Participants then received instructions for the memory tests. Participants were informed of the nature of the tests and were provided with the opportunity to practice and ask questions. In the object-object study phase, participants studied 51 object pairs (i.e. two practice pairs, four buffer pairs, and 45 critical pairs). Each object pair was displayed for 8 seconds to allow sufficient time for strategic encoding for both young and older adults (see Dunlosky & Hertzog, 1998, 2001; & Frankenmolen et al. 2016 for a similar approach). In the object-location study phase, participants studied 21 object-location pairs (i.e. two practice pairs, four buffer pairs, and 15 critical pairs). Each object-location pair was also displayed for 8 seconds. After each study phase, participants engaged in a distracting task (counting backwards by 3's) for 90 seconds to prevent rehearsal of the material. Following this interval, the corresponding test phase was administered (object-object or object-location). We always administered one study phase (object-object or object-location), followed by its corresponding test phase, prior to starting the other study and test sequence. We counterbalanced whether object-object memory or object-location memory was studied and tested first, or second.

For the object-object test phase, participants were exposed to one object of each pair (49 pairs) in a new randomized order. Each object presented was placed in its original location in the grid, and participants were asked to select the appropriate object to complete the original pair from a list of four previously studied foils (i.e. objects from other pairs). The location of the target in this list of four boxes was randomized. The test phase was self-paced. Participants were

encouraged to guess if they could not remember. For the object-location test phase, participants were exposed to one of the object-location's of each pair (19 pairs) placed in its original location in the grid, in a newly randomized order. Participants were asked to select the location in which the second object-location was previously located from a list of four alternatives (one accurate location and three locations from previously studied object-location pairs).

Following both study and test sequences, strategy production was measured with retrospective, trial-by-trial self-report. Participants were presented with strategy descriptions (see Appendix A for further details). Using different types of strategies or not using strategies on each trial was normalized, and participants were encouraged to report this when this was the case. Participants were asked to report only one strategy for each trial. In cases in which more than one strategy was used, participants were encouraged to report the most prominent strategy. Following these instructions, the encoding stimuli of both tests were once again presented. For each object-object pair and object-location pair, participants were asked to report and describe their use of an encoding strategy. Participant responses were recorded by the experimenter.

Participants then completed the following tests from the executive functioning battery in the following order: FAS test, Backward Digit Span, Mental Control, and WCST. Participants then completed the MMQ and PEP questionnaires.

Results

Memory Performance

First, we asked whether there were age-related differences in both associative memory tasks, and whether any age-related differences were larger in the between-association memory task than the within-association memory task. Data screening revealed that one distribution was

skewed ($z = -2.34$) (see Appendix B for histogram). We conducted a 2 (age group: young vs. older adults) X 2 (type of association: within vs. between) repeated-measures ANOVA. The analysis revealed a main effect of type of association ($F(1, 64) = 61.70, p < .001, \eta_p^2 = .491$), with participants correctly recalling a significantly higher proportion of object-object pairs ($M = .82, SD = .15$) than object-location pairs ($M = .63, SD = .18$). In addition, there was no main effect of age ($F(1, 64) = 1.920, p = .171, \eta_p^2 = .029$), indicating comparable performance between age groups. Finally, although the interaction between type of association and age was not statistically significant, ($F(1, 64) = 1.567, p = .215, \eta_p^2 = .024$), the means suggested that there was a larger difference between age groups on the object-object test (.08 difference) compared to on the object-location test (.02 difference). Our observed power was .59, because the size of the interaction effect was smaller than anticipated. These results are presented in Figure 5.

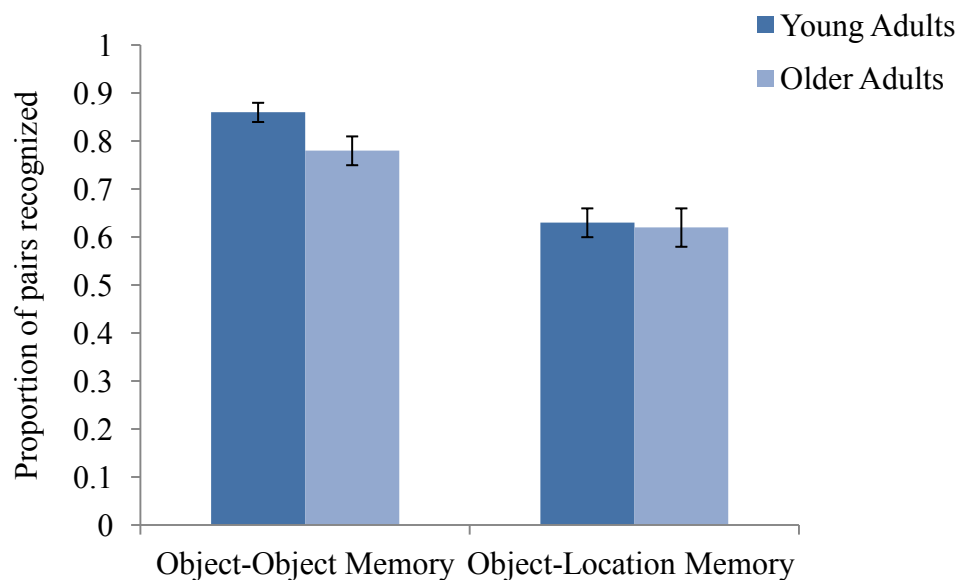


Figure 5. Proportion of correctly recognized pairs by age group and type of association

Strategy use

Prior to running our analyses, we divided strategies into two broad categories: mediators vs. non-mediator strategies. The strategies we included in the mediator strategy category for the object-object and the object-location tests were the following: integrative imagery (i.e. creating a mental image which integrates both objects and/or object and location to be encoded), sentence generation (i.e. creating a sentence incorporating both objects and/or object and location), personal relatedness (i.e. relating both objects and/or object and location to a personally-experienced event), visual similarity (i.e. focusing on similar visual characteristics of the objects such as in shape and colour), semantic relatedness (i.e. relating objects based on a common function or characteristic), and phonetic similarity (i.e. identifying that both objects start with the same letter when applicable). We used a more global definition of “mediator” than has been used in word-word paradigms, to account for other types of mediators that participants could generate to encode visual-spatial associations. Every strategy included in the mediator category involved creating some kind of link between the objects or an object and its location.

The strategies we included in the non-mediator category for the object-object test were the following: focal attention (i.e. focusing on the objects and/or object and location by looking or staring at it until the items can be seen in one’s mind), rote repetition (i.e. repeating the object names and/or object and location over and over), and no strategy (i.e. anytime a strategy was not used or an attempt to use a strategy was made, but the participant ran out of time). For the object-location test, the non-mediator category also included counting grids (i.e. counting the number of grids between object-location pairs, or between object-locations and the edge, side, or corner of the grid). All strategies included in the non-mediator category involved no elaboration on the associative link between objects or object and location..For both memory tests, we excluded

from analysis any strategies falling within the “other strategy” category, because the nature of these strategies was ambiguous (see Dunlosky & Hertzog 1998, 2001; and Kuhlman & Touron, 2012 for a similar approach). Proportions of items that participants reported studying by given strategies are presented in Appendix C.

First, we asked whether there was an age difference in mediator production on both the object-object test and object-location test, and whether the proportion of mediators produced depended on the type of association to be encoded. Data screening revealed no significant issues with outliers or normality. We conducted a 2 (age group: young vs. older adults) X 2 (type of association: within vs. between) repeated-measures ANOVA on the proportion of items reported to have been encoded with a mediator. The analysis revealed a main effect of type of association ($F(1, 64) = 128.845, p < .001, \eta_p^2 = .491$), with participants reporting using more mediators on the object-object test ($M = .73, SD = .16$), than on the object-location test ($M = .29, SD = .28$). In addition, there was no main effect of age ($F(1, 64) = 0.012, p = .913, \eta_p^2 = .001$), indicating comparable mediator production between age groups. Finally, the interaction between the type of association and age on mediator production was not statistically significant, ($F(1, 64) = .006, p = .939, \eta_p^2 = .001$). These results are presented in Figure 6.

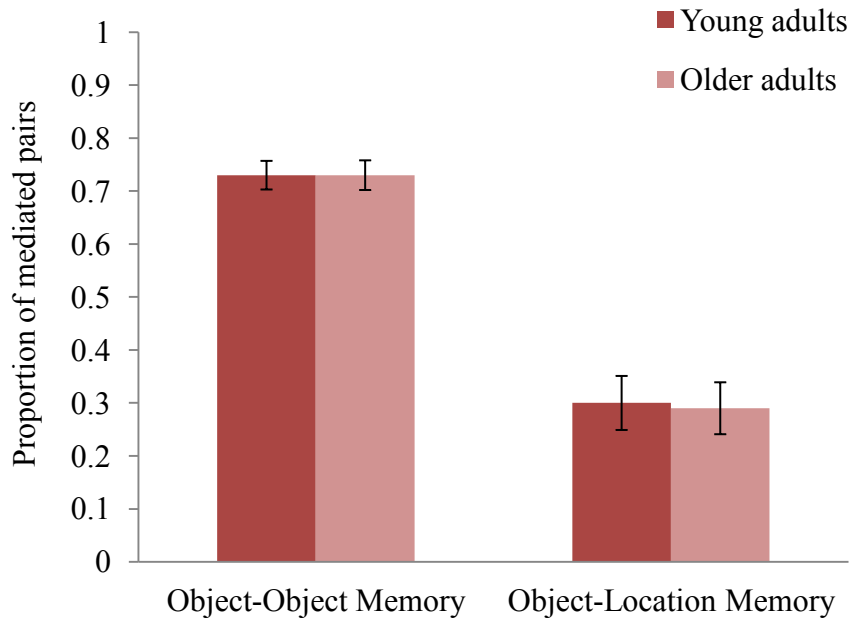


Figure 6. Proportion of mediators reported by age group and type of association

Second we asked whether there was an age difference in accuracy on the object-object test for pairs encoded either with mediators or with non-mediator strategies. The data of one young adult were dropped from these analyses because they did not report strategies in both categories (i.e. they only reported using mediators). Proportions of correct paired-associate recognition performance as a function of the strategies participants reported producing during encoding are presented in Appendix D. Data screening revealed significant skew of accuracy for mediated pairs for both young ($z = -2.59$) and older adults ($z = -3.31$), and significant skew of accuracy for non-mediated pairs for young adults ($z = -2.33$). The histograms of these skewed distributions are presented in Appendix B. These negatively skewed distributions reflect the high performance of young and older adults on the object-object task when using mediators. The fact that the young adult's accuracy when using non-mediators was also negatively skewed suggests that they may not have needed elaborative strategies to perform well on this task. We conducted

a 2 (age group: young vs. older) X 2 (strategy type: mediator vs. non-mediator) repeated measures ANOVA on object-object accuracy. The analysis revealed a main effect of strategy type; mediator strategies led to greater accuracy on the object-object test ($F(1, 63) = 48.679, p < .001, \eta_p^2 = .436$). In addition, there was a main effect of age indicating that young adults had higher overall accuracy than did older adults ($F(1, 63) = 5.046, p = .028, \eta_p^2 = .074$). Finally, the interaction between age group and strategy type was not significant ($F(1, 63) = .105, p = .747, \eta_p^2 = .002$). Given more significant skew we also ran non-parametric Mann-Whitney U post-hoc tests to follow-up on these results. These results suggested that young adults *did* have greater accuracy than older adults on the object-object test on pairs that were reported to be encoded with a mediator ($U = 362.00, p = .019, r = .29$). Young and older adults did not differ on object-object accuracy on pairs that were reported to be encoded with a non-mediator ($U = 410.00, p = .121, r = .19$). Means are presented in Figure 7.

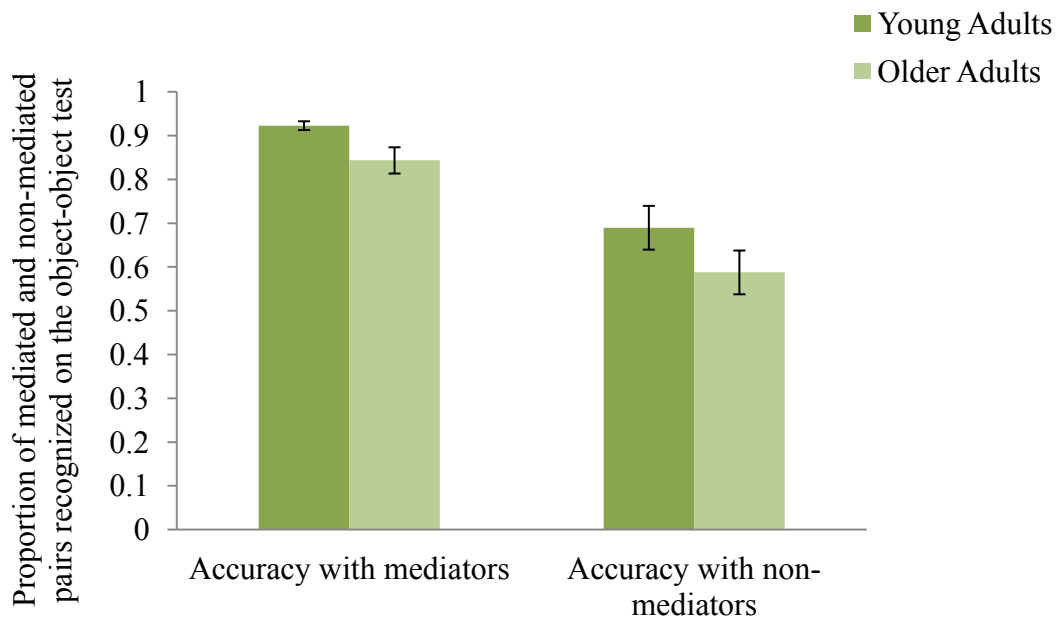


Figure 7. Proportion of correct object-object recognition by age group and by type of strategy used at encoding (mediator vs. non-mediator)

Third, we asked whether there was an age difference in accuracy on object-location memory for pairs encoded either with mediators or with non-mediators. The data of 14 young adults and 9 older adults were excluded from this analysis because they had not reported strategies in both categories. Data screening revealed significant skew of accuracy on object-location memory for mediated pairs in older adults ($z = -2.53$, histogram presented in Appendix B). We conducted a 2 (age group: young vs. older) X 2 (strategy type: mediator vs. non-mediator) repeated measures ANOVA on object-location accuracy. The analysis revealed a main effect of strategy type, with mediators leading to greater accuracy ($F(1, 41) = 5.92, p = .019, \eta_p^2 = .126$). The main effect of age was not significant, indicating comparable accuracy between age groups on object-location memory ($F(1, 41) = 1.020, p = .318, \eta_p^2 = .024$). Finally, the interaction between age and strategy type on accuracy was also non-significant ($F(1, 41) = .042,$

$p = .838$, $\eta_p^2 = .001$). We ran non-parametric Mann-Whitney U post-hoc tests to follow-up on these results. These results were in line with the results of the parametric analysis: there was no significant difference between young and older adults on their object-location accuracy on pairs that were reported to be encoded with a mediator ($U = 199.00$, $p = .311$, $r = .15$) or with non-mediator strategies ($U = 441.00$, $p = .729$, $r = .04$). Means are presented in Figure 8.

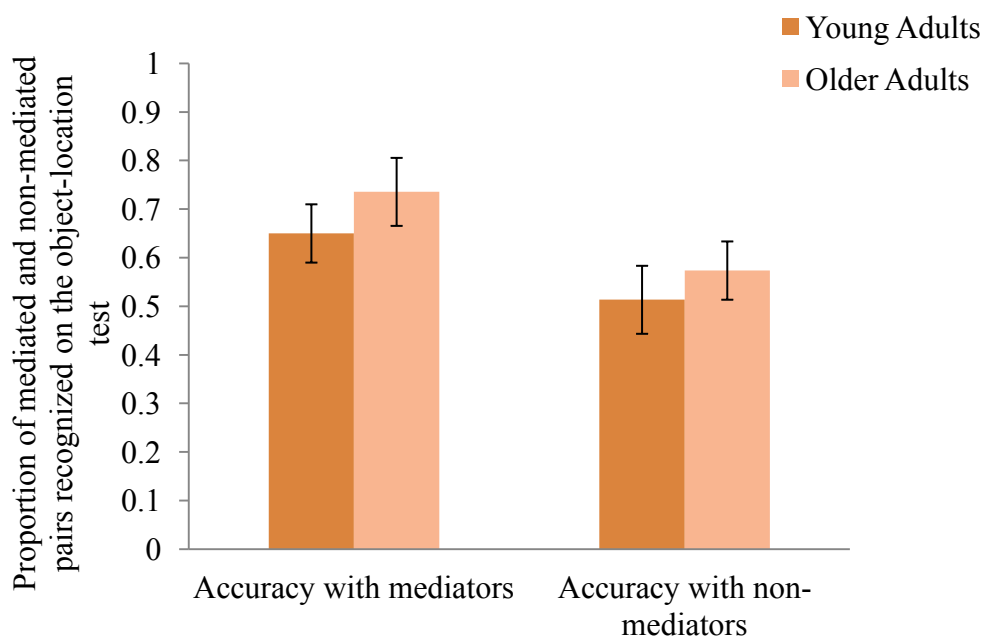


Figure 8. Proportion of correct object-location recognition by age group and by type of strategy used at encoding (mediator vs. non-mediator)

Discussion

The results of this experiment hinted that aging does not affect memory for different types of associations to the same degree. However, in contrast the idea that between-domain associations may tax binding more heavily (Borders et al., 2017; Mayes et al., 2001; 2002; Vargha-Khadem, et al. 1997) and thus may be more affected by aging (Bastin & Van der Linden, 2006; Troyer et al., 2011), our results hinted that within-domain associations may yield greater

age differences in memory. Indeed, although the interaction between age and performance by type of association was not statistically significant, numerically, the age difference favouring young adults was larger for the object-object task, whereas there was no statistically significant difference in performance between age groups on the object-location task. This was the first question we sought to follow up on in Experiment 2.

In addition to conducting this close comparison between within-domain and between-domain associations, we also measured strategies generated at encoding by young and older adults to assess their unique contributions to associative memory, and their interaction with the type of association to be encoded. Our strategy report data do not support the strategy production deficit hypothesis: despite not being instructed or informed to do so, older adults reported generating the same number of mediators as did young adults. Interestingly, both young and older adults reported encoding a much larger proportion of object-object trials using a mediator than for object-location trials suggesting either that participants found it more difficult to generate mediators for the object-location task, or that they judged that doing so would not support their object-location memory. Either way, our results suggest that age-related differences in strategy production did not account for any age-related differences in associative memory.

Our results do however support the strategy utilization deficit hypothesis of aging and suggest that age-related differences in strategy effectiveness may at least partially drive the age-related difference in performance on the object-object task. Indeed, young adults had (numerically) greater accuracy than older adults on object-object recognition for pairs reported to have been encoded with mediators. Although mediators also seemed to improve object-location memory for both age groups, there were no age-related differences in accuracy of recognition for pairs reported to have been encoded with mediators. Overall, these results suggest that one of the

reasons aging may not affect within- and between-domain associations to the same degree is that different types of associations may elicit different strategic demands. In addition, these results suggest that mediators that have been shown to be effective for encoding word pairs also improve memory for object-object and object-location associations.

It is important to note however, that the age difference in performance on the object-object task was not large (and indeed was not statistically significant). The effect size of this age-difference was of $d = .50$, compared to the age-related associative memory deficit effect size of $d = .92$ reported in the Old and Naveh-Benjamin (2008). This relatively small age difference on the object-object task and the absence of an age difference on the object-location task may be due to the high level of environmental support provided in the current experiment. Specifically, the 4AFC format of the test may have reduced the need for participants to rely on strategies elaborated at study. Indeed, the accuracy of both age groups for pairs that were reported to have been encoded with “no strategy” was relatively high (see Appendix D). Reducing environmental support and increasing demands on self-initiated processes could increase the age-related associative memory deficit.

CHAPTER 3: EXPERIMENT 2

Objectives and hypotheses

Our main objective in Experiment 2 was to increase age differences on both memory tests by augmenting the levels of demands on self-initiated processes (i.e. going from a 4AFC task to a 20AFC). We expected that doing so would lead to young adults outperforming older adults on both tasks. We also expected that age differences would be larger in the object-location task. In addition, we expected young adults to produce more mediators and achieve greater accuracy for mediated pairs compared to older adults on both tasks.

Methods

Thirty-one undergraduate students from the University of Ottawa (age range = 18-26), and thirty-one community dwelling older adults (age range = 59-83) participated in this experiment. Undergraduate students received partial credit towards their introductory psychology course, and older adults received 25\$. The data of three young and one older participant were excluded because of high scores on the CES-D (≥ 34), suggesting the presence of moderate to severe depressive symptoms. Demographic information of included participants is presented in Table 2. Included participants were exempt of any current psychiatric or neurological illness and did not show signs of any significant cognitive impairment. Although we had overestimated the size of the effect in Experiment 1 and ended up being underpowered, we anticipated a larger effect size in Experiment 2 because of the increase in difficulty. Thus, we used an estimated medium effect size of 0.25 for our a priori sample size calculations. Based on this expected effect size, our calculated a priori sample size was of 25 per group ($N=50$) to obtain 80% power (G*Power 3: Faul et al., 2007).

Table 2

Participant Demographic Information Experiment 2

	<i>n</i>	Age		CES-D		PSQI		Education Years		MOCA	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Young	31	19.13	1.48	12.74	7.64	6.33	2.75	12.53	.86	--	--
Older	31	70.45	7.29	9.90	6.33	3.34	14.00	16.45	2.83	27.45	1.88

Materials

The materials used in Experiment 2 were identical to those used in Experiment 1, with the following exception: the test phase of both object-object and object-location tests used a twenty-alternative forced-choice method (see Figure 9 and 10). On both tests, the 19 foils were previously studied objects or locations. The set of foils were different and randomized on each trial.

