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Prior Knowledge and Age Effects in Memory

Implications for Episodic and Short-term/ Immediate Memory

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Declaration

I declare that the work presented in this thesis is a product of my own efforts. All of the data was collected by myself. The work presented in this thesis was funded by a studentship obtained from City University, London. Chapters 2-4 were written to be published as journal articles.

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Abstract

The ageing literature shows robust age-related declines in immediate (e.g. Bopp & Verhaeghen, 2005; Multhaup, Balota & Cowan, 1996; Verhaeghen, 2002; Verhaeghen, Marcoen & Goosens, 1993) and episodic memory (Fleischman, Wilson, Gabrieli, Bienias & Bennett, 2004; Park, 2000; Schaie, 2005; Singer, Lindenberger & Baltes, 2003). However, older adults also consistently show stable or even improving levels of semantic knowledge (Surprenant & Neath, 2007). In younger adults, Hemmer and Steyvers (2009) showed that episodic memory for the properties (i.e. size) of familiar items is influenced by multiple levels of pre-existing knowledge. In this thesis, I developed their paradigm to systematically explore these knowledge effects in healthy ageing for both episodic memory and short-term/ immediate memory. This was done by comparing memory for familiar relative to unfamiliar faces, as well as for the size of familiar everyday objects relative to unfamiliar, random shapes.

Across all experiments, both age groups appeared to rely on pre-existing item-based knowledge for the familiar items to the same extent, suggesting no age-related decrement in the use of prior knowledge. Moreover, the result showed that item-specific knowledge for the unfamiliar items develops over the course of the experiment. This became apparent in cases when the distribution of target item sizes was bimodal, as this made session-based learning of the item statistics easier to observe; this experiment-based knowledge/ learning was again equivalent for both age groups. The older adults, however, consistently demonstrated greater reconstruction variability and overall error. I interpreted this as evidence of noisier memory representations of the studied items for the older adults (e.g. Noack, Lovden & Lindenberger, 2014); the findings suggest that this increase in error does not lead to more knowledge-based bias in older adults.

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Chapter 1: Introduction

1.1 Knowledge and age effects on memory

This dissertation involves an examination of the interaction between knowledge, short-term memory and episodic memory in healthy older adults. The fact that episodic memory is influenced by pre-existing knowledge is a relatively well established idea (e.g. Brewer & Treyens, 1981; Conway & Pleydell-Pearce 2000; Payne Nadel, Allen, Thomas, Jacobs, 2002; Schacter, Norman, & Koutstaal, 1998; Hemmer & Steyvers, 2009). In essence, research in the field has demonstrated that knowledge gained from past experiences can improve the accuracy of noisy or incomplete episodic representations (Hemmer & Persaud, 2014). Such research is also increasingly prominent within the immediate/ working memory field (e.g. Brady & Alvarez, 2011; Brady & Tenenbaum, 2013; Heussen, Poirier, Hampton & Aldrovandi, 2011; Lew & Vul, 2013). Research by Huttenlocher and colleagues (Huttenlocher, Hedges & Duncan, 1991; Huttenlocher, Hedges & Vevea, 2000), for example, examined immediate reconstruction of an item’s size from memory. They used artificial stimuli such as the length of lines or the width of schematic fish and showed that recollection was biased by the central tendency of a set of stimuli previously studied in the same task (i.e. shows regression towards the mean value).

The research establishing the use of prior knowledge in memory may prove to be of particular significance in the area of cognitive ageing. The ageing literature consistently shows that whilst the longer-term products of processing seem to be unaffected, with older adults showing steady levels of semantic knowledge (Surprenant & Neath, 2007), there are consistent age-related declines in both episodic (e.g. Nilsson, 2003; Park, 2000; Schaie, 2005; Singer et al., 2003) and immediate memory functioning (e.g. Bopp & Verhaeghen, 2005; Multhaup et al., 1996; Verhaeghen, 2002; Verhaeghen et al., 1993). This has led to recent findings that suggest that reliance on prior knowledge can lead to age-invariance in memory performance (e.g. Castel, 2005; McGillivray & Castel, 2010), or that such knowledge can significantly alleviate or even eliminate age-related memory deficits in episodic recall (e.g. Badham & Maylor, 2015; Matzen & Benjamin, 2013; Naveh-Benjamin, Hussain, Guez & Bar-on, 2003). To my knowledge, however, there is no research examining whether these effects of knowledge are also applicable to immediate memory recall in healthy ageing. Moreover, there has not been any systematic investigation of the simultaneous biasing and supportive effects of prior knowledge as a function of age.

The general aim of the current research was thus to contribute to this literature by examining how the use of knowledge in memory might change with age. A greater understanding of these processes is particularly important given our ageing population. Such research can help define normal patterns of ageing and can help to determine typical changes in healthy ageing relative to changes that require medical or psychological attention. More specifically, therefore, in this research the main aims were to systematically explore a) whether older adults demonstrate more reliance upon knowledge when retrieving from memory than younger adults or whether there was age-invariance in the use of knowledge b) whether older adults exhibited more error in their memory representations than younger adults and c) whether the level of reliance on knowledge varied as a function of level of error. The studies discussed herein were designed to test these hypotheses. To examine this I adopted an approach recently advocated by Hemmer and Steyvers (2009). Their paradigm was called upon to measure both episodic and short-term memory reconstruction within the visual domain using different naturalistic stimuli. Before considering this paradigm in more detail, however, the current aims will first be explored within the broader framework of how memory changes in healthy ageing. The latter will be examined with a particular focus upon the episodic, semantic and immediate/ short-term memory systems.

1.2 Memory in healthy ageing

To date, the evidence suggests that the pattern of age-related changes in memory is complex, with some functions more affected than others (Craik & Luo, 2008). Across a wide array of materials and procedures, the experimental literature on healthy cognitive ageing reveals a pattern of strengths and weaknesses, characterised by relative deficits for immediate/ episodic compared to semantic memory (e.g. Park, Lautenschlager, Hedden, Davidson, Smith & Smith, 2002), for recall relative to recognition (e.g. Craik & McDowd, 1987), for recollection over familiarity (e.g. Hay & Jacoby, 1996; Jacoby, 1999; Jacoby, Bishara, Hessels & Toth, 2005), for associative memory over memory for individual items (e.g. Naveh-Benjamin, 2000) and for self-initiated as opposed to environmentally supported tasks (e.g. Craik, 1994). Older adults also demonstrate overall deficits in source (e.g. Craik, 1986; Hashtroudi, Johnson, & Chrosniak, 1989; 1990) and contextual memory (e.g. Hess & Pullen, 1996; Kessels, Hobbel & Postma, 2007), as well as a propensity towards bias induced by post-event information (e.g. Cohen & Faulkner, 1989) and semantic resemblance (e.g. Benjamin, 2001; Norman & Schacter, 1997; Tehan, 2010; Tun, Wingfield, Rosen, & Blanchard, 1998). Of particular relevance to the current dissertation, I will focus my discussion on the effects of ageing on episodic, short-term and semantic memory.

1.2.1 Ageing and Short-Term Memory (STM)

Tasks measuring STM reliably demonstrate age-related declines in memory. The ‘storage component’ of STM refers to the maintenance of information over a short period of time and has been shown to consistently decline with age (e.g. Baker, Tehan and Tehan, 2012; Kausler, 1994; Multhaup et al., 1996; Verhaeghen, 2002; Verhaeghen et al. 1993). This component is most typically measured through immediate serial recall, where a series of stimuli (digits, letter or words) are presented visually or auditorily, with participants required to repeat each stimulus in the order presented. More robust age-related declines, however, have been reliably observed in more complex working memory (WM) tasks (e.g. reading span, operation span, counting span), where performance is considered to be determined by the combined function of storage and processing of new and existing information (e.g. Backman, Small & Wahlin, 2001; Gilinsky & Judd, 1994; Hartley, Speer, Jonides, Reuter-Lorenz, & Smith, 2001; Hartman, Dumas, & Nielsen, 2001; Salthouse, 1992).

WM tasks involve a number of cognitive mechanisms and processes and are often used to explain age-related deteriorations in processing resources or higher-order cognition (Salthouse, 1991; 1994). Various lines of evidence suggest that age-related declines in functioning are particularly prominent when the demands of the task increase (Craik & Rabinowitz, 1984; Salthouse, 1994; Sander, Lindenberger & Werkle-Bergner, 2012). Luo, Hendricks & Craik (2007), for example, demonstrated that when a task involves two inputs at the same time, such as when words are presented simultaneously with related sound effects, older adults have significantly greater difficulty combining the two sources of information. The studies presented in this thesis were concerned with the common ‘storage component’ which underlies both the complex WM and the simple recall tasks (e.g. Cowan, 1999; Engle, Kane, & Tuholski, 1999; Colom, Shih, Flores-Mendoza, & Quiroga, 2006), and so the research related to this basic function is given more consideration.

In a meta-analysis of the literature examining age differences in simple STM tasks, Bopp and Verhaegen (2005) reported age-related declines in all aspects of memory over the short-term. In particular, these declines have been well-documented in verbal STM (e.g. Multhaup et al., 1996). Salthouse (1991), for example, demonstrated that when adults reached their 60's-70's, their STM performance was approximately 1SD below the level of adults in their 20s, with slightly greater declines for words than for digits. In one attempt to account for these age-related deficits, Maylor, Vousden and Brown (1999) presented younger and older adults with lists of letters either visually or auditorily and asked them to immediately recall each list in serial position. They found that the younger participants performed better than the older in both modalities, suggesting age-related declines for memory. However, Maylor et al. showed that when the effects of fluid intelligence or perceptual speed were eliminated, the correlation between STM performance and age disappeared. Nevertheless, they argue that these global measures did not capture the rich pattern of age-related error pattern differences. To examine the latter, they applied a computational model of serial order to the data; this led to the suggestion that it is both slower encoding and slower output which generated the pattern of age-related declines in performance.

Conversely, Multhaup et al., (1996) examined the relationship between memory span and speech (rehearsal) rate in older and younger adults by testing memory for words of various lengths. To measure speech rate, participants repeated pairs of items ten times. They found a linear relationship between speech rate and memory span; younger adults had larger spans and faster speech rates than older adults and so the reduction in memory span for older adults was predictable from their slower speech rate. The authors postulate that active articulatory rehearsal maintains a memory trace and so memory span corresponds to the number of items that can be articulated; age-related declines in memory spans are thus proposed to be the result of slower rates of rehearsal.

To date, research exploring visual STM with ageing is scarcer, though a number of studies have demonstrated greater age differences for span tasks in the visuo-spatial than the verbal domain (e.g. Chen, Hale, & Myerson, 2003; Myerson, Emery, White, & Hale, 2003b; Park et al., 2002; Verhaeghen, Cerella, & Basak, 2006). Data collected by Lezak (1995), for instance, showed that immediate recall of visual patterns was found to decrease by 2.6 SD below the level of 20-29 year olds for 80-92 year olds. The processes that underlie age-related declines in visual STM are not clearly defined, though several lines of evidence suggest differences in processing visual information with age, with a change or reduction in visual attention (e.g. Ball, Owsley, Sloane, Roenker & Bruni, 1993; Steinman, Steinman, Trick & Lehmkuhle, 1994). Other research, conversely, points to factors such as proactive interference, where older adults demonstrate greater interference from earlier examined non-target items than younger adults (Sapkota, van der Linde & Pardhan, 2015). The data collected in the current research will be within the visual modality, so can potentially contribute to a better understanding of visual STM in ageing.

1.2.2 Ageing and Episodic Memory

Episodic memory is defined as the conscious recollection of experienced events and so necessitates that different elements of the same event be bound together, whilst simultaneously being kept separate from features of other events (O’Reilly & Norman, 2002; Zimmer, Mecklinger & Lindenberger, 2006). The capacity to integrate different features of an event into a distinctive and organized representation is thus critical. Episodic memory is consistently found to decline with age (Craik & Jennings, 1992; Nilsson, 1992; Park, 2000). The literature generally suggests that throughout the lifespan, episodic memory undergoes numerous changes, with rapid increases during childhood (e.g. Johnson, 2001; Schneider & Pressley, 1997), a gradual decrease throughout adulthood (Kausler, 1994) and more rapid declines in older age (Fleischman, Wilson, Gabrieli, Bienias & Bennett, 2004; Singer et al., 2003). Most cross-sectional research suggests that adults demonstrate a linear decrease in episodic functioning which begins as early as the 20s (Li, Lindenberger, Hommel, Aschersleben, Prinz & Baltes, 2004; Nilsson, Backman, Erngrund, Nyberg, Adolfson, Bucht, Karlsson, Widing & Winblad, 1997), though longitudinal studies that control for variables such as practice effects and educational differences indicate that it remains stable until an individual reaches approximately 60-65, after which a fast decline is typically observed (e.g. Ronnlund, Nyberg, Backman & Nilsson, 2005; Schaie, 2005).

Age-related difficulties in episodic functioning can be clearly illustrated through the differential pattern of memory decline for recall relative to recognition tasks. Most studies show that the performance of older adults for recognition tests is equivalent to that of younger adults. In a meta-analysis by Verhaeghen and Salthouse (1997), for example, ageing was found to have very little effect on episodic tasks of recognition. Conversely, older adults are found to perform consistently worse in tests of recall which require a greater degree of cognitive effort. Dunlosky and Hertzog (1998), for example, asked both older and younger adults to learn unrelated word-pairs. They found that both age groups were initially able to learn all of the associations, yet in a later test of free recall, younger participants recalled significantly more than the older. The evidence thus suggests that in tasks of recognition, the performance of older adults is relatively unaffected. However, when the task requires more effortful processing and lacks environmental support/ relevant cues, such as in a recall task, older adults show greater deficits (e.g. Daum, Graber, Schugens & Mayes, 1996; Park, Hertzog, Leventhal, Morrell, Leventhal, Birchmore, Martin & Bennett, 1999; Smith, Park, Earles, Shaw & Whiting, 1998; Whiting & Smith, 1997). This data also implies that the older adults have the necessary units of information available in episodic memory at the point of recall but that they cannot access them as easily as the younger adults unless given a recognition cue (Kemps, Newson, 2006; Park, Smith, Morrell & Puglisi, 1990).

Age-related declines in episodic memory have been further explored through the examination of memory for context. This type of episodic memory is for the spatial, temporal or social characteristics of a specific situation or condition in which a memory is formed and is thus critical to episodic functioning. A number of studies have demonstrated that memory for the context of remembered information declines with age (e.g. Dixon, Hultsch, Simon & von Eye, 1984; Old & Naveh-Benjamin, 2008; Spencer & Raz, 1995). Across a range of diverse contexts, such as who presented the information (Schacter, Kaszniak, Kihlstrom & Valdiserri, 1991), the modality in which the information was presented (Craik, Morris, Morris & Loewen, 1990; McIntyre & Craik, 1987) and the room, colour or set of stimuli in which the item was previously seen (Park & Puglisi, 1985; Spencer & Raz, 1994), older adults perform significantly worse than younger adults.

This type of memory appears to show significantly greater declines than memory for content. Through meta-analysis, Spencer and Raz (1995) suggested that context memory declines disproportionally with age relative to content memory, as recall of contextual information is heavily dependent on the integration of an event's content with its context and is thus more cognitively taxing. Schacter, Harbluk &

McLachlan (1984), for example, demonstrated that although older adults could recall new facts after a delay, they had difficulty remembering when they had learned them. Schacter et al. (1991) also demonstrated this when presenting participants with fictitious facts by either a male or female experimenter. They showed that despite no real age-deficits for remembering the facts, older adults were impaired when asked to remember the gender of the experimenter who presented them. This data thus again suggests that older adults demonstrate relatively more difficulty with tasks that are effortful, strategic and complex.

Alternatively, such data has been taken to support an age-related associative deficit hypothesis and has been replicated with words, pictures and faces (Naveh-Benjamin, Guez & Marom, 2003a; Naveh-Benjamin, Hussain, Guez & Bar-on, 2003b). In a series of experiments, Naveh-Benjamin (2000) presented younger and older adults with a list of paired items, followed by independent memory tests for the items and for the associations between the items. Across four studies, he found that older adults demonstrated a deficit for various different types of associations, including inter-item (i.e. word-word or nonword-word pairs) and intra-item relations (i.e. a word and a presented characteristic, such as its font), despite good memory performance for the separate components. These findings were taken to suggest that older adults have difficulties binding unrelated discrete units of information together. However, he found that this deficit can be mitigated by semantic relations between the units and so in certain situations age-related declines can be minimised.

Although older adults consistently demonstrate episodic declines, therefore, the relationship between age, cognitive support and performance is not straight-forward. As demonstrated by Naveh-Banjamin (2000), age-related declines can be reduced or eliminated when access to relevant support is available, such as when there are semantic relations between the to-be-remembered stimuli. This is in line with the well-established finding that recall in older adults can be supported by semantic memory, which is an area that remains relatively stable with age (e.g. Surprenant & Neath, 2007); this will be explored further in the section below. I will later return to consider both episodic memory and STM in more detail in the section exploring knowledge effects in ageing. As indicated by the discussion in this thesis, however, it is apparent that there is considerably less research examining ageing and STM than ageing and episodic memory; in the current research I examine knowledge in ageing in both STM and episodic memory but consider the former to a greater extent in an attempt to bridge this gap within the literature.

1.2.3 Ageing and Semantic Memory

Semantic Memory refers to the system where knowledge is represented and maintained. One conventional way of understanding semantic memory is through the semantic spreading activation model (e.g. Anderson, 1983; Collins & Loftus, 1975). This postulates that knowledge is stored as an organised network of concepts (‘nodes’), which are connected to other related concepts through associative or semantic pathways. By exposing or directing attention to a word or concept, a ‘node’ is activated and activation spreads from one node to other related nodes in the network; this is thought to make the latter more accessible for processing. The semantic priming paradigm is used to measure this and involves presenting two stimuli sequentially (a prime and a target), with the relationship between them manipulated. Performance on various tasks (i.e. naming, lexical, semantic judgement) is faster and more accurate when the second word (nurse) is semantically related to the first (doctor), compared to an unrelated control word (shoe); it is assumed that activation spreads from nurse to doctor in the underlying semantic network while this cannot happen to the same degree for nurse and shoe. Most of the existing literature demonstrates that older adults produce slightly larger or very similar semantic priming effects to younger adults suggesting that the semantic network remains relatively stable with age (e.g. Balota & Duchek, 1998).

Moreover, there is evidence to suggest that semantic memory increases with age due to the accumulation of knowledge across the lifespan (e.g. Beier & Ackerman, 2001; Giambra, Arenberg, Zonderman, Kawas & Costas, 1995; Kemper & Sumner, 2001; Uttl, 2002; Verhaeghen, 2003). In studies of general knowledge, older adults typically outperform younger adults (Dixon, Rust, Feltmate & See, 2007), with knowledge of historical facts found to increase with age (Perlmuter, Scharff, Karsh & Monty, 1980). Park et al. (2002) demonstrated that whilst fluid intelligence for processes such as WM and processing speed decline with age, factual knowledge (as indexed by vocabulary) increases across the lifespan.

However, there is evidence to suggest that there is some decline in much later life (e.g. Singer, Verhaeghen, Ghisletta, Lindenberger & Baltes, 2003) and some data has shown a reduction for semantic tasks that demand significant attention. If participants are required to maintain prime information for a prolonged period of time, for example, they do show some deficits (Balota, Black & Cheney, 1992). Moreover, relative to younger adults, older adults report a greater number of blocks to their memories, where they cannot recall information that they are certain that they know and can later recognise. This seems to be particularly pronounced for proper names (Old & Naveh-Benjamin, 2012).

One of the most common memory complaints of older adults is the Tip of the Tongue (TOT) phenomenon, where an individual attempts to recall somebody else's name or a low-frequency word but cannot generate it from memory (Sunderland, Watts, Baddeley, & Harris, 1986). This phenomenon has been demonstrated in both diary and experimental studies (e.g. Burke, MacKay, Worthley & Wade, 1991) and has consistently been shown to increase with age as the ability to rapidly retrieve words declines (Brown, 2012; Heine, Ober & Shenaut, 1999). Maylor (1990c) showed that when participants were shown images of famous faces and given a short time frame in which to retrieve their names, the number of identified correct names decreased linearly with age, while the level of TOT issues increased. It has been postulated that the greater number of TOT incidents in older adults are the result of a larger semantic capacity where greater knowledge means that there are more opportunities for TOT issues to occur (Dahlgren, 1998; Schwartz & Frazier, 2005). Dahlgren (1998) supported this by demonstrating a positive linear relationship between TOT incidents and vocabulary capacity. Conversely, it has been suggested to reflect a deficit in accessing the phonological units necessary to access the word from activated semantic/ lexical routes (Burke et al., 1991). However, almost all of these TOT issues are eventually resolved; suggesting that semantic knowledge remains intact but speed of access is impaired (Maylor, 1990c).

Thus, despite some inconsistencies, the preservation of semantic ability in healthy ageing is generally well-established. Moreover, recent research has demonstrated that semantic memory can be used to support memory performance in other domains. Troyer, Hafliger, Cadieux and Craik (2006), for example, showed that when semantic encoding and retrieval aids were available during a recognition task, older adults were better able to learn name and face information. This suggests that age-related deficits can be mitigated in conditions where semantic memory can play a role. However, to date, this supportive role of semantic knowledge in episodic functioning has not been as systematically examined as other functions. The aim of the current research, therefore, was to explore this area of cognitive functioning in healthy ageing using a paradigm which allowed me to consider the influences of prior knowledge, error and the representation of the presented value in memory reconstruction separately. A better understanding of this interaction may offer benefits to older adults in terms of helping them develop strategies for remembering and for showing that memory in healthy ageing is not just a collection of relative declines. Current trends within this literature are reviewed in more detail below.

1.3 The Effect of Prior Knowledge on Memory in Healthy Cognitive Ageing

Overall, the research discussed above generally indicates that older adults show difficulties encoding or retrieving immediate and episodic memories (e.g. Hess, 2005). However, knowledge is assumed to be utilised automatically (e.g., Craik & Jennings, 1992; Light, 1991, 1992), being readily active whenever required (e.g., Balota, Dolan & Duchek, 2000; Lachman & Lachman, 1980; Naveh-Benjamin, Craik, Guez, & Krueger, 2005). Recent research indicates that we show a propensity towards relying on prior knowledge when memories are incomplete or erroneous (e.g., Bayen, Nakamura, Dupuis, & Yang, 2000; Hay & Jacoby, 1999; Jacoby, 1999; Spaniol & Bayen, 2002).

1.3.1 Facilitation of memory reconstruction as a function of pre-existing knowledge

There is a considerable amount of research, mainly in the episodic memory domain, which suggests that ageing declines can be alleviated or eliminated when prior knowledge can be relied upon. The literature has demonstrated that older adults show no age-related associative deficits when to-be-remembered words are semantically related (Badham, Estes & Maylor, 2012; Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003b). Such facilitative effects can also be extended beyond just word material. This has been demonstrated when older adults demonstrate enhanced recognition of line drawings which are structurally congruent with prior knowledge relative to drawings which were incongruent (Schacter, Cooper, & Valdiserri, 1992). The use of prior knowledge can also be observed for better recall of items in organised scenes relative to unorganised scenes (Hess & Slaughter, 1990) and for the recall of realistically priced grocery items relative to unrealistically priced items (Castel, 2005). In the latter study, Castel (2005) asked older and younger adults to study and recall the prices of various grocery items; in one condition prices were realistic whereas in the other they were unrealistic. The results showed that age-related deficits interacted with the realism of the material. When the prices were unrealistic, older adults performed significantly worse than the younger adults. However, when the prices were realistic - and could hence benefit from the support of prior-knowledge - age-related differences were eliminated.

Moreover, in some cases prior knowledge has been found to benefit older adults to a greater extent than younger adults within the episodic domain. It is generally assumed, for example, that knowledge of vocabulary and faces appears to be stable or even increase with age (McCabe, Roediger, McDaniel, Balota & Hambrick, 2010; Verhaeghen, 2003), with older adults recalling more words than younger adults when the material capitalises upon their schematic verbal knowledge (Matzen & Benjamin, 2013). Older adults are also found to be more adept at memory tasks than younger adults when they can spontaneously use analogies and thereby rely upon their rich knowledge base (Caplan & Schooler, 2001).