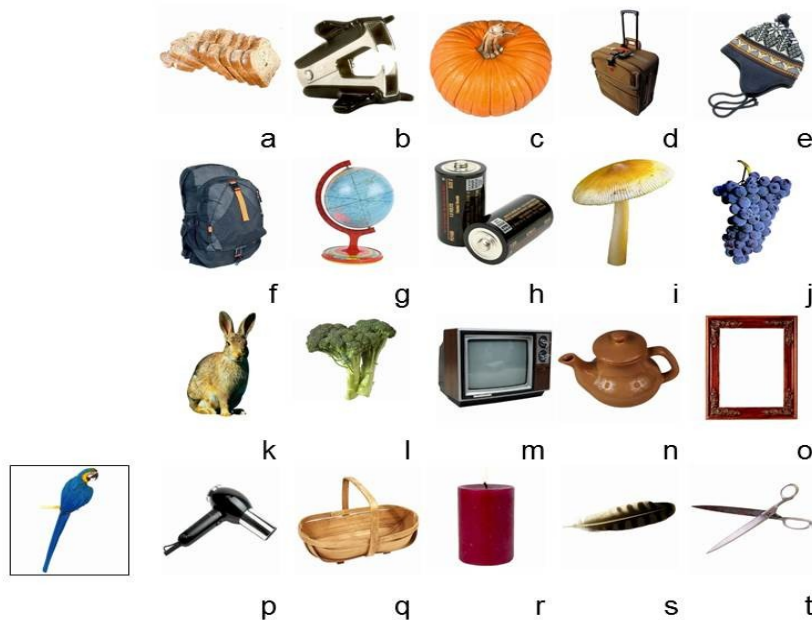


Figure 9. Test trial for the object-object test in Experiments 2 and 3

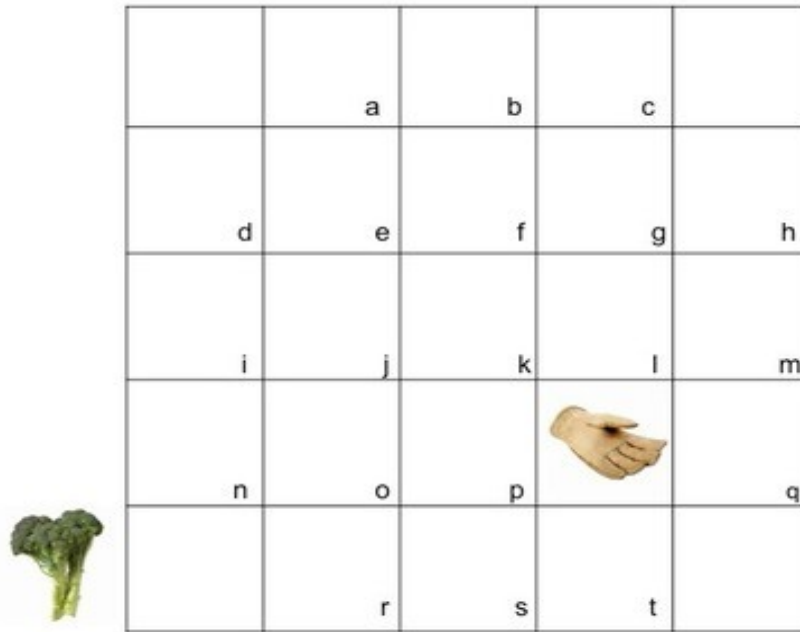


Figure 10. Test trial for the object-location test in Experiments 2 and 3

Procedure

The procedure was identical to that in Experiment 1, with the following exceptions: 1) young adults did not complete the executive functioning battery; 2) the mental arithmetic task was added to the executive functioning battery completed by the older adults; 3) the strategy report procedure was computerized, such that participants were asked to press a key to identify the strategy used to encode each pair instead of reporting these strategies orally to the experimenter.

Results

Memory Performance

First, we asked whether there were age-related differences in both associative memory tasks, and whether any age-related differences were larger in the between- than the within-domain association task. Data screening revealed that proportion of object-location pairs

recognized was skewed in older adults ($z = 2.55$). (See histogram presented in Appendix E). No other significant issues with outliers or normality were identified. We conducted a 2 (age group: young vs. older adults) X 2 (type of association: within vs. between) repeated-measures ANOVA. The analysis revealed a main effect of type of association ($F(1, 60) = 69.767, p < .001, \eta_p^2 = .538$), with participants correctly recalling a significantly higher proportion of object-object pairs ($M = .54, SD = .22$) than object-location pairs ($M = .28, SD = .20$). In addition, there was no main effect of age ($F(1, 60) = 2.240, p = .140, \eta_p^2 = .036$), indicating comparable performance between age groups. Finally, the statistical interaction between age and type of association was statistically significant, ($F(1, 60) = 9.829, p = .003, \eta_p^2 = .141$). Univariate ANOVA tests of simple main effects of age revealed that compared to older adults, young adults had significantly better performance on the object-object test ($F(1, 60) = 9.141, p = .004, \eta_p^2 = .132$) but not on the object-location test ($F(1, 60) = .522, p = .473, \eta_p^2 = .009$). Our observed power for this interaction effect was of .99. Results are presented in Figure 11.

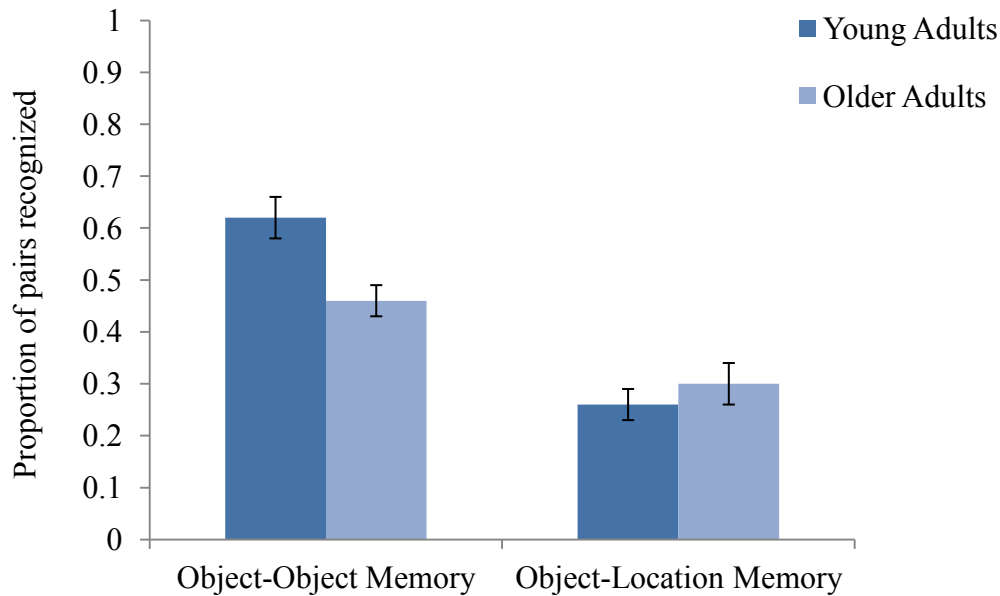


Figure 11. Proportion of correctly recognized pairs by age group and type of association

Strategy use

Strategies were divided in the same categories as used in Experiment 1: Mediator vs. non-mediator strategies. As was done in Experiment 1, strategies that fell into the “other” category were excluded from the analysis. Proportions of items that participants reported studying by given strategies are presented in Appendix F. First we asked whether there was an age difference in mediator production on the object-object test and the object-location test and whether the proportion of mediators produced depended on the type of association to be encoded. Data screening revealed significant positive skew of mediator production in young adults ($z = 2.23$) and older adults ($z = 3.05$), reflecting relatively high levels of mediator production in both age groups. Non-mediator production on the object-object test was also positively skewed in older adults ($z = 2.96$), suggesting that some older adults also reported high proportions of non-mediator strategies (See histograms in Appendix E). We conducted a 2 (age

group: young vs. older adults) X 2 (type of association: within vs. between) repeated-measures ANOVA on the proportion of pairs reported to have been encoded with a mediator. The analysis revealed a main effect of type of association ($F(1, 60) = 209.171, p < .001, \eta_p^2 = .777$), with participants reporting using more mediators on the object-object test ($M = .67, SD = .18$), than on the object-location test ($M = .19, SD = .23$). In addition, there was no main effect of age ($F(1, 60) = 3.034, p = .087, \eta_p^2 = .048$), indicating comparable mediator production between age groups. Finally, the interaction between the type of association and age on mediator production was not statistically significant, ($F(1, 60) = .711, p = .403, \eta_p^2 = .012$). Means are presented in Figure 12. A Mann-Whitney U follow-up test of age on mediator production on the object-location test was conducted. The results of this analysis were in line with the results of the parametric analysis: no age difference was found for mediator production on the object-object test ($U = 404.500, p = .284, r = .14$), or on the object-location test ($U = 402.500, p = .258, r = .14$).

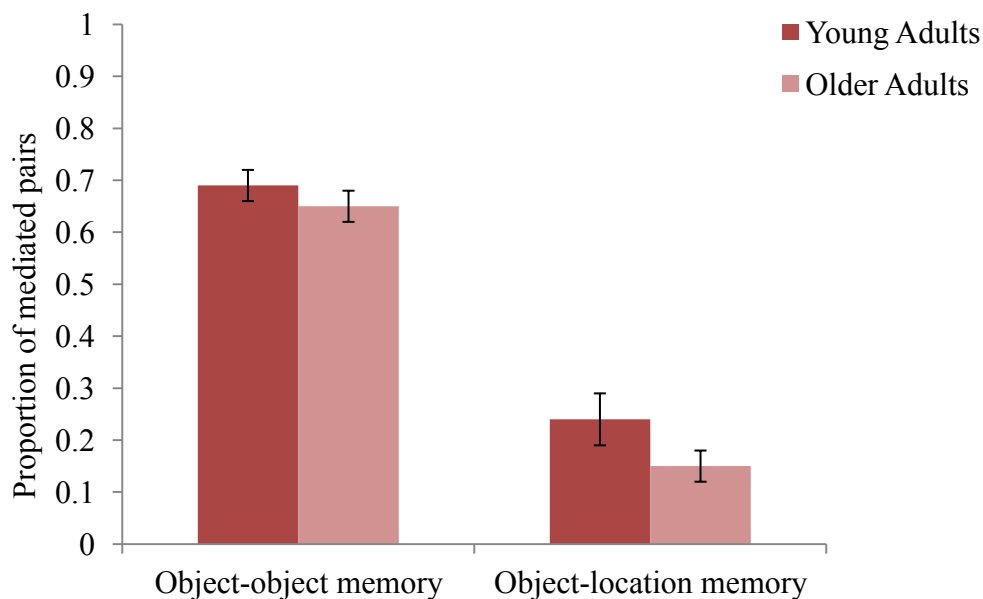


Figure 12. Proportion of mediators reported by age group and type of association

Second we asked whether there was an age difference in accuracy on the object-object test for mediated and non-mediated pairs. Proportions of correct paired-associate recognition performance as a function of the strategies participants reported producing during encoding are presented in Appendix F. Data screening revealed significant skew of the following distributions: object-object accuracy of mediated pairs for young adults ($z = -3.26$), and object-object accuracy of non-mediated pairs for both young ($z = 2.55$), and older adults ($z = 3.54$). In addition, object-object accuracy of non-mediated pairs for older adults was also kurtotic ($z = 2.96$). However, this distribution had an extreme outlier ($z = 3.31$). Removing this outlier from analyses significantly reduced skew (although it was still large: $z = 2.96$) and eliminated issues with kurtosis. Thus, we decided to remove this outlier from further analyses. The histograms of these skewed distributions are presented in Appendix E. The negatively skewed distribution of object-object accuracy of mediated pairs for young adults reflects their high accuracy for these pairs. Conversely, the positively skewed distributions of object-object accuracy for non-mediated pairs in young and older adults, reflects relatively lower performance for these poorly encoded pairs. We conducted a 2 (age group: young vs. older) X 2 (strategy type: mediator vs. non-mediator) repeated measures ANOVA on object-object accuracy. The analysis revealed a main effect of strategy type; mediators led to greater accuracy on the object-object test ($F(1, 59) = 130.673, p < .001, \eta_p^2 = .689$). In addition, there was a main effect of age indicating that young adults had higher overall accuracy than did older adults ($F(1, 59) = 8.962, p = .004, \eta_p^2 = .132$). Finally, the interaction between age group and strategy type was not significant ($F(1, 59) = .036, p = .851, \eta_p^2 = .001$). These results are presented in Figure 13. We ran non-parametric Mann-Whitney U post-hoc tests to follow-up on these results. These results suggested that young adults *did* have greater accuracy than older adults on the object-object test on pairs that were reported to

be encoded with a mediator ($U = 256.500, p = .003, r = .39$) and with a non-mediator strategy ($U = 304.000, p = .020, r = .30$).

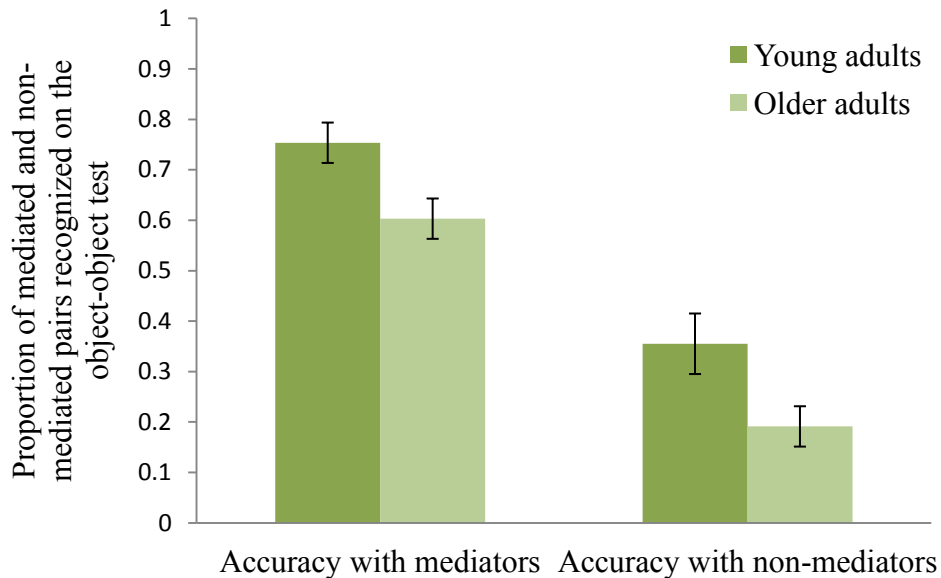


Figure 13. Proportion of correct object-object recognition by age group and by type of strategy used at encoding (mediator vs. non-mediator)

Third, we asked whether there was an age difference in accuracy on the object-location test for pairs encoded either with mediators or with non-mediators. Proportions of correct paired-associate recognition performance as a function of the strategies participants reported producing during encoding are presented in Appendix G. The data of 11 young adults and 13 older adults were excluded because they had not reported strategies in both categories. Data screening revealed that object-location accuracy for mediated pairs was skewed in young adults ($z = 2.36$), and object-location accuracy under non-mediated pairs was skewed in older adults ($z = 2.62$). Histograms are presented in Appendix E. The positively skewed distributions illustrate young and older adults' lower performance on this task, even for mediated pairs. We conducted a 2 (age group: young vs. older) X 2 (strategy type: mediator vs. non-mediator) repeated measures ANOVA on object-location accuracy. The analysis revealed no main effect of strategy type ($F(1,$

36) = .004, $p = .952$, $\eta_p^2 = .001$). The main effect of age was also non-significant, indicating comparable performance between age groups on the object-location task ($F(1, 36) = 1.210$, $p = .279$, $\eta_p^2 = .033$). Finally, the interaction between age and strategy type on accuracy was also non-significant ($F(1, 36) = .003$, $p = .957$, $\eta_p^2 = .001$). These results are presented in Figure 14. We ran non-parametric Mann-Whitney U tests to follow-up on these results. These results were consistent with those of the parametric analyses: there was no significant difference of object-location accuracy in young and older adults either for mediated pairs ($U = 173.00$, $p = .620$, $r = .08$) or non-mediated pairs ($U = 384.000$, $p = .439$, $r = .10$).

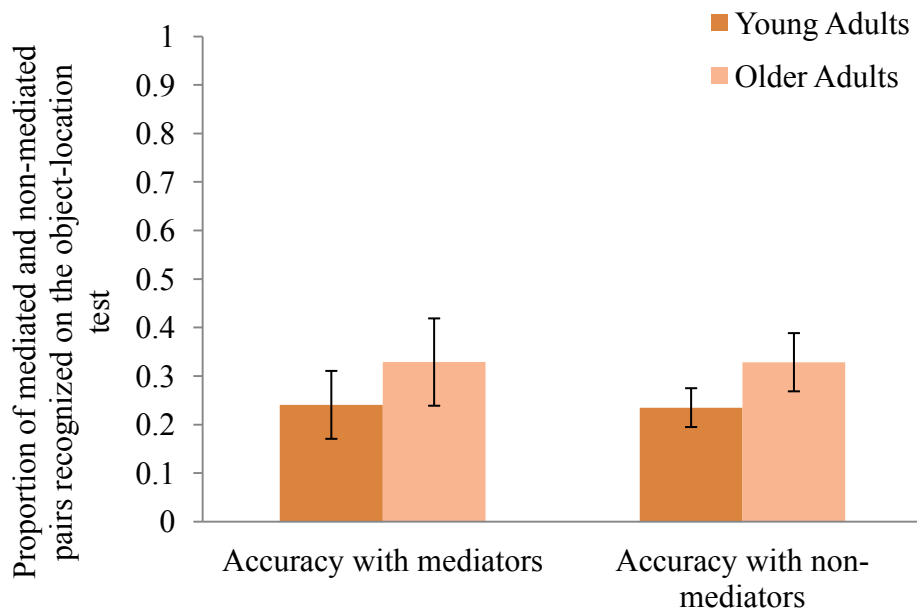


Figure 14. Proportion of correct object-location recognition by age group and by type of strategy used at encoding (mediator vs. non-mediator)

Discussion

The aim of Experiment 2 was to increase the difficulty of the associative memory tasks by augmenting demands on self-initiated processes (i.e. going from a 4AFC test in Experiment 1 to a 20AFC in Experiment 2). We predicted that doing so would increase age differences on memory performance for both types of associations. Surprisingly, although we did successfully increase the age difference on the object-object memory test, once again, there was no statistically significant age difference in performance on the object-location memory test. Thus, despite increasing demands on self-initiated processes, we replicated the hint of an interaction effect we obtained in Experiment 1, suggestive of an age-related dissociation in associative memory.

Mirroring again the results obtained in Experiment 1, without any strategy instructions, older adults produced as many mediators as did young adults. These data again do not support the strategy production deficit account of age differences in associative memory. Thus, even under conditions which significantly increased demands on self-initiated processes, older adults were just as proficient as young adults in producing mediators. Similarly to Experiment 1, both young and older adults reported producing a greater number of mediators on the object-object task ($M = .67$, $SD = .18$) than on the object-location task ($M = .19$, $SD = .23$). This pattern of results again suggests that participants either found it difficult to apply mediators to encode object-location associations, or judged them unnecessary for their learning.

Similarly to the results of Experiment 1, the results of Experiment 2 supported the strategy utilization deficit account of age differences in associative memory. First, mediator production was associated with increased performance for both young and older adults on the object-object task. Second, young adults had (numerically) greater accuracy on the object-object

test for pairs that they reported encoding with a mediator. In contrast, object-location performance was not significantly associated with mediator production on the object-location task. In addition, there was no age difference in accuracy on object-location memory for mediated pairs. In conjunction with the results from the previous experiment, these results support the idea that aging may differently affect memory for different types of associations, and that age differences in strategy effectiveness appear to at least partially drive this effect.

The results of Experiments 1 and 2 suggest that object-location memory is not associated with mediator use, which might explain why there is no age difference in performance on that task. However, there are certain task characteristics of the object-location test that could have made it difficult for both age groups to implement mediators. Indeed, compared to the object-object task where there was only one association to encode, on the object-location task, there were several (e.g. association between both objects, association between each object and its absolute location, association between each object and its location relative to the other object). Thus, in Experiment 3, we sought to exert more experiment control on strategies by providing strategy instructions, and make changes to the object-location task to make it more amenable to mediator use by indicating the critical object-location to be encoded (i.e. the one that would need to be relocated in the grid at the time of the test) at study.

CHAPTER 4. EXPERIMENT 3

Objectives and hypotheses

Our main objective in Experiment 3 was to exert more experimental control by providing strategy instructions, and to make the object-location task more amenable to mediator use. We expected young adults to outperform older adults on both associative tasks. In addition, we expected the age difference to be larger in the between-domain association task compared to the within-domain association task. Finally, we expected young adults to produce more mediators and achieve greater accuracy for mediated pairs than older adults on both tasks.

Method

Participants

Thirty-two undergraduate students from the University of Ottawa (age range = 17-26) and thirty-one community dwelling older adults (age range = 60-85) participated in this experiment. Undergraduate students received partial credit towards their introductory psychology course, and older adults received 25\$. No data were excluded from analyses. Participant demographic information is presented in Table 3. Participants were exempt of any current psychiatric or neurological illness and did show signs of cognitive impairment. Based on the estimated medium effect size of 0.25, our calculated a priori sample size was of 25 per group ($N=50$) to obtain 80% power (G*Power 3: Faul et al., 2007).

Table 3

Participant Demographic Information Experiment 3

	<i>n</i>	Age		CES-D		PSQI		Education Years		MOCA	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Young	32	19.28	2.07	13.88	8.69	6.03	2.68	13.00	1.32	--	--
Older	31	69.45	5.82	9.26	8.16	5.19	3.39	16.32	1.72	27.48	2.03

Materials

The materials used in Experiment 3 were identical to those used in Experiment 2 with the following exception: the encoding trials now included an arrow pointing to the critical object to be encoded. For the object-object encoding trials, the arrow pointed towards the object that would need to be identified to complete the pair at the time of the object-object test. For the object-location encoding trials, the arrow pointed towards the object that would need to be relocated in the grid at the time of the object-location test (see Figure 15 and 16 for examples of the study trials for the object-object and the object-location test).

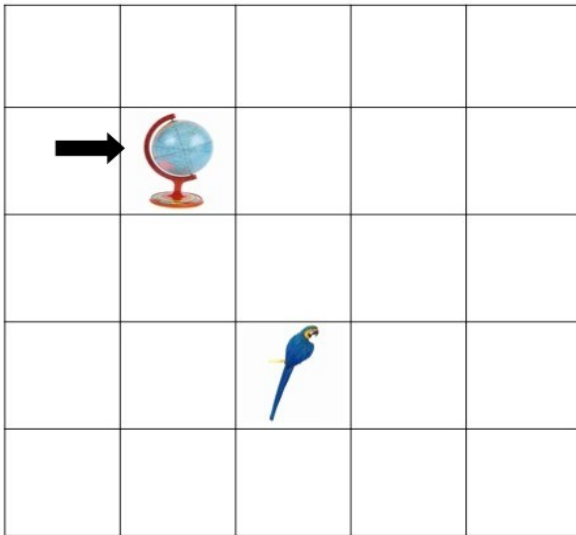


Figure. 15. Encoding trial for the object-object test in Experiment 3.

Note. The arrow is pointing to the object that will have to be matched to the other at the time of the test.

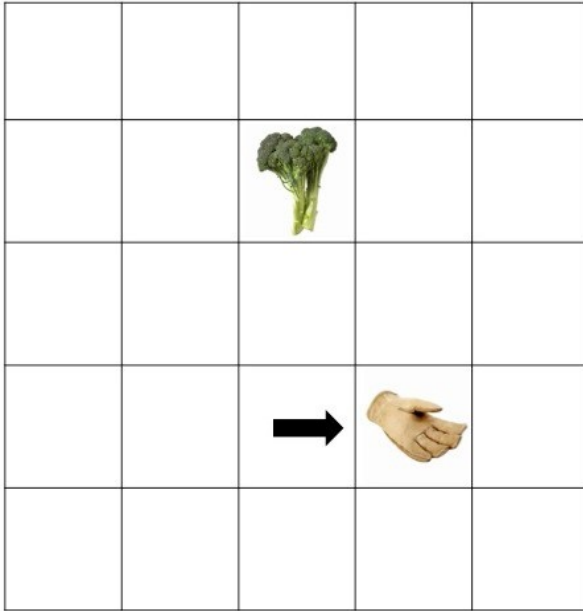


Figure 16. Encoding trial for the object-location test in Experiment 3.

Note. The arrow identifies the object that will have to be relocated in the grid at the time of the test.

Procedure

The procedure is identical to Experiment 2, with the exception that participants were provided with strategy information before the memory tasks. They were told that research has shown that forming a mental image integrating both objects (i.e. integrative imagery) and forming a sentence integrating both objects (i.e. sentence generation) are two very effective strategies to help remember associations between objects, or between an object and its location. Descriptions and examples of both strategies were provided. Participants were encouraged to use either one of these two strategies on each trial. They were encouraged to practice generating these strategies during the practice trials prior to the encoding stage of each test. If participants struggled generating integrative images or sentences during practice, examples were provided by the experimenter, until it was clear that the participant was able to generate integrative imagery and sentences on his or her own.

Results

Memory Performance

First, we asked whether there were age-related differences in both associative memory tasks, and whether any age-related differences were larger in the between-domain association memory task than the within-domain association memory task. Data screening revealed that the proportion of object-object pairs recognized was skewed in young adults ($z = -2.29$) (See histogram presented in Appendix H). No other significant issues with outliers or normality were identified. We conducted a 2 (age group: young vs. older adults) X 2 (type of association: within vs. between) repeated-measures ANOVA. The analysis revealed a main effect of type of association ($F(1, 61) = 73.40, p < .001, \eta_p^2 = .546$), with participants correctly recalling a significantly higher proportion of object-object pairs ($M = .73, SD = .22$) than object-location pairs ($M = .49, SD = .18$). In addition, there was a main effect of age ($F(1, 61) = 16.917, p < .001, \eta_p^2 = .217$), indicating that young adults generally outperformed older adults. Finally, the statistical interaction between age and type of association was statistically significant, ($F(1, 61) = 10.589, p = .002, \eta_p^2 = .148$). Univariate ANOVA's on simple main effects of age revealed that young adults outperformed older adults on the object-object test ($F(1, 61) = 26.180, p = .001, \eta_p^2 = .300$), but not on the object-location test ($F(1, 61) = 1.510, p = .224, \eta_p^2 = .024$). These results are presented in Figure 17.

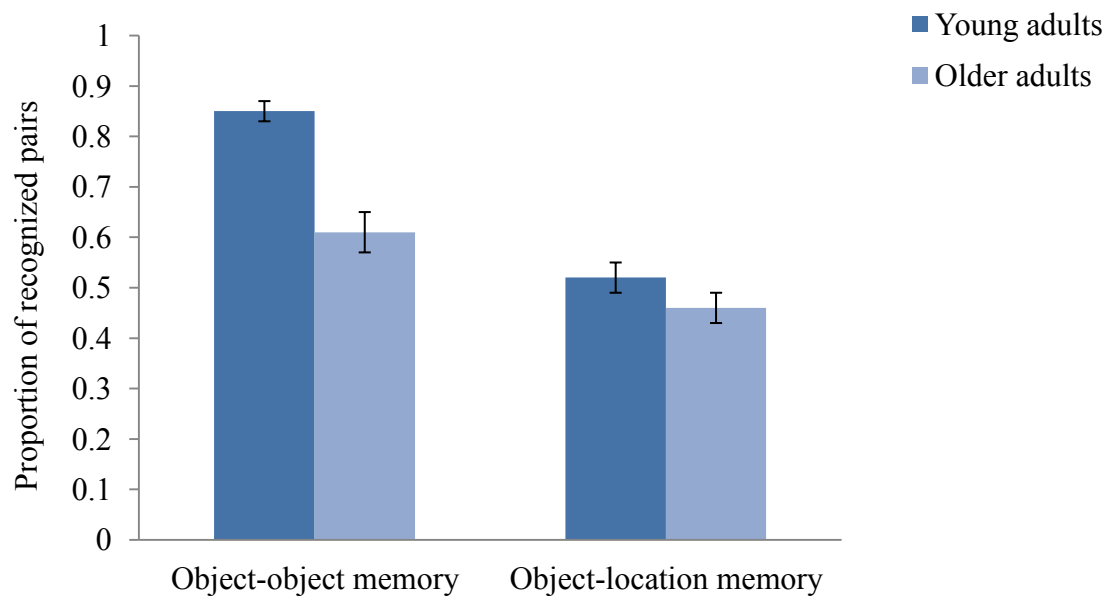


Figure 17. Proportion of correctly recognized pairs by age group and type of association

Strategy use

The strategies were divided into the same two categories as Experiments 1 and 2: mediator and non-mediator strategies. However, in this experiment, the only two strategies that were included in the “mediator” category were the strategies participants were instructed to use: integrative imagery and sentence generation. All other mediator strategies included in Experiments 1 and 2 (i.e. personal relatedness, visual similarity, semantic relatedness, and phonetic similarity) were excluded from analyses. The non-mediator strategy category remained the same as in Experiments 1 and 2 (i.e., rote repetition, focal attention, counting grids, and no strategy). In addition, all “other” strategies were excluded from analyses. Proportions of items that participants reported studying by given strategies are presented in Appendix I.

First, we asked whether there was an age difference in mediator production on the object-object test and the object-location test. Data screening revealed no issues with outliers or

normality. We conducted a 2 (age group: young vs. older adults) X 2 (type of association: within vs. between) repeated-measures ANOVA on the proportion of items reported to have been encoded with a mediator. The analysis revealed a main effect of type of association ($F(1, 61) = 7.794, p = .007, \eta_p^2 = .113$), with participants reporting generating more mediators on the object-location test ($M = .78, SD = .19$), than on the object-object test ($M = .70, SD = .22$). In addition, there was no main effect of age ($F(1, 61) = 1.142, p = .289, \eta_p^2 = .018$), indicating comparable mediator production between age groups. Finally, the interaction between the type of association and age on mediator production was not statistically significant, ($F(1, 61) = 1.807, p = .184, \eta_p^2 = .029$). These results are presented in Figure 18.

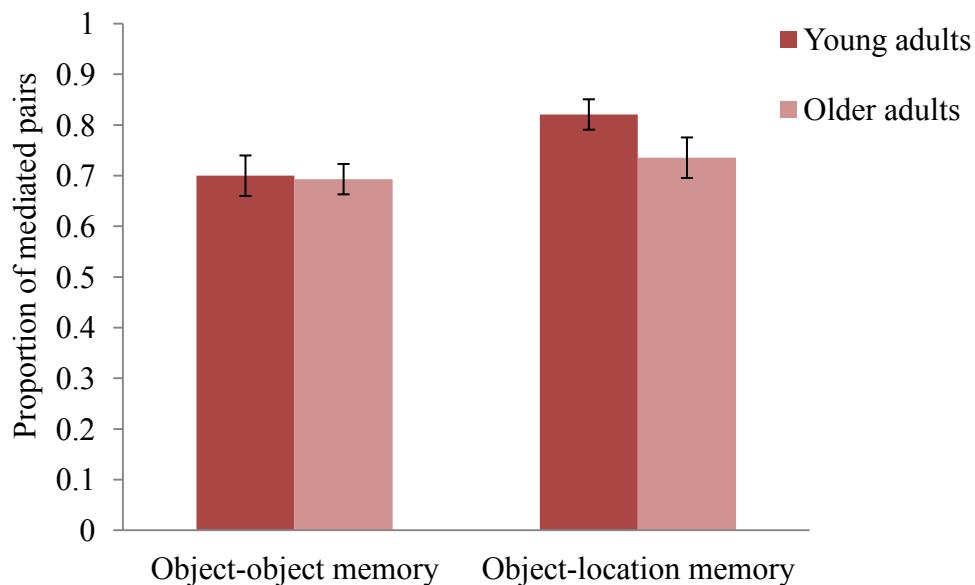


Figure 18. Proportion of mediators reported by age group and type of association

Second, we asked whether there was an age difference in accuracy on the object-object test for pairs encoded either with mediators or with non-mediators. Proportions of correct paired-associate recognition performance as a function of the strategies participants reported producing

during encoding are presented in Appendix J. The data of 10 young and 3 older adults were excluded from further analysis because they had not provided strategy reports in both categories (i.e. all of these participants reported using integrative imagery or sentence generation on all trials). Screening revealed significant skew of object-object accuracy under mediator encoding instructions for young adults ($z = -2.40$). This negatively skewed distribution reflects young adults' high rates of object-object recall for mediated pairs. The histogram of this skewed distribution is presented in Appendix H. We conducted a 2 (age group: young vs. older) X 2 (strategy type: mediator vs. non-mediator) repeated measures ANOVA on object-object memory. The analysis revealed a main effect of strategy type; mediators (i.e. integrative imagery and sentence generation) led to greater accuracy on the object-object test ($F(1, 48) = 15.948, p < .001, \eta_p^2 = .249$). In addition, there was a main effect of age indicating that young adults had higher overall accuracy on object-object memory than older adults ($F(1, 48) = 9.007, p = .004, \eta_p^2 = .158$). Finally, the interaction between age group and strategy type was not significant ($F(1, 48) = 3.082, p = .086, \eta_p^2 = .060$), although numerically, young adults did obtain greater object-object accuracy than did older adults for mediated pairs. These results are presented in Figure 19.

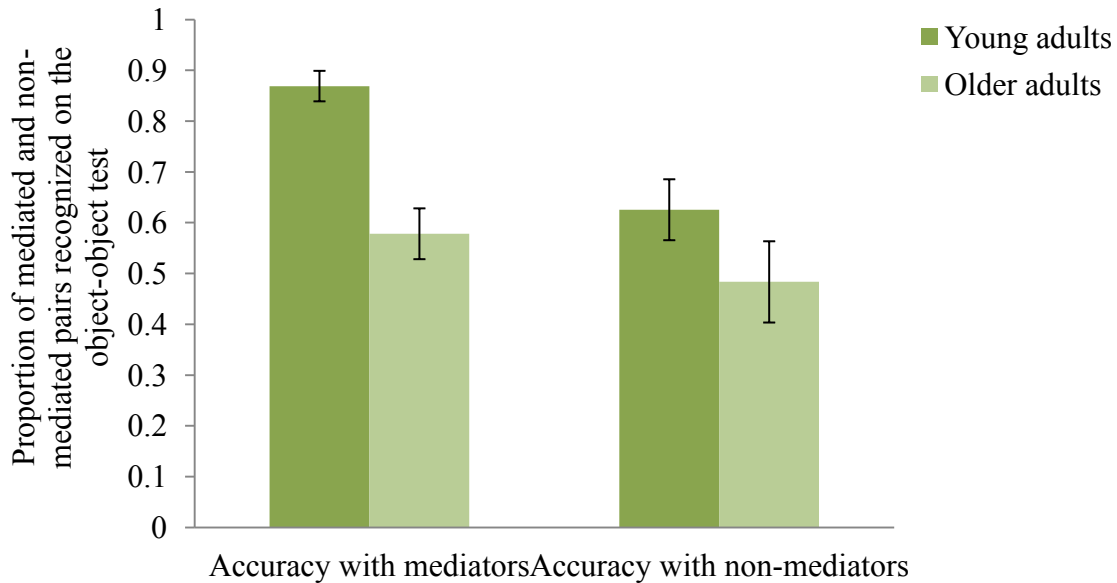


Figure 19. Proportion of correct object-object recognition by age group and by type of strategy used at encoding (mediator vs. non-mediator)

Third, we asked whether there was an age difference in accuracy on the object-location test for pairs encoded either with mediators or with non-mediators. Proportions of correct paired-associate recognition performance as a function of the strategies participants reported producing during encoding are presented in Appendix I. The data of 12 young adults and 10 older adults were excluded because they had not reported strategies in both categories (i.e. all of these participants reported using mediators on all trials). Data screening revealed no issues with outliers or normality. We conducted a 2 (age group: young vs. older) X 2 (strategy type: mediator vs. non-mediator) repeated measures ANOVA on object-location memory. The analysis revealed no main effect of strategy type ($F(1, 39) = .045, p > .833, \eta_p^2 = .001$). The main effect of age was also non-significant, indicating comparable performance between age groups on the object-location task ($F(1, 39) = .962, p = .333, \eta_p^2 = .024$). Finally, the interaction between age

and strategy type on accuracy was also non-significant ($F(1,39) = .067, p > .797, \eta_p^2 = .002$).

These results are presented in Figure 20.

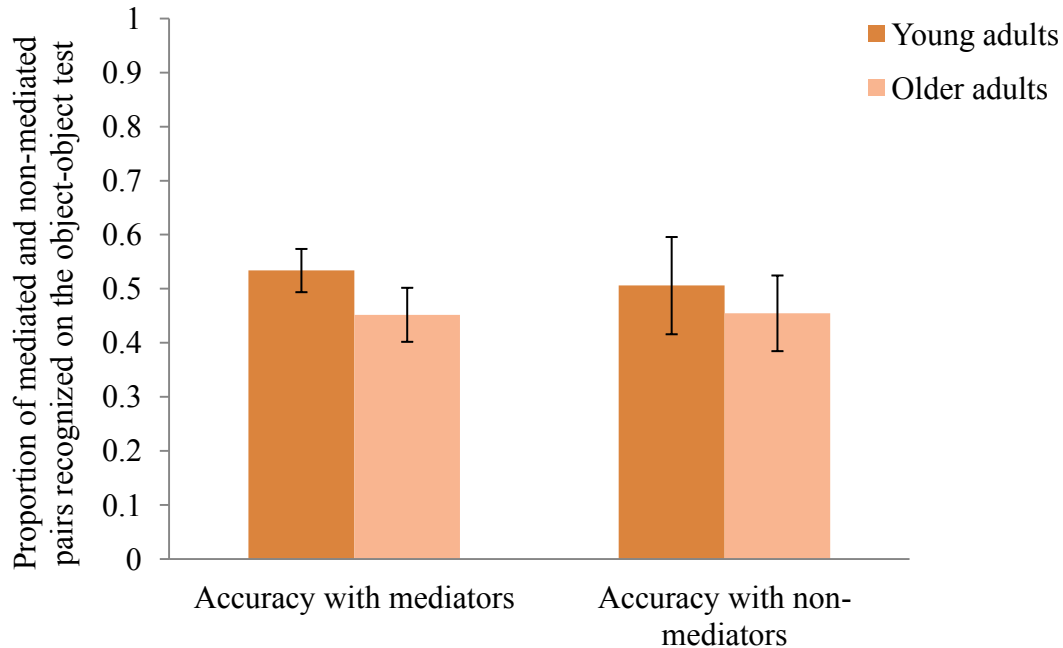


Figure 20. Proportion of correct object-location recognition by age group and by type of strategy used at encoding (mediator vs. non-mediator)

Discussion

Experiment 3 had two main objectives: 1) exert more experimental control on strategies by providing strategy instructions, and 2) make modifications to the object-location test to make it more amenable to mediator use. By making these changes, particularly the changes made to the object-location test, we expected that we would increase the age difference on both tasks, and perhaps even obtain the larger age difference favouring young adults for the between-domain task as expected. Despite our success in increasing overall mediator use in young and older on the object-location task, age differences in memory performance followed the same pattern

established in Experiments 1 and 2: young adults outperformed older adults on the object-object memory test, but there was no reliable age difference on object-location memory.

Results of Experiment 3 again do not support the strategy production deficit hypothesis of age differences in associative memory: when provided with strategy instructions, older adults were just as likely to produce as many mediators as young adults. In contrast to Experiments 1 and 2, in Experiment 3 we succeeded in significantly increasing the number of mediators young and older adults produced on the object-location task ($M = .78$, $SD = .19$), such that it slightly exceeded the number of mediators produced on the object-object task ($M = .70$, $SD = .22$).

Replicating the results of Experiments 1 and 2, results of Experiment 3 also support the strategy utilization deficit account of age differences in associative memory: young adults had (numerically) greater accuracy on object-object memory for pairs that they reported to have encoded with a mediator compared to older adults. In contrast, object-location memory was not significantly associated with mediator production. In addition, there was no age difference in accuracy on the object-location task for pairs reportedly encoded with a mediator.

Data from Experiment 3 produces more convincing evidence that the age difference in object-object performance is at least partially related to age-related differences in strategy effectiveness (i.e. accuracy for pairs encoded with mediators). There is more evidence that this age-related difference has more to do with strategic processes than it does with binding; if it had more to do with binding, then we would expect an equivalent deficit for both types of associations or even a greater deficit for the between-associations. In comparison, the absence of an age-difference on object-location memory despite our success in increasing the use of mediators on this task suggests that this type of association may be less dependent on strategic processing.

**CHAPTER 5: THE IMPACT OF INTER-INDIVIDUAL VARIABILITY ON
ASSOCIATIVE MEMORY PERFORMANCE AND STRATEGIC BEHAVIOUR**

Objectives and research questions

The overarching goal of these exploratory analyses was to investigate the role of variations in age, years of education, MoCA, meta-memory, and EF on object-object and object-location memory in older adults. In addition, we tested whether these individual differences were associated with the strategic processes that support associative memory (i.e. strategy production and strategy effectiveness). Finally, we tested whether individual differences correlated with, or had any predictive power on, associative memory and strategy effectiveness, above and beyond any effects of age.

Method

Overview of measures

Executive functioning. We derived a z-score for each participant based on a composite measure of EF derived by factor analysis in Glisky and Routhiaux (1995). The composite factor included the following variables: 1) Number of categories completed on the WCST; 2) Mental Control, 3) Verbal Fluency (FAS test); 4) Backwards Digit Span; and 5) Mental Arithmetic. Older Adults from Experiment 1 did not complete the Mental Arithmetic task because the EF battery was also administered to young adults and Mental Arithmetic was found to not load onto the executive functioning factor in young adults (Glisky & Kong, 2008).

Meta-memory. We measured different aspects of meta-memory with the Multifactorial Memory Questionnaire (MMQ: Troyer & Rich, 2002). The MMQ is comprised of three scales which measure different aspects of meta-memory. The first scale assesses feelings towards one's own memory (MMQ-Feelings). Participants are asked to rate how much they agree with both positive and negative feelings towards their memory (e.g. "I am generally pleased with my memory ability"). Higher scores are associated with greater satisfaction with one's own memory

functioning. The second scale assesses self-appraisal of memory ability (MMQ-Mistakes). Participants are asked to rate how often they judge that they make different types of memory mistakes (e.g. “Misplace something I use often like my keys or my glasses”). Higher scores are indicative of better self-appraisal of memory/lower frequency of perceived memory mistakes. The third scale assesses self-reported use of strategies (MMQ-Strategies). Participants are asked to rate how often they use different types of strategies (e.g. “Use a timer or an alarm to remind you to do something”). Higher scores are indicative of greater use of strategies.

We also used the Personal Encoding Preference Questionnaire (PEP: Dunlosky & Hertzog, 2004) to assess participants awareness of the effectiveness of mediators for associative learning. On this questionnaire, participants were asked to rate how effective they believed different types of strategies were (both effective mediator type strategies, such as integrative imagery, and less effective strategies, such as rote repetition). For our “strategy knowledge” variable, we used the averaged the ratings provided by participants for effective mediator type strategies.

General cognitive abilities. We used years of education and MoCA scores as an estimate of general cognitive abilities.

Results and Discussion

Correlational analyses. Pearson product-moment correlations were run to determine whether individual variations in age, education, MoCA, meta-memory, and EF were associated with: 1) object-object and object-location memory; 2) mediator production on both tasks, and 3) mediator accuracy (i.e. % correct for mediated pairs) on both tasks. Partial correlations were also used to assess whether any associations remained after controlling for age. All correlations analyses were run separately by experiment. Given the exploratory nature of these analyses, we

first used an unadjusted alpha level of .05, and then used adjusted alpha levels based on Holm-Bonferroni sequential correction to account for multiple comparisons (Holm, 1979). See Table 4 for the zero-order and partial correlations of Experiment 1; Table 5 for Experiment 2; and Table 6 for Experiment 3.

The relationship between each IV and DV was linear, as assessed by visual inspection of bivariate scatterplots. A number of potential bivariate outliers were identified. All correlations were conducted with and without these outliers to determine their impact on the results. In most cases, removing outliers had no impact on the results. Given the exploratory nature of these analyses, we decided to keep all outliers and flag any instances where removal of these outliers resulted in a significant change in the strength of the association between two variables.

With few exceptions¹, the assumption of normality was met as assessed by visual inspection of histograms and z-tests conducted on skew and kurtosis. Given the robustness of Pearson correlations to deviations to normality and the exploratory nature of these analyses, we decided to proceed with Pearson correlations without transforming our data.

Are age, education, MoCA, meta-memory, and EF associated with memory performance? Pearson correlations revealed different patterns of correlations between individual differences and object-object vs. object-location memory. In general, object-object memory was correlated with more individual differences than was the case for object-location memory. Specifically, object-object memory showed moderate to strong positive correlations with variables associated with strategic processes, such as EF ($r(29) = .552, p = .001$ in Expt. 1), ($r(30) = .527, p = .002$ in Expt. 2), ($r(29) = .409, p = .022$ in Expt. 3); MMQ-Feelings ($r(27) =$

¹ MoCA (Expt. 3) was skewed ($z = -3.278$), and kurtotic ($z = 2.267$), with two outliers with particularly low MoCA scores (22); Object-object memory (Expt. 1) was skewed ($z = -3.307$); Object-location memory was skewed (Expt.2) ($z = 2.697$), as well as object-location mediator production ($z = 3.184$).

.387, $p = .038$ in Expt. 3); MMQ-Mistakes ($r(30) = .443$, $p = .011$ in Expt. 2), ($r(27) = .492$, $p = .007$ in Expt. 3); MMQ-Strategies ($r(30) = .399$, $p = .024$ in Expt. 1); and strategy knowledge ($r(29) = .408$, $p = .023$ in Expt. 1), and ($r(27) = .407$, $p = .028$ in Expt. 3). In contrast, with the exception of a moderate correlation with strategy knowledge ($r(29) = .354$, $p = .050$ in Expt. 1) object-location was not significantly correlated with these variables², and instead, only showed a significant correlation with MoCA ($r(30) = .516$, $p = .003$) and with education ($r(30) = .443$, $p = .011$) in Experiment 1³. These findings support the hypothesis that object-location memory may be less related to strategic processing and instead may be more related to general cognitive functioning.