Besides these studies indicating the advantage of making inferences from every day, general knowledge, some studies demonstrate that specific expertise can serve as a protective function against age-induced memory deficiencies. Arbuckle, Vanderleck, Harsany and Lapidus (1990), for example, tested older, middle-aged and younger adults with varying degrees of music expertise for scripts that were either relevant or irrelevant to music. They found that expertise benefitted all age groups to the same extent, with greater recall for the music relevant passages relative to the irrelevant passages. Similar effects have been observed for cooking expertise (Miller, 2003), for habitual or well-learned routines (Light & Anderson, 1983) and for number information for accountants and bookkeepers (Castel, 2007). Despite a dearth of research investigating the role of knowledge in STM/ WM, the effects of expertise have also been shown to generalize beyond just episodic tasks and have also been observed in tasks which contrast groups of adults with low and high WM (Soederberg-Miller, 2009). In the latter task, participants with varying degrees of cooking knowledge were required to read and recall a series of passages about cooking. The results showed that reading efficiency increased with levels of knowledge among older adults but not younger adults. In particular, those with smaller WM capacities showed greater benefit from increased knowledge. Such effects have also been found for chess players (Charness, 1989) and for skilled typists (Salthouse, 1984).

In addition to these effects of domain-specific expertise on WM, there is also evidence of the effect of redintegration on STM. Despite little prior examination of the use of prior knowledge in STM, Neale and Tehan (2007) demonstrated the role of redintegration, which refers to the use of long-term knowledge to facilitate recall. Across two tasks, younger and older participants were required to serially recall lists of semantically or phonologically similar or dissimilar items. The level of difficulty of these lists was manipulated by varying the length of the lists and by testing them either immediately or after a 2 or 4-second delay. In the semantic condition, they found a similarity advantage when item scoring was used as a measure but not order accuracy. Conversely, in the phonological condition, there was a similarity decrement under easy difficulty levels when order accuracy was measured but this becomes an advantage when difficulty increases. For both older and younger adults, the effects of similarity became stronger as task difficulty increased. They suggest that this linear function was consistent with a redintegration hypotheses, where increases in task difficulty led to increases in the likelihood that long-term memory would be accessed. They suggest that similarity acted as a cue to narrow the number of potential candidates for recall; this use of knowledge was equivalent for both age groups.

1.3.2 Greater error/bias as a function of pre-existing knowledge

In some circumstances, however, the adaptive function of prior knowledge leads to bias and errors. There is evidence within the episodic domain to suggest that older adults think in a more stereotypical fashion, generalise inappropriately and falsely remember non-encountered stimuli (e.g., Hess, McGee, Woodburn, & Bolstad, 1998; Labouvie-Vief & Schell, 1982; Radvansky, Copeland, & von Hippel, 2010). In support of this approach, older adults have been found to experience difficulties recalling recently encountered information when it contradicts their pre-existing knowledge. Despite being able to correctly identify misspellings during a reading task, for example, older adults have greater difficulty recalling misspellings that contradict pre-existing knowledge (MacKay, Abrams, & Pedroza, 1999). Older adults also demonstrate a greater propensity to spell homophones (e.g. weight, wait) in the form most frequently seen in everyday language (e.g. wait), even after hearing a sentence which used the infrequent form (Howard, 1988). They also exhibit a tendency to mis-remember recently learned word-pairs in a way that enhances the semantic meaning (Rabinowitz et al., 1982), as well as difficulties learning and recalling adapted versions of famous fairytales due to the strength of their pre-existing knowledge (Dalla Babba, Attali & LaCorte, 2010). Such data implies that older adults are less able to ignore prior knowledge when it contradicts recent leaning, supporting the hypothesis that older adults demonstrate proactive interference of recently encountered information (e.g. Borella, Delaloye, Lecerf, Renaud, & de Ribaupierre, 2009; Jacoby, Hessels, & Bopp, 2001) and inhibition of irrelevant knowledge (e.g. Anderson, Reinholz, Kuhl & Mayr, 2011; Hasher, Tonev, Lustig, & Zacks, 2001; Hasher & Zacks, 1979, 1988).

Moreover, previous research has demonstrated that older adults are more susceptible to misleading and deceptive information than younger adults (Rhodes & Kelley, 2005). Numerous studies clearly show that older adults exhibit a greater propensity to falsely recall items and events that are consistent with their prior knowledge than younger adults (Schacter, Koutstaal, & Norman, 1997; Schacter et al., 1992; Singer 1998). In tasks of list learning, for example, older adults are less able than younger adults to distinguish between studied and unstudied items and so were more likely to recognise a ‘new’ item as ‘old’ than reject it (Bastin & Van der Linden, 2003). These effects have been observed even when older adults were warned of the deceptive nature of the task and the likelihood of misremembering a critical lure (Jacoby & Rhodes, 2006; McCabe & Smith, 2002).

Jacoby (1999) demonstrated that this greater level of error/ bias in older adults is often the result of a high level of familiarity, combined with a lack of clear recollection. He visually presented older and younger adults with eighty words, divided into four separate categories, where each item was presented either once, twice, thrice or not at all. In a second condition, participants heard a second list of words and were asked to remember them. In a later recognition task, participants were required to accept the auditory presented items but reject the visually presented items. Repetition of the visual list aided the younger adults' rejection of the items, yet made older adults more likely to falsely recognise a repeated visual item as an auditory item due to increased familiarity with that item. It appears that they were less able to recollect the initial presentation of the item, leading to increased errors. As a result, Jacoby (1999) suggested that remembering is the conjunction of controlled processes (recollection) and automatic processes (familiarity). It is assumed that older adults demonstrate greater impairments for the controlled relative to the automatic processes. A reduced capacity to recall the specific episodic details necessary to counteract the sense of familiarity leads to higher rates of false memories in older adults (Pierce, Sullivan, Schacter & Budson, 2005).

Nevertheless, although it is apparent that reliance upon prior knowledge can lead to more bias in responses, the benefits of using prior knowledge tend to outweigh the costs due to an overall improvement in accuracy. There is a good argument for the adaptive value of this way of functioning (e.g. Huttenlocher et al., 1991; 2000). Recently, researchers such as Huttenlocher and colleagues and Hemmer and Steyvers (2009) have called upon relatively well established models of categorisation to explore the role of knowledge in memory. These models incorporate the relative trade-off between more bias and greater overall accuracy in recall. In the current research, I call upon these models to offer a systematic way to explore this trade-off and thus examine how knowledge varies as a function of age and relative error in memory representations.

1.4 Categorical Knowledge

It has been well established within the literature that pre-existing knowledge can support memory functioning. However, the use of categorical knowledge is yet to be explored in ageing populations. The existing literature also lacks a systematic examination of both the facilitative and the biasing effects of prior knowledge in ageing within the same paradigm. Research examining the effect of pre-existing categorical knowledge for younger adults shows that developing knowledge of the regularities within the environment mitigates the cognitive complexity of our surroundings and improves the efficiency of action and behaviour (Chun & Turk-Browne, 2008). Barsalou (1999, 2003a) suggested that categorical knowledge provides rich expectations about the world; for each experience, individuals can profit from knowledge of existing category members. These categories encompass schematic representations which extract the significant, representative features of a category whilst removing irrelevant properties.

Numerous rational models have been developed to account for the interaction between memory and categorical knowledge (e.g. Shiffrin & Steyvers, 1997; Steyvers & Griffiths, 2008; Steyvers, Griffiths & Dennis, 2006; Xu & Griffiths, 2010). Within the visual domain, Huttenlocher and colleagues (Crawford, Huttenlocher & Engebretson, 2000; Hutenlocher, Hedges & Duncan, 1991; Huttenlocher et al., 2000) formulated a model of category effects, where reconstruction from memory is assumed to be dependent upon the weighted average of both the memory trace and the strength of prior categorical knowledge. In the current dissertation, this theoretical perspective was adopted in an attempt to better understand the interaction between knowledge, short-term and episodic memory in ageing. This model was employed because it enabled me to separately consider the relative influences of prior knowledge, the representation of the memory and the level of noise error in memory reconstruction; this will be considered in greater detail.

1.4.1 The Category Adjustment Model (CAM)

Huttenlocher and colleagues (Huttenlocher et al., 1991; Huttenlocher et al., 2000) developed their model of how category knowledge supports memory through a series of empirical studies. In the first instance, this model was applied to STM for the spatial arrangement of stimuli (Huttenlocher et al., 1991). This was later extended to other stimulus types, such as the fatness of fish (Huttenlocher et al., 2000). The latter studies will be discussed in more detail due to greater relevance to the current research.

Across three experiments, Huttenlocher et al. (2000) presented participants with categories of stimuli comprising varying line lengths, different shades of grey and differing widths of fish. Each individual stimulus was presented for a few seconds; once this was removed, participants were required to immediately reproduce the relevant dimension (a new exemplar, with a random value on the relevant dimension was provided). In short, participants were asked to reproduce the greyness of a square, the length of a line or the fatness of fish. Each of these materials was embedded within one of three underlying distributions: a normal, a broad uniform, or a narrow uniform distribution. It was assumed that if people use category information to increase the accuracy of their judgments, then the structure and characteristics of the distribution should affect their estimations.

For normal distributions, the probability of membership reduces with distance from the category centre. If an inaccurately represented stimulus is considered to be a category member, it will be adjusted towards the category centre, leading to an increase in bias. If it is not considered a category member, it will not be adjusted towards the mean and so will not be biased; there is thus less bias at more extreme locations. Conversely, estimates for a stimulus embedded in a more concentrated, tightly clustered category were expected to be more accurate than estimates for stimuli in a sparser category as the latter will provide less information about the presented stimulus. For a uniform distribution, the level of bias should be equal across all items as they are equally likely to be category members. Through these manipulations, they found that the observer's responses were a blended combination of the coarser-grained categorical information of the average presented item (i.e. the average shade of grey, line length or fish width) with the finer-grained information for the metric properties of the target. Responses were also dependent upon the distribution in which they were embedded, which moderated the degree of accuracy and bias.

Huttenlocher and colleagues thus proposed that reconstruction from memory is a Bayesian process which integrates these two types of information to form an estimate of the stimulus. In their model, prior category information is represented by an explicit distribution of the potential values. The imprecision of the fine-grained information is depicted as a sampling distribution of inexactness around the value of the presented stimulus. Estimates are thought to be a weighted average of these two sources of information; the weight allocated to the fine-grain and category levels vary as a function of the distribution of the category, as well as the level of imprecision around the fine-grained memory.

Combining these partially redundant sources of information introduces bias in estimation but can also improve the overall accuracy and stability of stimulus approximations. Bias is reflected by the discrepancy between the actual value of the stimulus and the estimate. It is induced by relying on the category prototype as it causes estimates to systematically shift towards the centre of the categorical value. The weight attributed to category information is contingent upon the inexactness of the stimulus representation, with exact representations making the category information redundant. When the fine-grained information is inexact, category-level information is ascribed greater weight, marking a relative trade-off between greater bias and reduced inaccuracy.

The key hypotheses of CAM have been supported several times, such as for estimating when an event occurred (Huttenlocher, Hedges, & Bradburn, 1990; Huttenlocher, Hedges, & Prohaska, 1988; Lee & Brown, 2003) and for recall of the ethnicity or gender of photographs of morphed faces (Corneille, Huart, Becquart, & Bredart, 2004; Huart, Corneille, & Becquart, 2005). Furthermore, it has been developed to examine the role of schematic prior knowledge in episodic memory. Hemmer and Steyvers (2009) devised this theory by using a category of naturalistic items for which the participants have pre-existing knowledge at multiple levels; these object priors were extracted from the participants own knowledge. This use of realistic, everyday stimuli to examine the role of prior knowledge in memory increased the reliability and validity of this paradigm and so I used the premises of this model to inform the current research; this is considered in greater detail below.

1.4.2 Episodic Memory and Categorical Knowledge

Hemmer and Steyvers (2009) examined the role of categorical knowledge in episodic memory while relying on the approach developed within CAM. They postulate that our cognitive systems cope with environmental complexities by forming multiple, hierarchically structured categories. Like Huttenlocher and colleagues (1991; 2000), they thus suggest that memory is the product of the weighted average from categorical information and the event-specific information from the recently encountered instance. When the memory trace is weak or incomplete, categorical knowledge is used to ‘fill-in-the-gaps’. Hemmer and Steyvers outlined two over-arching types of categorical knowledge, coined the object-level and the superordinate-level categories. The former category reflects fine-grained knowledge for individually encountered stimuli and is represented as a distribution of all potential values sampled around the average of the considered feature (i.e. the distribution of all possible sizes of an apple). The latter refers to knowledge obtained from the central tendency of the aggregate category from which the finer-grained object was sampled (i.e. the overall distribution of the size of all fruits).

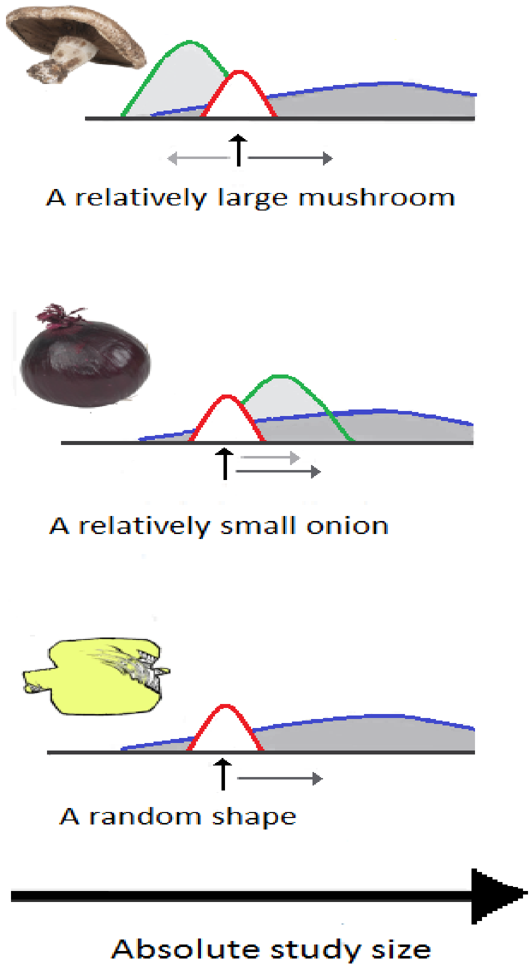

Figure 1.1. The effect of the object and superordinate category priors on three objects of exactly the same study size; one object from the random shapes category, one from the vegetable category with a relatively larger study size and the other from the vegetable category but with a relatively small study size. The distribution outlined in blue represents superordinate knowledge, the distribution outlined in green reflects object-level knowledge and the distribution outlined in red represents the presented value.

In line with Huttenlocher and colleagues (Huttenlocher et al., 1991; 2000), Hemmer and Steyvers (2009) propose that by weighting an inexact memory representation by the prototypical exemplar of its respective category, there is a reduction in inaccuracy. This is because individuals are more likely to encounter stimuli with values closer to the mean of their corresponding categories than stimuli with extreme or rare values. However, this increase in accuracy necessitates an increase in bias as all values consistently regress towards the mean (prototypical) value. The extent of this bias-accuracy trade-off, however, depends on the strength of the memory trace. Furthermore, they propose that the level of familiarity (strength of the semantic knowledge) for any given stimulus also determines how well the pre-existing knowledge can complete erroneous memories. This can be generalised to areas in which individuals have little prior experience to improve performance and so categorical knowledge can be applied to new categories or areas with limited pre-existing knowledge.

Hemmer and Steyvers (2009) tested this empirically using a continuous recognition paradigm. Prior to testing, they collected normative data to ascertain the perceived mean sizes of various common fruit and vegetables, as well as the smallest and largest reasonable sizes, with the assumption that this reflected the participants' prior knowledge for these items. During the experimental phase, participants were presented with pictures of these fruits and vegetables at randomly selected realistic sizes (constrained by realistic sizes determined by the normative data), as well as random shapes for which the participants had no prior knowledge. The size of the random shapes was yoked to the size of the vegetables to ensure that the only difference between the two categories was familiarity. Study and test instances were randomly interleaved within the procedure. After varying lags, the studied items were shown again at a different size; participants were required to reproduce the initial size to the currently tested item.

Hemmer and Steyvers (2009) found that when studying known objects, individuals use their pre-existing knowledge of typical sizes to aid their reconstruction and correct an otherwise noisy memory trace. At the superordinate category level, a small object (e.g. a raspberry) tended to be overestimated while a larger object (e.g. a pineapple) tended to be underestimated. At the object level, objects presented at a small size relative to their normative mean (e.g. a small apple relative to the prototypical apple) were overestimated, while larger objects (e.g. a relatively large apple) were underestimated. Separating out the contributions from the object and the superordinate category levels is difficult because the effects often operate in the same direction (see Figure 1.1). For example, if an object was studied at a relatively smaller size at both the category and object level, pre-existing knowledge at both levels results in overestimation and thus positive bias. However, if an object was studied at a relatively larger size at the object-level but at a relatively small size at the category level, superordinate knowledge leads to overestimation while object-level knowledge lead to an underestimation of the object at reconstruction. Two objects studied at the exact same size can thus be differentially biased when the objects are associated with different prior knowledge. For the random shapes, however, due to the absence of prior knowledge, it was assumed that reconstruction was only dependent upon the strength of the memory for the most recently encountered instance and the mean of the superordinate distribution of presented items throughout the study.

Hemmer and Steyvers (2009) thus suggested that this superordinate category prior had effects at both levels of familiarity, though had a greater influence for the unknown items as there was no available object-level prior knowledge. Conversely, the fruit and vegetables had relatively strong object priors from reasonably accurate memory samples and so were less influenced by the overall category prior. Furthermore, they found that in the absence of recognition (determined by confidence ratings), there was less error for the fruit and vegetable items as they were associated with pre-experimental knowledge than without such knowledge (i.e. the random shapes) (Hemmer & Steyvers, 2009; Hemmer, Steyvers & Miller, 2010; Hemmer, Tauber & Steyvers, in revision).

A number of studies have replicated this pattern of knowledge effects using an array of different stimuli, including height stimuli where object level knowledge for the typical heights of males and females biased recall (Hemmer & Steyvers, 2010), for naturalistic scenes (Hemmer & Steyvers, 2009), for the temporal frameworks of stereotypical events (Hemmer, Steyvers & Millers, 2010) and for prior knowledge of the hue values of colour categories (Persaud & Hemmer, 2014). Persaud and Hemmer (2014), for example, showed that colours are associated with pre-experimental knowledge of an expected hue range. This knowledge was found to influence memory reconstruction, as hue values less than the mean value of a basic colour were overestimated, whilst those greater than the mean were underestimated. This influence of pre-existing categorical knowledge has also been generalised to working/immediate memory (Heussen et al., 2011) and the hierarchical use of categorical knowledge has also been demonstrated in tasks of visual short-term memory (e.g. Brady & Alvarez, 2011).

In the latter case, Brady and Alvarez (2011) briefly presented participants with green, red and blue different sized circles but told them that they were to only remember the sizes of the red and blue ones. Following a delay, another circle appeared in the same location as one of the target circles and subjects were asked to resize this second circle to match the size of the one originally presented at that location. The results suggested that the reconstructed size was biased towards the average size of the same coloured circles in the display. However, to rule out the possibility that instructing participants to focus on colour led to a greater propensity for colour-based encoding, a second study was conducted but with the green circles removed—so, all the presented items could be tested targets. Participants no longer demonstrated bias towards the same-coloured circles but instead were biased towards the mean of all of the circles in the display. This finding was interpreted as indicating that participants flexibly encode stimuli at multiple levels of abstraction. To account for this data, Brady and Alvarez (2011) developed a two-level hierarchical model. This was based on the assumption that the circles were encoded at a finer-scale level, where each item was encoded individually (individual encoding) and at a coarser-scale level, where items were represented through summary statistics of all of the presented items in a display (the mean of all of the circles in the display). They thus found that the representation of one item is dependent on the representation of other feature-relevant items. Unlike Hemmer and Steyvers (2009), therefore, who consider knowledge brought to the experiment, as well as knowledge developed during the experiment, Brady and Alvarez only measure what is present on the trial. Nevertheless, this data clearly demonstrates the robustness of Bayesian approaches and justifies their use for the current research programme; it suggests that the basic premises of this particular paradigm would enable us to examine knowledge for both episodic and immediate memory functioning.

1.5 General Hypotheses

Overall, therefore, the general aims of the current research were to capitalise upon well-established effects to systematically examine the impact of prior knowledge on memory reconstruction for both older and younger adults. To explore this, I thus called upon an approach related to the one developed by Hemmer and Steyvers (2009). Unlike the majority of studies investigating schematic support of memory in older adults - where the stimuli used are either strictly consistent or inconsistent with prior knowledge - this paradigm examines the graded benefit of the effects of knowledge. Similar to a recent study by Badham and Maylor (2015), the paradigm that was adopted here examined the continuous effects of pre-existing knowledge on memory.

More specifically, I used a reconstruction task to explore age differences in how knowledge interacts with the participants’ representations of the most recently presented stimulus. As outlined above, age-related research has generated an array of observable relative strengths and deficits (Bireta & Surprenant, 2008). It is generally assumed, for example, that many age-related memory deficiencies are the result of difficulties forming new associations between separate components of an experience (Naveh-Benjamin, 2000), with particular difficulty encoding contextual information (Spencer & Raz, 1995). The encoding of such information is particularly relevant for generating distinctiveness between individual events, with a failure to do so leading to the absorption of the to-be-remembered items into a more generic category with a loss of fine-grained detail. The literature has typically supported this, showing that older adults tend to have difficulty remembering specific information but are able to recall more general, coarser grain details (Castel, Farb & Craik, 2007). The general trend of data thus indicates that the more temporary, fine-grained components of ongoing experience are more difficult to encode/retrieve in older age.

The above thus suggests that older adults show more error in their memory representations, leaving an opening for pre-existing knowledge to ‘fill-in the gaps’ and thereby bias what is remembered. In terms of episodic memory, there is a large amount of evidence to suggest that knowledge can aid the recall of older adults and even improve their performance. However, there is no real systematic examination of how episodic memory, prior knowledge and error[1]interact. There is also little data examining how STM and knowledge interact in healthy ageing. To tackle this scarcity, I thus aimed to systematically examine which of two alternative hypotheses was more accurate; 1) the participants’ use of knowledge increased in parallel with the level of error or 2) declines in memory representations are independent of level of knowledge. Below, I report a series of studies exploring these hypotheses in episodic memory and immediate memory/ STM, using a range of different stimuli.

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[1] In this thesis, therefore, the term error is used to refer to the encoding and storing of size information about a presented image; this creates a level of random distortion which leads to inaccurate retrieval when asked to recreate the presented size.

Chapter 2: Categorical knowledge in immediate memory functioning in healthy older adults

2.1 Introduction

One of the key functions of our memory system is to enable previously obtained knowledge to support current cognitive activities. From this perspective, episodic recall can be seen as a reconstructive process that relies on the interaction between noisy or incomplete representations and knowledge gained from past experiences (Hemmer & Persaud, 2014). This is of particular significance in the area of cognitive ageing, as recent findings indicate that reliance on prior knowledge can significantly reduce or even eliminate age-related memory deficits in episodic recall (e.g. Badham & Maylor, 2015; Castel, 2005; Naveh-Benjamin, Hussian, Guez & Bar-on, 2003).

The fact that episodic memory is reconstructive is a reasonably uncontroversial idea (e.g. Brewer & Treyens, 1981; Conway & Pleydell-Pearce 2000; Hemmer & Steyvers, 2009; Payne, Nadel, Allen, Thomas, Jacobs, 2002; Schacter, Norman & Koutstaal, 1998). This view is also increasingly influential within the immediate memory/ working memory field (e.g. Brady & Alvarez, 2011; Brady & Tenenbaum, 2013; Heussen, Poirier, Hampton & Aldrovandi, 2011; Lew & Vul, 2013). Research by Huttenlocher and colleagues (Huttenlocher et al., 1991; Huttenlocher et al., 2000) and Brady and colleagues (e.g. Brady & Alvarez, 2011), for example, showed that memory reconstruction is biased by the central value of a set of presented stimuli (i.e. shows regression towards the mean studied value). They demonstrated this for STM tasks using artificial stimuli, such as line length, arbitrary colours or fatness of fish. In this experiment, we examine the interplay of knowledge and visual STM[2] in normal ageing.

The ageing literature consistently shows age-related declines in immediate memory (e.g. Bopp & Verhaeghen, 2005; Multhaup et al., 1996; Verhaeghen, 2002; Verhaeghen, Marcoen, Goosens & 1993). This has been particularly well documented for verbal STM. Salthouse (1991), for example, demonstrated that adults in their 60's and 70's perform approximately 1SD below the level of adults in their 20s. Research exploring visual STM with ageing is scarcer, though data collected by Lezak (1995) demonstrated that immediate recall of visual patterns was found to decrease by 2.6 SD below the level of 20-29 year olds for 80-92 year olds. This suggests that older adults show more error in their immediate memory representations for visual patterns.

However, to our knowledge, there is very little existing literature examining how prior knowledge moderates age-related declines in immediate memory. We found one previous study by Neale and Tehan (2007) that measured the influence of long-term memory representations on recall. In their study, they examined the effect of redintegration (how long-term memory supports reconstruction of degraded traces) in STM for older and younger adults. Their results supported the effects of redintegration, where memory recall was affected by both phonological and semantic similarity, yet the use of this long-term information was not affected by ageing. In the current study, however, we wanted to more explicitly measure how much younger and older adults rely on prior knowledge and to determine whether this reliance changes as memory ages in an attempt to bridge this gap within the literature. Moreover, unlike in previous research, we wanted to examine how knowledge might interact with error in memory representations.

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[2] In this thesis, we use the terms STM and immediate memory interchangeably.

In order to explore this, Experiment 1 examined memory over the short-term in younger and older adults by calling upon meaningful stimuli for which participants had general expertise: faces. The second experiment included a more specific level of knowledge as famous faces were also called upon. We suggest that noisy representations of recently encountered stimuli are combined with prior knowledge (when available). To explore how this broader expertise and more specific knowledge impacted reconstruction, we developed a paradigm which allowed us to systematically explore how knowledge influences immediate reconstruction in younger and older adults. We now turn to the literature on knowledge effects related to this type of paradigm.

2.1.1 Knowledge effects

A number of models have been devised to account for the interaction between memory functioning and existing knowledge (e.g. Shiffrin & Steyvers, 1997; Steyvers & Griffiths, 2008; Steyvers, Griffiths & Dennis, 2006; Xu & Griffiths, 2010). Of particular relevance to the current experiments, Huttenlocher and colleagues (Huttenlocher et al. 1991; Huttenlocher et al., 2000) developed a model of category effects on stimulus judgment. In their studies, participants are asked to reconstruct the feature of an item (e.g. line length) that had just been presented. Hence, these paradigms shed light on how knowledge interacts with immediate memory. In their model, recall is assumed to be dependent upon a noisy representation of the stimulus value as well as the average or prototypical representation of the category to which the item belongs (e.g. the average line length presented during the experiment). This was demonstrated empirically when Huttenlocher at al. (1991) presented participants with a series of randomly distributed dots within a circular space and asked them to immediately reproduce the spatial location of the dots from memory. They found that the observer’s estimations of the stimuli was drawn away from the major axes of symmetry within the circle and drawn towards the midpoint of each of the four quadrants. They postulated that these axes form categories, with the centre of each of these quadrants representing the category prototype.

When estimating the location of a stimulus from memory, therefore, participants’ responses reflected a combination of the coarser-grained categorical information from each of the four quadrants with the finer-grained information about the approximate location of the stimulus. In their model, the imprecision of the fine-grained information is depicted as a distribution of inexactness, centred around the value of the stimulus. The model assumes that estimates are a weighted average of these two sources of information. Overall, this should reduce error/ variability in reconstruction but introduces systematic bias due to reliance on the category averages. Huttenlocher et al. (2000) also demonstrated the use of categorical information when recalling other arbitrary stimuli such as the greyness of squares, line length and the width of schematic fish.

Hemmer and Steyvers (2009) extended such findings to episodic memory and also examined the influence of more than one level of knowledge. As in the work of Huttenlocher and colleagues, they postulate that memory reconstruction is the product of the weighted average from categorical information and the item-specific memory traces. Hemmer and Steyvers outlined two types of categorical knowledge, coined the object-level and the superordinate-level categories. The former category reflects finer-grained pre-existing knowledge related to a given stimulus and is represented as a distribution of all potential values sampled around the actual encountered stimulus (i.e. the distribution of all possible sizes of an apple). The latter refers to knowledge obtained from the central tendency of the aggregate category from which all of the individual events or stimuli were sampled (i.e. the overall distribution of the size of all fruits).

To test this, they called upon a continuous recognition paradigm which involved presenting lists of 144 items with study and test items randomly interleaved. Both familiar (fruits and vegetables) and unfamiliar (random shapes) lists were presented. The items in the familiar lists were presented at realistic sizes, which were determined by pre-obtained normative data. The sizes of the unfamiliar items, for which participants had no prior knowledge, were yoked to the sizes of the familiar items. When an item reappeared in the list, participants were asked to reproduce the size of the most recently studied version. Their results demonstrated that recall for the familiar items was biased by the item-specific memory trace, the overall distribution of presented fruits and vegetables (superordinate-level knowledge) and by the object-level knowledge (e.g. knowledge about the typical size of an individual item). As the participants had no pre-existing knowledge for the unfamiliar items, their responses were only biased by the superordinate distribution of the items presented throughout the course of the study, as well as the memory trace. These findings have been generalised to other types of stimuli, including the height of individuals and prototypical colours (Hemmer, Shi & Steyvers, 2010; Hemmer & Persaud, 2014). Similar patterns of results also held when using a task which examined STM (Heussen et al., 2011).

Researchers such as Brady and Alvarez (2011) also demonstrated that the memory representations that support STM are organised hierarchically. In a task of visual STM, they briefly presented participants with different sized circles coloured in either green, red or blue but told them to only remember the sizes of the red and blue circles. After a delay, a new circle appeared in the same location as one of the originally presented red or blue circles and subjects were asked to resize it to match the circle originally presented at the location. They found that the reconstructed size of the circle was influenced by the size of the presented item, the average size of the same coloured circles in the display and the average of all of the items in the display. They thus proposed that at a finer-scale level, each item is encoded individually, yet at a coarser level, estimation is biased by summary statistics of all the items of the same colour, as well as all of the presented items in the display. However, they argued that by instructing participants to focus on colour, they increased the salience of this particular feature, leading to colour-based encoding of the items. To investigate this, they conducted a second study but with no green circles. Participants no longer demonstrated bias towards the same-coloured circles but continued to show bias towards the mean of all of the circles in the display, indicating that participants flexibly encode stimuli at multiple levels. This data thus clearly demonstrates how several sources of information contribute to reconstruction.

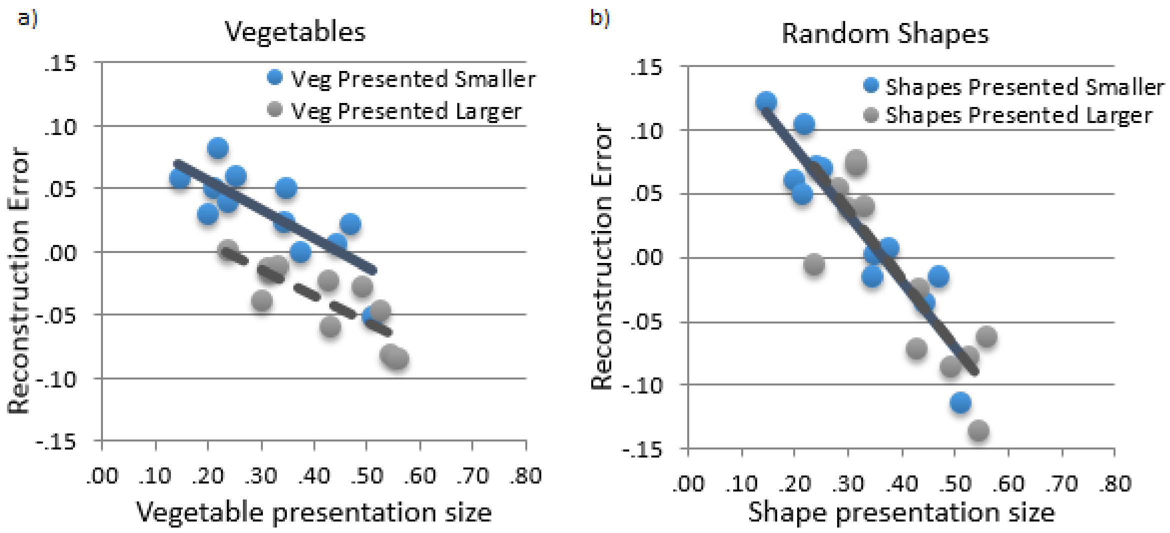
In the current task, we wanted to develop existing research by examining how multiple levels of knowledge in STM change as a function of normal cognitive ageing. To explore this, we used a version of Heussen et al.'s (2011) paradigm. In this task, participants were presented with short lists of unfamiliar (random shapes) or familiar (fruit and vegetable) items at various different sizes. The sizes of the familiar items were constrained by normative data obtained by Hemmer and Steyvers (2009) which provided the estimated mean size for each individual item, as well as the minimum and maximum reasonable sizes. The size of the shapes were yoked to those of the familiar items. Following each list, they were presented with one of the items again but at a different size and were asked to reconstruct its studied size. Similar to Hemmer and Steyver's (2009) task, participants' responses were influenced by multiple levels of knowledge but over the short-term. We thus used this paradigm to systematically examine if there were any age-related differences in the reliance on prior knowledge in immediate memory functioning.

2.2 Experiment 1

In this experiment, we aimed to study the impact of prior knowledge on immediate memory reconstruction for both older and younger adults. In particular, we wanted to explore how the knowledge used in memory reconstruction interacts with the participants' memory representations of the presented stimulus. The literature suggests that older adults show declines in immediate memory relative to younger adults. In terms of episodic memory, there is clear evidence showing that knowledge can aid the recall of older adults and even eliminate any age-related differences in recall. However, there is little data examining how STM and knowledge interact in healthy ageing. We aimed to systematically explore a) whether older adults demonstrated greater use of prior knowledge in immediate memory relative to younger adults b) whether older adults showed evidence of noisier STM representations and c) if older adults showed noisier memory representations, whether their use of prior knowledge increased in synchrony with the level of error or whether this increase in error was independent of level of knowledge.

To test this, in Experiment 1, we examined the influence of broader, coarser-grained knowledge/ expertise for non-familiar faces. We created morph continua which consisted of a series of photographs of faces, moving from one unfamiliar face to another in 100 increments. On each trial, participants were presented with two images which were selected from a different continuum. Immediately following presentation, one of the faces was shown again but at a different position along the original morph continuum. Participants were required to reproduce the studied face as closely as possible (using arrows to navigate up and down the continuum). In Experiment 2, we used the same methodology but tested the influence of specific prior knowledge by also testing familiar morphs (merging a famous face with a non-famous face).

To visually illustrate our aims, we consider representations of the data collected by Heussen et al. (2011) for the sizes of familiar vegetables and unfamiliar random shapes (Figures 2.1a and 2.1b respectively). To measure accuracy in the participant's responses, they obtained an estimation of reconstruction error (presented size minus remembered size or response) for each individual's response. This reconstruction error was examined as a function of presented size.



Figures 2.1 a-b. Representations of the data obtained from Heussen et al. (2011), demonstrating estimates of the sizes of shapes and vegetables separately.

As can be seen in Figure 2.1, the data demonstrated a general regression towards the superordinate category mean for the vegetables and the shapes (shown by the negative slopes). This meant that large items presented at a larger size were made smaller (adjusted to be closer to the mean), whilst items presented at a smaller size were made larger. In addition, the vegetables showed an intercept difference that varied as a function of relative size; in this task, items were presented at a size that was either smaller than their respective normative means or larger (determined by the normative data). The intercept difference demonstrated the item-specific influence of knowledge, where items which were presented smaller than their normative means were made larger, whilst those presented larger were made smaller. For the unfamiliar random shapes, there was no intercept difference because there was little item-level knowledge for the individual items.

In the current task, we wanted to see how these effects change as a function of age in a task of STM using face stimuli which contain both general and item-specific knowledge. There is some evidence to suggest that similar category effects will be observed for both familiar and unfamiliar faces. It has been demonstrated that when viewing sets of unfamiliar faces, observers tend to merge the expression or identity from the sets of faces into an average representation, including the mean emotion of the set (e.g. Haberman & Whitney, 2007; Haberman & Whitney, 2009; Roberson, Damjanovic & Pilling, 2007), the mean gender (Haberman & Whitney, 2007) and the mean identity of the faces (de Fockert & Wolfenstein, 2009). Furthermore, Neumann, Schweinberger and Burton (2013) demonstrated this for famous faces. In this task, younger adults were presented with sets of familiar famous faces. Following each set, a single probe face was presented and participants' had to identify whether they had seen it in the most recent set or not. On a large proportion of trials, however, participants identified having seen probes that comprised an average of the displayed faces, suggesting that they also average familiar faces.

We thus anticipated that the data for the non-familiar faces would resemble the data for the unfamiliar shapes reported by Heussen et al. (2011) and Hemmer and

Steyvers (2009). As the participants have no item-specific prior knowledge for these faces, they should just demonstrate a regression towards the mean of the face of the morph continua. If the older adults used their knowledge to the same extent as the younger adults, we expected that graphs plotted to represent the responses of each age group separately would illustrate the same level of bias (regression) and so their slopes will be equivalent. Conversely, if older adults used their knowledge to a greater extent, then we expected that they would show more regression (steeper slope) to the mean face. If they were using knowledge to a lesser extent, we would expect a shallower slope. We expected no intercept difference for either age group given that there was no item-specific knowledge for the non-familiar faces yet in line with previous research, we predicted that the older participants would show more error in their response than the younger adults due to poorer immediate memory functioning. What we wanted to determine, therefore, was whether prior knowledge interacted with this greater level of error or whether the two remained independent.

2.2.1 Method

2.2.1.1. Participants

One hundred participants were recruited for an internet based study; 50 older adults (*m* = 68.9, *SD* = 4.38) and 50 younger adults (*m* = 22.7, *SD* = 3.01), matched in terms of gender, educational attainment and IQ; assessed using the Wechsler abbreviated scale of intelligence (WASI; 2010) [two subtest form; block design and vocabulary]. Participants were recruited from an existing research database from City University. Participants were recruited via an email which clearly outlined the ethical treatment of their data and obtained informed consent.

2.2.1.2 Materials and Procedure

The materials used were obtained from a selection of high-resolution grey-scale photographs of famous and non-famous faces created by Eimer, Gosling & Duchaine (2012)[3]. For this task, we selected 12 pairs of non-famous faces. These 24 images were equally matched for gender, face orientation, expression and distinguishing facial features. All faces were restricted to an oval shape to remove hairstyle, so no faces displayed any hair unless some fell onto the face. Each face was surrounded by a homogenous grey square of the same size and orientation. None of the faces possessed any additional identifying features, such as glasses or jewellery.

These paired images were used to create 12 non-familiar morph continua (one non-famous face merged with another non-famous face). Each morph continuum was created using Win Morph 3.01 and moved from one face to another in 100 increments. In the task, however, only images ranging between the positions of 20 and 80 along the morph continuum were used as stimuli; faces above or below these limits were more defined and so clearer than for the rest of the morphed continuum. This may have led participants to reconstruct faces based on abstract features such as contrast or blurriness. At position 50 it was estimated that the morph stopped resembling one face and began to display the other face. The distribution of positions used at study was uniform.

During the experiment, participants were presented with 24 trials comprising two photographs of faces shown for 2 seconds each. Each image was extracted from a different morph continuum at random. Each morph was used four times in total (but only tested twice). The orientation of the continuum was switched evenly between presentations; on two occasions face A was orientated to position 0 and on the other two occasions it was oriented to position 100.

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[3] We would like to thank Eimer and colleagues (Eimer et al., 2012) for their stimuli.

One second after the presentation of these two images, one of the faces was shown again but at a different position along the original morph continuum - with one constraint: it had to be at least +/- 15 positions away from the originally presented face to ensure a noticeable difference (plus and minus shifts were used equally often). Underneath the test face was a mouse-controlled slider bar which could display the entire range of the morph continuum (from 0-100). Participants were required to use the slider bar, moving along the continuum, to reproduce the studied experimental face as closely as possible. Once participants were happy with their response, they clicked the ‘next’ button to proceed to the subsequent trial. A bespoke programme was used to control the presentation of the stimuli and record responses.

2.2.2 Results

For simplicity of analysis, the upper half of the continuum was flipped so that both sides of each morph continuum were represented by the same values, from the start value to the mid-point. The continuum was flipped at position 50 as this was taken as the mid-point between the 2 faces that contributed to the morphs. This flipping creates a situation where all the values are on the same side of the mean – so regression can only go in one direction (i.e. away from the extremes and closer to the mean). To differentiate between the two faces within each morph, the face initially presented to the left of the continuum was labelled face A and the face presented on the right was face B. This provided us with two data sets to examine the relationship between studied face and remembered face.

Figure 2.2 presents the recalled position as a function of the studied position. This figure suggests that responses were systematically related to the studied position on the morph continua, as responses are linearly related to studied positions. Regression towards the mean can be seen by examining the difference between the diagonal line representing perfect performance and the best fitting lines included in the figure.

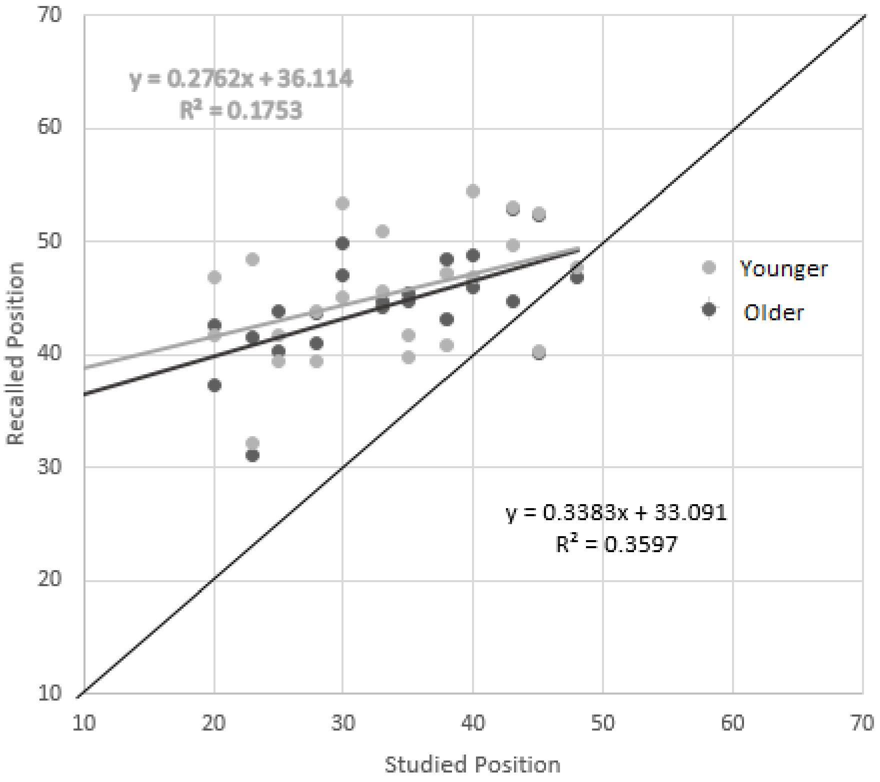

Figure 2.2. Recalled morph position as a function of studied position for older and younger adults.

Reconstruction error (reconstructed size minus studied size) as well as absolute error were used in the inferential statistics. In the first analysis, absolute error was used instead of raw error to prevent positive and negative errors from cancelling each other out. Group differences in the mean absolute error were assessed using a between samples *t*-test (see Figure 2.3). This revealed a significant difference between the two groups; *t*(98) = -2.35, *p* = .01, with older adults generating more error than the younger adults (younger; *m* = 16.83, *SD* = 13.56, older; *m* = 19.31, *SD* = 15.65).

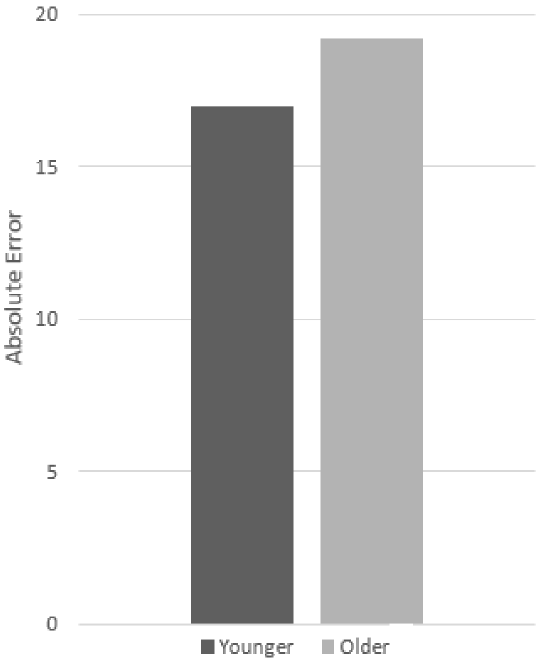

Figure 2.3. Absolute error for each age group for the control faces.

Following Hemmer and Steyvers (2009) and Heussen et al. (2011), regression towards the mean was examined by analysing the raw error scores as follows. Separate regression models were fit for each participant, examining how error was predicted by the position of the face along the morph continuum (see Figure 2.4 a-b for the individual regressions across participants). This was done separately for faces A and B. Each regression hence involved three parameters; two intercept parameters corresponding to face A and face B and one slope parameter relating studied and remembered sizes.

Like in Hemmer and Steyvers (2009) study, the negative slopes in the figures illustrate regression towards the average face. In this study, the continuum was flipped at the central value (position 50, i.e. the mean). This means that items presented at the extremes of the continuum (i.e. position 20) showed more positive error, as they were adjusted towards position 50. To illustrate this (see Figures 2.4a-b), an item presented at position 20 shows an error of approximately +20. This means that the face is being adjusted to approximately position 40 and thus closer to the average face. An item presented at position 40, conversely, shows little error as its value is already close to the mean. Moreover, as we can see and as expected, there is no difference between the two regression lines; this was predicted as there is no pre-existing knowledge of these faces, thus only regression towards the average face was observed. The average slopes and intercepts for each group are reported in Table 2.1.

Table 2.1. Mean Slopes and Intercepts by category and face-type for each age group.