Compared to Experiment 1 where associative memory tasks were easiest (i.e. 4AFC), in Experiment 2 and 3 with harder tasks and greater demands on self-initiated processes (i.e. 20AFC), object-object memory was moderately negatively correlated with age ($r(30) = -.398$, $p = .024$, in Expt. 2, $r(29) = -.417$, $p = .020$ in Expt. 3). In addition, in Experiment 3, object-object memory was also moderately negatively correlated with MoCA ($r(29) = -.409$, $p = .022$). This pattern is consistent with Craik's dual environmental support/self-initiated processes account of age-related changes in aging (1983, 1986) which predicts that increases in demands on self-initiated processes amplifies the effect of age on associative memory. In addition, the strong positive correlation between education and object-object memory in Experiment 2 ($r(30) = .537$, $p = .002$) suggests that education may confer some type of advantage in circumstances with high demands on self-initiated processes.

² EF was also moderately associated with object-location in Expt. 2 ($r(30) = .349$, $p = .050$). However, after removing two bivariate outliers, the correlation was no longer statistically significant ($r(28) = .191$, $p = .311$).

³ The correlation between MoCA and object-location memory (Expt. 3) became statistically significant after removing two outliers (With outliers: $r(29) = .226$, $p = .221$; without outliers: $r(27) = .391$, $p = .036$).

Overall, controlling for age led to very few differences in the degree of correlation between the above mentioned variables. Thus, even when controlling for any effects of age, there were significant correlations between EF, meta-memory and object-object memory. This further supports the importance of identifying and measuring individual differences beyond age to better understand associative memory in aging.

The p-values of these correlations were subjected to a Holm-Bonferroni sequential correction to account for inflated type 1 error rates which can occur with multiple comparisons (Holm, 1979). Even with adjusted p-values ($p' = .008$ in Exp. 1 and $p' = .016$ in Exp. 2), the association between EF and object-object memory in Experiments 1 and 2 remained significant. The other correlations that remained significant after the correction were education years and object-object memory in Experiment 2 ($p' = .021$), and MoCA and object-location memory in Experiment 1 ($p' = .024$). Bivariate scatterplots of the correlations between EF and object-object memory in the three experiments are presented in Figures 21 to 23.

Are age, education, MoCA, meta-memory, and EF associated with mediator production? The prevalent finding is the absence of any statistically significant correlations between age, education, MoCA, meta-memory, and EF with mediator production on either the object-object or the object-location test. This remained true even after controlling for any effects of age. Exceptions to this rule were only revealed when removing outliers⁴. Generally, mediator production appeared to be unrelated to individual variations in age, education, MoCA, meta-memory and EF. These results further support the hypothesis that deficits in strategy production have little to do with age-related impairments in associative memory.

⁴ The following correlations shifted from non-significant to significant after removing outliers: MMQ-Feelings and object-location mediator production (Expt. 2) ($r(30) = -.256, p = .157$ to $r(29) = -.373, p = .039$); MMQ-Mistakes and object-location mediator production (Expt. 2) ($r(30) = -.194, p > .289$ to $r(28) = -.547, p = .002$); age and object-object mediator production (Expt. 3) ($r(29) = -.235, p = .204$ to $r(28) = -.390, p = .033$).

Are age, education, MoCA, meta-memory and EF associated with mediator accuracy?

Pearson correlations again revealed different patterns of correlations between individual differences and mediator accuracy by type of associative memory test. Specifically, mediator accuracy on the object-object test was moderately to strongly correlated with age ($r(30) = -.460$, $p = .008$, Expt. 2); with MoCA ($r(30) = .389$, $p = .028$, Expt. 1; $r(29) = .359$, $p = .047$, Expt. 3); as well as with a number of factors associated with strategic processes: MMQ-Feelings ($r(30) = .376$, $p = .034$, Expt. 1; $r(27) = .380$, $p = .042$, Expt. 3); MMQ-Mistakes ($r(27) = .450$, $p = .014$, Expt. 3), MMQ-Strategies ($r(30) = .421$, $p = .017$, Expt. 1), and EF ($r(29) = .417$, $p = .019$, Expt. 1; $r(30) = .409$, $p = .020$, Expt. 2). In contrast, accuracy on the object-location task was only associated with age in Experiment 1 ($r(21) = -.415$, $p = .049$). These results again support the hypothesis that object-location memory is less associated with strategic processes. However, none of these correlations remained significant once subjected to the Holm-Bonferonni sequential correction.

Hierarchical Regressions

Memory Performance. Hierarchical multiple regressions were run to determine if the addition of education, MoCA, MMQ (Feelings, Mistakes, & Strategies), strategy knowledge, EF and variations in demands on self-initiated processes (i.e. Experiment 1 vs. 2. vs. 3) improved the prediction of object-object performance over and above age alone. See Table 7 for full details of each regression model.

There was independence of residuals, as assessed by a Durbin-Watson statistic of 1.896. Linearity and homoscedasticity were confirmed as assessed by partial regression plots and a plot of studentized residuals against the unstandardized predicted values. There was no indication of multicollinearity as assessed by inspection of correlation coefficients (i.e. no correlations

between IV's were larger than 0.7) and as assessed by tolerance values greater than 0.1. There was no evidence of outliers (i.e. no standardized residual ± 3 standard deviations), high leverage points (i.e. no leverage values above .25), or high influential points (i.e. all values for Cook's distance below 1). Finally, the assumption of normality was met, as assessed by visual inspection of the P-P plot.

The full model of age, the experiment, education, MoCA, MMQ (Feelings, Mistakes, & Strategies), EF, strategy knowledge and object-object mediator production was statistically significant, $R^2 = .650$, $F(11, 91) = 13.503$, $p < .001$; adjusted $R^2 = .602$. The addition of the experiment, education, MoCA, MMQ (Feelings, Mistakes, & Strategies), EF, strategy knowledge and object-object mediator production (Step 2) led to a statistically significant increase in R^2 of .585, $F(10, 80) = 13.364$, $p < .001$. However, the influence of these factors on object-object memory was not equivalent. Specifically, age, levels of demands on self-initiated processes (Experiment 1 vs. 2 vs. 3), EF, and strategy knowledge contributed significantly to explaining the variance of object-object memory. Education, MoCA, MMQ (Feelings, Mistakes, & Strategies) and object-object mediator production were not statistically significant predictors of object-object memory.

A second hierarchical multiple regression was run to determine if the addition of the aforementioned individual differences and variations in demands on self-initiated processes (i.e. Experiment 1 vs. 2 vs. 3) improved the prediction of object-location performance over and above age alone. See Table 8 for full details on each regression model.

There was independence of residuals, as assessed by a Durbin-Watson statistic of 2.219. Linearity and homoscedasticity were confirmed as assessed by partial regression plots and a plot of studentized residuals against the unstandardized predicted values. There was no indication of

multicollinearity as assessed by inspection of correlation coefficients (i.e. no correlations between IV's were larger than 0.7) and as assessed by tolerance values greater than 0.1. There were two outliers (i.e. standardized residual greater than 3 standard deviations). We decided to keep these outliers, since there was no evidence of these data having high leverage or high influence. No other values were found to have high leverage or influence. Finally, assumption of normality was met, as assessed by visual inspection of the P-P plot.

The full model of age, the experiment, education, MoCA, MMQ (Feelings, Mistakes, & Strategies), EF, strategy knowledge and object-location mediator production was statistically significant, $R^2 = .446$, $F(11, 91) = 5.845$, $p < .001$; adjusted $R^2 = .369$. The addition of the experiment, education, MoCA (Feelings, Mistakes, & Strategies), EF, strategy knowledge, and object-location mediator production (Step 2) led to a statistically significant increase in R^2 of $.445$, $F(10, 80) = 6.426$, $p < .001$. However, the influence of these factors on object-location memory was not equivalent. Specifically, levels of demands on self-initiated processes (Experiment 1 vs. 2 vs. 3), education, and MoCA were significant predictors of object-location memory. Age, MMQ (Feelings, Mistakes, & Strategies), EF, strategy knowledge, and mediator production were not significant predictors of object-location memory.

Overall, these results further support the hypothesis that not all types of associations are equally affected by aging. Indeed, age was a significant predictor of object-object memory but not of object-location memory. In addition, over and above any effects of age, object-object memory was significantly associated with, and predicted by, a number of variables that may impact strategic processes, with EF emerging as a particularly important predictor. For object-object memory, the question that follows then is whether EF predicts individual variability in strategic processes. Object-location on the other hand was not predicted by variables associated

with strategic processes, but rather to variables associated with general cognitive functioning (i.e. education and MoCA).

Mediator Accuracy. A hierarchical multiple regression was run to determine if the addition of the experiment, MoCA, MMQ (Feelings, Mistakes, & Strategies), EF, and strategy knowledge improved the prediction of accuracy for mediated pairs on the object-object test over and above age alone. See Table 9 for full details on each regression model.

There was independence of residuals, as assessed by a Durbin-Watson statistic of 1.848. Linearity and homoscedasticity were confirmed as assessed by partial regression plots and a plot of studentized residuals against the unstandardized predicted values. There was no indication of multicollinearity as assessed by inspection of correlation coefficients (i.e. no correlations between IV's were larger than 0.7) and as assessed by tolerance values greater than 0.1. There was no evidence of outliers (i.e. no standardized residual \pm 3 standard deviations), high leverage points (i.e. no leverage values above .23), or high influential points (i.e. all values for Cook's distance below 1). Finally, assumption of normality was met, as assessed by visual inspection of the P-P plot.

The full model of age, the experiment, education, MoCA, MMQ (Feelings, Mistakes, & Strategies), EF, and strategy knowledge was statistically significant, $R^2 = .479$, $F(11, 91) = 6.685$, $p < .001$; adjusted $R^2 = .407$. The addition of the experiment, education, MoCA, MMQ (Feelings, Mistakes, & Strategies), EF, and strategy knowledge (Step 2) led to a statistically significant increase in R^2 of .443, $F(10, 80) = 6.795$, $p < .001$. However, the influence of these factors on object-object mediator accuracy was not equivalent. The experiment and education significantly contributed to explaining variability in mediator accuracy on the object-object test. In contrast,

MoCA, MMQ (Feelings, Mistakes, and Strategies), strategy knowledge, and EF were not significant predictors of mediator accuracy on the object-object test.

These results suggest that over and above effects of age, declines in strategy effectiveness were predicted by task difficulty/levels of demands on self-initiated processes, and education. Surprisingly, these results do not support the hypothesis that individual differences in EF predict strategy effectiveness, and instead suggest that other factors, such as education, may be more important. These results mirror the findings of Frankenmolen et al., (2016) and Ariel et al., (2015) which suggest that IQ and high fluid intelligence is associated with older adults' ability to improve their associative memory under strategy instructions (i.e. strategy effectiveness).

Table 4
Zero-Order Correlations and Partial Correlations Controlling for Age among Outcomes and Predictors in Older Adults in Experiment 1

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Age	1													
2. Education	.10	1												
3. MoCA	.17	-.14	1											
	--	(-.18)	--											
4. MMQ_Feelings	-.11	.03	.10	1										
	--	(-.05)	(.05)	--										
5. MMQ_Mistakes	-.07	-.17	.07	.22	1									
	--	(-.04)	(.15)	(.42*)	--									
6. MMQ_Strategies	.03	-.07	.41*	.27	.02	1								
	--	(-.17)	(.37)	(.37)	(.21)	--								
7. Executive Functioning	.15	.32	.28	-.05	-.37*	.21	1							
	--	(.00)	(.20)	(-.22)	(-.52*)	(.23)	--							
8. Strategy Knowledge	-.02	-.12	.27	.36*	.08	.29	.02	1						
	--	(-.19)	(.06)	(.29)	(.05)	(.35)	(-.11)	--						
9. Mediator Production_O-O	-.13	.34	.13	.24	.13	.24	.30	.18	1					
	--	(.22)	(.03)	(.26)	(.34)	(.18)	(-.03)	(.22)	--					
10. Mediator Production_O-L	.18	-.06	.23	-.16	-.14	.32	.01	.01	.05	1				
	--	(-.08)	(.24)	(-.09)	(-.19)	(.16)	(.10)	(.00)	(-.01)	--				
11. % Correct Med. Pairs_O-O	.06	.23	.39*	.38*	-.02	.42*	.42*	.17	.55**	.03	1			
	--	(.23)	(.25)	(.25)	(.30)	(.21)	(.16)	(-.04)	(.55**)	(-.27)	--			
12. % Correct Med. Pairs_O-L	-.42*	-.26	.20	-.11	-.29	-.37	-.13	.17	-.02	.00	-.04	1		
	--	(-.22)	(.25)	(-.15)	(-.31)	(-.46*)	(-.03)	(.11)	(-.06)	(.05)	(-.01)	--		
13. % Correct_O-O	-.20	.21	.29	.28	-.24	.40*	.55**	.41*	.61**	.15	.60**	.21	1	
	--	(-.07)	(.39)	(.13)	(-.23)	(.45*)	(.44*)	(.43*)	(.52*)	(.24)	(.50*)	(.13)	--	
14. % Correct_O-L	.06	-.01	.52**	.20	-.16	.22	.11	.35	.15	.19	.31	.70**	.31	1
	--	(-.14)	(.41)	(.12)	(-.11)	(-.10)	(-.09)	(.18)	(.08)	(.13)	(-.08)	(.71**)	(.16)	--

Note. Correlations not in parentheses are zero-order correlations. Correlations in parentheses are partial correlations controlling for age. O-O = Object-object memory test. O-L = Object-Location memory test. All independent variables were included in the same correlation matrix to simplify data presentation. Correlations between variables 10 (% Correct Mediated Pairs_O-O) and 12 (% Correct_O-O) as well as between 11 (% Correct Mediated Pairs_O-L) and 13 (% Correct_O-L) are particularly high because they are based on the same score.

* $p < .05$ ** $p < .01$

Table 5
Zero-Order Correlations and Partial Correlations Controlling for Age among Outcomes and Predictors in Older Adults in Experiment 2

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Age	1													
2. Education	-.13	1												
3. MoCA	-.07	.26	1											
	--	(.54*)	--											
4. MMQ_Feelings	.00	.11	.48**	1										
	--	.21	(.53*)	--										
5. MMQ_Mistakes	-.15	.41*	.41*	.47**	1									
	--	.48*	(.62**)	(.43)	--									
6. MMQ_Strategies	-.08	-.21	.16	.10	-.08	1								
	--	(-.12)	(.30)	(.07)	(-.16)	--								
7. Executive Functioning	-.12	.38*	.50**	.16	.46**	-.22	1							
	--	(.48*)	(.69**)	(.22)	(.76**)	(-.14)	--							
8. Strategy Knowledge	.00	.06	.30	.25	.29	.02	.15	1						
	--	(.06)	(.41)	(.20)	(.25)	(.16)	(.23)	--						
9. Mediator Production_O-O	-.12	.33	.32	.13	.29	-.07	.33	.15	1					
	--	(.35)	(.38)	(.15)	(.26)	(-.13)	(.32)	(.27)	--					
10. Mediator Production_O-L	.23	.23	-.12	-.26	-.19	-.21	.15	-.26	.02	1				
	--	(.39)	(-.01)	(-.13)	(-.02)	(-.26)	(.14)	(-.29)	(.22)	--				
11. %Correct Med. Pairs O-O	-.46**	.45*	.22	.06	.26	-.25	.41*	.15	.14	-.06	1			
	--	(.67**)	(.34)	(.12)	(.41)	(-.46*)	(.52*)	(.08)	(.28)	(.10)	--			
12. %Correct Med. Pairs O-L	-.20	.45	.40	.16	.39	.00	.35	.12	.02	.00	.48*	1		
	--	(.43)	(.40)	(.19)	(.37)	(.04)	(.31)	(.13)	(-.02)	(-.04)	(.45)	--		
13. % Correct_O-O	-.40*	.54**	.25	.23	.44*	-.22	.53**	.26	.52**	-.07	.73**	.43	1	
	--	(.56*)	(.48)	(.39)	(.53*)	(-.33)	(.64**)	(.17)	(.63**)	(.09)	(.72**)	(.39)	--	
14. % Correct_O-L	.02	.44*	.21	.09	.18	-.18	.35*	.03	-.02	.26	.45*	.68**	.38*	1
	--	(.50*)	(.32)	(.07)	(.46)	(-.38)	(.52*)	(-.02)	(.08)	(.26)	(.65**)	(.73**)	(.57*)	--

Note. Correlations not in parentheses are zero-order correlations. Correlations in parentheses are partial correlations controlling for age. O-O = Object-object memory test. O-L = Object-Location memory test. All independent variables were included in the same correlation matrix to simplify data presentation. Correlations between variables 10 (% Correct Mediated Pairs_O-O) and 12 (% Correct_O-O) as well as between 11 (% Correct Mediated Pairs_O-L) and 13 (% Correct O-L) are particularly high because they are based on the same score.

* $p < .05$ ** $p < .01$

Table 6
Zero-Order Correlations and Partial Correlations Controlling for Age among Outcomes and Predictors in Older Adults in Experiment 3

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Age	1													
2. Education	.03	1												
3. MoCA	-.22	-.31	1											
	--	(-.21)	--											
4. MMQ_Feelings	-.11	-.05	.03	1										
	--	(-.02)	(-.01)	--										
5. MMQ_Mistakes	-.27	-.05	.18	.58**	1									
	--	(.04)	(.10)	(.57**)	--									
6. MMQ_Strategies	.26	.07	-.35	-.19	-.68**	1								
	--	(-.01)	(-.29)	(-.17)	(-.65**)	--								
7. Executive Functioning	-.31*	-.13	.75**	-.10	.23	-.35	1							
	--	(-.11)	(.77**)	(-.15)	(.17)	(-.30)	--							
8. Strategy Knowledge	.00	-.17	.22	.47**	.25	.15	.17	1						
	--	(-.18)	(.23)	(.48**)	(.26)	(.16)	(.18)	--						
9. Mediator Production_O-O	-.24	-.11	.00	.23	.01	-.08	-.24	.05	1					
	--	(.10)	(-.18)	(.20)	(-.11)	(.02)	(-.38)	(.05)	--					
10. Mediator Production_O-L	-.26	.13	.01	.25	.19	-.17	.09	.05	.31	1				
	--	(.06)	(.00)	(.24)	(.15)	(-.14)	(.02)	(.05)	(.37*)	--				
11. % Correct Mediated Pairs_O-O	-.28	.03	.36*	.38*	.45*	-.15	.34	.30	-.05	-.14	1			
	--	(-.01)	(.41*)	(.37*)	(.42*)	(-.10)	(.26)	(.30)	(-.07)	(-.27)	--			
12. % Correct Mediated Pairs_O-L	.01	-.21	.11	.36	.17	.01	-.06	.35	.07	-.22	.09	1		
	--	(-.04)	(.03)	(.35)	(.13)	(.05)	(-.09)	(.35)	(-.06)	(-.17)	(.15)	--		
13. % Correct_O-O	-.42*	-.04	.41*	.39*	.49**	-.19	.41*	.41*	-.11	-.02	.91**	.11	1	
	--	(-.02)	(.44*)	(.37*)	(.45*)	(-.12)	(.32)	(.43*)	(-.18)	(-.18)	(.91**)	(.19)	--	
14. % Correct_O-L	-.07	.08	.23	.32	.09	-.03	.11	.22	.12	-.12	.21	.80**	.22	1
	--	(.24)	(.17)	(.30)	(.05)	(.02)	(.07)	(.22)	(.04)	(-.10)	(.21)	(.79**)	(.22)	1

Note. Correlations not in parentheses are zero-order correlations. Correlations in parentheses are partial correlations controlling for age. O-O = Object-object memory test. O-L = Object-Location memory test. All independent variables were included in the same correlation matrix to simplify data presentation. Correlations between variables 10 (% Correct Mediated Pairs_O-O) and 12 (% Correct_O-O) as well as between 11 (% Correct Mediated Pairs_O-L) and 13 (% Correct_O-L) are particularly high because they are based on the same score.

* $p < .05$ ** $p < .01$

Table 7
Hierarchical Regression Predicting Object-Object Memory from Age, the Experiment, Education, MoCA, MMQ (Feelings, Mistakes, and Strategies), Executive Functioning, Strategy Knowledge, and Mediator Production

Variable	Object-Object Memory					
	Step 1			Step 2		
	B	SE	β	B	SE	β
Constant	1.292	.269		.613	.365	
Age	-.010*	.004	-.255	-.007*	.003	-.196
Experiment 2				-.288**	.039	-.604
Experiment 3				-.159**	.039	-.325
Education				.012	.007	.129
MoCA				.003	.010	.028
MMQ_Feelings				.003	.002	.128
MMQ_Mistakes				.001	.002	.023
MMQ_Strategies				.000	.002	-.013
Executive Functioning				.096**	.027	.292
Strategy Knowledge				.028*	.010	.199
Mediator Production				.130	.093	.099
R^2	.065			.650		
F	6.277			13.503		
ΔR^2	.065			.585		
ΔF	6.277			13.364		

Note. $N = 92$. * $p < .05$ ** $p < .001$

Table 8
Hierarchical Regression Predicting Object-Location Memory from Age, the Experiment, Education, MoCA, MMQ (Feelings, Mistakes, and Strategies), Executive Functioning, Strategy Knowledge, and Mediator Production

Variable	Object-Location Memory					
	Step 1			Step 2		
	B	SE	β	B	SE	β
Constant	.503	.299		-.484	.494	
Age	-.001	.004	-.016	-.001	.004	-.025
Experiment 2				-.315**	.053	-.614
Experiment 3				-.170**	.053	-.322
Education				.024*	.009	.234
MoCA				.030*	.014	.231
MMQ_Feelings				.003	.002	.139
MMQ_Mistakes				-.003	.002	-.129
MMQ_Strategies				-.002	.002	-.074
Executive Functioning				-.002	.037	-.007
Strategy Knowledge				.016	.014	.110
Mediator Production				-.090	.130	-.064
R^2	.000			.446		
F	.022			5.845		
ΔR^2	.000			.445		
ΔF	.022			6.426		

Note. $N = 92$. * $p < .05$ ** $p < .001$

Table 9

Hierarchical Regression Predicting Mediator Accuracy on Object-Object Memory from Age, the Experiment, Education, MoCA, MMQ (Feelings, Mistakes, and Strategies), Executive Functioning, and Strategy Knowledge

Variable	Mediator Accuracy on Object-Object Memory					
	Step 1			Step 2		
	B	SE	β	B	SE	β
Constant	1.213	.283		.428	.453	
Age	-.007	.004	-.191	-.007*	.003	-.179
Experiment 2				-.245**	.048	-.496
Experiment 3				-.250**	.049	-.494
Education				.019*	.008	.194
MoCA				.014	.013	.110
MMQ_Feelings				.003	.002	.151
MMQ_Mistakes				.001	.002	.045
MMQ_Strategies				-.001	.002	-.052
Executive Functioning				.060	.034	.176
Strategy Knowledge				.013	.013	.091
R^2	.036			.479		
F	3.394			7.435		
ΔR^2	.036			.442		
ΔF	3.394			7.633		

Note. $N = 92$. * $p < .05$ ** $p < .001$

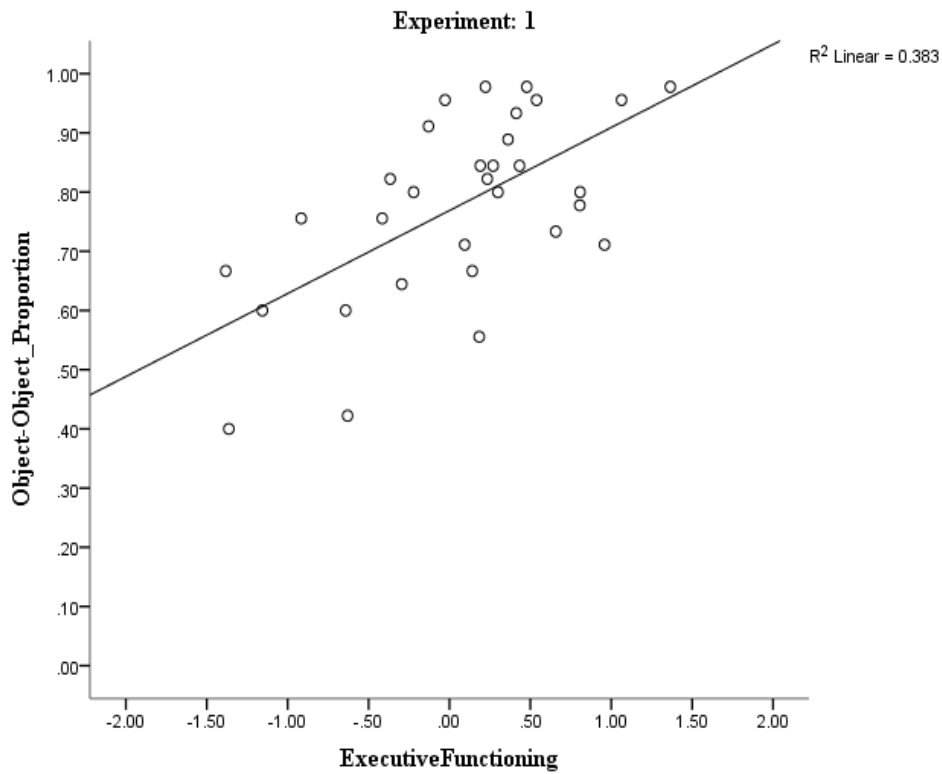


Figure 21. Bivariate scatterplot of correlation between EF and object-object memory in Experiment 1.