		Younger	Older
Slopes		-.65	-.70
Intercepts	Face A	33.16	35.31
	Face B	32.30	35.63

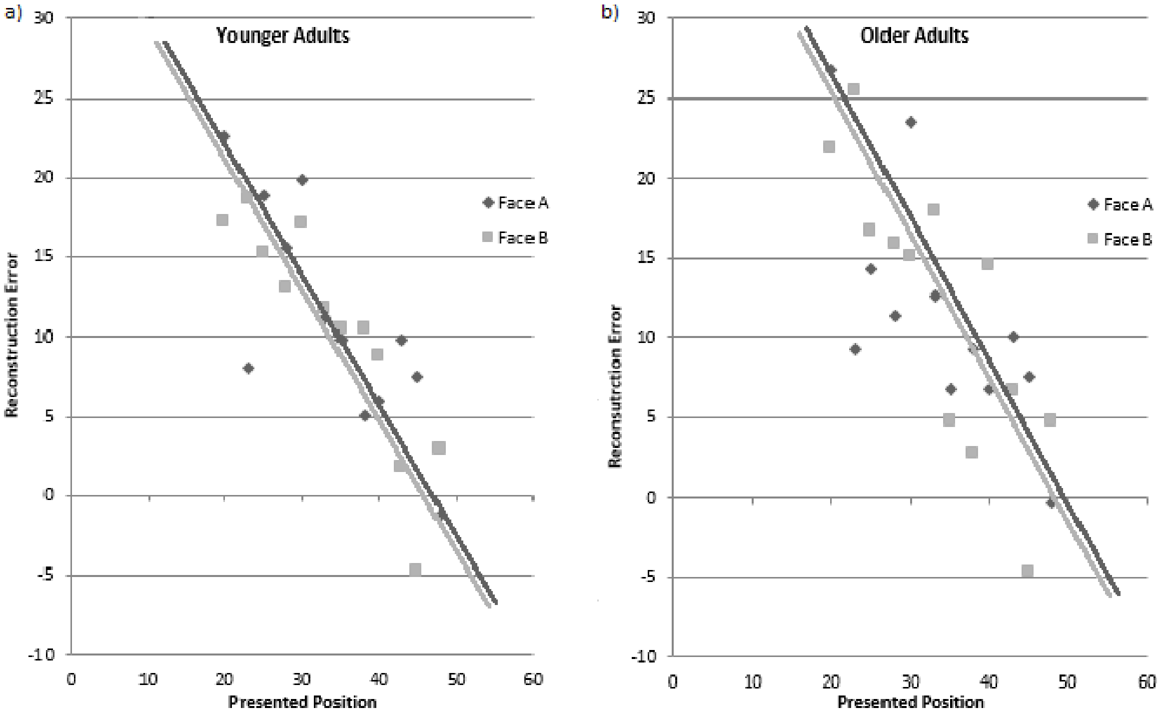

Figure 2.4 a-b. Reconstruction error as a function of study position along the continuum, for both age groups (negative values indicate bias towards the famous face).

One-sample *t*-tests confirmed the hypothesis that the slopes were different from zero; indicative of a regression towards the mean. The slopes for both the younger; *t*(49) = -11.25, *p* < .001 and older adults; *t*(49) = -8.93, *p* < .001) were different from zero. However, a between-group t-test demonstrated no age-related slope differences; *t*(98) =

.517, *p* = .61. The older and the younger adults were thus showing approximately the same level of regression towards the mean.

2.2.2.1 Distribution of responses

In an attempt to ascertain why older adults demonstrate more absolute error but similar patterns of bias to their younger counterparts, we obtained the average SD for each individual (based on their error scores) averaged across the different faces. Whilst the test of absolute error measured the participants deviations from the correct answer, the SD allows us to look at deviation away from the subjects own answer. A between-samples t-test was conducted on the SD for each participant. This revealed a significant group difference; t(98) = -2.3, p =.011, with the younger adults (*m* = 17.94, *SE* = .48) showing less variation than the older adults (*m* = 20.39, *SE* = .45).

2.2.3 Discussion

In this first experiment, we examined how knowledge of the stimuli called upon within an experiment affects immediate reconstruction in older and younger adults. The findings demonstrated that people appear to average across the presented stimuli and thus show a central tendency bias. The distribution of positions used at study was uniform. If the distribution had been normal, there would have been fewer items with ‘extreme’ positions and so regressing, or answering closer to the middle positions would have been an adequate strategy under uncertainty. As the distribution was uniform and participants were still regressing towards the mean, this was a more convincing demonstration that the average face was influencing estimates.

In terms of our predictions, the data suggests that older and younger adults demonstrate the same level of regression/ bias. It thus appears that older adults benefit from categorical knowledge to the same extent as the younger adults. This suggests age-invariance when experiment-based knowledge is called upon to support reconstruction. However, as predicted, the older adults demonstrated a greater level of absolute error, suggesting noisier representations of the presented stimuli (i.e. as a result of less efficient immediate memory). It thus appears that despite showing greater error, the older adults did not compensate for this through a greater reliance on knowledge of the “average” face.

However, it is possible that the older adults did not rely upon their knowledge to a greater extent in this experiment because said knowledge was not brought to the experiment – it had to be developed during the session. We thus wanted to determine whether older adults rely upon their knowledge to a greater extent when it is available prior to the experiment. We thus tested this in a similar paradigm but with the addition of finer-grained, object-specific knowledge; this was done by using familiar faces. In the second study, therefore, we aimed to determine whether level of noise in memory representations and the use pre-existing knowledge vary as a function of age.

2.3 Experiment 2

In this second experiment, we aimed to explore the added influence of pre-existing knowledge on reconstruction from immediate memory. To examine this, we adopted the same methodology as in Experiment 1 but used familiar morph continuums instead (a famous face morphed into a non-famous face). We predicted that as in the previous experiment, the participants would demonstrate a regression towards the “average” presented face. However, we also anticipated that this influence would be item-specific knowledge for the famous faces. Such knowledge would be demonstrated through greater bias towards the famous end of the continuum; using the same graphs as in Experiment 1, this result would be visually depicted through an intercept difference between the regression line which reflects reconstruction of the famous face and the regression line depicting the non-famous faces. This difference would demonstrate bias towards the famous face end of the continua. We suggest that if the older adults were relying on knowledge to a greater extent, the intercept difference between the two regression lines would be larger.

To illustrate this, let’s consider a continuum which morphs an unfamiliar face with someone familiar, such as Barack Obama. If the initially presented image resembles Barack Obama, when the participants are shown the image again at test but at a different position along the continuum, they should show a tendency to adjust the face towards the end of the continuum representing Barack Obama. Conversely, when the image does not show likeness to Barack Obama, the participants should rely on the average face to a greater extent. We thus expected two biasing effects of knowledge: 1) a regression towards the average face as observed in Experiment 1 and 2) in the case of the famous end of the morph continuum, the added influence of the object/ face-specific knowledge, pulling the response toward the famous end of the continuum. We also wanted to determine whether more familiar stimuli meant less error in the reconstruction for the older adults.

2.3.1 Method

2.3.1.1 Participants

The same one hundred participants were used in this study as in Experiment 1. There was an hour delay between the completion of the first and the second Experiments to reduce interference.

2.3.1.2 Materials and Procedure

Prior to running this experiment, we employed a separate subgroup of participants to obtain normative data with the aim of selecting famous faces which were well recognised by both the younger and the older age groups. To examine this, we used a group of twenty younger participants (m = 24.3) and twenty older participants (m = 69.4), recruited from within City University or from an existing database of participants. As in Experiment 1, the materials used were obtained from a selection of photographs collated by Eimer et al. (2012). We used the famous faces stimuli in a judging task to obtain subjective ratings for each of the famous faces. Participants were asked the following question: “How clearly do you recognise this person’s face?” They were required to rank each face separately on a scale of 0-8, with 0 representing ‘No familiarity’ at all and 8 signifying ‘Strong familiarity’. We used this data to determine which faces were most familiar for each age group. The final 12 famous faces selected and their respective confidence ratings are displayed in the table below (see Table 2.2). Of the most famous faces, we ensured that there were equal genders and a range of ages, as previous research indicates that younger adults demonstrate enhanced memory for contemporary over dated famous figures and vice versa for older adults (e.g. Ebner, Johnson, Rieckmann, Durbin, Johnson, Fischer, 2013; Wiese, Komes & Schweinberger, 2013).

These 12 selected famous images were matched with a non-famous face and used to create 12 familiar morph continua (one famous face merged with a non-famous face) in the same way as in Experiment 1 (See Figure 2.5). Besides differences in the stimuli used, the design of this study was a replication of the first. However, after completing this experiment, the participants were asked to provide familiarity ratings for the famous faces seen in this study. This was conducted despite the pre-obtained normative data, to allow us to determine whether familiarity ratings of those participating in this study were influencing reconstruction. During this phase of the experiment, participants were shown each of the original faces one at a time. For each face they had to provide a yes or no judgement for whether or not they recognised the individual. They also provided a certainty rating for their decision, ranked on a scale of 0 (no certainty) to 8 (very certain).

Table 2.2. The famous faces selected to be used as stimuli with their averaged confidence ratings for each age group separately.

Famous Face	*Younger Adults (Average)*	*Older Adults (Average)*
Amy Winehouse	7.6	7.2
Audrey Hepburn	7.1	7.8
Barack Obama	8	8
Charles Windsor	7.5	8
Cilla Black	7.1	7.7
Daniel Radcliffe	7.3	6.9
George Clooney	6.8	7.4
Jennifer Anniston	7.3	6.8
John Travolta	7.2	7.3
Judy Dench	7.4	7.5
Julia Roberts	7.1	7
Rowan Atkinson	7.8	8

Figure 2.5. Examples of a famous face continuum at positions 0, 25, 50, 75 and 100.

2.3.2 Results

For the purposes of analysis, we re-organised the continua so that all items presented at a value <50 represented famous faces, where the lower the value, the greater the influence of the famous face. Conversely, all items presented at a value of 50 or higher depicted the non-famous half of the continua. For continuity, the continuum was once again split into two halves and flipped at position 50 so that both the famous and the non-famous faces were represented by the same values. This enabled us to explicitly compare how reconstruction differed between the famous and the non-famous faces and thereby examine the influence of prior knowledge.

Figure 2.6 presents the recalled size as a function of the studied size for the famous faces and the non-famous faces separately. As before, this figure suggests that responses were related to the studied position on the morph continua, as responses are linearly related to studied positions. Comparison with the diagonal line representing perfect performance shows there was clear regression towards the mean. We again used reconstruction error and absolute error to measure participants’ performance. The mean values for absolute error are in Table 2.3. The difference in absolute error between older and younger participants was measured using a 2 (group; younger vs. older) x 2 (face type; famous vs. non-famous) mixed factor ANOVA. This revealed main effects of group; *F*(1, 98) = 8.44, *p* = .005, with more error for the older adults, and face type; *F*(1, 98) = 23.39, *p* < .001 with more error for the non-famous faces. There was no significant interaction for group by face type; *F*(1, 98) = 1.74, *p* = .190 (see Figure 2.7). The data thus suggests that knowledge for the famous faces led to less absolute error than for the non-famous faces, though the older adults exhibited greater overall error.

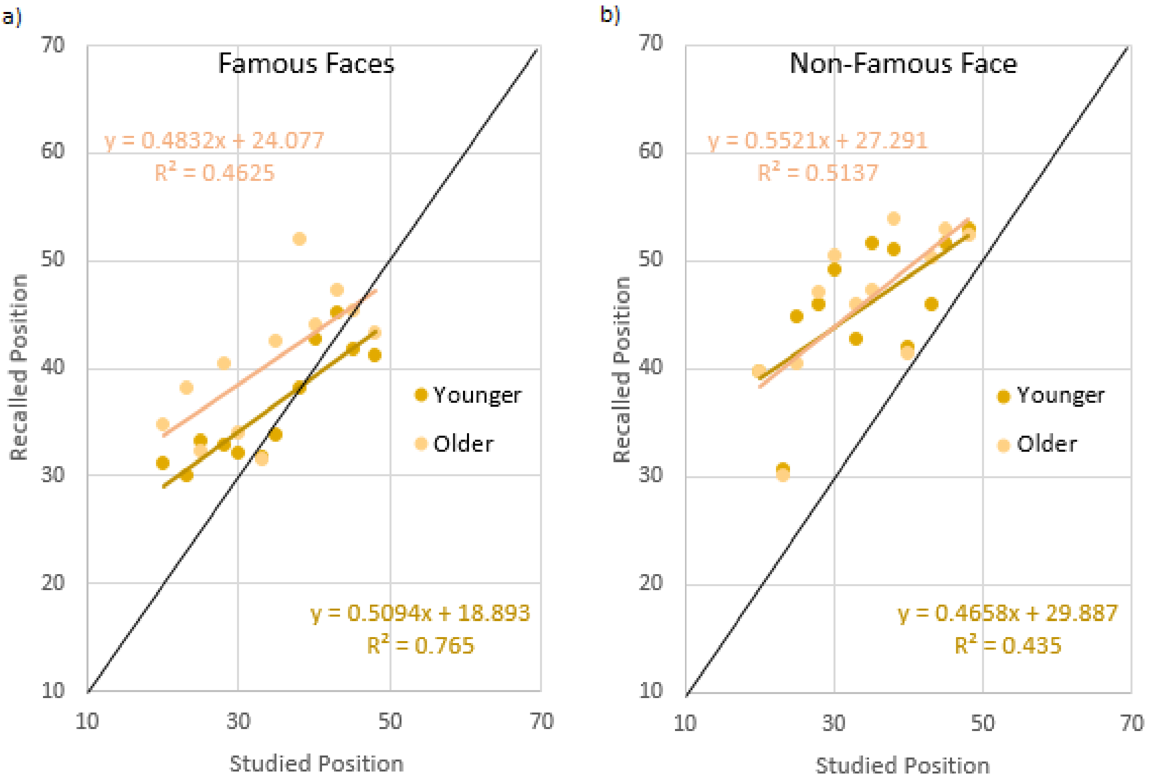

Figure 2.6 a-b. Recalled position as a function of studied position for older and younger adults for the famous face end of the continuum (a) and the non-famous faces (b) separately.

Table 2.3. Means and SDs (in brackets) for absolute error for both younger and older adults as a function of category and familiarity.

	Famous	Non-famous
Younger	13.56 (12.06)	17.07 (13.64)
Older	17.13 (14.01)	18.93 (14.82)

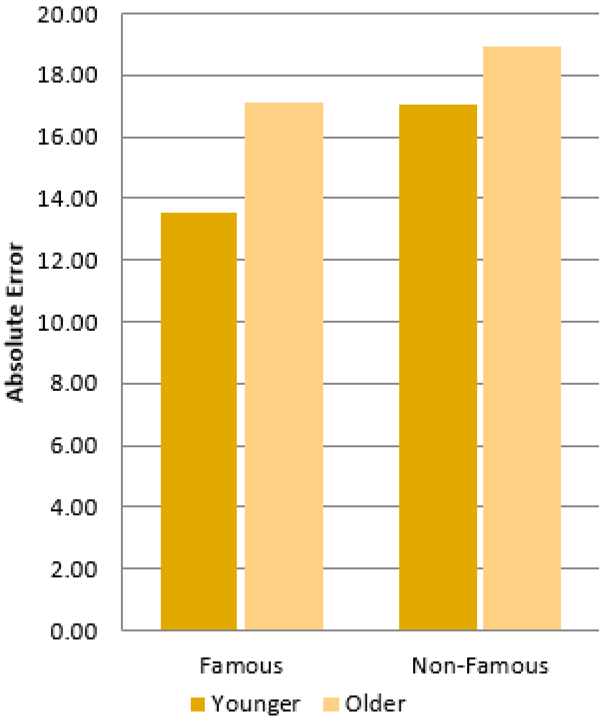

Figure 2.7. Absolute reconstruction error per age, category and relative size.

Again, to examine the effects of knowledge on short-term reconstruction, separate regression models were fitted for each participant examining how error was predicted by the type of face (famous or non-famous) and the presented position (see Figures 2.8a-b). Again, the negative slopes indicated bias towards the mean face. The two distinct regression lines reflected the influence of prior knowledge for the famous faces. A visual inspection of these regression lines suggests that the famous faces are reconstructed more frequently towards the famous end of the continuum; this is indicative of the use of item-specific knowledge. The average slopes and intercepts for each group are reported in Table 2.4.

Table 2.4. Average slopes and intercepts by category and relative object size for each group.

		Younger	Older
Slopes		-.51	-.49
Intercepts	Famous	19.9	22.87
	Non-famous	29.15	28.58

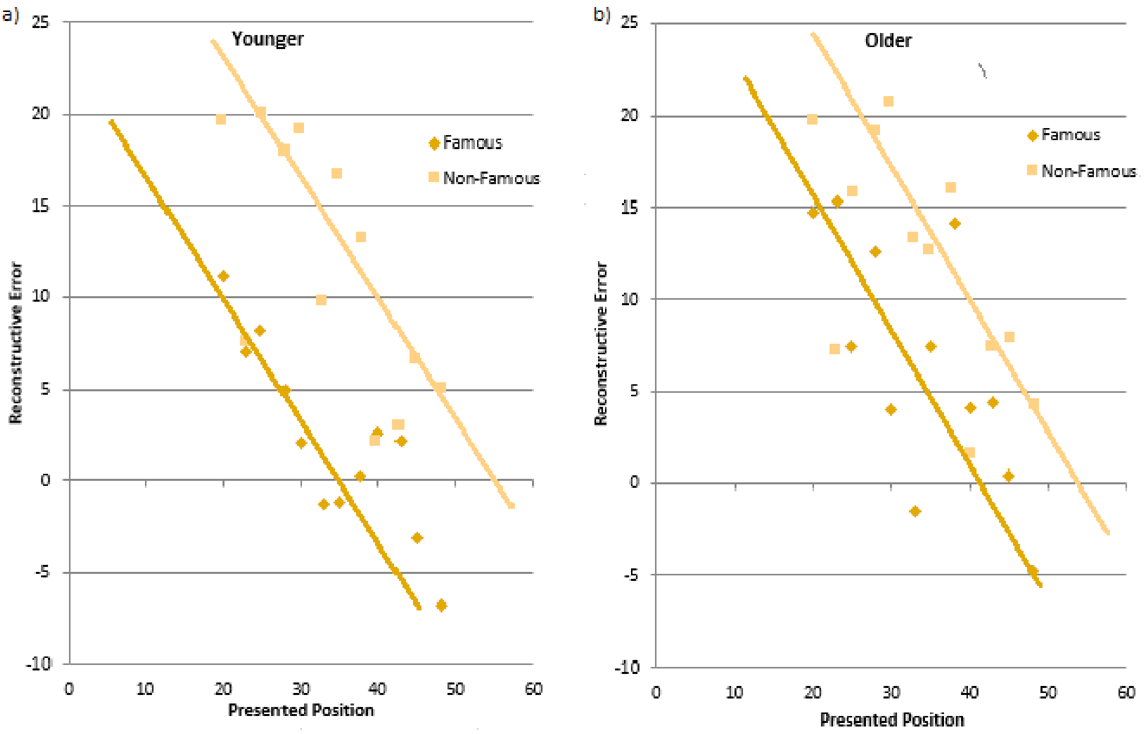

Figure 2.8a-b. Reconstruction error as a function of position and type of face for both age groups.

One-sample *t*-tests confirmed that the slopes were different from zero and thus demonstrated a bias towards the central face. Both age groups showed a significant slope (younger; *t*(49) = -10.02, *p* < .001, older; *t*(49) = -11.25, *p* < .001) and so regressed towards the average face. However, an independent-samples t-test found no slope difference between the two groups; *t*(98) = -.312, *p* =.76, again demonstrating the same level of regression towards the average face.

To determine any between group and condition intercept differences, a 2 (group; younger vs. older) x 2 (face type; famous vs. non-famous) mixed factor ANOVA was conducted, demonstrating a main effect of face type; *F*(1, 98) = 65.23, *p* < .001, which showed an intercept difference between the two regression lines. This suggests the use of pre-existing knowledge. There was a non-significant main effect of group; F(1, 98) =

1.66, p = .2 and a non-significant group by intercept interaction; *F*(1, 98) = 3.48, *p* = .065), suggesting no age difference.

2.3.2.1 Familiarity Analyses

To test the relationship between the recognition of the faces (scaled from 0; no recollection to 8; remembered clearly) and recall performance, we ran a 2 (group; younger vs. older) x 2 (face type; famous vs. non-famous) ANCOVA analysis with recognition as a covariate. When the analysis was run without the covariate, there were main effects of face type; *F*(1, 2396) = 4.84, *p* =.028 and a significant group by face type interaction; *F*(1, 2396) = 4.31, *p* =.038, with less error for the younger adults for the famous faces. When recognition was added as a covariate, however, there was no longer a significant effect of face type; *F*(1,2396) = .391, *p* = .532 or a significant interaction; *F*(1,2396) = 3.42, *p* = .064. Recognition was found to be a significant covariate; *F*(1,2396) = 5.44, *p* = .020.

To attempt to alleviate the role of recognition in our analyses (equate the two groups), we re-ran the regression analyses but with data restricted to the morph continuums containing only the 6 mutually most recognised famous faces. Table 2.5 shows the top 6 most recognised faces and their corresponding average rankings. These statistics were obtained from the participants' estimates in the recognition task.

We conducted one-sample *t*-tests to determine if the data still demonstrate a regression towards the mean. Both age groups showed a significant slope (younger: *t*(49) = -5.28, *p* < .001; older: *t*(49) = -4.88, *p* < .001). We also conducted one-sample *t*-tests for the intercept difference between the famous and non-famous faces. This revealed a significant difference between the younger (*t*(49) = -5.48, *p* < .001) and the older participants (familiar: *t*(49) = -3.98, *p* < .001). Thus, despite exerting greater control over the stimuli used, the same overall pattern of results was found, indicating that our initial data was reliable.

Table 2.5. Percentage of participants who reported recognising these faces as famous with average certainty rankings for both age groups.

Famous Face	Younger Adults (Average)	Older Adults (Average)
Rowan Atkinson	7.8	7.4
Charles Windsor	7.1	7.8
Judi Dench	7.2	6.9
John Travolta	6.8	7.1
Audrey Hepburn	6.4	7.5
Cilla Black	7.3	7.8

2.3.2.2 Distribution of Responses

In an attempt to ascertain why older adults demonstrate more absolute error but similar patterns of bias to their younger counterparts, we obtained one SD for the famous faces per participant and one SD for the non-famous faces. A 2 (age group; younger vs. older) x 2 (face type; famous vs. non-famous) mixed-factor ANOVA was conducted on the SD of responses per position. This revealed a significant main effect of group; $F(1, 98) = 7.52$, $p = .007$ with less variation for the younger ($m = 16.60$, $SE = .78$) than the older adults ($m = 19.66$, $SE = .79$). There was a non-significant main effect of face type; $F(1, 98) = .828$, $p = .365$, and a non-significant interaction; $F(1, 98) = .790$, $p = .376$.

2.3.2.3 Anchoring

Lastly, the participants' responses were analysed to assess whether their responses were influenced by the position of the item shown at test by running a regression per participant determining whether test size was a significant predictor of participants' responses. Test size was a non-significant predictor for all participants bar four (two younger and two older), suggesting that test position had little systematic effect upon responses. These four participants possibly used the test position as an 'anchor' to influence their reconstruction response, but removing the participants made no overall difference to the model.

2.3.3 Discussion

In this study, we examined the effect of stimulus specific knowledge, available prior to the experiment, on immediate memory. The observed intercept difference - which was absent in Experiment 1 when there was no item-specific knowledge - is the pattern expected from knowledge-based bias. This means that when participants could capitalise upon knowledge for the famous faces, they tended to adjust their responses towards the famous end of the continuum.

However, once again, the results suggest age-invariance in the use of prior knowledge. Moreover, as in the first study, older adults demonstrated greater absolute error, indicative of noisier representations. We supported this further by finding more variation in the responses of the older adults. The data thus indicates that older adults use the session-based and the prior knowledge to the same extent as the younger adults, despite older adults demonstrating fuzzier memory traces. We ruled out potential confounding variables, such as age-differences in the recognition of the famous stimuli. This also eliminated other potential issues, such as greater difficulties for older adults recalling contemporary relative to dated faces (e.g. Ebner et al. 2013; Wiese et al. 2013), as the six mutually most recognised faces were in the dated age bracket.

2.4 General Discussion

The overall aim of the work presented herein was to systematically examine the use of prior knowledge in short-term reconstruction for older and younger adults. Overall, the data clearly demonstrated the use of broader (continuum-level), as well as item-specific (famous-face) knowledge for immediate memory using naturalistic stimuli. In Experiment 1, calling upon non-familiar continua, where the participants only have general expertise for the stimuli, we found no particular bias towards either end of the continuum, but an overall regression towards the mean of the two morphed faces. Conversely, in Experiment 2, with continua that had a familiar half, we observed reconstruction bias: responses were drawn towards the famous end of the familiar continuum. Hence, when the knowledge was available, an object-level influence of knowledge was found. This lends support for data such as that by Heussen et al. (2011) who showed that reconstruction for the sizes of familiar and unfamiliar fruit and vegetables was biased by the value of the presented item, item-specific knowledge for the size of the familiar items, as well as the overall distribution of all of the presented items.

Furthermore, one of the aims of this work was to examine how the level of error in memory representations and the use of knowledge vary as a function of age. Our findings demonstrate the adaptive use of prior knowledge for improving accuracy, as both groups of participants demonstrated less error for the familiar than unfamiliar faces. However, older adults produced significantly more overall error and variation in their responses than the younger adults. This suggests that the older adults' representations of the presented stimuli were fuzzier/ noisier than the younger adults. However, the results of both experiments suggest that older adults rely on prior knowledge to the same extent as younger adults. This thus generally indicates age-invariance in the use of prior knowledge, similar to research showing no age-related declines in areas such as cooking expertise (Miller 2003) and typical actions (Light & Anderson, 1983).

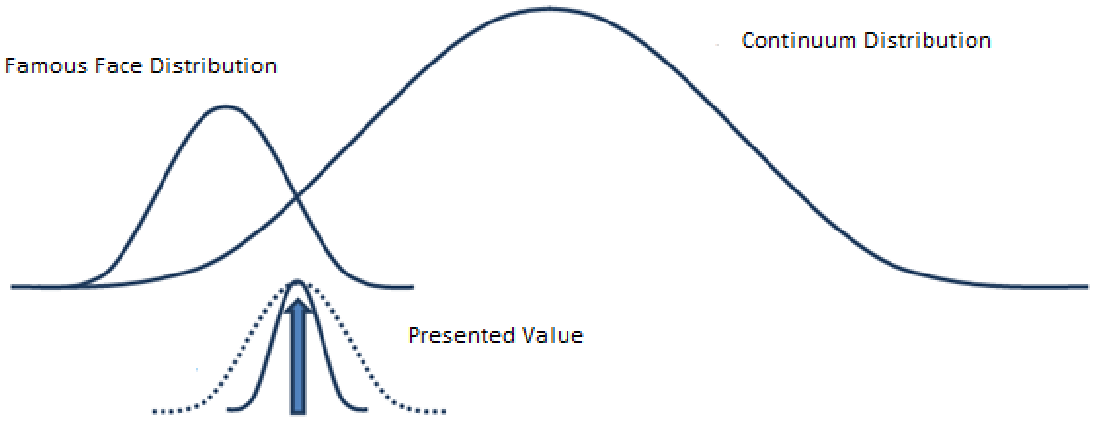

Figure 2.9. Representations of the overall distribution, the object distribution and the episodic representation of the presented value for younger and older adults (dotted = older).

One interpretation of the findings reported here is hence as follows. The specific representation associated to a studied stimulus can be thought of as a distribution of error around the presented value. Our findings can be seen to suggest that older adults have representations that are more widely distributed than those of the younger adults. In Figure 2.9 we visually illustrate this point. This figure shows the two levels of knowledge (continuum distribution and famous face distribution), as well as the specific representation distribution representing the uncertainty around the studied value. The continuum distribution represents the mid-continuum face, whilst the famous-face distribution reflects prior knowledge for the individual faces. We suggest that these two influences are equal for both age groups. The distribution of the specific representation is depicted by a dashed line for the older adults and a solid line for the younger adults. The implication is that older adults produced more variable responses, as observed in both studies.

In line with our hypothesis, therefore, older and younger adults use prior knowledge to the same degree but the older adults generate more error/ noisier representations. We propose that this is due to the distribution of the presented value (i.e. the participants memory representation) being wider for the older adults than the younger adults (see Figure 2.9) and so the impact of knowledge just averaging out. This would explain why older adults only demonstrate more error when we use absolute error as a measure, as the values are prevented from just cancelling each other out.

Overall, therefore, the present study successfully extends previous research by clearly exhibiting the impact that prior knowledge has upon immediate memory. The results systematically demonstrate the pervasiveness of knowledge bias over a shorter time-frame for face stimuli. We found that older and younger adults utilise their pre-existing knowledge to the same extent, yet older adults generate more overall error. It thus appears that older adults do not capitalise upon their existing knowledge to compensate for deficits in memory. However, in future research we want to explore this idea further with different stimuli and with greater manipulation over the task to rule out alternative hypotheses.

In the next Chapter, we continue to examine STM/ immediate memory in healthy ageing but adapted the paradigm to study knowledge for the sizes of familiar (fruits and vegetables) and unfamiliar (random shape) items instead. By using fruits and vegetables, we were able to examine the influence of the object-level and the superordinate-level influences of knowledge simultaneously. This is because fruits and vegetables can be represented as an overall category (i.e. the size of an average fruit or vegetable), as well as at the individual level for each particular item (i.e. the specific size of an apple or a mushroom). We will discuss this in more detail in the Chapter below.

Chapter 3: Prior knowledge and immediate memory reconstruction in healthy ageing

3.1 Introduction

When memory performance is examined in healthy ageing, a complex pattern of both declining and preserved capabilities is typically reported (Goh & Park, 2009). Research generally suggests that older adults show deteriorations in episodic (e.g. Fleischman, Wilson, Gabrieli, Bienias & Bennett, 2004; Park, 2000; Schaie, 2005; Singer, Lindenberger & Baltes, 2003) and short-term (STM)/ immediate memory[4] functioning (e.g. Multhaup, Balota & Cowan, 1996; Verhaeghen, 2002; Verhaeghen, Marcoen & Goosens 1993). Immediate memory refers to the maintenance of information in memory over the short-term in the absence of direct input. In particular, age-related declines in verbal STM have been well-documented. Salthouse (1991), for example, demonstrated that when adults reached their 60's-70's, their memory performance was approximately 1SD below the level of adults in their 20's, with slightly greater declines for words than digit span memory. To date, research exploring visual STM with ageing is scarcer, though similar data collected by Lezak (1995) demonstrated that immediate recall of visual patterns was found to decrease by 2.6 SD below the level of 20-29 year olds for 80-92 year olds.

Conversely, the longer-term products of processing appear to be unaffected (e.g. semantic memory). Hence, healthy older adults typically show stable or even improving levels of semantic knowledge (Surprenant & Neath, 2007). This pattern has recently lead to some research showing that when retrieval from episodic memory is supported by prior knowledge, in some circumstances at least, age-related memory decline can be

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[4] In the current paper, we use the terms immediate memory and STM interchangeably.

significantly reduced or eliminated (e.g. Badham, Estes, & Maylor, 2012; Castel, 2005; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003). Whether this type of knowledge-based support can also be observed in immediate memory has not, however, been systematically examined; this was the general objective of the work reported herein.

In younger adults, a growing body of research has found that when the to-be-remembered items reflect characteristics of the environment, prior knowledge leads to biases but also overall improved accuracy (Huttenlocher et al., 1991, 2000; Steyvers & Hemmer, 2012). Hemmer and Steyvers (2009) propose that recollection from episodic memory is often noisy or incomplete and so the use of knowledge which coincides with environmental regularities (i.e. semantic knowledge) can compensate for inaccuracies. Heussen, Poirier, Hampton and Aldrovandi (2011) showed that this type of analysis can also be applied to immediate memory.

In this paper, therefore, we examined how prior knowledge interacts with visual memory for the very recent past (immediate memory) in older and younger adults. In order to do so, we called upon an immediate reconstruction task, where participants reproduce the size of recently studied objects from memory. We first aimed to characterise any ageing effects in immediate reconstruction for both familiar and unfamiliar objects; based on previous research, we predicted increased variability in the representations of the to-be-recalled items for older adults, leading to increased error in immediate reconstruction (e.g. Multhaup et al., 1996; Verhaeghen, 2002; Verhaeghen et al., 1993). We also aimed to systematically examine whether reliance on prior knowledge when retrieving from immediate memory changes with age. More specifically, we derived predictions from a Bayesian view that has shown promise in other domains (e.g. Brady & Alvarez, 2011; Hemmer & Stevyer, 2009). The basic suggestion is that imperfect representations of recently encountered stimuli are combined with prior knowledge (when available). However, the overall contribution of prior knowledge can be hypothesised to vary with age or, conversely, to be age-invariant. The experiments reported here were designed to determine which of these hypotheses is more appropriate.

3.1.1 Immediate memory and knowledge

There has been a wealth of research exploring the relationship between STM and long-term knowledge; however, this has mostly been within the verbal domain. Saint-Aubin and Poirier (1999), for example, demonstrated that long-term semantic factors such as word frequency and familiarity have a positive influence on word recall in STM. Similar effects have also been reported for concreteness (Romani, McAlpine & Martin, 2008; Walker & Hulme, 1999), lexicality (Hulme, Maughan, & Brown, 1991; Saint-Aubin & Poirier, 2000; Schweickert, 1993), for non-words with familiar phonemic components (Thorn & Frankish, 2005), as well as for associative relatedness (Tehan, 2010). Tehan (2010) adapted the Deese-Roediger-Dermott (DRM) paradigm within an immediate memory task. Participants were presented with lists of items that were all associated to a non-presented lure. He showed that associative knowledge led to greater recall relative to control lists, but also heightened levels of false memory for the non-presented lure.

In the area of immediate memory for visual material, Heussen et al. (2011) adapted a paradigm developed by Hemmer and Steyvers (2009) to examine the interaction between knowledge and immediate memory. The original paradigm was used to measure the impact of pre-existing knowledge on episodic memory for the sizes of everyday, familiar fruits and vegetables compared to unfamiliar random shape control items. They based their predictions on models such as that of Huttenlocher and her collaborators (e.g. Huttenlocher et al. 1991; Huttenlocher et al., 2000) who showed how categorical knowledge was beneficial in memory and perception. Hemmer and Steyvers developed this idea by suggesting that multiple levels of knowledge can contribute to retrieval when episodic memory traces are incomplete or noisy. In their 2009 paper, they investigated the influence of two levels of categorical knowledge, namely an object-level and a superordinate-level. The object-level category reflects fine-grained knowledge for one particular stimulus (e.g. the typical size of apples) and was represented as a distribution of potential values around the mean (i.e. the distribution of all possible sizes of an apple). The superordinate level knowledge referred to the aggregate category to which the objects belonged (e.g. the distribution of the size of all fruits)

Hemmer and Steyvers (2009) postulated that memory reconstruction is based on the weighted average of the specific episodic memory trace as well as a contribution from both the object level and superordinate category level. They proposed that adjusting an inexact representation of a stimulus (noisy distribution of the studied item) towards its prototypical mean or towards the overall superordinate category mean would usually reduce inaccuracy as said stimulus is more likely to reflect a value closer to the respective mean than an extreme or rare value.

However, this increase in accuracy is accompanied by an increase in knowledge-based biases as recalled values consistently regress towards the typical or average values (e.g. Huttenlocher et al. 1991; Huttenlocher et al., 2000). Hemmer and Steyvers (2009) tested these ideas and obtained patterns that were consistent with the predictions above. This has also been extended to pre-existing knowledge for other stimuli, including knowledge of heights for men and women (Hemmer & Steyvers, 2010) and for colour categories (Persaud & Hemmer, 2014).

The current study called upon the task used by Heussen et al. (2011) to test the influence of long-term knowledge on immediate memory in the visual domain for both older and younger participants. Heussen et al. used normative data collected by Hemmer and Steyvers (2009); this data provided the perceived mean size of various familiar items (fruit and vegetables), as well as the smallest and largest reasonable sizes for these objects. The authors also used random shapes, for which participants had no pre-existing knowledge; the latter were yoked to the more familiar items in terms of size. Both types of items were used in an immediate memory task. Each trial consisted of a series of six consecutive images from the same category, either vegetables or random shapes. The images were presented at different sizes and could be smaller, larger or average, relative to their own mean size. Immediately after the sixth image was shown, one of the items was shown again but at a different size and participants were required to use a mouse-operated sliding bar to reproduce the initially studied size.

The Heussen et al. (2011) findings replicated those of Hemmer and Steyvers (2009) but over a much shorter time-frame; the reported results hence demonstrated that memory reconstruction for familiar items was systematically biased by both the superordinate and object categorical level, even when the reconstructed item had been studied only seconds ago. Object-level prior knowledge for each of the individually presented items caused the size of an object to be overestimated if the studied instance was smaller than the average size (i.e. a small carrot) and to be underestimated if the studied instance was larger than the average (i.e. a large carrot), thus demonstrating a regression towards the normative object mean. Superordinate category knowledge also led to reconstructive bias, such that there was regression towards the overall average size of the studied items in the category: the size of small items (e.g. a mushroom) tended to be overestimated, whilst the size of large items (e.g. a cabbage) were underestimated. For the unfamiliar items, however, with little knowledge available, reconstruction was dependent upon the quality of the memory, and only showed evidence of regression towards the superordinate mean of the items presented throughout the study.

3.2 Experiment 3

In this paper, we aimed to systematically examine the impact of prior knowledge on immediate memory reconstruction for both older and younger adults. More specifically, we wanted to determine whether both the level of knowledge used in memory reconstruction and the memory representations of the presented stimulus change with age. We sought to examine how these two systems interact to determine whether a) as the level of error increases, the use of knowledge does also, or b) whether the contribution of prior knowledge is independent of the quality of the memory representations available. Despite focusing predominantly upon episodic memory, the previous literature suggests that knowledge can aid the recall of older adults and even improve their performance to reach the level of younger adults, yet there is little evidence of how STM (particularly VSTM) and knowledge integrate.

To clarify the hypotheses tested here, the main findings of Heussen et al. (2011) are reproduced in Figure 3.1 a-b. These graphs plot reconstruction error as a function of presented size and include the best fitting linear regression functions. The data illustrate a general regression towards the superordinate category mean for both the vegetables and the shapes (shown by the negative slope; items that are large relative to the overall sample were made smaller, whilst small items were made larger).

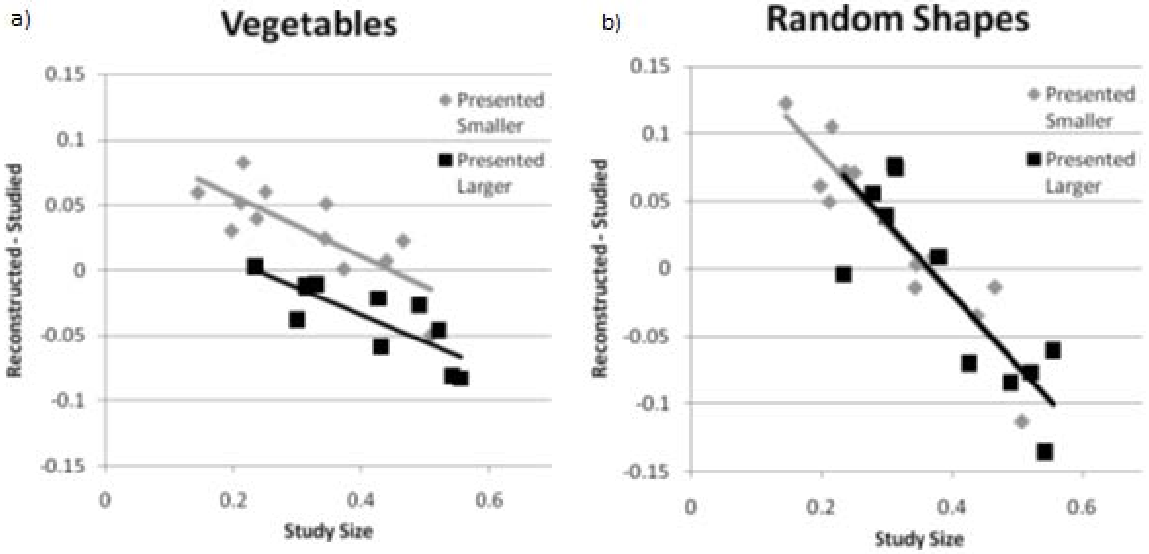
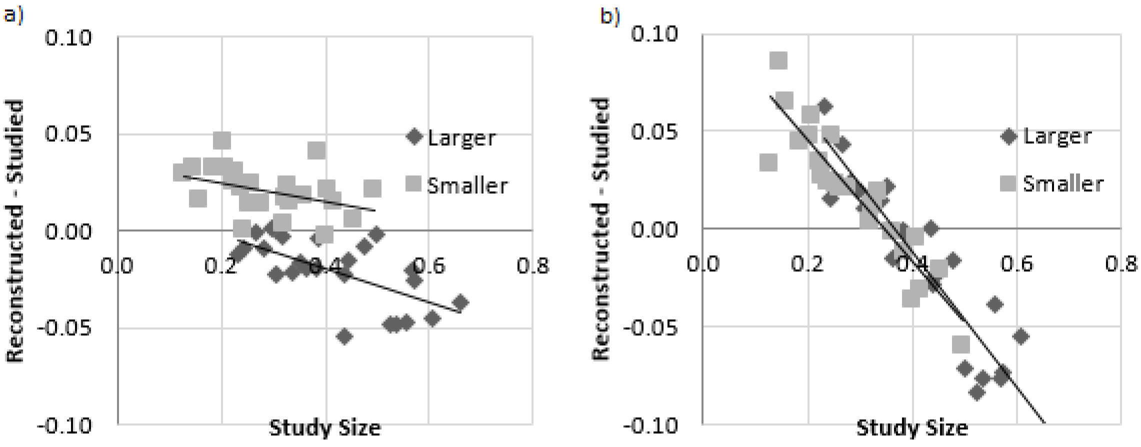


Figure 3.1 a-b. Data reproducing the results of Heussen et al. (2011) for vegetables (3.1a) and random shapes (3.1b).

In addition, for the familiar items, Figure 3.1a shows that the studied size – relative to the object-level normative mean—produced an intercept difference. This finding illustrates the influence of object-level knowledge, where items which were presented smaller than their own normative mean tended to be made larger (top regression line in Fig. 3.1a), whilst those presented larger were made smaller (bottom regression line in Fig. 3.1a). So, two familiar objects, studied at the same size, could be remembered differently. If a large plum was studied at the same size as a small apple, the error in recall for these two items tended to go in opposite directions: the plum’s size would remembered as being smaller than it actually was, while the apple’s size would be remembered as being somewhat larger than it actually was. For the unfamiliar random shapes, in Figure 3.1b, there was no intercept difference because there was little item-level knowledge for these items. Heussen et al. (2011) collected their data using younger participants and supported the findings of Hemmer and Steyvers (2009) but over a shorter timeframe.

Here the question is what happens to this pattern of knowledge with age. If the older adults use their knowledge to the same extent as the younger adults, we expected the pattern illustrated above would hold for both age groups. To allow us to quantify our prediction for the older adults, we ran simulations based on the studied item sizes used in the current experiment and the normative data obtained from Hemmer and Steyvers (2009). The simulations assumed that responses were a weighted average of the studied size, of the superordinate category knowledge (average studied size across the experiment) and of the object-level category knowledge (normative mean per item). The studied size representation was assumed to be equal to the studied size plus a value sampled from a normal distribution (with a mean of 0 and an SD of 1), the latter representing error. This normal distribution means that half of the values were presented negatively and half positively, so the noise meant that the item was sometimes made bigger and sometimes made smaller. The weight of the episodic value is never changing – the only thing that changes is the noise of the representations around the presented item.

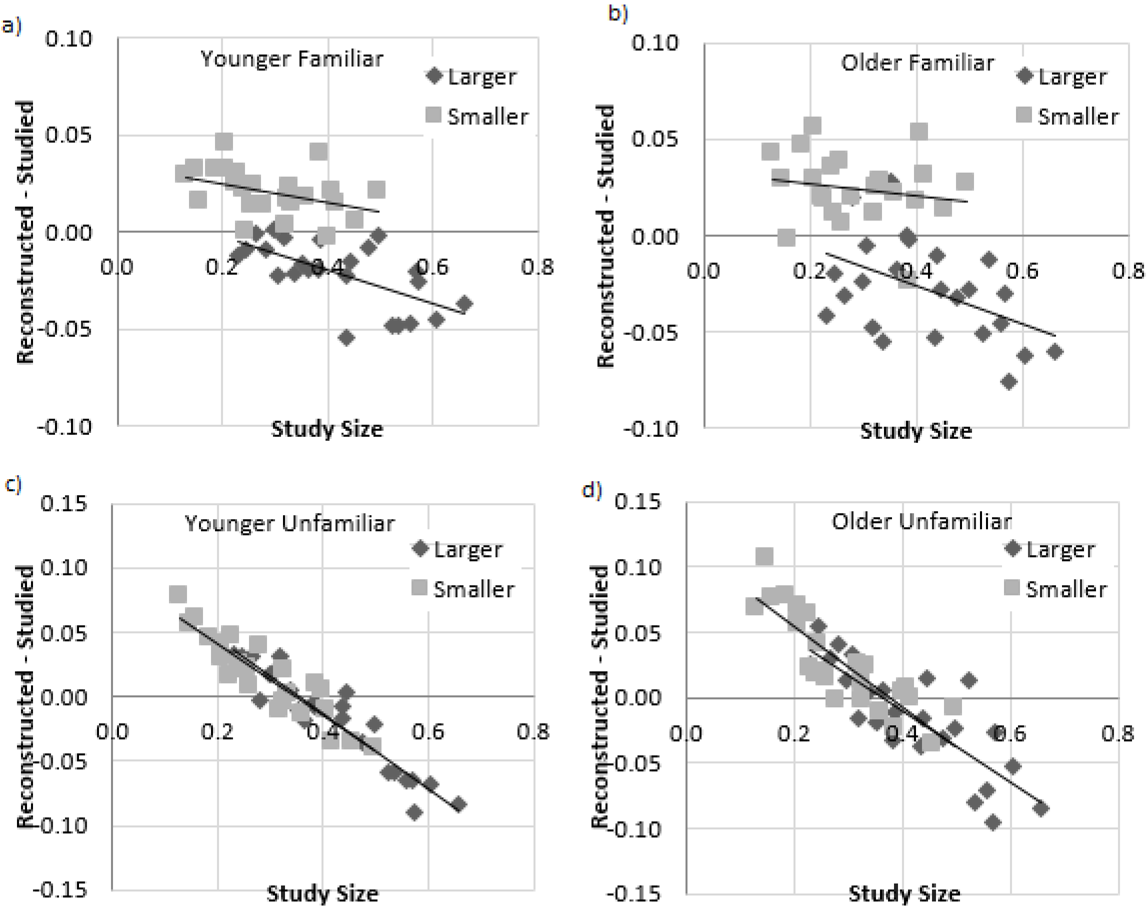
The simulations assumed that the studied size would be the most important influence (weight = .6), followed by the object-level normative mean (weight = .3.5), and finally the superordinate category mean (weight = 0.5). The starting values for each of these parameters was random. A number of 48 trials per participant went into the simulation. There were 60 participants in total - 30 in the younger group and 30 in the older. With these simple steps implemented, we first verified if the pattern of data from Heussen et al. (2011) was reproduced. As can be seen in Figures 3.2a and b, the said pattern was well reproduced.



Figures 3.2 a-b. Data simulated to reproduce the results from Heussen et al. (2011). Figure a represents reconstruction for familiar items, whilst Figure b represents unfamiliar items.

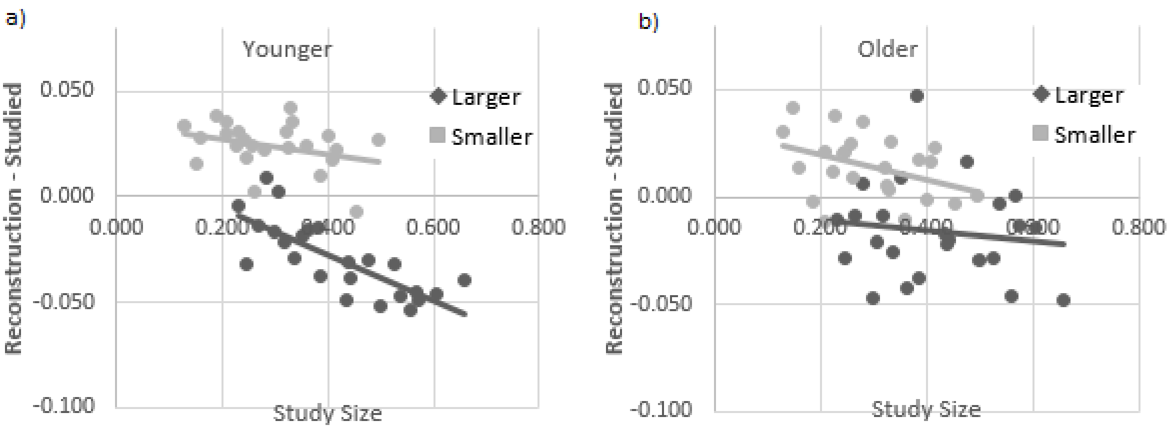
To examine what would happen when the error associated with the memory representation increased, all the weights were maintained as described above, but we manipulated the level of error between the two groups; we assumed that for the older adults, the main change would be increased error in the immediate memory representation. For the younger adults, the error was as before; however, the SD was increased to 1.5 for the older adults (we inputted fuzzier representations for the older adults without changing the weight to see if this would give more dispersion).