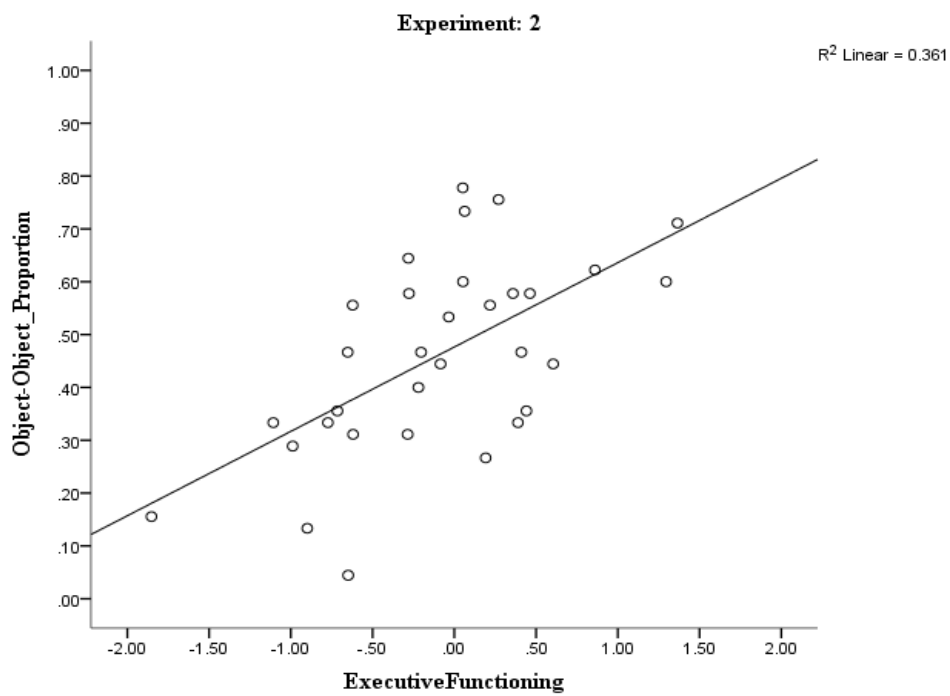


Figure 22. Bivariate scatterplot of correlation between EF and object-object memory in Experiment 2.

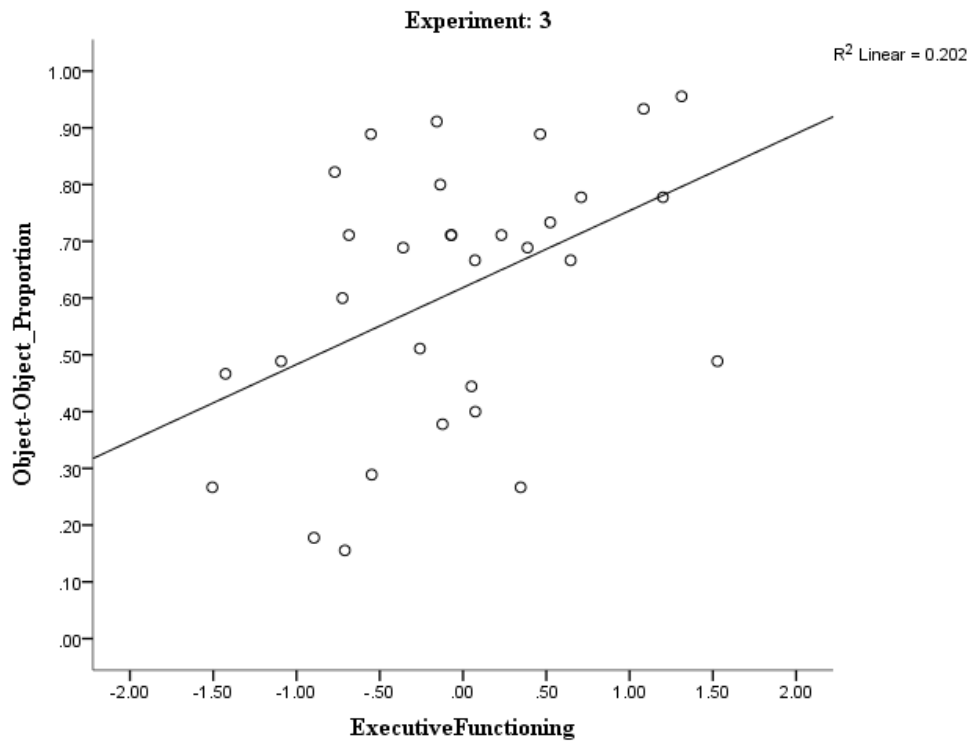


Figure 23. Bivariate scatterplot of correlation between EF and object-object memory in Experiment 3.

CHAPTER 6: GENERAL DISCUSSION

General Discussion

The last decades have seen a boom of research trying to characterize and understand the mechanisms underlying changes in memory functioning in healthy aging. Although some types of memory are relatively spared in aging, one of the most consistent findings is that healthy aging is associated with associative memory decline. These declines are thought to originate from both impaired binding processes (i.e. creating and retrieving links between units of information) and strategic processes (i.e. cognitive control operations that support encoding and retrieval). Imaging research findings suggest that aging may affect the integrity of both of these components as well as their functional connectivity. However, these components have rarely been examined concurrently and have instead been addressed in two parallel literatures.

Studies that have investigated the role of binding processes in age-related differences in associative memory have found that older adults have poorer memory for bound information, compared to their memory for single features (Chalfonte & Johnson, 1996: binding deficit hypothesis). This deficit was also found to affect memory for all kinds of bound information, including between-domain associations (i.e. associations between different types of information), and within-domain associations (i.e. associations between same kinds of information) (Naveh-Benjamin, 2000: associative deficit hypothesis). One important question that has received very little attention is whether aging affects memory for different types of associations to the same degree. Results of lesion data and the domain-dichotomy hypothesis of the MTL suggest that between-domain associations may be more affected by aging than within-domain associations. The only two studies that have tested this hypothesis in healthy older adults in a within-participant design have found that age-related differences are indeed larger for between-domain associations (Bastin & Van der Linden, 2005; Troyer et al., 2011).

Studies that have investigated the role of strategies in age-related differences in associative memory have generated mixed results. Overall, results from these studies suggest that aging may be associated with a reduction in the number of effective strategies produced at encoding (i.e. strategy production deficit hypothesis), and reduced efficacy of strategies produced (i.e. strategy utilization deficit hypothesis). However, the vast majority of these studies have focused on within-domain associations (e.g. word-word pairs). The question that has received significantly less attention is whether there is an age-related strategy production or utilization deficit for between-domain associations.

In this series of experiments, we aimed to address these two questions by combining both literatures and studying both binding and strategic processes concurrently. By doing so, we also aimed to assess the potential interactions between these two factors in age-related differences in associative memory. More specifically, we asked whether greater demands on binding would be associated with larger age-related strategy deficits. To achieve these objectives, we varied the demands on binding within experiments and measured and/or controlled strategic behaviour. Levels of demands on binding processes were manipulated by directly comparing performance on within- and between-domain associations. Strategies were measured using trial-by-trial self-report in all three experiments, and were controlled in Experiment 3 with a strategy instruction condition.

In line with previous findings, we hypothesized that young adults would outperform older adults on both the within- and the between-domain associative memory tasks, and that this age difference would be larger in the between- than in the within-domain association task. In terms of strategy production and effectiveness, we expected that young adults would produce more effective strategies and would achieve greater strategy effectiveness than older adults both on the

within- and the between-domain associations tasks, but that this age difference would be larger in the between-domain task.

Above and beyond age-group related differences, inter-individual variability in aging is considered to play an important role in episodic memory performance (Lindenberger, 2014; Lindenberger & Ghisletta, 2009; Morse, 1993; Wilson, 2002) and the ability to effectively generate and use strategies (Ariel, Price, Hertzog, 2015; Fandakova, Shing, & Lindenberger, 2012; Frankenmolen et al., 2016). Following our main analyses, we also ran exploratory analyses investigating the role of inter-individual variability in executive functioning meta-memory, and general cognitive functioning on associative memory performance and strategic behaviour.

In this discussion, we first provide an overview of the main results (i.e. across experiments), followed by an interpretation of these results in the context of the binding and strategic deficit hypotheses of age-related declines in associative memory. The theoretical, methodological and practical implications of this research are then discussed. We conclude by addressing the strengths and limitations of this dissertation and highlight important future research directions.

Overview of results

Memory for different types of associations

The results of all three experiments suggest that the size of the age-related difference on associative memory depends on the type of association to be encoded. In other words, it appears that not all associations are equally affected by aging. Against previous findings and our predictions, the age-related difference was larger for the within-domain associations (i.e. object-object memory), than it was for the between-domain association (i.e. object-location memory). Specifically, although there was an age-related difference favouring young adults on object-object performance, there was no reliable and statistically significant difference in performance

between age groups on the object-location task. This age-related dissociation was found in all three experiments, despite significant variations in levels of environmental support/self-initiated processes (i.e. going from a 4AFC test to a 20AFC from Experiment 1 to 2, and providing strategy instructions in Experiment 3).

Strategy production and effectiveness

Our results suggest that there were no age-group differences in strategy production for either within- or between-domain associations: older adults were just as likely as young adults to self-initiate the generation of effective mediators (in Experiment 1 and 2), and to generate instructed strategies in Experiment 3. Thus, age-related differences in strategy production do not explain age-related differences in performance on the object-object test or the age-related dissociation (i.e. interaction between age and type of association on associative memory performance). In Experiments 1 and 2, both young and older adults reported encoding a much higher proportion of object-object pairs using a mediator than object-location pairs. In Experiment 3, with minor changes made to each associative memory test (i.e. identifying the critical object with an arrow) and by providing participants strategy instructions, participants actually ended up encoding slightly more mediators on the object-location task than on the object-object task. This suggests that both young and older adults are equally capable of generating mediators for both types of associations. Overall, our findings do not support the strategy production deficit account of age-related associative memory deficits in either within- or between-domain associations.

Despite no age group differences in strategy production, our results suggest that there were age-related differences in strategy effectiveness (i.e. success rate on mediated pairs) on the object-object memory tests. Specifically, across all three experiments, young adults had greater

accuracy on the object-object test for mediated pairs. These results support the strategy utilization deficit hypothesis of age-related associative memory deficits: older adults may be just as proficient as their young counterparts in generating mediators, but their ability to effectively use the strategies generated at encoding to support retrieval may be compromised. The results from our exploratory analyses suggest that above and beyond the effect of age, individual variability in education was a significant predictor of strategy effectiveness on the object-object task.

Comparatively, performance on the object-location test was unrelated to mediator production. Likewise, there were no age-related differences in strategy effectiveness on this task. These results suggest that some associations may be less dependent on elaborative strategies at encoding. The results from our exploratory analyses suggest that object-location memory was predicted by MoCA scores and years of education.

Interpretation of results in the context of the binding and strategic deficit hypotheses of age-related associative memory deficits

The binding/associative deficit hypothesis of aging suggests that older adults are impaired at binding both within- and between-domain associations to a similar degree. The domain-dichotomy hypothesis of the hippocampus suggests that the age-related impairment in binding may be greater for between-domain associations compared to within-domain associations. This is indeed what has been previously found in lesions studies (Borders et al., 2017; Mayes et al., 2001; 2002; 2004; Vargha-Khadem et al., 1997) and with healthy older adults in the experiments conducted by Bastin and Van der Linden (2005) and Troyer et al., (2011). Our results however, showed the opposite pattern: age-related differences favouring young adults were larger for within- (i.e. object-object) than for between-domain (i.e. object-

location) associations. In addition, in contrast to previous conclusions (e.g. Old & Naveh-Benjamin, 2008) the absence of a significant age-difference in the object-location test suggests that older adults may not be impaired on all types of associations. Our results provide convincing evidence that not all types of associations are equally affected by aging.

One of the most important difference between the current series of experiments and the ones conducted by Bastin and Van der Linden (2005) and Troyer et al., (2011) is that they did not attempt to measure or control strategies. In addition, both experiments presented stimuli at a rate of 3 seconds per pair (compared to a study time of 8 seconds in the current experiments). This very limited study time likely did not afford participants the opportunity to generate mediators. Indeed, a presentation rate of 8s has previously been recommended as an appropriate study time for both young and older adults for strategy generation (Dunlosky & Hertzog, 1998; 2001; Frankenmolen et al., 2016). If they had indeed provided sufficient time at encoding, perhaps participants would have been able to generate strategies at encoding, and then an age-related dissociation favouring within-associations may have emerged. On the other hand, it is possible that this short study time selectively disadvantaged older adults due to age-related reductions in processing speed (Salthouse 1996). Some participants (i.e. most likely young adults) may have then been able to generate strategies even during this short amount of time. Given that neither experiment attempted to measure or control strategic behaviour, this possibility cannot be ruled out, and the important role of strategies remains unclear.

In the context of the current series of experiments, measuring and controlling strategies provide us with a more complete picture of associative memory processes. Indeed, the fact that age-related differences occurred only on the associative memory test that was associated with mediator use highlights the importance of strategic factors in explaining age-related differences

in associative memory. More specifically, age-related differences on the object-object test were associated to age-related differences in the successful application of strategies (i.e. strategy effectiveness). In contrast, the absence of an age-related difference on object-location memory despite our success in increasing the use of mediators in Experiment 3 suggests that this type of association may be less dependent on strategic processes. The results from our exploratory analyses further support this hypothesis: object-location memory was associated with MoCA scores and years of education, but not with variables related to strategic processes.

Overall, our findings can be interpreted in at least two ways. The first possibility is that binding object-location associations relies on different neural correlates that may be spared or less affected by aging than those used to bind object-object associations. If object-location associations are indeed less “taxing” on MTL-mediated binding, then we might expect this type of association to also place lower demands on PFC-mediated strategic processes, thus buffering against potential effects of age on object-location memory. A second possibility is that binding both types of associations is equally taxing on MTL-mediated binding processes, but that object-location associations place lower demands on self-initiated processes because of the nature of the information to be encoded (i.e. is less reliant on strategic processes). This pattern could then, in turn, buffer against any potential effects of age on object-location performance. We will explore these two possibilities and our findings on inter-individual variability in more detail in our discussion of the theoretical and methodological implications of this research, below.

Theoretical and Methodological Implications of the Research

Do different types of associations rely on different neural correlates?

Medial temporal lobes. There is a general consensus in the literature that distinct MTL sub-regions (i.e. hippocampus, parahippocampal cortex (PHc), perirhinal cortex (PRc),

entorhinal cortex (EC)) contribute in separate and different ways to support memory; however, the specific function of each sub-region is still under debate (e.g. see reviews by Ranganath, 2010; Davachi, 2006; Mayes, Montaldi & Migo, 2007). The domain-dichotomy hypothesis of the MTL predicts that the hippocampus is preferentially important for binding between-domain associations and thus more sensitive to the effects of aging, compared to binding within-domain associations which may be processed in closely adjacent brain regions such as the perirhinal cortex (Mayes, Montaldi & Migo, 2007). However, an alternative view of MTL functioning suggests that MTL sub-regions may be more selective to the type of material being processed (i.e. object-object vs. object-location) rather than to the type of association (i.e. within- vs. between-domain).

The Binding of Items and Context (BIC) model proposed by Eichenbaum, Yonelinas, and Ranganath (2007) suggests differing roles for the PRc and PHc. Specifically, the PRc is thought to primarily process object information, including associations between objects, whereas the PHc is thought to primarily process context information (Davachi 2006; Diana, Yonelinas, Raganath, 2007; Eichenbaum, Yonelinas, and Ranganath 2007; Ranganath, 2010). In this model, (and many others; e.g. relational model: Eichenbaum & Cohen, 2001), the hippocampus is considered to play a specific role in binding objects or items to their context. Applying the BIC model to the current data, we would expect that object-object memory would activate the PRc and the hippocampus, and that object-location memory would activate the PHc and hippocampus. Given that there is evidence to suggest that the PHc is preferentially affected by aging compared to the PRc (Burgmans et al., 2009), we would expect age-related differences to be larger in object-location memory than in object-object memory. Predictions stemming from the BIC model thus do not provide clear explanations for our data.

Another proposal stemming from one of the very rare imaging studies that have directly compared object-object to object-location memory in young adults propose a functional dissociation between the anterior and posterior parts of the PHc (Aminoff, Groneau, & Bar, 2007). More specifically, object-object binding activated the anterior PHc, and object-location binding activated the posterior PHc. Given the evidence suggesting that posterior PHc is preferentially affected by aging (Damoiseaux, Viviano, Yuan, & Raz, 2016), we would again predict larger age-related differences in object-location than in object-object memory.

Prefrontal cortex. Another interesting question to ask is whether different types of associations differentially activate the prefrontal cortex. The few studies that have directly compared memory for associations between items (e.g. object-object) and memory for associations between items and their context (e.g. object-location) in a within-participant design with young adults have yielded interesting findings. Indeed, the results of two studies suggest differential activation of the left inferior frontal gyrus (LIFG) – a region that has been involved with strategic processes such as generating a “mental image” incorporating both items (Jackson & Shacter, 2004) - based on the type of association to be encoded. Specifically, LIFG activations have been linked to successful encoding of item-item associations, but not of item-context associations (Park, Shannon, Biggan, & Spann, 2012; Wong, de Chastelaine, & Rugg, 2013). Wong et al. (2013) interpret this pattern as suggesting that item-context binding may not require controlled retrieval (i.e. strategic processes) since contextual information are perceptual features that can be integrated in a “bottom-up” fashion. Importantly, Wong et al. (2013) used location (left or right) as the contextual information to be bound to words. These results provide one possible explanation of our age-related dissociation: object-location memory may be less reliant

on age-sensitive strategic processing because location is experienced as being a perceptual feature of the object.

In sum, there is some evidence to suggest that object-object and object-location binding may rely on different neural correlates both in the MTL (Aminoff, Groneau, & Bar, 2006; Diana, Yonelinas, Ranganath, 2007; Eichenbaum, Yonelinas, and Ranganath 2007; Ranganath, 2010) and in the PFC (Park, Shannon, Biggan, & Spann, 2012; Wong, de Chastelaine, & Rugg, 2013). Although there is no evidence of object-object binding relying on neural correlates that are preferentially affected by aging in the MTL, this may be the case in the PFC: object-object binding may rely to a greater extent on PFC structures – namely the LIFG. However, the conclusions we can draw from these findings are very limited due to significant methodological differences between these studies and the current experiments, but most importantly, due to the fact that these experiments have only be conducted with young adults. Given the evidence suggesting that the neural correlates of associative memory change with age (Dalton, Tu, Hornberger, Hodges, and Piguet, 2013) and because of general age-related changes in patterns of neural activation (e.g. HAROLD – Cabeza, 2002; and PASA – Grady et al., 1994), these findings must be interpreted with caution.

Is object-location memory indeed less reliant on PFC-mediated strategic processes?

We raised the very speculative possibility that object-location binding may not engage the PFC to the same extend as object-object location binding might (at least in young adults). One possibility raised by Wong et al., (2013), is that location information may be perceived as being a perceptual feature of an object and thus may be more likely to be automatically bound to object information without conscious, strategic effort. This hypothesis conflicts with several research findings that suggest that strategies can indeed improve object-location memory in both

young and older adults in multiple different types of object-location tasks (e.g. Hampstead, Stringer, Stilla, Giddens, & Sathian, 2010; Kuhlman & Touron, 2012; Meulenbroek et al., 2010).

An alternative possibility is that object-location memory binding is indeed reliant on strategic processes, but that these strategies are not be mediated by the PFC. Indeed, different types of strategies have been shown to activate different areas of the brain. In an imaging study with young adults, Kirchoff and Buckner (2006) found that verbal elaboration strategies were correlated with activation in the PFC, and visual elaboration strategies were correlated with activation in the extrastriate cortex (i.e. a region of the brain associated with object processing). Similarly, in Wong et al., (2013), object-location memory performance was associated with activation in the fusiform cortex (i.e. a module within the extrastriate cortex). Although we cannot know for sure whether participants in the Wong et al., (2013) study did indeed use a visual elaboration strategy because strategies were not measured or controlled, this remains an interesting possibility.

Overall, the results of the current experiments highlight the importance of comparing memory for different types of associations and measuring/controlling strategies in future efforts to continue characterising age-related associative memory deficits. Our behavioural data only afford us the possibility of speculating on whether different types of associative memory rely on different neural substrates. Imaging studies comparing within- to between-domain associative memory in young and older adults and measuring/controlling strategies could help increase our understanding of the neural correlates of: 1) successful associative memory performance for different types of associations in aging and; 2) strategies for different types of associations in aging.

Do differences in associative memory have more to do with age or other individual differences?