Under these assumptions, Figures 3.3 a-d show that older and younger adults would demonstrate the same influence of prior knowledge at the object-level and superordinate category levels, yet the older adults show more scatter around the regression lines, indicative of greater error. The unfamiliar items should show only an influence of the superordinate category knowledge and the memory representation. Again, reconstruction should show more error for the older adults, demonstrated by more scatter around the regression lines.



Figures 3.3 a-d. Representations of the simulated data for noisier representations for older adults but the same level of prior knowledge for both age groups. Figures a and b show reconstruction of the familiar items for both age-groups separately, whilst Figures c and d illustrate the unfamiliar items.

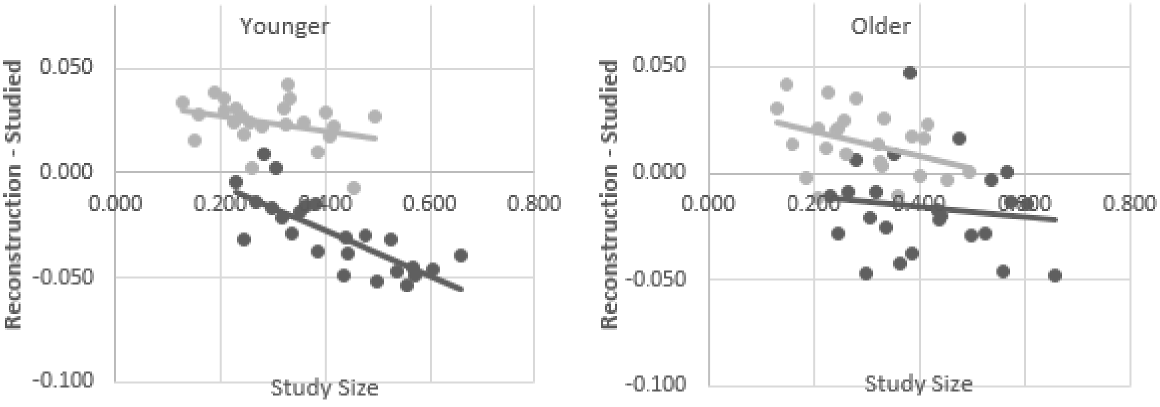
We also examined what would happen if the weight of the object-level knowledge changed. For these simulations, we kept the level of error the same as in the last simulation (mean of 0 and SD of 1 for the younger adults and 1.5 for the older). However, for older adults the weight of the object-level knowledge was increased from 0.4 to 0.55, implying that the weight of the item representation was reduced from 0.55 to 0.4 (and so the weight attributed to the overall distribution was .05).



Figures 3.4 a-b. Representations of the simulated data for more object-level knowledge for older adults but the same level as before for the younger adults.

Figures 3.4a and b illustrate the result of these changes for the familiar items for both age groups. This is what we would have expected if the older adults generated more error than the younger adults and compensated for this by relying on their prior knowledge to a greater extent. This graph illustrates that if the older adults use their object-level knowledge to a greater extent, the intercept difference would be larger. There would also have been less of a superordinate category influence, shown by a flatter slope.

Lastly, we examined what would happen if the weight of the object-level knowledge was reduced. For these simulations, we kept the level of error the same (mean of 0 and SD of 1 for the younger adults and 1.5 for the older). However, for older adults the weight of the object-level knowledge was reduced to from 0.4 to 0.25, implying that the weight of the item representation was increased to 0.7 (the weight of the overall distribution remained at .05). Figures 3.5a and b illustrates the result of these changes for the familiar items for both age groups. This is what we would have expected if the older adults generated more error than the younger adults but also relied on their prior knowledge to a lesser extent. This graph illustrates that if the older adults use their object-level knowledge to a lesser extent, we see that the intercept difference is smaller and the regression lines are flatter, indicating less regression towards the mean. We will thus test these hypotheses to see which simulation best represents our data.



Figures 3.5 a-b. Graphs representing simulated data for less object-level knowledge for older adults but the same level as before for the younger adults.

3.2.1 Method

3.2.1.1 Participants

Participants comprised 60 adults (30 aged 18-30; m = 24.8, SD = .087 and 30 over 65; m = 68.9, SD = 1.02). The younger and older participants were matched in terms of gender, years of education and IQ, which was assessed using the Wechsler abbreviated scale of intelligence (WASI; 2010) [two subtest form; block design and vocabulary]. Participants were recruited through advertisements in local and regional newspapers, a participant database and from within the university community. Preliminary phone interviews were used to recruit healthy adults, with no history of neurological or psychiatric disorders and no history of illnesses that impact cognitive function. Older participants also needed to obtain a score of at least 27 on the Mini-

Mental State Examination (Folstein, Folstein, & McHugh, 1975) to be retained in the sample. Despite this, two participants were removed from the sample (one from each age group) after completion of the task due to failure to understand the instructions[5].

3.2.1.2 Materials and Procedure

The materials used comprised a set of 12 high-resolution colour images of vegetables photographed against a white background. The images depicted common vegetables such as mushrooms, peas and peppers, but also less typical items including lady fingers, zucchini and ginger. The set of 12 was subdivided into 2 groups, one containing 6 smaller items (i.e. a mushroom) and one containing the 6 larger items (i.e. celery). Normative data for each item was obtained from Hemmer & Steyvers (2009), which consisted of average judgments[6] for the mean size of each item, as well as the largest and smallest reasonable sizes. The normative data was assumed to represent prior knowledge for the size of each object, which allowed for the estimation of knowledge-based biases in size memory.

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[5] When analysing the data, it was apparent that one of the older participants had not completed the task properly as they had not adjusted the size of the item at test for a single item. This participant and its matched younger participant were thus removed.

[6] Hemmer and Steyvers (2009) obtained these judgments from 18 participants. They were asked to estimate the average size of each item, as well as the minimum and maximum using a slider which controlled the size of the image. We would like to thank Hemmer and Steyvers for providing the materials and normative data.

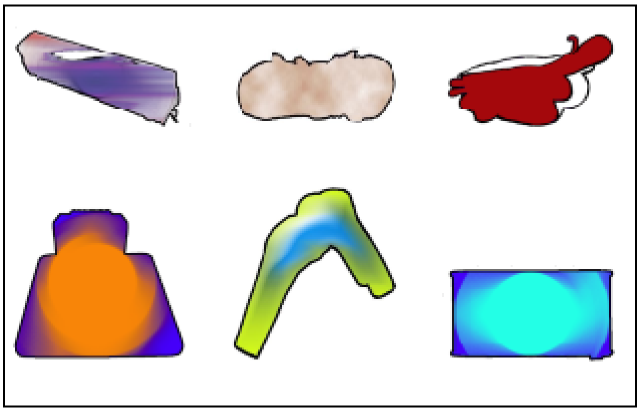

Figure 3.6. Examples of the random shape stimuli

We selected 12 items based on familiarity and to obtain a good range of sizes (from a mushroom to celery). To confirm our estimates of familiarity, we obtained ratings for each individual vegetable. Twenty five individuals of mixed age range (*m* = 38, *min* = 18, *max* = 67) were asked to rate each item in terms of familiarity on a scale of 1-10. A t-test was conducted to ensure that there was no significant difference between the mean familiarity ranking of the 6 smaller items and the 6 larger items, $t(11) = -.356$, $p = .729$. The test was non-significant, suggesting that there was no within list differences for familiarity rankings.

Each vegetable was paired with a control random shape that had a similar orientation. These shapes were used previously by Hemmer and Steyvers (2009) and Heussen et al. (2011), who presented all items in a homogeneous blue colour. In this experiment, they were adapted. We wished to better equate the random shapes and familiar items in terms of colour variation, patterning and texture, so that familiarity would be the main difference between the familiar and unfamiliar sets (see Figure 3.6 for some examples of unfamiliar items).

This collection of items was used to develop a computer-controlled task, comprising 48 trials split into 24 involving vegetables and 24 involving random shapes. On each trial, a series of 6 items from the same category—either all vegetables or all random shapes—were sequentially presented. No items were repeated within a trial. Based on the normative data, each item was presented in one of three relative sizes. Two of the items were presented at their own mean value (average size). Two of the items were presented in size that was larger than their own normative mean (relatively larger) and the two other items were presented in a size that was smaller than their normative mean. These item specific larger and smaller sizes were set at 60% of the range between the normative mean and the normative maximum and minimum, respectively.

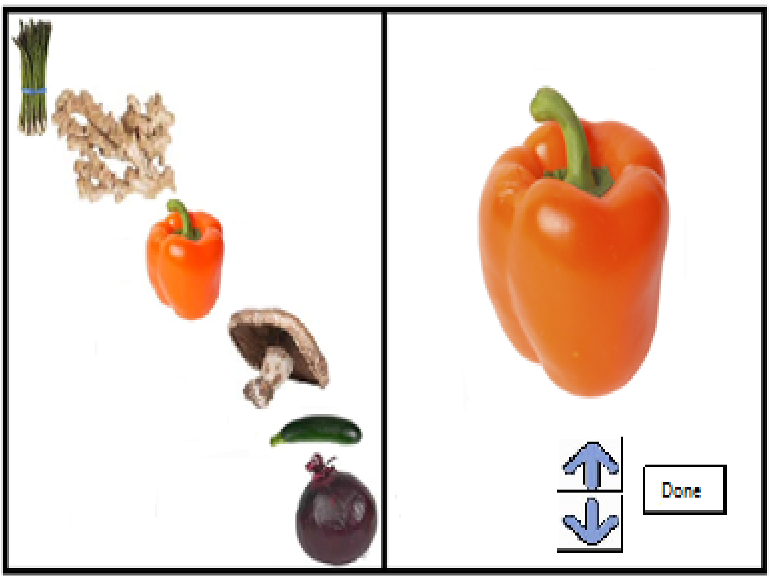

Figure 3.7. Example of an experimental sequence (items are shown individually) and test.

Of those six items, three were taken from the six items identified as small items and three from the pool of large items. Per category (familiar, unfamiliar), for every block of 4 trials, each item appeared once, so within 6 blocks of 4 trials, each item was shown 6 times in total (twice relatively smaller, twice larger and twice average). All participants were shown the same items at the same size, but presentation order of the trials and blocks was randomised within the constraints of the design of the study. Each item was presented for 2 seconds, with 0.5 seconds between each item.

Immediately following each series of six items, there was a memory test. For this test, one of the six items presented was shown again after a 0.5 second delay, but at a different size (only items presented relatively larger or smaller were tested). Participants were required to resize this item to replicate the size of the studied item using mouse-operated arrows (upward arrow increased the size, whilst the downwards arrow decreased it). The object remained on the screen for an indefinite time until the participant was happy with the size of the object and clicked a continue button (see Figure 3.7).

The objects and responses were measured on a scale of 0 to 1, where 0 corresponds to an object occupying 1 pixel of the screen and 1 corresponds to the maximum adjustable position, where the object fills the entire height or width of the screen. The presented size of the test item was selected at random from sizes .2, .4, .6 and .8 on this scale. Each serial position (1-6) was tested 4 times (twice relatively larger and twice smaller) across the study. Immediately after resizing the item, participants were asked to provide a confidence judgement. They were answered the following question: “How clearly do you remember the size of the item?” This was done using a 9-point scale where 0 represented ‘No recollection’ and 8 represented ‘Clearly remember’.

Following the memory task, participants were presented with a familiarity assessment task to obtain subjective ratings for each of the familiar items. Participants were asked to rank each item separately on a scale of 0-8, with 0 representing no familiarity at all and 8 signifying very strong familiarity. By presenting this task after repeated exposure to the items, it is possible that the ratings were slightly distorted (i.e. participants may have reported greater familiarity with the item due to recently seeing it). However, this was more desirable than presenting the task prior to the experimental condition, as this may have impacted participant’s performance due to factors such as demand characteristics. Participants were also presented with the category fluency test, which was obtained from the battery of Semantic Assessments; Adlam, Patterson, Bozeat & Hodges, 2010) to determine if level of semantic functioning influenced participants’ responses.

3.2.2 Results

Figure 3.8 presents the mean recalled size as a function of the studied size using the scale/ measurement units described above (averaged across participants). An inspection of this figure shows that performance was reasonably good; responses are linearly related to studied sizes. Regression towards the mean can be seen by examining the difference between the diagonal line representing perfect performance and the best fitting lines include in the Figure. As can be seen, items studied at the smaller sizes tended to be remembered slightly bigger while the reverse is true of the larger items presented.

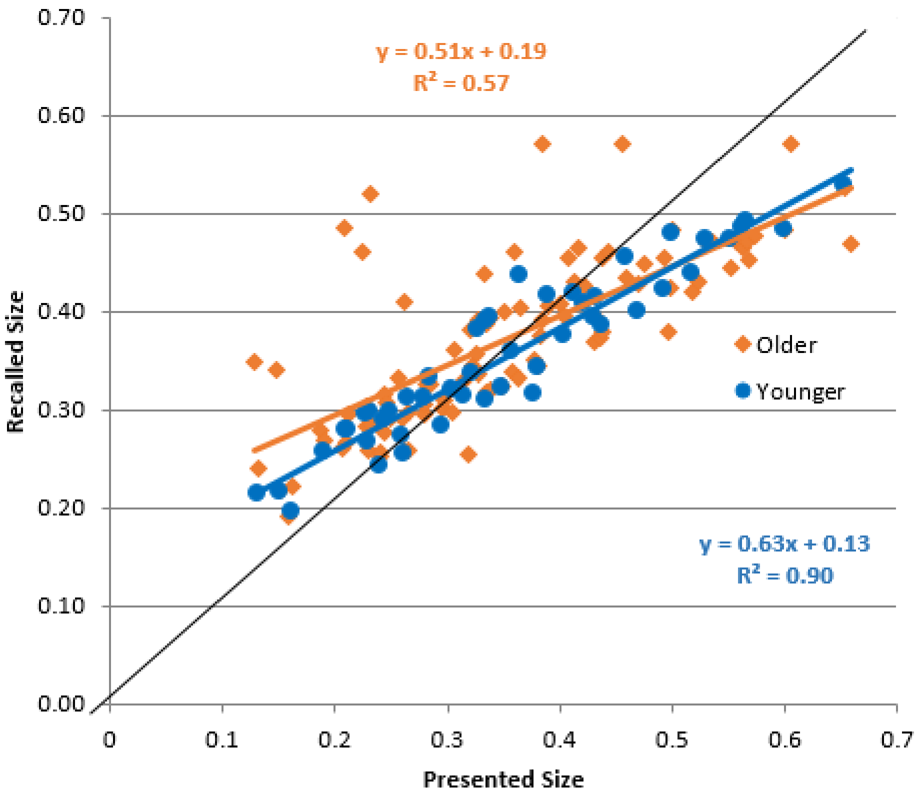

Figure 3.8. Presented size plotted against recalled size for older and younger adults.

Reconstruction error (reconstructed size minus studied size), as well as absolute error, were used in the inferential statistics. In the first analysis, absolute error was used instead of raw error to prevent positive and negative values cancelling each other out. The mean values are presented in Table 3.1.

Table 3.1. Means and SDs (in brackets) for absolute error for younger and older adults as a function of category and object relative size (studied smaller or larger than normative mean).

	Familiar		Unfamiliar	
	Smaller	Larger	Smaller	Larger
Younger	.065 (.064)	.067 (.055)	.074 (.070)	.085 (.075)
Older	.073 (.083)	.077 (.086)	.087 (.095)	.101 (.094)

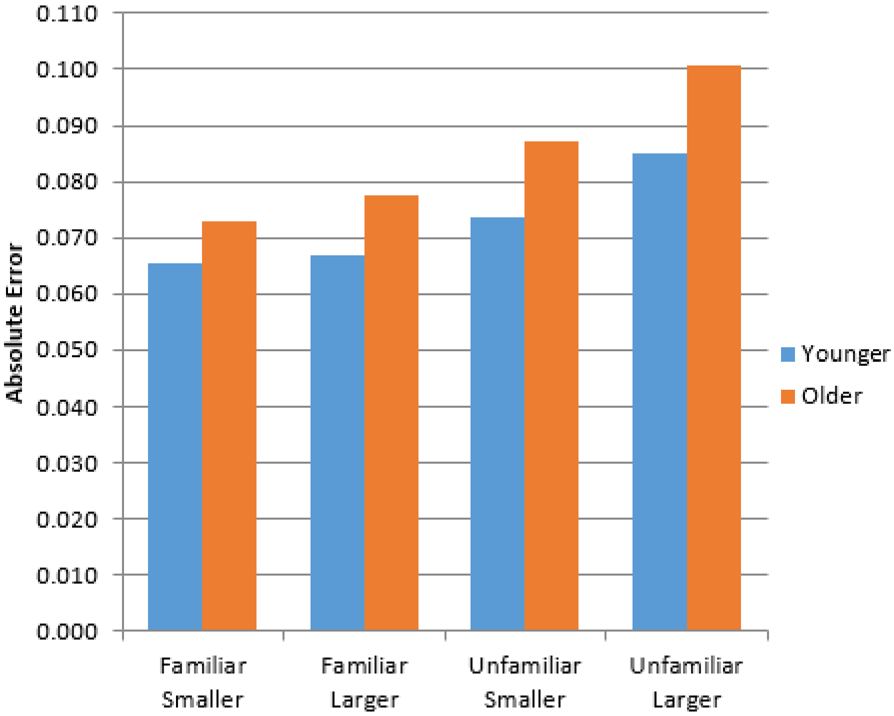

Figure 3.9. Absolute reconstruction error (reconstructed – studied size) per age group, category, and relative studied size.

Group differences in the mean absolute error in each condition were assessed using a 2 (group; younger vs. older adult) x 2 (category; familiar vs. unfamiliar) x 2 (relative size; smaller and larger than normative mean) mixed factor ANOVA. This revealed a significant main effects of age group; *F*(1, 58) = 4.80, *p* = .033, with younger adults showing less absolute error. There was also an effect of relative size with higher levels of error for items studied larger than their normative mean [*F*(1, 58) = 10.79, *p* = .002]. Finally, there was also an effect of category such that there was more absolute error produced when reconstructing unfamiliar random shapes [*F*(1, 58) = 51.19, *p* < .001]. There were no significant interactions for category by group; *F*(1, 58) = 3.26, *p* = .076, size by group; *F*(1, 58) = .532, *p* = .469 or 3-way interaction; *F*(1, 58) = 2.28, *p* = .137. There was a significant category by size interaction; F(1, 58) = 7.88, p = .007. Post-hoc analyses with Bonferroni corrections showed a significant difference between the smaller and larger shapes; t(59) = 3.69, p < .001 but no difference between the smaller and larger familiar items; t(59) = 1.19, = .240 (see Figure 3.9).

Following Hemmer and Steyvers (2009) and Heussen et al. (2011), the effects of both object-level and superordinate-level prior knowledge were examined by analysing the raw error scores as follows. Separate regression models were fitted for each participant and each type of material (familiar and unfamiliar), examining how error was predicted by the relative size of the items (smaller, larger than the norm) and the studied size (see Figure 3.10 a-d for the results averaged across participants). Each regression hence involved three parameters; two intercept parameters corresponding to the smaller and larger relative sizes and one slope parameter relating studied and remembered sizes.

Table 3.2. Mean Slopes and Intercepts by category and relative object size for each age group.

		Younger		Older	
		Familiar	Unfamiliar	Familiar	Unfamiliar
Slopes		-.196	-.481	-.151	-.434
Intercepts	Smaller	.108	.184	.087	.164
	Larger	.047	.160	.037	.130

The negative slopes in the Figure 3.10 a-d illustrate a central tendency bias or regression towards the mean, where smaller objects tend to be remembered larger (positive values in the Figures) and larger objects tend to be remembered smaller (negative values in the Figures). Moreover, for the familiar items both older and younger adults exhibit two distinct regression lines for items studied smaller than their normative mean and items studied larger that their normative mean, respectively. This intercept difference illustrates an effect of object-level knowledge in that two items studied at similar sizes will be remembered differently if one was studied smaller than its normative size and the other larger than its normative size. Surprisingly, the regression lines for the unfamiliar items also appear to diverge somewhat, despite participants having little knowledge of the items, though the difference is smaller. The average slopes and intercepts for each group are reported in Table 3.2.

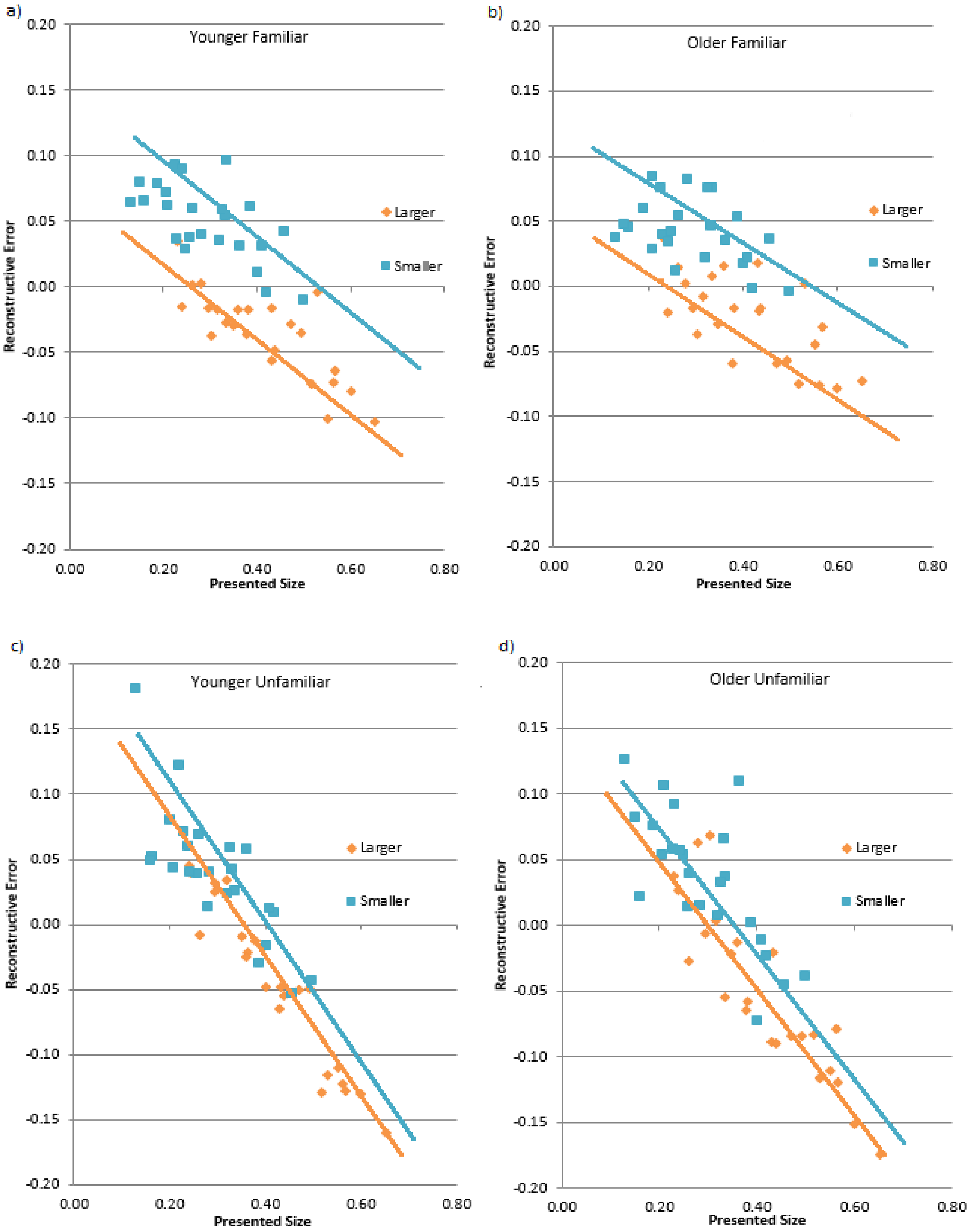

Figure 3.10 a-d. Figures a and b show mean reconstruction error as a function of study size for familiar items for both the younger and older adults. Figures c and d show reconstruction error as a function of study size for the unfamiliar items for both age groups seperately.