The results of our exploratory analyses suggest that the answer to that question depends on the type of associative memory. Age was significantly associated with and predictive of object-object memory, but not of object-location memory. General cognitive functioning (MoCA and education years) emerged as being more important predictors of object-location memory. These findings further support the hypothesis that object-location memory (at least the way it was tested in this paradigm) is less affected by age. However, even in the case of object-object memory where age did explain some of the variability in performance, the important role of individual differences over and above age was clear. Indeed, all significant correlations between individual differences and object-object memory remained significant even after controlling for age. Likewise, the addition of these individual differences to age in our regression significantly improved the prediction of object-object memory. In particular, executive functioning was highly associated to, and predictive of, object-object memory. The fact that education was not a significant predictor for object-object memory suggests that executive functioning had a unique effect on object-object memory that is independent of general cognitive functioning.

On a methodological level, these results underscore that comparing group differences is insufficient by itself to effectively understand and measure associative memory decline. It will be important for future studies to continue to identify the important variables that influence memory for different types of associations as this will help specify targets for intervention.

The impact of individual differences on strategy effectiveness

Our analyses on individual differences are also informative of the role of different factors beyond age that may affect the effective use of a strategy on an associative memory task.

Specifically, years of education emerged as a significant predictor of strategy effectiveness on the object-object task. This finding aligns well with previous research that has found that IQ (Frankenmolen et al., 2016) and high fluid intelligence (Ariel et al., 2015) mediate older adults' ability to improve their associative memory under strategy instructions. Given the strong association we found between executive functioning and object-object memory, it was surprising that executive functioning was not a significant predictor of strategy effectiveness. An important consideration is that we measured strategic processes at encoding only. The potential role of executive functioning with strategic processes at retrieval is an interesting question that merits further investigation.

Practical & Clinical implications

The results of this series of experiments also serve to inform memory training endeavours in healthy aging. Overall, our results remind us that strategies are important, not only to measure or control in an experimental design, but also to consider in the context of memory training. Indeed, at least in this paradigm, age-related differences in associative memory appeared to be more strongly related to age-deficits in strategic processes than to impaired binding processes. Thus, impaired strategic processes are an important target for memory training. However, our findings also inform us that not all associations are reliant on strategies, or perhaps are simply not helped (or best helped) by what are essentially verbal or verbalizable mediators (e.g. sentence generation and interactive imagery). Further research testing the effect of different types of strategies on object-location memory is of theoretical and practical interest, given the ecological validity and frequency of occurrence of object-location associations in everyday life.

Measuring and controlling strategies also tells us about the locus of age-related strategic deficits. Older adults do not appear to be impaired in generating mediators at time of study,

whether being provided with strategy instructions or not. Although there were no age differences in strategy production, improving strategy knowledge may be an interesting and relatively cost and time-effective target for intervention. Indeed, strategy knowledge was a significant predictor for object-object memory performance in older adults. Thus, providing older adults with information regarding the relative effectiveness of different types of strategies may help support their associative memory.

Whereas older adults were unimpaired at strategy production, they were relatively impaired at effective strategy execution. Difficulties with strategy execution can occur at several levels. Older adults may produce more general or gist-based mediators than young adults (Palladino & De Beni, 2003), or may be less likely to further elaborate on mediators once they have been generated (Kamp & Zimmer, 2015). Another possibility is that older adults may struggle to use mediators on several sequential pairs because of their high demands on cognitive processes, compared to relatively easier strategies such as rote repetition (Uittenhove, Burger, Tacconat, & Lemaire, 2015). Probably the best way to measure the effect of these potential deficits is to focus on strategic processes at retrieval. Indeed, aging is associated with a deficit in both accurately retrieving mediators generated at study and decoding these mediators (i.e. failure to reconstruct mediated pair) (Dunlosky, Hertzog, & Powell-Moman, 2005; Hertzog, Fulton, Mandviwala, & Dunlosky, 2013). With the exception of these two studies that used word-word paired associate learning paradigms, age-related mediator retrieval and decoding deficits have rarely been studied. Replication of these results and with different types of associations would certainly contribute to establishing this hypothesis as an important target for intervention.

Another potential target for improving strategy effectiveness may be focusing on processes underlying associative memory, such as executive functioning (EF) or binding. Rather

than focus on teaching specific encoding or retrieval strategies, process-based training targets more general processing capacities (e.g. see review by Willis & Shaie, 2009) Research on process-based training for associative memory in older adults is still in its infancy. Two recent studies focused on training binding processes have yielded mixed findings: one found that process-based training improved older adult's associative memory (Zimmermann, von Bastian, Röcke, Martin, & Eschen, 2016), Although the other failed to find a significant effect on associative memory performance (Bellander et al., 2016). In our exploratory analyses in Chapter 5, EF was the individual difference variable that was most strongly associated with, and predictive of, object-object memory. EF process-based training can help older adults improve their EF (e.g. see Karbach & Verhaeghen, 2014, for a review). However, whether process-training relating improvements in EF would translate to improved associative memory remains an open and important question.

Potential Limitations, Strengths, and Future Directions

Although we have treated the binding and strategic component as two distinct components, in reality, it is difficult to know where one begins and the other ends. In interpreting the results of the current experiments, this makes it inherently difficult to ascertain whether the source of the age-related dissociation is binding, strategies, or some interaction between both. This challenge is not unique to the current experiments. For example, other studies that have attempted to measure both binding and strategies concurrently, have manipulated binding “load” by varying degrees of pre-existing associations between the items to be paired (Addis et al., 2014; Shing et al., 2008). In this case, similarly to our own, it is not possible to directly pinpoint the source of any age-related differences in associative memory and strategies. One alternative and complementary approach has been used in studies that have attempted to isolate the strategic

from the binding component. For example, Cohn, Emrich and Moscovitch (2008) compared associative memory in young and older adults under conditions with high demands on strategic processes (i.e. associative identification and recall-to-reject), and under conditions with low demands on strategic processes (i.e. associative reinstatement and recall-to-accept). The authors found that older adults were impaired only in conditions with high demands on strategic processes. In contrast, older adults were unimpaired on a test dependent on binding processes alone (i.e. associative reinstatement). Based on these results, the authors concluded that impairments in strategic retrieval account for age-related associative memory deficits to a greater extent than do any binding deficits. Applying this kind of experimental paradigm to comparing memory for within- and between-domain associations in young and older adults could help further elucidate the relative contributions of the binding and strategic component to any age-related differences in different types of associative memory tasks.

Another potential limitation concerns the retrospective strategy self-report methodology. Specifically, because participants are asked to report their strategies retrospectively (i.e. after all learning and testing is completed), strategy reports are dependent on long-term memory and thus vulnerable to forgetting. It is therefore reasonable to wonder whether older adults are particularly disadvantaged compared to young adults in reporting their strategies in this way. Previous studies that have evaluated the reliability of retrospective strategy reports have contrasted these reports with concurrent strategy reports (i.e. trial-by-trial strategy reports collected at the time of study). These studies have found that the reliability between both types of reports is moderate and ranges from 61% to 64% (Dunlosky & Hertzog, 2001; Kuhlmann & Touron, 2012). Most importantly however is that both studies found no age differences in the reliability of

retrospective reports (Dunlosky & Hertzog, 2002; Kuhlmann & Touron, 2012). Thus, any age differences in strategic behaviour are likely not attributable to the strategy report methodology.

There are other potential limitations that could affect the generalizability of the results. One of these limitations concerns the particular task characteristics of the object-location paradigm. Task paradigms differ in how much they afford mediator-based strategy use, and older adults' might be particularly sensitive to a tasks' strategy affordance (Bottiroli, Dunlosky, Guerini, Cavallini, & Hertzog, 2010; Touron & Hertzog 2004). Specifically, there were two relative dimensions participants were encouraged to consider in encoding an object-location: the left-right dimension and the top-down dimension (in relation to the "anchor" object). Although participants were encouraged to generate one image or sentence integrating both dimensions, anecdotal evidence suggests that participants sometimes generated two images or sentences to encode both dimensions. This could have made the attentional or processing costs too high to retain, retrieve and decode mediators at retrieval, thus limiting both young and older adult's ability to effectively use strategies on this task. Future experiments could attempt to resolve this issue either by simplifying the object-location task, such that there would be only one dimension to be encoded, or to further investigate the effectiveness of visual elaboration strategies for visuo-spatial stimuli.

Another potential limitation relates to the particular sample characteristics of older adults in the current experiments. The older adults that participated in these experiments have a higher level of educational attainment than the general population: all of the older adults in my sample held some type of post-secondary education compared to 58.9% of older adults in the Canadian population (Statistics Canada, 2011). Since intellectual abilities may be associated with older adult's ability to generate and effectively use strategies (Frankenmolen et al., 2016; Ariel, Price,

& Hertzog, 2015), and educational attainment has been associated with greater PFC activation at encoding (Peterson et al., 2016), any age-related differences in memory and/or strategies may have been reduced. Indeed, the results from our exploratory analyses identify years of education as a predictor of both object-location memory and strategy effectiveness on the object-object task. It is possible that the minimal age difference on the object-location task could be related to the relatively high level of educational attainment of my sample. Thus, potential cohort effects, particularly in comparing our results to those obtained in studies supporting age-related strategy production deficits (e.g. Canestrari, 1963; Hulicka & Grossman, 1967; Treat, Poon & Fozard, 1981; Treat & Reese, 1976), cannot be dismissed. Indeed, older adults participating in these earlier studies may have had generally lower levels of education than older adults of the current generation. Longitudinal studies on strategies and associative memory in aging could help resolve this problem. Finally, another factor that may have reduced any age-related differences in the current experiments is the relatively high proportion of bilingual older adults in my sample. Indeed, bilingualism may confer some cognitive protective effects in aging (Kousaie & Taler, 2015).

Despite these potential limitations, these experiments provide a significant contribution to the literature. This series of experiments is the first that has directly compared memory for different kinds of associations between young and older adults, while measuring and/or controlling strategic processes. This has offered the opportunity to concurrently assess the role and interactions of two major hypotheses of age-related associative memory impairment. The findings of these experiments further our understanding of the scope and mechanisms of age-related associative memory changes and have shed light on the role of strategies in encoding

different types of associations. These results may inform the methodology of future research of associative memory in aging and may also inform memory training programs in healthy aging.

There are specific methodological strengths of these experiments that merit mention. The most noteworthy feature of our experimental design is the similarity between the two types of memory tests. We designed the tasks such that the study trials were identical (i.e. studying a pair of objects in a 5x5 grid for 8 seconds) and the test trials were as similar as possible between memory tests (i.e. number of foils equated). Although the previous studies directly comparing memory for two types of associations also took care to equate test trials, (Bastin & van der Linden, 2005, and also, but to a lesser extent, Troyer et al., 2011), this series of experiments is the first to have equated study trials between tests. In addition, we equated the type of material to be encoded by comparing two types of associative memory involving visuo-spatial stimuli. This was not the case in the study conducted by Troyer et al. 2011, in which word-word and face-name memory were compared. Moreover, extensive pilot testing was conducted to avoid floor and ceiling effects, and to match the difficulty level between tasks. Although the difficulty level ended up being greater in the object-location task, age-related differences cannot be attributed to this. Indeed, when looking at overall performance levels, older adults had higher levels of performance on the within-domain association task/ (age-related differences were larger in the easier task). Overall, our careful task design allowed us to conduct a very close comparison between the two types of memory tests, thus helping to isolate any differential effects of age on memory by type of association.

Applying the trial-by-trial retrospective strategy report method (Dunlosky & Hertzog, 1998) to compare learning of within and between-domain associations in aging was an important and novel contribution of this research. This is one of the first applications of this method to

associations other than within-domain word-word pairs. Our results provide important information about the differential effectiveness (or importance) of strategies depending on the type of association to be encoded. This strategy report method also helped to identify the source of age differences in performance on the object-object test.

Finally, the results of this study were remarkably consistent across the three experiments. Indeed, the main findings were replicated three times, despite varying degrees of environmental support/demands on self-initiated processes across experiments. An independent replication of these experiments would certainly contribute to further estimating the reliability of these data.

In conclusion, results of the current experiments support the increasingly prevalent notion that researchers can no longer take a blanket approach to describing age-related associative memory deficits. The type of association to be encoded has been an overlooked, yet important factor in determining the size of any age-related differences in memory performance. Indeed, our results are the first to suggest that at least under some conditions, age-related differences may be larger for within- than between-domain associations. Our results also highlight the importance of directly measuring strategies at encoding (and perhaps as well at retrieval), as this provides valuable information about the locus of age-related differences in associative memory. Finally, our results suggest important new avenues for future research; in particular, it will be important to further characterize the neural correlates of associative memory and strategies for different types of associations in aging, and to continue to identify the individual differences that predict associative memory and strategic processes above and beyond any effects of age.

References

- Addis, D. R., Giovanello, K. S., Vu, M.-A., & Schacter, D. L. (2014). Age-related changes in prefrontal and hippocampal contributions to relational encoding. *NeuroImage, 84*, 19–26.
- Alexander, M. P., Stuss, D., & Gillingham, S. (2009). Impaired list learning is not a general property of frontal lesions. *Journal of Cognitive Neuroscience, 21*, 1422-1434.
- Aminoff, E., Groneau, N., & Bar, M. (2007). The parahippocampal cortex mediates spatial and non-spatial associations. *Cerebral Cortex, 27*, 1493-1503.
- Angel, L., Fay, S., Bouazzaoui, B., & Isingrini, M. (2010). Individual differences in executive functioning modulate age effects on the ERP correlates of retrieval success. *Neuropsychologia, 48*(12), 3540–3553.
- Ariel, R., Price, J., & Hertzog, C. (2015). Age-related associative memory deficits in value-based remembering: The contribution of agenda-based regulation and strategy use. *Psychology and Aging, 30*(4), 795–808.
- Bäckman, L., Lindenberger, U., Li, S-C., & Nyberg, L. (2010). Linking cognitive aging to alterations in dopamine neurotransmitter functioning: Recent data and future avenues. *Neuroscience and Biobehavioral Reviews, 34*, 670-677.
- Banich, M. T. (2009). Executive functioning: The search for an integrated account. *Current Directions in Psychological Science, 18*(2), 89-94.
- Baltes, P. B., & Lindenberger, U. (1997). Emergence of a powerful connection between sensory and cognitive functions across the adult life span: A new window to the study of cognitive aging? *Psychology and Aging, 12*(1), 12-21.

- Bartzokis, G., Beckson, M., Lu, P. H., Nuechterlein, K. H., Edwards, N., Mintz, J. (2001). Age-related changes in frontal and temporal volume in men: A magnetic resonance imaging study. *Archives of General Psychiatry*, *58*, 461–465.
- Barulli, D. J., Rakitin, B. C., Lemaire, P., & Stern, Y. (2013). The influence of cognitive reserve on strategy selection in normal aging. *Journal of the International Neuropsychological Society*, *19*(7), 841-844.
- 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.
- Becker, N., Laukka, E. J., Kalpouzos, G., Naveh-Benjamin, M., Bäckman, L., & Brehmer, Y. (2015). Structural brain correlates of associative memory in older adults. *NeuroImage*, *118*, 146–153.
- Bender, A. R., Naveh-Benjamin, M., & Raz, N. (2010). Associative deficit in recognition memory in a lifespan sample of healthy adults. *Psychology and Aging*, *25*(4), 940–948.
- Bender, A. R., & Raz, N. (2012). Age-related differences in recognition memory for items and associations: Contribution of individual differences in working memory and metamemory. *Psychology and Aging*, *27*(3), 691–700.
- Benjamin, A. S. (2010). Representational explanations of “process” dissociations in recognition: The DRYAD theory of aging and memory judgments. *Psychological Review*, *177*, 1055-1079.
- Bellander, M., Eschen, A., Lövdén, M., Martin, M., Bäckman, L., & Brehmer, Y. (2017). No evidence for improved associative memory performance following process-based associative memory training in older adults. *Frontiers in Aging Neuroscience*, *8* (326), 1-11.
- Borders, A. A., Aly, M., Parks, C. M., & Yonelinas, A. P. (2017). The hippocampus is particularly important for building associations across stimulus domains. *Neuropsychologia*, *99*, 335–342. <https://doi.org/10.1016/j.neuropsychologia.2017.03.032>

- Bottiroli, S., Dunlosky, J., Guerini, K., Cavallini, E., & Hertzog, C. (2010). Does task affordance moderate age-related deficits in strategy production? *Neuropsychology, development, and cognition. Section B, Aging, neuropsychology and cognition*, 17(5), 591-602.
- Bouazzaoui, B., Iningrini, M., Fay, S., Angel, L., Vanneste, S., Clarys, D., & Taconnat, L. (2010). Aging and self-reported internal and external memory strategy uses: The role of executive functioning. *Acta Psychologica*, 135(1), 59–66.
- Bower, G. H. (1970). Imagery as a relational organizer in associative learning. *Journal of Verbal Learning and Verbal Behavior*, 9, 529-533.
- Bower, G. H., & Winzenz, D. (1970). Comparison of associative learning strategies. *Psychonomic Science*, 20, 119-120.
- Brehmer, Y., Shing, Y. L., Heekeren, H. R., Lindenberger, U., & Bäckman, L. (2016). Training-induced changes in subsequent-memory effects: No major differences among children, younger adults, and older adults. *NeuroImage*, 131, 214–225.
- Bryan, J., Luszcz, M. A., & Pointer, S. (1999). Executive Function and Processing Resources as Predictors of Adult Age Differences in the Implementation of Encoding Strategies. *Aging, Neuropsychology, and Cognition (Neuropsychology, Development and Cognition: Section B)*, 6(4), 273–287.
- Bunce, D. (2003). Cognitive support at encoding attenuates age differences in recollective experience among adults of lower frontal lobe function. *Neuropsychology*, 17(3), 353–361.
- Burgsmans, S., van Boxtel, M. P., van den Berg, K. E. Gronenschild, E. H. Jacobs, H. I., Jolles, J., & Uylings, H. B. (2011). The posterior parahippocampal gyrus is preferentially affected in age-related memory decline. *Neurobiology of aging*, 32(9), 1572-1578.

- Cabeza, R. (2002). Hemispheric asymmetry reduction in older adults: The HAROLD model. *Psychology and Aging, 17*(1), 85–100.
- Cabeza, R. (2006). Prefrontal and medial temporal lobe contributions to relational memory in younger and older adults. In H. D. Zimmer, A. Mecklinger, & U. Lindenberger (Eds.). *Handbook of Binding and Memory: Perspectives from Cognitive Neuroscience*. New York: Oxford University Press.
- Canestrari, R. E. (1963). Paced and self-paced learning in younger and elderly adults. *Journal of Gerontology, 18*, 165-168.
- Castel, A. D., & Craik, F. I. M. (2003). The effects of aging and divided attention of memory for item and associative information. *Psychology and Aging, 18*, 873-885.
- Chalfonte, B. L., & Johnson, M. K. (1996). Feature memory and binding in younger and older adults. *Memory & Cognition, 24*(4), 403–416.
- Cohen, N. J., & Eichenbaum, H. (1994) *Memory, Amnesia, and the Hippocampal System*. Massachusetts: MIT Press.
- Cohn, M., Emrich, S. M., & Moscovitch, M. (2008). Age-related deficits in associative memory: The influence of impaired strategic retrieval. *Psychology and Aging, 23*(1), 93–103.
- Craik, F. I. M. (1983). On the transfer of information from temporary to permanent memory. *Philosophical Transactions of the Royal Society Series B: Biological Sciences, 302*(1110), 341-359.
- Craik, F. I. M. (1986). A functional account of age differences in memory. In F. Klix, & H. Hagendorf (Eds.), *Human Memory and Capabilities: Mechanisms and Performances*. (pp.409-422). Amsterdam: Elsevier.
- Craik, F. I. M. (2002). Levels of processing: Past, present, and future? *Memory, 10*, 305-318.

- Davachi, L. (2006). Item, context and relational episodic encoding in humans. *Current Opinion in Neurobiology*, *16*, 693-700.
- Davachi, L., & Wagner, A. D. (2002). Hippocampal contributions to episodic encoding: insights from relational and item-based learning. *Journal of Neurophysiology*, *88*, 982-980.
- Davis, S. W., Dennis, N. A., Daselaar, S. M., Fleck, M. S., Cabeza, R. (2008). Qué PASA? The posterior-anterior shift in aging. *Cerebral Cortex*, *18*(5), 1201-1209.
- Davidson, P. S. R., & Winocur, G. (2017). Aging and Cognition. In Reference module in neuroscience and biobehavioural psychology, 1-7.
- Dalton, M. A., Tu, S., Hornberger, M., Hodges, J. R., & Piguet, O. (2014). Medial Temporal Lobe Contributions to Intra-Item Associative Recognition Memory in the Aging Brain. *Frontiers in Behavioral Neuroscience*, *7*.
- Damoiseaux, J. S., Viviano, R. P., Yuan, P., & Raz, N. (2016). Differential effect of age on posterior and anterior hippocampal functional connectivity. *Neuroimage*, *133*, 468-476.
- Dennis, N. A., & Cabeza, R. (2008). Neuroimaging of healthy cognitive aging. In F. I. M. Craik, & Salthouse, T. A. (Eds.) *The handbook of aging and cognition – III* (pp. 1-54). New York: Psychology Press.
- Dennis, N. A., Hayes, S. M., Prince, S. E., Madden, D. J., Huettel, S. A., & Cabeza, R. (2008). Effects of aging on the neural correlates of successful item and source memory encoding. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(4), 791–808.
- 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 Science*, *11*(9), 379-386.
- Drag, L. L., & Bieliauskas, L. A. (2010). Contemporary review 2009: Cognitive aging. *Journal of Geriatric Psychiatry and Neurology*, *23*(2), 75-93.

- Driscoll, I. (2003). The Aging Hippocampus: Cognitive, Biochemical and Structural Findings. *Cerebral Cortex*, *13*(12), 1344–1351.
- Dunlosky, J., & Hertzog, C. (1998). Aging and deficits in associative memory: What is the role of strategy production? *Psychology and Aging*, *13*(4), 597.
- Dunlosky, J., & Hertzog, C. (2001). Measuring strategy production during associative learning: The relative utility of concurrent versus retrospective reports. *Memory & Cognition*, *29*(2), 247–253.
- Dunlosky, J., Hertzog, C., & Powell-Moman, A. (2005). The Contribution of Mediator-Based Deficiencies to Age Differences in Associative Learning. *Developmental Psychology*, *41*(2), 389–400.
- Eichenbaum, H. (2000). A cortical-hippocampal system for declarative memory. *Nature Reviews Neuroscience*, *1*, 41-50.
- Eichenbaum, H. & Cohen, N. J. (2001). *From Conditioning to Conscious Recollection: Memory Systems of the Brain*. New York: Oxford University Press.
- Eichenbaum, H., Yonelinas, A. P., & Ranganath, C. (2007). The medial temporal lobe and recognition memory. *Annual Review of Neuroscience*, *30*, 123-152.
- Fandakova, Y., Shing, Y. L., & Lindenberger, U. (2012). Heterogeneity in memory training improvement among older adults: A latent class analysis. *Memory*, *20*(6), 554–567.
- Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3 : A flexible statistical power analysis program for the social, behavioural, and biomedical sciences. *Behavior Research Methods*, *39*, 175-191.
- Fjell, A. M., & Walhovd, K. (2010). Structural brain changes in aging: courses, causes and cognitive consequences. *Reviews in the Neurosciences*, *21*(3), 187-222.

- Frankenmolen, N. L., Altgassen, M., Kessels, R., de Waal, M. M., Hindriksen, J.-A., Verhoeven, B., ... Oosterman, J. M. (2016). Intelligence moderates the benefits of strategy instructions on memory performance: an adult-lifespan examination. *Aging, Neuropsychology, and Cognition*, 1–17.
- Froger, C., Bouazzaoui, B., Isingrini, M., & Tacconat, L. (2012). Study time allocation deficit of older adults: The role of environmental support at encoding? *Psychology and Aging*, 27(3), 577–588.
- Gershberg, F. B. & Shimamura, A. P. (1995). Impaired use of organizational strategies in free recall following frontal lobe damage. *Neuropsychologia*, 33(10), 1305-1333.
- Giovanello, K. S., & Schacter, D. L. (2012). Reduced specificity of hippocampal and posterior ventrolateral prefrontal activity during relational retrieval in normal aging. *Journal of Cognitive Neuroscience*, 24(1), 159–170.
- Glisky, E. L., Rubin, S. R., & Davidson, P. S. (2001). Source memory in older adults: An encoding or retrieval problem? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 27(5), 1131-1146.
- Glisky, E. L., & Kong, L. L. (2008). Do younger and older adults rely on different processes in source memory tasks? A neuropsychological study. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 34, 809-822.
- Glisky, E. L., Polster, M. R., & Routhieaux, B. C. (1995). Double dissociation between item and source memory. *Neuropsychology*, 9(2), 229.
- Grady, C. L., Maisog, J. M., Horwitz, B., Ungerleider, L. G., Mentis, M. J., Salerno, J. A., et al. (1994). Age-related changes in cortical blood flow activation during visual processing of faces and location. *Journal of Neuroscience*, 14(3, Pt 2), 1450-1462.

- Grady, C. L., McIntosh, A. R., Horwitz, B., Maisog, J. M., Ungerleider, L. G., Mentis, M. J., et al. (1995). Age-related reductions in human recognition memory due to impaired encoding. *Science*, *269*(5221), 218-221.
- Gunning-Dixon, F. M., & Raz, N. (2000). The cognitive correlates of white matter abnormalities in normal aging: A quantitative review. *Neuropsychology*, *14*(2), 224–232.
- Gutchess, A. H., Welsh, R. C., Hedden, T., Bangert, A., Minear, M., Liu, L. L., et al. (2005). Aging and the neural correlates of successful picture encoding: frontal activations compensate for decreased medial temporal activity. *Journal of Cognitive Neuroscience*, *17*, 84-96.
- Hampstead, B. M., Stringer, A. Y., Stilla, R. F., Giddens, M., & Sathian, K. (2012). Mnemonic strategy training partially restores hippocampal activity in patients with mild cognitive impairment. *Hippocampus*, *22*(8), 1652–1658.
- Hara, Y., & Naveh-Benjamin, M. (2015). The role of reduced working memory storage and processing resources in the associative memory deficit of older adults: simulation studies with younger adults. *Aging, Neuropsychology, and Cognition*, *22*(2), 129–154.
- Hedman, A. M., van Haren, N. E., Schnack, H. G., Kahn, R. S., Kulschoff Pol, H. E. (2012). Human brain changes across the life span: a review of 56 longitudinal magnetic resonance imaging studies. *Human Brain Mapping*, *33*, 1987-2002.
- Hertzog, C., & Dunlosky, J. (2004). Aging, metacognition, and cognitive control. *Psychology of Learning and Motivation*, *45*, 215-251.
- Hertzog, C., Fulton, E. K., Mandviwala, L., & Dunlosky, J. (2013). Older adults show deficits in retrieving and decoding associative mediators generated at study. *Developmental Psychology*, *49*(6), 1127–1131.

- Hertzog, C., & Hultsch, D. F. (2000). Metacognition in adulthood and old age. In F. I. M. Craik, & T. A. Salthouse (Eds.). *The Handbook of Aging and Cognition, 2nd edition*. (pp-417-466). Mahwah, New Jersey: Erlbaum.
- Hertzog, C., McGuire, C. L., Horhota, M., & Jopp, D. (2010). Does Believing in “Use It or Lose It” Relate to Self-Rated Memory Control, Strategy Use, and Recall? *The International Journal of Aging and Human Development, 70*(1), 61–87.
- Hinault, T., Lemaire, P., & Touron, D. (2016). Aging effects in sequential modulations of poorer-strategy effects during execution of memory strategies. *Memory, 1*–11.
- Holm, S. (1979). A simple sequential rejective method procedure. *Scandinavian Journal of Statistics, 6*, 65-70.
- Hulicka, I. M., & Grossman, J. (1967). Age-group comparisons for the use of mediators in paired-associate learning. *Journal of Gerontology, 22*, 46-51.
- Hutchens, R. L., Kinsella, G. J., Ong, B., Pike, K. E., Clare, L., Ames, D., ... Parsons, S. (2013). Relationship Between Control Beliefs, Strategy Use, and Memory Performance in Amnesic Mild Cognitive Impairment and Healthy Aging. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 68*(6), 862–871.
- Jackson, O., & Shacter, D. L. (2004). Encoding activity in anterior medial temporal lobe supports subsequent associative recognition. *Neuroimage, 21*, 456-462.
- Jernigan, T. L., Archibald, S. L., Fenema-Notestine, C., Gamst, A. C., Stout, J. C., Bonner, J., Hesselink, J. R. (2001) Effects of age on tissues and regions of the cerebrum and cerebellum, *Neurobiology of Aging, 22*, 581–594.
- Kamp, S.-M., & Zimmer, H. D. (2015). Contributions of attention and elaboration to associative encoding in younger and older adults. *Neuropsychologia, 75*, 252–264.

- Kaplan, R., Bush, D., Bonnefond, M., Bandettini, P. A., Barnes, G. R., Doeller, C. F., & Burgess, N. (2014). Medial prefrontal theta phase coupling during spatial memory retrieval. *Hippocampus*, *24*(6), 656-665.
- Karbach, J., & Verhaeghen, P. (2014). Making working memory work: A meta-analysis of executive control and working memory training in younger and older adults. *Psychological Science*, *25*(11), 2027-2037.
- Kausler, D. H. (1994). Adult age differences in paired-associate learning. *Learning and Memory in Normal Aging* (pp. 66-98). Academic Press: California.
- Kirchhoff, B. A. (2009). Individual Differences in Episodic Memory: The Role of Self-initiated Encoding Strategies. *The Neuroscientist*, *15*(2), 166–179.
- Kirchhoff, B. A., & Buckner, R. L. (2006). Functional-Anatomic Correlates of Individual Differences in Memory. *Neuron*, *51*(2), 263–274. <https://doi.org/10.1016/j.neuron.2006.06.006>
- Kirchhoff, B. A., Gordon, B. A., & Head, D. (2014). Prefrontal gray matter volume mediates age effects on memory strategies. *NeuroImage*, *90*, 326–334.
- Korchin, S. J., Basowitz, H. (1957). Age differences in verbal learning. *Journal of Abnormal and Social Psychology*, *54*, 64-69.
- Kousaie, A., & Taler, V. (2015). The bilingual advantage: Elusive but worth the effort? *Cortex*, *73*, 338-339.
- Kovalenko, L. Y., Chaumon, M., & Busch, N. A. (2012). A Pool of Pairs of Related Objects (POPORO) for Investigating Visual Semantic Integration: Behavioral and Electrophysiological Validation. *Brain Topography*, *25*(3), 272–284.

- Kuhlmann, B. G., & Touron, D. R. (2012). Mediator-based encoding strategies in source monitoring in younger and older adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 38(5), 1352–1364.
- Kuhlmann, B. G., & Touron, D. R., Relate it! Objective and subjective evaluation of mediator-based strategies for improving source memory in younger and older adults, *Cortex* (2016).
- Lachman, M. E., & Andreoletti, C. (2006). Strategy use mediates the relationship between control beliefs and memory performance for middle-aged and older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, 61(2), P88–P94.
- Lachman, M. E., Bandura, M., Weaver, S. L., & Elliott, E. (1995). Assessing memory control beliefs: The memory controllability inventory, 2(1), 67-84.
- Leshikar, E. D., Gutchess, A. H., Hebrank, A. C., Sutton, B. P., & Park, D. C. (2010). The impact of increased encoding demand on frontal and medial temporal function in older adults. *Cortex*, 4, 507-521.
- Light, L. L., & La Voie, D. (1993). Direct and indirect measures of memory in old age. In P. Graf & M. E. J. Masson (Eds.), *Implicit memory: New directions in cognition, development, and neuropsychology* (pp.207-230). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Lindenberger, U. (2014). Human cognitive aging: *Corriger la fortune?* *Science*, 346(6209), 572-578.
- Lindenberger, U., & Ghisletta, P. (2009). Cognitive and sensory declines in old age: Gauging the evidence for a common cause. *Psychology and Aging*, 24, 1-16.
- Logan, J. M., Sanders, A. L., Snyder, A. Z., Morris, J. C., & Buckner, R. L. (2002). Under-recruitment and nonselective recruitment: dissociable neural mechanisms associated with aging. *Neuron*, 33(5), 827–840.

- Mayes, A., Montaldi, D., & Migo, E. (2007). Associative memory and the medial temporal lobes. *Trends in Cognitive Sciences, 11*(3), 126–135.
- Mayes, A. R., Holdstock, J. S., Isaac, C. L., Montaldi, D., Grigor, J., Gummer, A., ... Norman, K. A. (2004). Associative recognition in a patient with selective hippocampal lesions and relatively normal item recognition. *Hippocampus, 14*(6), 763–784.
- Mayes, A. R., Isaac, C. L., Holdstock, J. S., Hunkin, N. M., Montaldi, D., Downes, J. J., ... Roberts, J. N. (2001). Memory for single items, word pairs, and temporal order of different kinds in a patient with selective hippocampal lesions. *Cognitive Neuropsychology, 18*(2), 97–123.
- Meulenbroek, O., Kessels, R. P. C., de Rover, M., Petersson, K. M., Rikkert, M. G. M. O., Rijpkema, M., & Fernández, G. (2010). Age-effects on associative object–location memory. *Brain Research, 1315*, 100–110.
- Miller, E. K., & Cohen, J.D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*, 167-202.
- Mitchell, K. J., & Johnson, M. K. (2009). Source monitoring 15 years later: What have we learned from fMRI about the neural mechanisms of source memory? *Psychological Bulletin, 135*(4), 638–677.
- Mitchell, K. J., Johnson, M. K., Raye, C. L., & D'Esposito, M. (2000). fMRI evidence of age-related hippocampal dysfunction in feature binding in working memory. *Cognitive Brain Research, 10*(1), 197–206.
- Morse, C. K. (1993). Does variability increase with age? An archival study of cognitive measures. *Psychology and Aging, 8*(2), 156-164.
- Moscovitch, M. (1992). Memory and working-with-memory: A component process model based on modules and central systems. *Journal of Cognitive Neuroscience, 4*(3), 257-267.

- Moscovitch, M., & Winocur, G. (1995). Frontal lobes, memory, and aging. *Annals of the New York Academy of Sciences*, 769(1), 119–150.
- Moscovitch, M. & Winocur, G. (2002). The frontal cortex and working with memory In Stuss D. T. & Knight R. T. (Eds.), *Principles of frontal lobe function* (pp. 188-209). Oxford, UK: Oxford University Press.
- Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I, ... Chertkow, H. (2005). The Montreal cognitive assessment, MoCA : A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society*, 53(4), 695-699.
- 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.
- 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.
- Naveh-Benjamin, M., Craik, F. I. M., Guez, J., & Kreuger, S. (2005). Divided attention in younger and older adults: Effects of strategy and relatedness on memory performance and secondary task costs. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 31(3), 520–537.
- 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.
- 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.
- Nyberg, L., Bäckman, L., Erngrund, K., Olofsson, U., & Nilsson, L. G. (1996). Age differences in episodic memory, semantic memory, and priming: relationships to demographic, intellectual, and

- biological factors. *The Journals of Gerontology: Series B, Psychological Sciences and Social Sciences*, 51(4), 234-240.
- 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.
- Paivio, A., & Yuille, J. C. (1967). Mediation instructions and word attributes in paired-associate learning. *Psychonomic Science*, 8, 65-66.
- Paivio, A., Yuille, J. C., & Smythe, P. C. (1966). Stimulus and response abstractness, imagery, and meaningfulness, and reported mediators in paired-associate learning. *Canadian Journal of Psychology*, 20, 362-377.
- Palladino, P., & De Beni, R. (2003). When mental images are very detailed: image generation and memory performance as a function of age. *Acta Psychologica*, 113(3), 297–314.
- Park, H., Shannon, V., Biggan, J., & Spann, C. (2012). Neural activity supporting the formation of associative memory versus source memory. *Brain Research*, 1471, 81–92.
- Pfefferbaum, A., Sullivan, E. V., Rosenbloom, M. J., Mathalon, D. H., Lim, K. O. (1998). A controlled study of cortical gray matter and ventricular changes in alcoholic men over a 5-year interval. *Archives of General Psychiatry*, 55, 905–912.
- Peterson, D. J., Gargya, A., Kopeikin, K. S., & Naveh-Benjamin, M. (2016). The impact of level of education on age-related deficits in associative memory: Behavioral and neuropsychological perspectives. *Cortex*.
- Postma, A., Kessels, R. P. C., & van Asselen, M. (2005). How the brain remembers and forgets where things are: The neurocognition of object-location memory. *Neuroscience and Biobehavioral Reviews*, 32, 1339-1345.

- Preston, A. R., & Eichenbaum, H. (2013). Interplay of hippocampus and prefrontal cortex in memory. *Current Biology*, 23, 764-773.
- Radloff, L. S. (1977). The CES-D scale: A self-report depression scale for research in the general population. *Applied Psychological Measurement*, 1(3), 385-401.
- Ranganath, C. (2010). A unified framework for the functional organization of the medial temporal lobes and the phenomenology of episodic memory. *Hippocampus*, 20, 1263-1290.
- Raz N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In F. I. M. Craik, T. A. Salthouse (Eds.), *Handbook of aging and cognition – II* (pp. 1-90), New Jersey: Erlbaum.
- Raz, N., (2005). The aging brain observed in vivo: Differential changes and their modifiers. In R. Cabeza, Nyberg, L., & Park, D. (Eds.), *Cognitive neuroscience of aging* (19-57). New York: Oxford University Press.
- Raz, N., Lindenberger, U., Rodrigue, K. M., Kennedy, K. M., Head, D., Williamson, A., et al. (2005). Regional brain changes in aging healthy older adults: General trends, individual differences and modifiers. *Cerebral Cortex*, 7(3), 268-282.
- Raz, N., & Kennedy, K. M. (2009). Neuroanatomical changes, their modifiers, and cognitive correlates. In W. Jagust, M. D'esposito (Eds.) *Imaging the aging brain*, (pp. 43-70), Oxford University Press: New York.
- Raz, N., Rodrigue, K. M., Head, D., Kennedy, K. M., & Acker, J. D. (2004). Differential aging of the medial temporal lobe a study of a five-year change. *Neurology*, 62(3), 433-438.
- Resnick, S. M., Pham, D. L., Kraut, M. A., Zonderman, A. B., & Davatzikos, C. (2003). Longitudinal magnetic resonance imaging studies of older adults: a shrinking brain. *The Journal of Neuroscience*, 23(8), 3295-3301.

- Reuter-Lorenz, P. A., Jonides, J., Smith, E. E., Hartley, A., Miller, A., Marshuetz, C., et al. (2000). Age differences in the frontal laterization of verbal and spatial working memory revealed by PET. *Journal of cognitive neuroscience* 23(8). 3295-3301.
- Reuter-Lorenz, P. A., & Park, D. C. (2010). Human Neuroscience and the Aging Mind: A New Look at Old Problems. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, 65B(4), 405–415.
- Richardson, J. T. (1998). The availability and effectiveness of reported mediators in associative learning: A historical review and an experimental investigation. *Psychonomic Bulletin & Review*, 5(4), 597–614.
- Roediger, H.L., Marsh, E. J., & Lee, S. C. (2002). Varieties of Memory. In H. Pashler & D. Medin (Eds.) *Stevens' Handbook of Experimental Psychology*. (3rd ed.). New York: John Wiley & Sons.
- Rogers, W. A., Hertzog, C., & Fisk, A. D. (2000). An individual differences analysis of ability and strategy influences: age-related differences in associative learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 26(2), 359.
- Rosetti, H. C., Lacritz, L. H., Cullum, C. M., & Weiner, M. F. (2011). Normative data for the Montreal Cognitive Assessment (MoCA) in a population-based sample. *Neurology*, 77(13), 1272-1275.
- Ruch, F. L. (1934). The differentiative effects of age upon human learning. *Journal of General Psychology*, 11, 261-286.
- Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review*, 103(3), 403-428.

- Salthouse, T. A., Kausler, D. H., & Saults, J. S. (1988). Investigation of student status, background variables, and feasibility of standard tasks in cognitive aging research. *Psychology and Aging, 3*, 158-166.
- Scahill, R. I., Frost, C., Jenkins, R., Whitwell, J.I., Rossor, M.N., & Fox, N. C. (2003). A longitudinal study of brain volume changes in normal aging using serial registered magnetic resonance imaging. *Archives of Neurology, 60*, 989–994.
- Schott, B.H., Wüstenberg, T., Wimber, M., Fenker, D.B., Zierhut, K.C., Seidenbecher, C.I., Richardson-Klavehn, A., (2013). The relationship between level of processing and hippocampal-cortical functional connectivity during episodic memory formation in humans. *Human Brain Mapping, 34*, 407–424.
- Shing, Y. L., Brehmer, Y., Heekeren, H. R., Bäckman, L., & Lindenberger, U. (2016). Neural activation patterns of successful episodic encoding: Reorganization during childhood, maintenance in old age. *Developmental Cognitive Neuroscience, 20*, 59–69.
- Shing, Y. L., Werkle-Bergner, M., Brehmer, Y., Müller, V., Li, S.-C., & Lindenberger, U. (2010). Episodic memory across the lifespan: The contributions of associative and strategic components. *Neuroscience & Biobehavioral Reviews, 34*(7), 1080–1091.
- Shing, Y. L., Werkle-Bergner, M., Li, S.-C., & Lindenberger, U. (2008). Associative and strategic components of episodic memory: A life-span dissociation. *Journal of Experimental Psychology: General, 137*(3), 495–513.
- Simons, J. S., & Spiers, H. J. (2003). Prefrontal and medial temporal lobe interactions in long-term memory. *Nature Reviews Neuroscience, 4*(8), 637–648.
- Souchay, C., & Isingrini, M. (2004). Age related differences in metacognitive control: Role of executive functioning. *Brain and Cognition, 56*(1), 89–99.

- Spencer, W. D., & Raz, N. (1995). Differential effects of aging on memory for content and context: a meta-analysis. *Psychology and Aging, 10*(4), 527-539.
- Squire, L. R. (1992). Declarative and nondeclarative memory: Multiple brain systems supporting learning and memory. *Journal of Cognitive Neuroscience, 4*, 232-243.
- Statistics Canada (2011). National Household Survey, Statistics Canada Catalogue no. 99-012-X2011035.
- Stern, Y. (2009). Cognitive Reserve. *Neuropsychologia, 47*(10), 2015–2028.
- Tabachnick, B. G., & Fidell, L. S. (2007). Using multivariate statistics. Boston, MA: Allyn and Bacon
- Taconnat, L., Baudouin, A., Fay, S., Clarys, D., Vanneste, S., Tournelle, L., & Isingrini, M. (2006). Aging and implementation of encoding strategies in the generation of rhymes: The role of executive functions. *Neuropsychology, 20*(6), 658–665.
- Taconnat, L., Clarys, D., Vanneste, S., Bouazzaoui, B., & Isingrini, M. (2007). Aging and strategic retrieval in a cued-recall test: The role of executive functions and fluid intelligence. *Brain and Cognition, 64*(1), 1–6. <https://doi.org/10.1016/j.bandc.2006.09.011>
- Touron, D. R., & Hertzog, C. (2004). Strategy shift affordance and strategy choice in younger and older adults. *Memory and Cognition, 32*(2), 298-310.
- Treat, N. J., Poon, L. W., & Fozard, J. L. (1981). Age, imagery, and practice in paired-associate learning. *Experimental Aging Research, 7*(3), 337–342.
- Treat, N. J., & Reese, H. W. (1976). Age, pacing, and imagery in paired-associate learning. *Developmental Psychology, 12*(2), 119-124.
- Troyer, A. K. & Craik, F. I. (2000). The effect of divided attention on memory for items and their context. *Canadian Journal of Experimental Psychology, 54*(3), 161-171.

- Troyer, A. K., D'Souza, N. A., Vandermorris, S., & Murphy, K. J. (2011). Age-related differences in associative memory depend on the types of associations that are formed. *Aging, Neuropsychology, and Cognition*, *18*(3), 340–352.
- Troyer, A. K., & Rich, J. B. (2002). Psychometric properties of a new metamemory questionnaire for older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *57*(1), 19–27.
- Troyer, A. K., Winocur, G., Craik, F. I., & Moscovitch, M. (1999). Source memory and divided attention: reciprocal costs to primary and secondary tasks. *Neuropsychology*, *13*(4), 467–474.
- Tulving, E. (1972). Episodic and semantic memory. In E. Tulving & W. Donaldson (Eds.), *Organization of Memory* (pp.381-403). New York: Academic Press.
- Turriziani, P., Fadda, L., Caltagirone, C., & Carlesimo, G. A. (2004). Recognition memory for single items and for associations in amnesic patients. *Neuropsychologia*, *42*(4), 426–433.
- Uittenhove, K., Burger, L., Tacconnat, L., & Lemaire, P. (2015). Sequential difficulty effects during execution of memory strategies in younger and older adults. *Memory*, *23*(6), 806–816.
- Van Petten, C. (2004). Relationship between hippocampal volume and memory ability in healthy individuals across the lifespan: review and meta-analysis. *Neuropsychologia*, *42*(10), 1394–1413. <https://doi.org/10.1016/j.neuropsychologia.2004.04.006>
- Vargha-Khadem, F. (1997). Differential Effects of Early Hippocampal Pathology on Episodic and Semantic Memory. *Science*, *277*(5324), 376–380.
- Verhaeghen, P., Marcoen, A., & Goossens, L. (1993). Facts and fiction about memory aging: A quantitative integration of research findings. *Journal of Gerontology*, *48*(4), P157–P171.