One-sample *t*-tests were used to confirm that the slopes were different from zero. The younger participants showed significant slopes for both the familiar (*t*(28) = -5.03, *p* < .001) and unfamiliar items (*t*(28) = -9.82, *p* < .001), as did the older participants (familiar: *t*(28) = -2.75, *p* = .011, unfamiliar: *t*(28) = -9.93, *p* < .001). To determine if any group differences emerged for the obtained slopes, a 2 (group; young vs. old) x 2 (category; familiar vs. unfamiliar) mixed factor ANOVA was run. No group difference was found; however, there was a main effect of category; *F*(1,56) = 83.75, *p* < .001, indicating that the slopes for the unfamiliar items were steeper than those obtained for the familiar objects. The latter implies that there was more regression towards the overall mean size for the unfamiliar shapes; this suggests that the prior knowledge associated with the familiar objects contributes to reducing the central tendency bias relative to unfamiliar objects. The category by group interaction was non-significant; *F*(1,56) = .002, *p* = .963.

Differences in intercepts were examined by running a 2 (group; younger vs. older) x 2 (category; familiar vs. unfamiliar) x 2 (relative size; smaller vs. larger) mixed-factor ANOVA. This analysis produced a significant main effect of category; *F*(1,56) = 72.64, *p* < .001, suggesting that there was a difference between the intercepts for the familiar and unfamiliar items. There was also a main effect of relative size; *F*(1,56) = 106.30, *p* < .001, suggesting that there was a difference between items presented smaller and items presented larger. As predicted, there was also a significant interaction between category and relative size; *F*(1,56) = 12.73, *p* = .001. Planned contrasts with bonferroni adjustments showed that for the vegetables, items presented smaller had a larger intercept than those presented larger, *t*(58) = 10.01, *p* < .001, which was also the case for the unfamiliar items but to a lesser extent, *t*(58) = 5.38, *p* < .001. As expected, therefore, we found an intercept difference for the familiar items, indicative of object-level knowledge. However, we also found a smaller yet significant intercept difference for the unfamiliar items.

3.2.2.1 Further Analyses

Given the unexpected intercept difference for the shapes, we hypothesized that the separation of tested items into relatively extreme groups (60% above and below object normative means) may have led to participants learning that there were two size categories tested. This could have extended to both the familiar and unfamiliar items, perhaps increasing object knowledge effects somewhat for the familiar items and allowing participants to learn these categories for the unfamiliar items.

To test this hypothesis, the responses from the first and last eight trials for each participant for the unfamiliar items were called upon. In order to test for learning effects, the pattern of results at the outset and at the end of the experiment was compared and so we obtained separate regression estimates (as above) for each participant and each period. A 2 (group; younger vs. older) x 2 (relative size; smaller vs. larger) x 2 (period; first 8 vs. last 8) mixed-factor ANOVA was conducted on the intercept values to determine if this changed as a function of period. This revealed a significant main effect of size; $F(1, 56) = 8.68$, $p = .005$, with a larger intercept value for the smaller than the larger items (smaller, $m = .207$, $SE = .021$, larger, $m = .134$, $SE = .015$). There was also a main effect of period; $F(1, 56) = 14.86$, $p < .001$, with a smaller value for the first 8 trials ($m = .159$, $SE = .014$) than the last ($m = .182$, $SE = .013$). There was also no period by group interaction; $F(1, 56) = .618$, $p = .435$, no group by size interaction; $F(1, 56) = 3.09$, $p = .083$ and no three-way interaction; $F(1, 56) = .226$, $p = .636$. However, there was a significant period by size interaction; $F(1, 56) = 5.17$, $p = .027$. Post-hoc analyses with Bonferroni corrections revealed no intercept difference between the smaller and larger items for the first 8 trials; $t(58) =$ -

.005, p = .996 but there was a significant difference for the last 8 trials; t(58) = 2.34, p = .041. The latter points to an effect of learning, where knowledge for the bimodal category distribution of the shapes developed throughout the course of the study. However, this did not vary as a function of group, i.e. the older adults appeared to learn the size categories in a similar way to the younger adults.

3.2.2.2 Distribution of Responses

In an attempt to ascertain why older adults demonstrate more absolute error but similar patterns of bias to their younger counterparts, we obtained the average SD for each individual participant (based on their error scores) averaged across the familiar and unfamiliar items, presented both smaller and larger. Whilst the test of absolute error measured the participants deviations from the correct answer, the SD allows us to look at deviation away from the subjects own answer.

A 2 (age group; younger vs. older) x 2 (category; familiar vs. unfamiliar) x 2 (relative size) mixed-factor ANOVA was conducted on the SD of each participants averaged responses. This revealed a significant main effect of group; F(1, 56) = 4.17, p = .046 with less error for the younger (m = .057, SE = .005) than the older adults (m = .071, SE = .005). There was also a main effect of category; F(1, 56 = 47.70, p < .001, with more error for the unfamiliar items (m = .072, SE = .005) than the familiar items (m = .056, SE = .004), and a main effect of size; F(1, 56 = 5.73, p = .02, with more error for the larger (m = .067, SE = .003) than the smaller items (m = .061, SE = .003). Lastly, there was a category by size interaction; F(1, 56) = 6.12, p = .016. Post-hoc analyses with Bonferroni corrections showed no significant difference between the smaller and larger familiar items; t(57) = -.013, p = .99 but a significant difference between the smaller and larger unfamiliar items; t(57) = 3.11, p = .99.

3.2.2.3 Recognition response analyses

To test whether there were any differences between the two groups for their confidence ratings, we conducted a between-samples t-test which found no difference; $t(56) = 1.32$, $p =.191$. To test the relationship between the confidence ratings obtained (scaled from 0; no recollection to 8; remembered clearly) and recall performance, a 2 (group) x 2 (category) ANCOVA was conducted using absolute error, with the participants rankings of how clearly they remembered seeing the item used as a covariate (degree of recognition). This revealed significant main effects of group: $F(1, 112) = 7.2$, $p = .001$ and category: $F(1, 112) = 12.23$, $p < .001$, with older adults producing more error than younger, but a non-significant group by category interaction. When remembered response was entered into the model, this was found to be a non-significant covariate; $F(1, 112) = .230$, $p = .38$, suggesting that how well remembered an item was did not affect absolute error.

3.2.2.4 Additional variables/ factors

The impact of a number of other factors was also explored. The effect of each individual's familiarity rating for each vegetable was examined using a 2 (group; younger vs. older) x 2 (relative size; smaller vs. larger) ANCOVA for absolute error, though familiarity was a non-significant covariate; $F(1, 56) = .529$, $p = .467$. Each participants semantic capacity was also measured, demonstrating a significant group difference, with older adults demonstrating a higher capacity ($m = 15.45$, $SD = 3.50$) than younger participants ($m = 11.74$, $SD = 1.98$); $t(41) = -4.81$, $p < .001$, but when run as a covariate between the two groups in terms of absolute error it was also non-significant, $F(1,56) = 3.85$, $p = .055$.

Lastly, the participants' responses were analysed to assess whether their responses were influenced by the size of the item shown at test by running a regression per participant determining whether test size was a significant predictor of participants' responses. Test size was a non-significant predictor for all participants bar three (one younger and two older), suggesting that test position had little systematic effect upon responses. These three participants possibly used the test position as an 'anchor' to influence their reconstruction response, but removing the participants made no overall difference to the results obtained.

3.2.3 Discussion

The results of Experiment 3 show that immediate reconstruction responses tended to regress towards the superordinate category mean, with small items made larger and large items made smaller. There was also an effect of object-level categorical knowledge for the familiar items, with relatively smaller items made larger and relatively larger items made smaller. This pattern of responses revealed no group differences, suggesting that when hierarchical levels of semantic prior knowledge can be used, the performance of younger and older adults is comparable. More specifically, older adults did not show more knowledge-based bias than younger adults even though there was some evidence suggesting fuzzier representations in the case of older adults. This was demonstrated by a significant age difference in absolute error, with older adults generating more error than younger adults. The data suggests that this is in part due to the responses of the older participants being noisier/ more widely distributed around the presented size value than that of the younger participants (we will return to these findings and their relationship to the simulations/ predictions described earlier in the general discussion).

However, in contrast to Heussen et al.'s data, we found an intercept difference for the unfamiliar items. It appears that both age groups learned the underlying statistical regularities of the presented stimuli. One possible explanation for these learning effects could be the distribution of item sizes called upon here. Hemmer and Steyvers (2009) presented item sizes that were normally distributed. In their study, for each item, the range of presented sizes extended from the minimum to the maximum acceptable size, as determined by their normative data. This range was divided into 8 bins, with most of the study sizes selected from the central bins (closer to the average) and few from the more extreme sizes. This differed from the current study in which all tested items were presented at a size either smaller or larger than their own normative mean (set at 60% of the range between the normative mean and the normative minimum and maximum, respectively). It is thus possible that in the current study, participants were learning these two size categories (relatively smaller and larger). Moreover, in previous research Hemmer and Steyvers (2009) and Heussen et al. (2011) presented homogenous blue shapes, whereas in the current experiment the unfamiliar items differed in terms of pattern, colour and texture, creating more distinctive items, which could have made learning easier.

To test this learning hypothesis, we re-ran the current study with a distribution of sizes approximating a normal distribution. This fourth study thus serves as a replication of the first, but with a change in the distribution of the tested item sizes. The prediction was that this change would lead to the elimination of the intercept difference for the unfamiliar items. In the absence of two separate underlying distributions, the two regression lines for the unfamiliar items should sit on top of each other, as observed by Heussen et al. (2011).

3.3 Experiment 4

There is evidence that Experiment 3 provided a stimuli distribution/ structure that could be learned by the participants over the course of the experiment and hence produced object-based knowledge biases for the unfamiliar items. This may also have inflated the knowledge effects of the familiar items. In the following experiment, we employed the same methodology as the first but with this structure removed. This was done by using a series of graded distances from each object's normative sizes during study in a similar way to Hemmer and Steyvers (2009), with most sizes presented closer to the respective items normative mean.

3.3.1 Method

3.3.1.1 Participants

Participants comprised 90 adults (45 aged 18-30, m = 23.8, SD = 1.21 and 45 over 65, m = 69.6, SD = 1.27), matched and recruited in the same way as in Experiment 3.

3.3.1.2 Materials and Procedure

The same design as in the first study was used for this experiment, the only difference being the distribution of the presented and tested stimuli. To approximate a normal distribution, each experimental stimulus was tested twice; once at a size smaller than its own object mean and once at a size greater than its mean. Of the items that were tested smaller, five of them were presented at .2 of the range between the mean and the smallest value (determined by the normative data). Four items were presented at .4 of the range, two at .6 and one at .8. The larger items were tested in the reverse, at a position between the mean and the largest value. The presented sizes were constant across all participants.

3.3.2 Results

As before, Figure 3.11 presents recalled size as a function of studied size for the older and younger adults. Again, responses were linearly related to studied, though there was more scatter for the older adults.

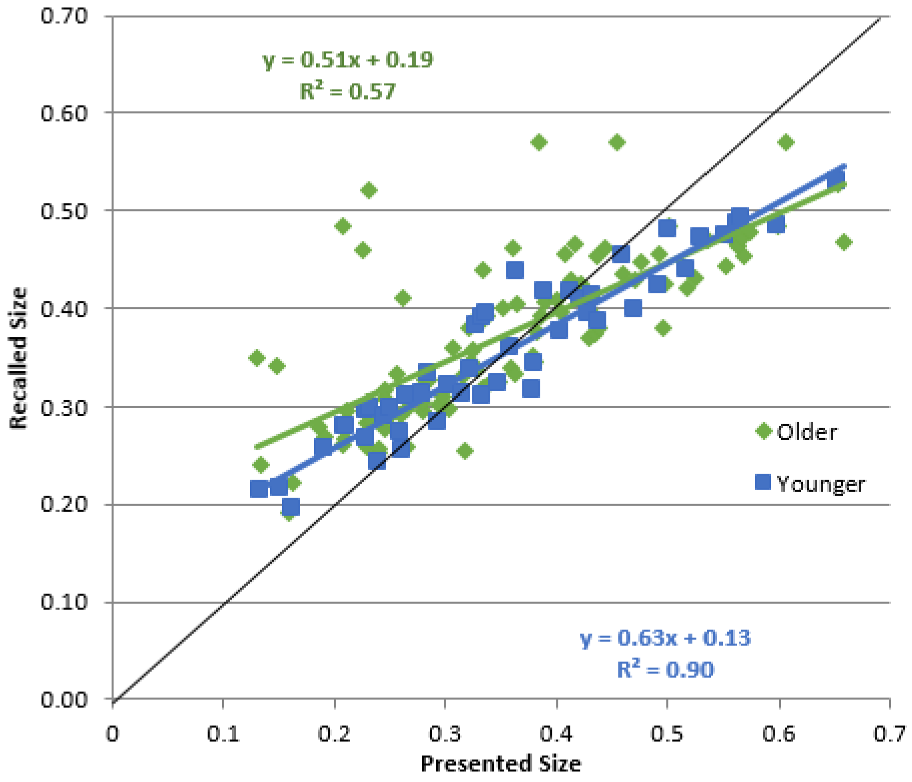

Figure 3.11. Recalled size as a function of presented size for older and younger adults.

Performance was measured through reconstruction error (reconstructed size minus studied size) and absolute error. The mean values for absolute error are presented in Table 3.3 and Figure 3.12.

Table 3.3. Means and SDs (in brackets) for absolute error for both younger and older adults.

	Familiar Smaller	Familiar Larger	Unfamiliar Smaller	Unfamiliar Larger
Younger	.053 (.050)	.062 (.058)	.078 (.076)	.082 (.070)
Older	.061 (.072)	.074 (.069)	.079 (.087)	.099 (.089)

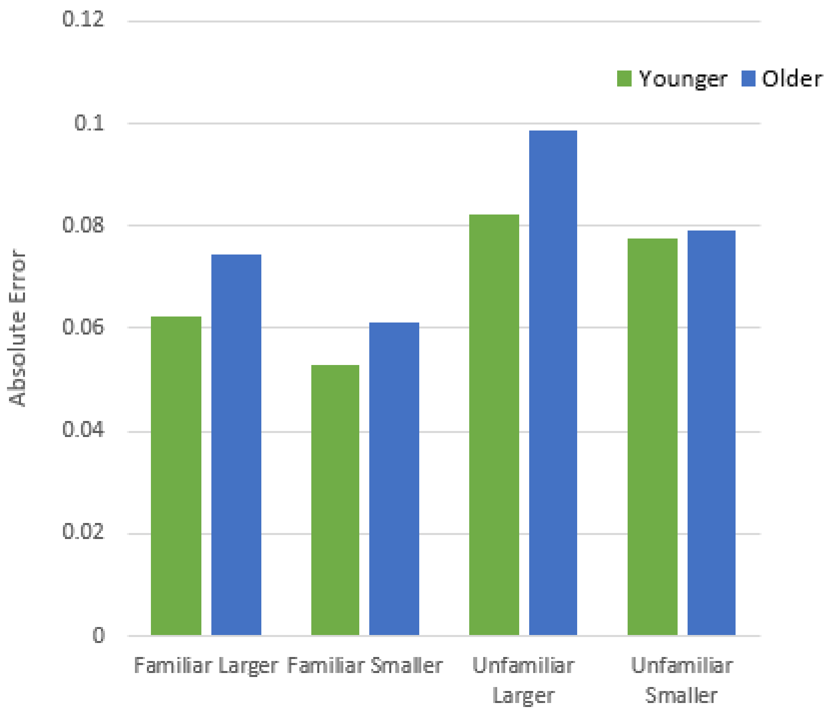

Figure 3.12. Absolute reconstruction error per age, category and relative size.

Differences in absolute error between older and younger participants were examined through a 2 (group; younger vs. older) x 2 (category; familiar vs. unfamiliar) x 2 (relative size; smaller vs. larger) mixed factor ANOVA. This revealed a main effect of group, *F*(1, 88) = 4.63, *p* = .034, with more error for the older than the younger adults. There was also main effects of relative size, *F*(1, 88) = 10.42, *p* = .002, with more error for the larger items, and a main effect of category; *F*(1, 88) = 125.42, *p* < .001), with greater error for the unfamiliar items. There were no significant interactions for category by group; *F*(1, 88) = .269, *p* = .605), size by group; *F*(1, 88) = 2.09, *p* = .152 or category by size; *F*(1, 88) = 1.27, *p* = .263. The three-way interaction was also non-significant; *F*(1, 88) = .086, *p* = .770 (see Figure 3.12). This again shows that prior knowledge supports recall, with less error for the familiar than unfamiliar items. However, older adults generated more overall error than the younger adults.

As before, to examine the effects of both superordinate and object-level knowledge on short-term reconstruction, separate regression models were fitted for each participant and each type of stimulus (familiar and unfamiliar), examining how raw error was predicted by the relative size of the items (smaller, larger than the norm) and the studied size (see Figure 3.13 a-d for the results averaged across participants).

Table 3.4. Average slopes and intercepts by category and relative object size for each group.

		Younger		Older	
		Familiar	Unfamiliar	Familiar	Unfamiliar
Slopes		-.234	-.557	-.201	-.493
Intercepts	Smaller	.094	.187	.079	.159
	Larger	.054	.181	.038	.152

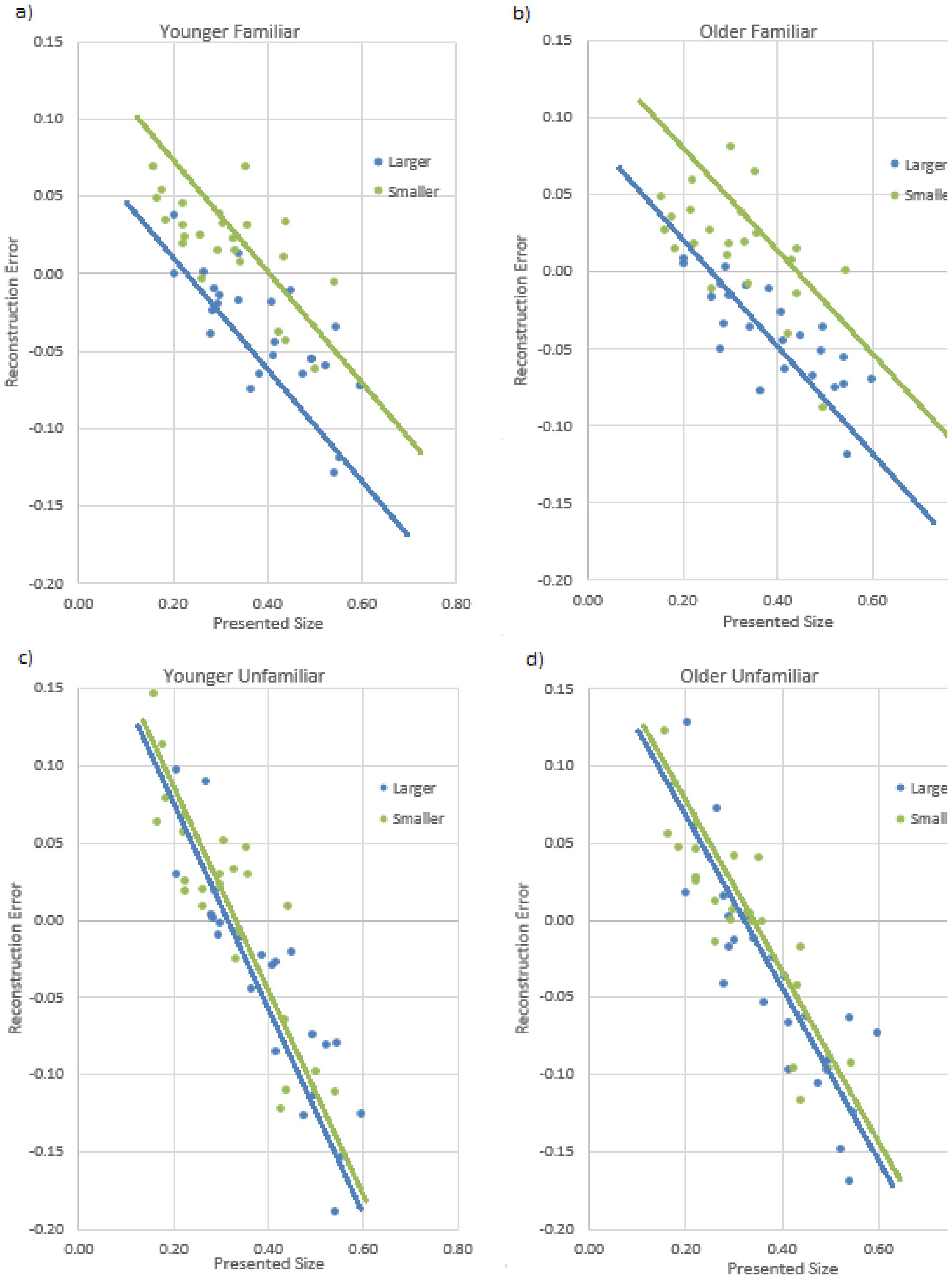

Figure 3.13 a-d. Error as a function of presented size for items presented smaller or larger than their mean size. Figures a-b represent familiar items and c-d unfamiliar items.

Again, the negative slopes indicated bias towards the mean size of the items for both type of stimuli. The two distinct regression lines for the familiar items reflect the influence of prior object knowledge. In contrast to study one, the two regression lines for the unfamiliar items are superimposed, i.e. there was no evidence that prior object knowledge effects estimates. As the sizes of the unfamiliar items were yoked to those of the vegetables, the difference cannot be attributed to studied size. The average slopes and intercepts for each group are reported in Table 3.4.

One-sample *t*-tests were used to test whether the slopes were different from zero and thus demonstrating a superordinate category level influence of prior knowledge. The younger participants showed a significant slope for both the familiar and unfamiliar items (familiar; $t(44) = -8.33$, $p < .001$, unfamiliar: $t(44) = -15.34$, $p < .001$), as did the older participants (familiar; $t(44) = -5.29$, $p < .001$, unfamiliar, $t(44) = -12.66$, $p < .001$). To determine if any group differences emerged for the obtained slopes, a 2 (group; younger vs. older) x 2 (category; familiar vs. unfamiliar) mixed factor ANOVA was conducted, which found no group difference ($F(1, 88) = .483$, $p = .489$), but a main effect of category, $F(1, 88) = 204.07$, $p < .001$. This revealed steeper slopes for the unfamiliar items than the familiar.

Differences in intercepts were examined by running a 2 (group; younger vs. older) x 2 (category; familiar vs. unfamiliar) x 2 (relative size; smaller vs. larger) mixed factor ANOVA. This demonstrated main effects of both category, $F(1, 88) = 198.26$, $p < .001$, with a larger difference for the familiar than the unfamiliar items, and relative size, $F(1, 88) = 78.60$, $p < .001$, with a larger intercept for the smaller items. This was qualified by a significant interaction between category and relative size, $F(1, 88) = 85.59$, $p < .001$, though no category by group interaction; $F(1, 88) = .731$, $p = .395$, size by group; $F(1,88) = .044$, $p = .834$ or three-way interaction; $F(1,88) = .000$, $p = .990$.