- Verhaeghen, P., & Salthouse, T. (1997). Meta-analyses of age-cognition relations in adulthood: Estimates of linear and nonlinear age effects and structural models. *Psychological Bulletin*, *122*(3), 231-249.
- Wagner, A. D., Shachter, D. L., Rotte, M., Koutstaal, W., Maril, A., Dale, A. M., ... Buckner, R. L. (1998). Building memories: remembering and forgetting of verbal experiences as predicted by brain activity. *Science*, *281*(5380), 1188–1191.
- Werkle-Bergner, M., Müller, V., Li, S.-C., & Lindenberger, U. (2006). Cortical EEG correlates of successful memory encoding: Implications for lifespan comparisons. *Neuroscience & Biobehavioral Reviews*, *30*(6), 839–854.
- Willis, S. L., & Shaie, K. W. (2009). Cognitive training and plasticity: theoretical perspective and methodological consequences. *Restorative Neurology and Neuroscience*, *27*(5), 375-389.
- Wilson, R. S., Beckett, L. A., Barnes, L. L., Schneider, J. A., Bach, J., Evans, D. A., Bennett, D. A. (2002). Individual differences in rates of change in cognitive abilities of older persons. *Psychology and Aging*, *17*, 179-193.
- Wong, J. X., de Chastelaine, M., & Rugg, M. D. (2013). Comparison of the neural correlates of encoding item-item and item-context associations. *Frontiers in Human Neuroscience*, *7*, 436.
- Zimmer, H. D., Mecklinger, A., & Lindenberger, U. (2006). Levels of binding. In H. D. Zimmer, A. Mecklinger, & U. Lindenberger (Eds.). *Handbook of Binding and Memory: Perspectives from Cognitive Neuroscience*. New York: Oxford University Press.
- Zimmerman, K, von Bastian, C. C., Röcke, C., Martin, M., & Eschen, A. (2016). Transfer after process-based object-location memory training in healthy older adults. *Psychology and Aging*, *31*(7), 798-814.

APPENDICES

Appendix A. Strategy Descriptions

Strategy Descriptions for Object-Object Test

Here is a description of various strategies. Please let us know which strategy you used (if any) to help you remember each object-object pair. Please take the time to familiarize yourself with these different categories before you begin.

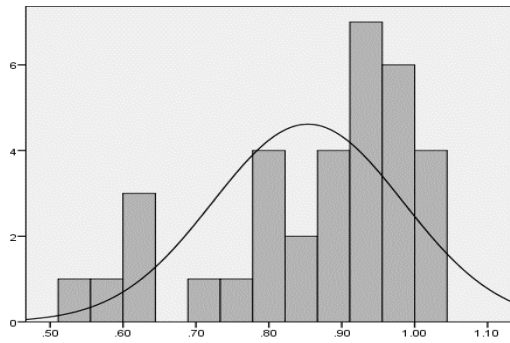
Letter	Strategy Type
a	Integrative Imagery: Imagining a scene using the two objects in it. For example: Imagining the <u>dog</u> wearing the <u>hat</u> to go to the beach.
b	Sentence Generation: Constructing a sentence using both of the objects. For example: « The <u>dog</u> hid the <u>hat</u> in the garden ».
c	Rote Repetition: Saying the object pair over and over. For example: dog-hat, <u>dog-hat</u> , <u>dog-hat</u> , <u>dog-hat</u> .
d	Personal Relatedness: Relating the object pair to something of meaning in your life. For example, remembering the time when your <u>dog</u> chewed up your <u>hat</u> .
e	Focal Attention: Focusing on the object pair by looking or staring at it until you can see the object pair clearly in your mind.
f	Visual Similarity: Focusing on the visual similarities of the pair of objects, either in terms of colour or shape.
g	Relating objects based on common function or characteristics: For example, both objects being in the same category of objects, made of the same kind of material, having a similar function, etc.
h	Other Strategy: Any other strategy that does not fall into one of these categories.
i	No Strategy: Anytime you did not use a strategy, or tried to use a strategy but ran out of time.

Instructions for Strategy Report for Object-Location Test

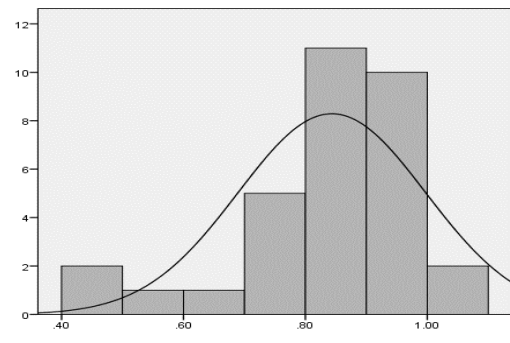
Here is a description of various strategies. Please let us know which strategy you used (if any) to help you remember each object-location pair. Please take the time to familiarize yourself with these different categories before you begin.

Letter	Strategy Type
a	Integrative Imagery: Imagining a scene integrating the object and its spatial positioning relative to the other object in the grid. For example, if the hat is the upper right corner and the dog is in the lower left corner, you could imagine the <u>dog's hat</u> being lifted up off his head by a gust of wind.
b	Sentence Generation: Describing a scene integrating the object and its spatial positioning relative to the other object in the grid. For example, if the hat is the upper right corner and the dog is in the lower left corner, you come up with the following sentence: "I need to put my <u>hat</u> on <i>before</i> I take my <u>dog</u> out for a walk".
c	Rote Repetition: Saying the object and their locations over and over. For example: <u>hat</u> up right, <u>dog</u> down left; <u>hat</u> up right, <u>dog</u> down left; <u>hat</u> up right, <u>dog</u> down left, etc.
d	Personal Relatedness: Relating the object pair to something of meaning in your life. For example, remembering the time when your <u>dog</u> chewed up your <u>hat</u> .
e	Focal Attention: Focus on the object pair and their locations by looking or staring at it until you can see the object pair and their locations clearly in your mind.
f	Visual Similarity: Focusing on the visual similarities of the pair of objects, either in terms of colour or shape.
g	Relating objects based on common function or characteristics: For example, both objects being in the same category of objects, made of the same kind of material, having a similar function, etc.
h	Counting grids: Counting the number of grids between object-location pairs, or between object-locations and the edge, side, or corner of the grid.
i	Any other strategy integrating object and location: Please describe to the experimenter.
j	No Strategy: Anytime you did not use a strategy, or tried to use a strategy but ran out of time.

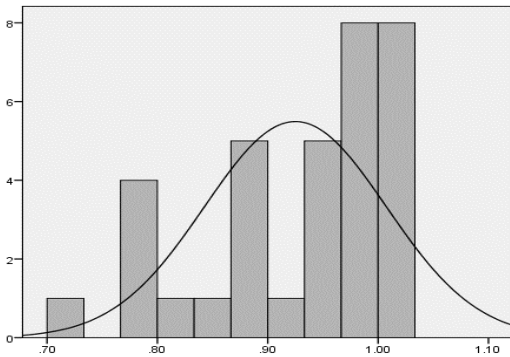
Appendix B. Histograms of (potentially) skewed distributions in Experiment 1



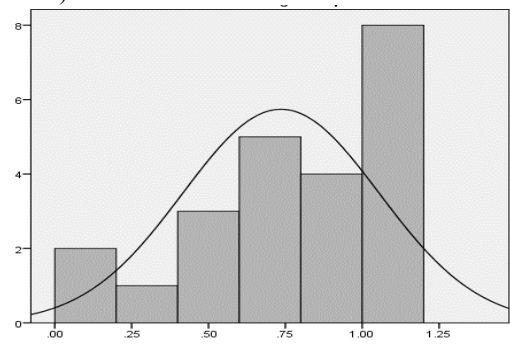
Proportion of object-object pairs correctly recognized in young adults ($z = -2.34$)



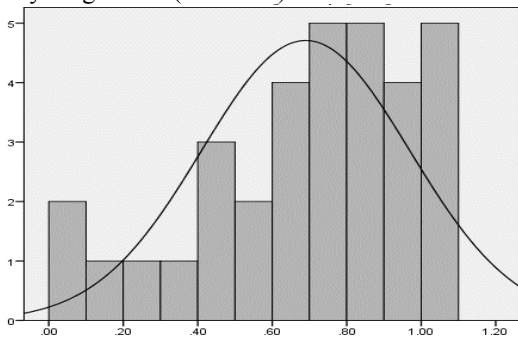
Proportion of correct object-object recognition for pairs encoded with a mediator in older adults ($z = -3.31$)



Proportion of correct object-object recognition for pairs encoded with a mediator in young adults ($z = -2.59$)



Proportion of correct object-location recognition for pairs encoded with a mediator in older adults ($z = -2.53$)



Proportion of correct object-object pair recognition encoded with a non-mediator in young adults ($z = -2.33$)

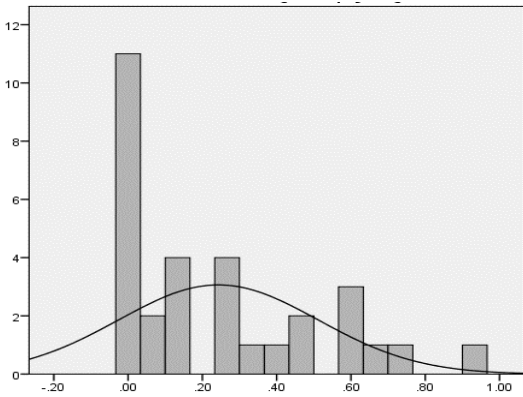
Appendix C. Proportion of pairs participants reported encoding by a given strategy (Experiment 1)

	Strategy Reported																					
	Elaborative Strategies											Non-elaborative Strategies										
	Imagery		Sentence		Personal		Visual		Semantic		Phonetic		Focal Att.		Repetition		Counting		No Strategy		Other	
	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD
Object-object																						
Young adults	.14	.14	.07	.07	.03	.03	.38	.16	.09	.06	.01	.03	.06	.12	.11	.13	--	--	.08	.09	.02	.02
Older adults	.13	.14	.10	.13	.03	.03	.34	.17	.13	.08	.01	.02	.06	.12	.03	.09	--	--	.16	.14	.01	.03
Object-location																						
Young adults	.08	.15	.02	.05	.00	.01	.16	.22	.02	.07	.00	.00	.34	.36	.08	.18	.10	.22	.08	.15	.11	.27
Older adults	.06	.11	.02	.04	.02	.05	.16	.21	.04	.06	.01	.03	.25	.33	.01	.04	.08	.21	.28	.34	.05	.18

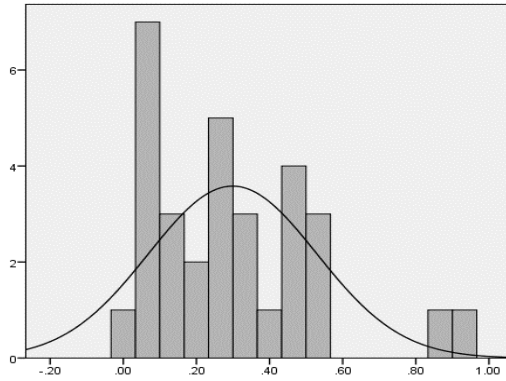
Appendix D. Proportion of correct paired-associate recognition performance as a function of the strategies participants reported producing at study Experiment 1.

	Strategy Reported																					
	Elaborative Strategies											Non-elaborative Strategies										
	Imagery		Sentence		Personal		Visual		Semantic		Phonetic		Focal Att.		Repetition		Counting		No Strategy		Other	
	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD
Object-object																						
Young adults	.93	.15	.97	.07	.94	.05	.88	.12	.93	.19	.96	.13	.73	.27	.72	.33	--	--	.68	.35	.98	.09
Older adults	.82	.25	.91	.23	.88	.28	.83	.12	.84	.26	.83	.36	.44	.40	.91	.16	--	--	.61	.29	.88	.27
Object-location																						
Young adults	.64	.37	.70	.45	--	--	.62	.32	.54	.42	--	--	.69	.27	.56	.33	.45	.37	.47	.40	.55	.30
Older adults	.67	.42	.94	.14	.70	.45	.67	.35	.97	.10	.50	.71	.51	.35	--	--	.76	.27	.66	.35	.69	.41

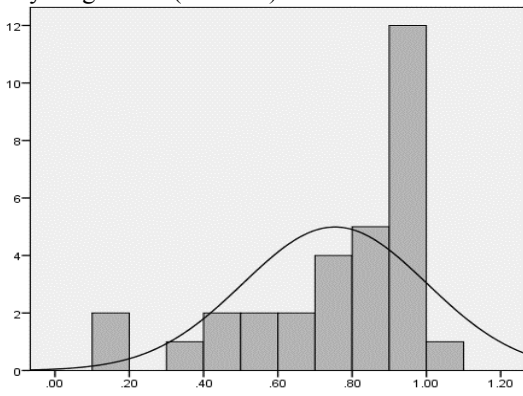
Appendix E. Histograms of potentially skewed distributions in Experiment 2



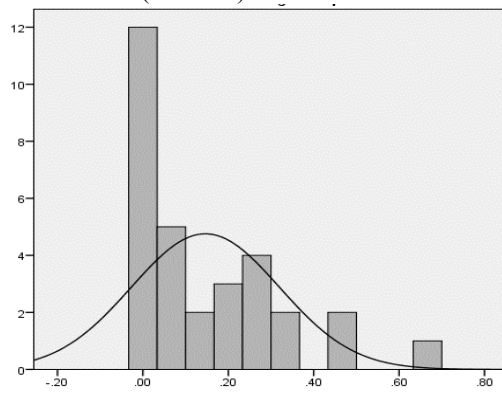
Proportion of object-location pairs studied with a mediator in young adults ($z = 2.23$)



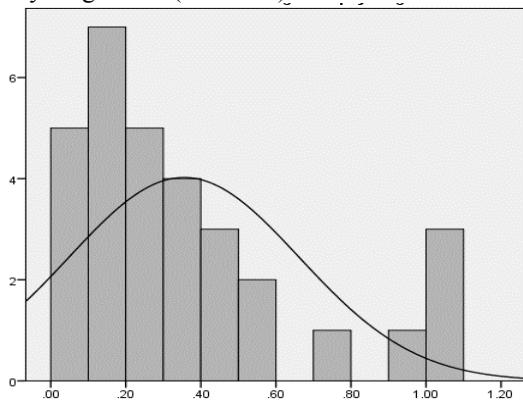
Proportion of object-location pairs accurately remembered in older adults ($z = 2.55$)



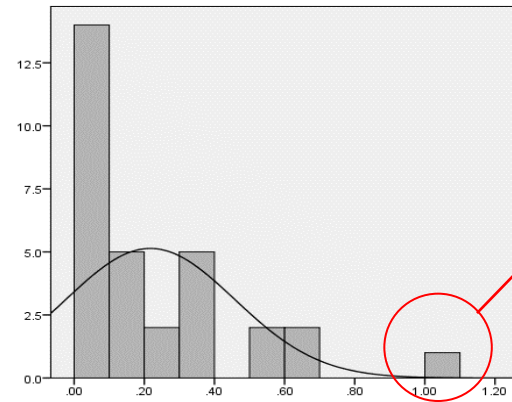
Proportion of correct object-object recognition for pairs encoded with a mediator in young adults ($z = -3.26$)



Proportion of object-location pairs studied with a mediator in older adults ($z = 3.05$)

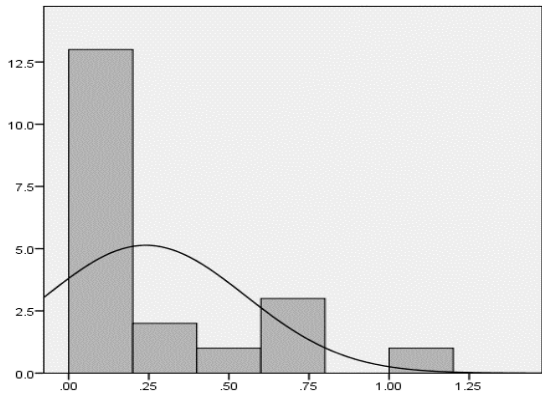


Proportion of correct object-object pair recognition encoded with a non-mediator in young adults ($z = 2.55$)

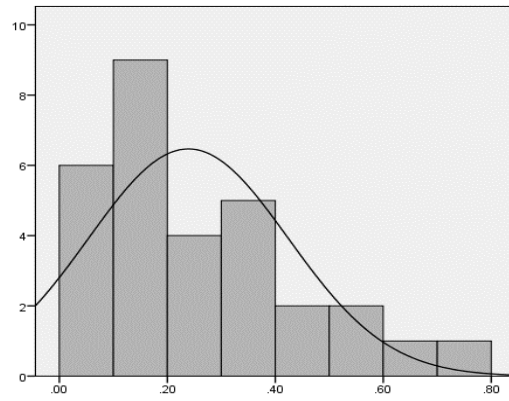


Proportion of correct object-object recognition encoded with a non-mediator in older adults ($z = 2.96$)

Outlier ($z=3.31$) removed from analyses



Proportion of correct object-location pair recognition encoded with a mediator in young adults ($z = 2.36$)



Proportion of correct object-location pair recognition encoded with a non-mediator in older adults ($z = 2.62$)

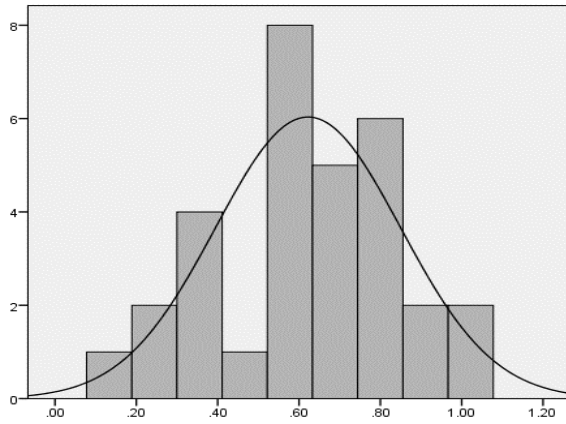
Appendix F. Proportion of pairs participants reported studying by a given strategy – Experiment 2

	Strategy Reported																					
	Elaborative Strategies											Non-elaborative Strategies										
	Imagery		Sentence		Personal		Visual		Semantic		Phonetic		Focal Att.		Repetition		Counting		No Strategy		Other	
	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD
Object-object																						
Young adults	.11	.14	.08	.15	.06	.08	.37	.19	.05	.06	.00	.01	.06	.14	.10	.13	--	--	.15	.13	.02	.03
Older adults	.09	.09	.03	.04	.02	.04	.38	.19	.11	.10	.02	.03	.10	.17	.01	.03	--	--	.20	.18	.05	.05
Object-location																						
Young adults	.03	.10	.01	.04	.01	.03	.18	.19	.01	.02	.01	.03	.11	.22	.01	.03	.34	.30	.13	.20	.14	.23
Older adults	.00	.01	.00	.00	.00	.00	.10	.14	.03	.05	.01	.05	.20	.30	.01	.05	.22	.33	.27	.35	.14	.26

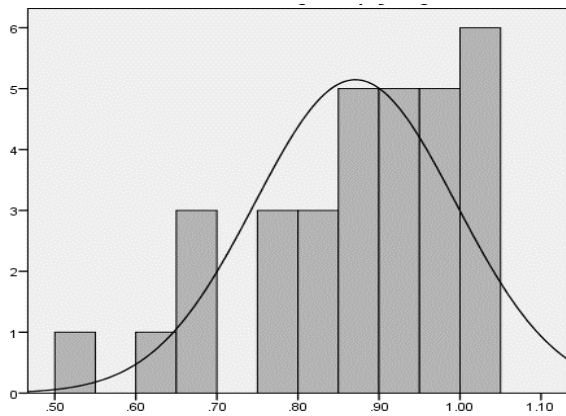
Appendix G. Proportion of correct paired-associate recognition performance as a function of the strategies participants reported producing at study in Experiment 2

	Strategy Reported																					
	Elaborative Strategies											Non-elaborative Strategies										
	Imagery		Sentence		Personal		Visual		Semantic		Phonetic		Focal Att.		Repetition		Counting		No Strategy		Other	
	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD
Object-object																						
Young adults	.87	.25	.81	.33	.89	.23	.75	.25	.88	.20	.63	.48	.35	.41	.54	.33	--	--	.25	.26	.83	.33
Older adults	.58	.35	.65	.39	.61	.45	.61	.22	.63	.34	.53	.44	.24	.33	.40	.47	--	--	.14	.17	.59	.40
Object-location																						
Young adults	.20	.45	.17	.24	.00	.00	.24	.27	.20	.45	.50	.71	.24	.30	.83	.29	.05	.25	.05	.19	.09	.39
Older adults	--	--	--	--	--	--	.26	.37	.45	.46	.42	.52	.38	.34	.13	.18	.30	.33	.28	.26	.54	.39

Appendix H. Histograms of (potentially) skewed distributions Experiment 3



Proportion of object-object pairs correctly recognized in young adults ($z = -2.09$)



Proportion of correct object-object recognition for pairs encoded with a mediator in young adults ($z = -2.33$)

Appendix I. Proportion of items that participants reported studying by a given strategy – Experiment 3

	Strategy Reported																					
	Elaborative Strategies											Non-elaborative Strategies										
	Imagery		Sentence		Personal		Visual		Semantic		Phonetic		Focal Att.		Repetition		Counting		No Strategy		Other	
	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD
Object-object																						
Young adults	.39	.29	.31	.23	.04	.06	.12	.12	.04	.07	.00	.00	.03	.07	.03	.09	--	--	.04	.06	.00	.01
Older adults	.34	.31	.36	.30	.02	.06	.11	.09	.04	.06	.00	.00	.02	.04	.02	.05	--	--	.08	.10	.02	.05
Object-location																						
Young adults	.41	.29	.40	.27	--	--	.01	.05	--	--	--	--	.01	.04	--	--	--	--	.09	.10	.07	.13
Older adults	.38	.34	.35	.31	--	--	--	--	--	--	--	--	.01	.06	--	--	--	--	.14	.16	.11	.18

Appendix J. Proportion of correct paired-associate recognition performance as a function of the strategies participants reported producing at study – Experiment 3

	Strategy Reported																					
	Elaborative Strategies												Non-elaborative Strategies									
	Imagery		Sentence		Personal		Visual		Semantic		Phonetic		Focal Att.		Repetition		Counting		No Strategy		Other	
	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD
Object-object																						
Young adults	.86	.14	.89	.14	.93	.15	.88	.18	.89	.29	--	--	.73	.35	.63	.34	--	--	.48	.31	--	--
Older adults	.60	.30	.59	.29	.69	.43	.83	.22	.61	.45	--	--	.53	.46	.43	.44	--	--	.49	.41	.69	.40
Object-location																						
Young adults	.59	.28	.52	.24	--	--	1.0	.00	--	--	--	--	.33	.58	--	--	--	--	.52	.39	.51	.41
Older adults	.45	.30	.48	.26	--	--	--	--	--	--	--	--	.70	.42	--	--	--	--	.44	.35	.54	.57