Planned contrasts with Bonferroni adjustments demonstrated a significant intercept difference for the familiar items, *t*(89) = 12.12, *p* < .001 but no difference for the unfamiliar items, *t*(89) = 1.97, *p* = .216. As expected, therefore, the data supports the use of prior knowledge for the familiar items but not the unfamiliar.

3.3.2.1 Distribution of Responses

As before, in an attempt to ascertain why older adults demonstrate more absolute error but similar patterns of bias to their younger counterparts, we obtained the average SD for each individual participant (based on their error scores) averaged across the familiar and unfamiliar items, presented both smaller and larger. Whilst the test of absolute error measured the participants deviations from the correct answer, the SD allows us to look at deviation away from the subjects own answer.

A 2 (age group; younger vs. older) x 2 (category; familiar vs. unfamiliar) x 2 (relative size) mixed-factor ANOVA was conducted on the SD of each participants averaged responses. This revealed a significant main effect of group; *F*(1, 88) = 4.85, *p* = .030 with less error for the younger (*m* = .059, *SE* = .005) than the older adults (*m* = .070, *SE* = .005). There was also a main effect of category; *F*(1, 88 = 58.2, *p* < .001, with more error for the unfamiliar items (*m* = .074, *SE* = .003) than the familiar items (*m* = .056, *SE* = .004).

3.3.2.2 Recognition/ confidence rating analyses

To test whether there were any differences between the two groups for their confidence ratings, we conducted a between-samples t-test which found no difference; *t*(44) = -1.24, *p* = .11. To test the relationship between the confidence ratings obtained (scaled from 0; no recollection to 8; remembered clearly) and recall performance, a 2 (group) x 2 (category) ANCOVA was conducted using absolute error, with the participants rankings of how clearly they remembered seeing the item used as a covariate (degree of recognition). This revealed significant main effects of group: $F(1, 88) = 7.52$, $p = .01$, with older adults producing more overall error than younger adults, and category: $F(1, 88) = 96.90$, $p < .001$, with more error for the unfamiliar items. There was no significant interaction; $F(1, 88) = .13$, $p = .72$. When remembered response was entered into the model, this was a significant covariate; $F(1, 88) = 72.64$, $p < .001$, suggesting that how well remembered an item was significantly affected absolute error but had no effect on the pattern of effects described above.

3.33 Discussion

In line with our predictions, the intercept difference for the unfamiliar items observed in study one was abolished when the structure of the studied stimuli was modified. This suggests that the said intercept difference appeared because participants were learning the underlying distribution of studied item sizes. In the third study, there were two separate distributions for the items, presented either smaller or larger than their relative mean. As a result, it appears that as the experiment progressed, participants tended to regress towards two separate distributions. In the case of the familiar items, conversely, the intercept difference remained because the participants had pre-existing knowledge for the items. This meant that they adjusted the sizes of the vegetables in the direction of their respective normative means.

3.4 General Discussion

In this paper, we aimed to systematically examine the use of prior knowledge in memory reconstruction for older and younger adults. We demonstrated that STM is influenced by prior knowledge for the size of objects at both the superordinate (the ensemble statistics of the presented items) and the item-specific categorical levels (e.g. the average size of an onion).

We found that the observed findings were best depicted by the simulation where the weight attributed to the memory representation, object-level knowledge and superordinate-level knowledge was constant across both age-groups. However, the error associated with the memory representation (SD of 1 for the younger adults and 1.5 for the older adults) was increased for the older adults (Figures 3.3 a-b). By adding error to the memory representation of the older adults, there was also an increase in absolute error in the simulation, as well as a pattern of results that is close to that observed in the current data. In contrast, the simulations where the weight ascribed to the object-level knowledge was increased relative to the weight attributed to the memory representation for the older adults did not capture the pattern of our findings. This was the same when the contribution of object-level knowledge was decreased for the older adults and the weight attributed to error was increased.

In terms of our original hypotheses, therefore, the findings of Experiments 3 and 4 suggests that older adults have increased variability of representations (error) relative to younger adults but this does not appear to lead to an increased reliance on prior-knowledge. Our simulations lend support to this; it could be argued that if the older adults showed more error in their representations, then the observed regression lines should become flatter (which is what noise typically does to correlated data). However, the simulations in our model clearly show that increasing noise has just the effect that we observed – greater scatter around the line but no change in slope. The findings also showed that older adults were able to learn the statistical regularities of the presented data to the same extent as the younger adults. Moreover, as the confidence ratings suggested, the greater variability does not affect confidence either. This will be discussed in more detail below.

We suggest that the best explanation for this pattern of findings is that knowledge biases the older adults' responses just like the younger adults, but as the distribution of remembered size is noisier; it appears that the impact of knowledge just averages out. Figure 3.14 below illustrates the influence of the superordinate and the object-level knowledge on memory reconstruction. It also shows the influence of the presented value, represented as a distribution of error centred at the presented value. The dotted line represents the hypothetical distribution for the older adults; this distribution is more varied/ widely distributed. As estimates for smaller items are overestimated and larger items are underestimated, any knowledge-based differences would cancel each other out. This would explain why older adults demonstrate more error when we use absolute error as a measure, as this prevents the values from just cancelling each other out.

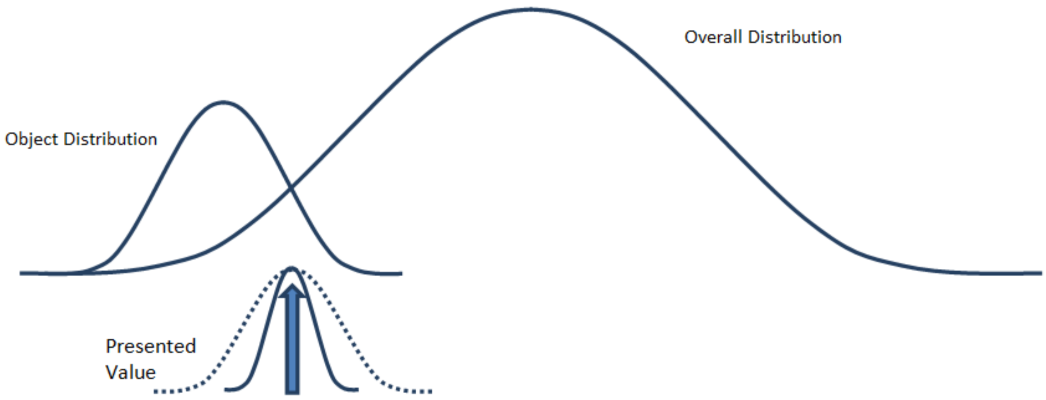

Figure 3.14. A Figure demonstrating the distributions of the various influences in memory reconstruction.

Moreover, the results of Experiment 3 differed from findings reported by Hemmer and Steyvers (2009) for episodic memory and Heussen et al. (2011) for immediate memory, as we observed an intercept difference for the unfamiliar items. Such a difference is typically indicative of an object-level knowledge-based bias. We suggested that the finding was attributable to participants learning the item-level statistics throughout the course of the study. This hypothesis was tested in the fourth experiment where each item was presented in a variety of sizes, with a distribution approximating normal. In this fourth study, there remained a clear effect of object knowledge for the familiar items. Conversely, the intercept difference for the unfamiliar items disappeared, supporting our learning interpretation of these results in Experiment 3. In the third study, it thus appears that participants, instead of extracting the statistics of the entire set, segmented the stimuli into two distributions representative of the two different size groups. By adding intermediate sizes between the two extremes in our second study, we increased the smoothness of the distribution and so all items were grouped together under the overall mean.

A number of studies have demonstrated that younger participants are sensitive to regularities within the environment (e.g. Brady & Alvarez, 2011; Brady, Konkle & Alvarez, 2009; Brady & Oliva, 2008; Chong & Treisman, 2003; Knowlton & Squire, 1993; Utochkin & Tiurina, 2014). Crawford, Huttenlocher and Hedges (2006), for example, demonstrated that the shape of the distribution in which the to-be-remembered items were embedded influenced the retrieved stimulus estimates. Similarly, across two experiments, Brady et al. (2009) presented participants with a display of items, where over trials some colour pairs were more likely than other colour pairs. They found that observers were able to remember more items from displays containing correlated colour pairs, indicating that individuals can effectively learn regularities between co-varied colour pairs. To our knowledge, however, this is the first systematic demonstration of both older and younger adults effectively learning the ensemble statistics. Interestingly, by the end of the experiment, both older and younger adults were equally sensitive to these distributions, suggesting older adults can adapt to structure/ regularities within the environment just as well as younger adults.

Moreover, our data demonstrates that familiarity for the individual familiar items did not moderate absolute error. Furthermore, despite finding a larger semantic capacity for the older adults, this was not found to co-vary with the degree of absolute error. This group-difference was surprising, however, as most research indicates that age negatively influences category fluency (e.g. Crossley, D'Arcy, & Rawson, 1997; Troyer, 2000). However, other research (e.g. Bank, MacNeill, & Lichtenberg, 2000; Rosen, 1980; Shao, Janse, Visser & Meyer, 2014), suggests that the deficit only occurs after the age of 80 and level of education moderates age-related declines (e.g. Bank et al. 2000; Brucki & Rocha, 2004; Crossley et al. 1997). This will need clarification but as semantic capacity did not moderate memory reconstruction, it is beyond the scope of this discussion.

Overall, therefore, our findings are in line with a simulation which showed that older and younger adults rely upon prior knowledge to the same extent yet older adults show reduced memory accuracy. The cause of this inaccuracy appears to be a noisier representation of item characteristics in older adults. Moreover, both older and younger adults were susceptible to learning the underlying distribution of presented items. However, it appears that older adults relied upon the overall mean to a greater extent in the absence of prior knowledge.

In the next chapter, we extended the findings from the previous studies to determine whether they also generalise to episodic memory. Using the fruit and vegetable stimuli again, we adapted two paradigms to allow us to measure this. As older adults typically demonstrate more robust declines in tasks of episodic memory (e.g. Schaie, 2005; Singer, Lindenberger & Baltes, 2003), we might be more likely to observe age-related knowledge effects. This will be discussed in more detail below.

Chapter 4: Prior knowledge and episodic memory in healthy ageing

4.1 Introduction

It is well established that prior knowledge can support storage and retrieval in episodic memory (e.g. Brewer & Treyens, 1981; Conway & Pleydell-Pearce 2000; Hemmer & Steyvers, 2009; Payne, Nadel, Allen, Thomas, Jacobs, 2002). Hemmer and Steyvers (2009), for example, suggested that, as episodic memory representations are often noisy or incomplete, prior knowledge can be used to reduce inaccuracy; they suggest this is particularly true when knowledge coincides with the regularities within the environment.

Previous literature suggests that older adults show declines in episodic memory relative to younger adults (e.g. Fleischman, Wilson, Gabrieli, Bienias & Bennett, 2004; Park, 2000; Schaie, 2005; Singer, Lindenberger & Baltes, 2003), though they show stable or even improving levels of semantic knowledge (Surprenant & Neath, 2007). This has led to recent research demonstrating that age-related declines in episodic memory can be significantly reduced or even eliminated when prior knowledge can be called upon (Badham et al., 2012; Naveh-Benjamin, 2000; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003). For example, Castel (2005) asked younger and older adults to remember the prices of grocery items. In one condition, participants could rely on prior knowledge to some extent as the prices were realistic; in the other condition, the prices were not. There was an age-related decline in performance in the latter case, but no difference between groups for the realistically priced items. Other research has also shown that older adults are able to recall more words than younger adults when the material capitalises upon their schematic verbal knowledge (Matzen & Benjamin, 2013). The case has thus been made that knowledge is used continuously when retrieving from episodic memory and it can alleviate or even in some case eradicate the typical age-related deficit in episodic recall.

However, from previous findings, it is not clear if knowledge (when available) is systematically relied upon more heavily with age. There is also little evidence about how knowledge use varies as a function of level of error in memory representations. Here, for both older and younger adults, we sought to systematically examine the effect of knowledge on episodic memory for the characteristics of visually presented objects. We called upon a strategy that allowed us to examine this interaction at a fine-grained level, while measuring both the biasing and supportive influence of knowledge. As will become clear, two types of knowledge were investigated. The first was categorical knowledge that the participants brought to the experiment. The second was knowledge developed over the course of the experiment, as performance was sensitive to the distribution and mean of studied stimuli (i.e. the average size of the set of stimuli). These two types of knowledge are discussed further below.

4.1.1 Categorical knowledge and episodic recall

A number of studies have shown that individuals capitalise upon their existing knowledge to ‘deblurr’ incomplete or noisy memories and thus reduce error (e.g. Anderson & Schooler, 1991; Brady & Alvarez, 2011; Hemmer & Steyvers, 2009; Huttenlocher, Hedges & Duncan, 1991; Huttenlocher, Hedges & Vevea, 2000). Items for which individuals have pre-existing knowledge are thus generally recalled with greater accuracy than items for which there is no prior knowledge (Griffiths & Tenenbaum, 2006; Hemmer & Steyvers, 2009; Steyvers & Hemmer, 2012).

Within the visual domain, Hemmer and Steyvers (2009) developed a model of categorical knowledge effects in episodic memory, grounded in the proposals of Huttenlocher and colleagues (Crawford, Huttenlocher & Engebretson, 2000; Huttenlocher et al., 1991; Huttenlocher et al., 2000). They based their model on the premise that episodic reconstruction interacts with hierarchically structured categorical information, including prior knowledge at the superordinate category level (e.g. average size of all presented fruits) and also at the object level (e.g. the average size of a strawberry). They proposed that when recalling a familiar object, observers use the prior knowledge from both levels to support reconstruction of an otherwise noisy memory trace.

In their 2009 paper, Hemmer and Steyvers supported this view using a task involving memory for the sizes of fruit and vegetables, for which participants have pre-experimental knowledge. In order to do so, they first obtained normative data for the average sizes of various fruits and vegetables as well as normative data for the smallest and largest reasonable sizes of each item; this data acted as an estimate of prior knowledge. These fruits and vegetables were then used in a continuous recognition task, where participants were shown a sequential series of images. The size of the items varied within their minimum and maximum normative estimate. At various intervals, some of these items were presented again but at a different size. The participants were required to reconstruct the previously encountered size. Participants were also tested with lists of random control shapes, for which they had no pre-existing knowledge; the size of these items was yoked to the size of the fruit and vegetables.

To examine performance, Hemmer and Steyvers (2009) obtained an estimate of recall error by calculating the difference between the recalled and studied sizes; hence a negative error value implied the item was remembered as being smaller than presented, while a positive error meant the item was remembered as being larger than presented. Figures 1a and 1b below illustrate their results. The familiar and unfamiliar items are plotted separately. An examination of these figures shows that for the control shapes, with no pre-existing knowledge, participants demonstrated a negative slope, where items were adjusted in the direction of the overall mean: small items tended to be remembered somewhat larger and large items tended to be made smaller. In essence, performance showed regression towards the overall superordinate category mean. We can observe similar effects for the familiar items.

However, for the familiar items we also observe an intercept difference between items presented smaller and items presented larger relative to their normative means. This pattern reflects the influence of object-level knowledge, where an item presented smaller than its normative mean (i.e. a small apple) was over-estimated when reconstructed and an item presented larger than its normative mean (i.e. a large apple) was under-estimated. This means that two familiar objects, studied at the same size, could be remembered differently. If a large plum was studied at the same size as a small apple, the error in recall for these two items was typically in opposite directions; participants tended to remembered the plums size as being smaller than it actually was, while the apple’s size tended to be remembered as being larger than it actually was.

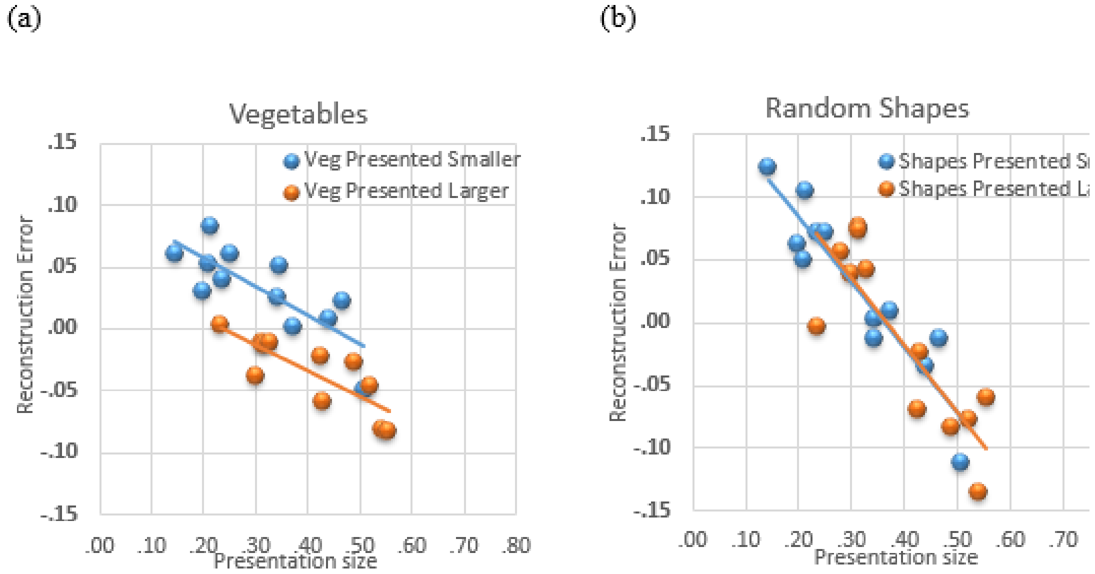

Figure 4.1. a-b: Adapted from the data of Hemmer and Steyvers (2009); reconstruction error as a function of studied size for (a) familiar items (fruits & vegetables) and (b) unfamiliar items (shapes).

These findings have been replicated with other types of stimuli, including gender-specific heights (Hemmer, Shi & Steyvers, 2010) and typical colours (Persaud & Hemmer, 2014). In the current study, we want to see how these category effects interact with age. We previously adapted Hemmer and Steyvers’ (2009) paradigm to examine how prior knowledge interacts with visual short-term memory (VSTM) in older and younger adults. We found that both groups showed the same level of knowledge-based bias in immediate memory reconstruction, yet older adults demonstrated more overall error (Daniel & Poirier, submitted). We proposed that older and younger adults rely on prior knowledge to the same extent but that the immediate memory representations of older adults had greater variability (e.g. were noisier).

4.2 Experiment 5

The objective of this paper was to establish whether the pattern of findings we previously observed in VSTM would also be found in tests of episodic memory. Although STM deficits in ageing are well established (Multhaup, Balota & Cowan, 1996; Verhaeghen, 2002; Verhaeghen, Marcoen & Goossens 1993), there is considerable agreement about the fact that episodic deficits are more pronounced (e.g. Craik, 2008; Nilsson, 2003). This could in part be attributable to less efficient use of prior knowledge, either through increased knowledge-based bias or through less reliance on knowledge (i.e. an age-related deficit in top-down processing). We thus sought to systematically examine the effect of prior knowledge on episodic memory reconstruction for both older and younger adults. To achieve this, we employed a version of the paradigm used by Daniel and Poirier (submitted) but with the inclusion of a 30-second fixed-delay before reconstruction. Therefore, the VSTM study in Experiment 4 (Chapter 3) and the current episodic experiment can be seen as conceptually identical, save that in the current experiment, the primary parameter of item representation differs dramatically; we wanted to determine how this affected the pattern of performance.

4.2.1 Method

4.2.1.1 Participants

Participants comprised 60 adults (30 aged 18-30 and 30 over 65). Younger and older participants were matched for gender, years of Education and IQ, which was assessed using the Wechsler abbreviated scale of intelligence (WASI; 2010) [two subtest form; block design and vocabulary]. Participants were recruited through a participant database. Preliminary phone interviews were used to recruit adults with no history of neurological or psychiatric disorders and no history of illnesses that impact cognitive function. Older participants also needed to obtain a score of at least 27 on the Mini-Mental State Exam (Folstein, Folstein & McHugh, 1975) to be retained in the sample.

4.2.1.2 Materials and Procedure

The materials used comprised a set of 12 high-resolution colour images of fruits photographed against a white background. The images depicted common items such as pears, oranges and strawberries, but also less typical items including mengkudu, papaya and green pumpkin. The set of 12 was subdivided into 2 groups, one containing 6 smaller items (e.g. a raspberry) and one containing the 6 larger items (e.g. a melon). Normative data for each item was obtained from Hemmer & Steyvers (2009); the norms were based on average judgments[7] of the mean size of each item, as well as of the largest and smallest reasonable sizes. The normative data was assumed to represent prior knowledge for the size of each object, which made it possible to estimate knowledge-based biases in size memory.

Each fruit was paired with a control random shape that had a similar orientation. These shapes were used previously by Hemmer and Steyvers (2009), who presented all items in a homogeneous blue colour. In this experiment, they were adapted to better equate the random shapes and familiar items in terms of colour variation, patterning and texture, so that familiarity would be the main difference between the sets.

This collection of items was used to develop a computer-controlled task, comprising 48 trials split into 24 involving fruits and 24 involving random shapes. Each trial contained a string of 6 items from the same category – either all fruit or all random

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[7] Hemmer and Steyvers (2009) obtained these judgments from 18 participants. They were asked to estimate the average size of each item, as well as the minimum and maximum using a slider which controlled the size of the image. We would like to thank Hemmer and Steyvers for lending us the materials and normative data.

shapes; each item was presented for 1.5 seconds with a 0.5 second delay before the next item appear (i.e. one item every 2 seconds). No items were repeated within a trial. Based on the normative data, each of the 6 items in a trial was presented at one of three relative sizes. Two of the items were presented at their own mean value (average size). Two of the items were presented in a size that was larger than their own normative mean (relatively larger) and the two other items were presented in a size that was smaller than their normative mean. These item specific larger and smaller sizes were set at 60% of the range between the normative mean and the normative maximum and minimum, respectively.

Of those six items, three were taken from the six items identified as small items and three from the large items. Per category (familiar, unfamiliar), for every block of 4 trials, each item appeared once, so within 6 blocks of 4 trials, each item was shown 6 times in total (twice relatively smaller, twice larger and twice average). Only items presented relatively smaller or larger than their mean were tested. All participants were shown the same items at the same size, but presentation order was randomised within the constraints of the design of the study.

Immediately following this experimental sequence there was a 30-second fixed delay period. Participants were required to continuously subtract three from a given three-digit number on the screen. Responses were typed to determine the level of interference per participant. Following this, one of the six items from the preceding trial was shown again after a 0.5 second delay, but at a different size (only items presented relatively larger or smaller were tested). Above the presentation of the item on the screen was the following question: - “What was the size of this object when you saw it at study?” Participants were required to resize this item to replicate its studied size using mouse-operated arrows (upward arrow increased the size, whilst the downwards arrow decreased it). The object remained on the screen until the participant was happy with the size of the object and clicked a continue button. The objects and responses were measured on a scale of 0 to 1, where 0 corresponds to an object occupying 1 pixel of the screen and 1 corresponds to the maximum adjustable position, where the object fills the entire height or width of the screen. The size of the test item was selected at random from sizes .2, .4, .6 and .8 on this scale. Immediately after resizing the item, participants were asked to provide a confidence judgement. They were asked the following question: “How clearly do you remember seeing the item?” This was answered using a 9-point scale where 0 represented ‘No recollection’ and 8 represented ‘Clearly remember’. Each serial position (1-6) was tested 4 times (twice relatively larger and twice smaller) across the study.

Following the memory task, participants were presented with a familiarity assessment task to obtain subjective ratings for each of the familiar items. Participants were asked to rank each item separately on a scale of 0-8, with 0 representing no familiarity at all and 8 signifying very strong familiarity. By presenting this task after repeated exposure to the items, it is possible that the rankings were slightly distorted (i.e. participants may have reported greater familiarity with the item due to recently seeing it). However, this was more desirable than presenting the task prior to the experimental condition, as this may have impacted participant’s performance due to factors such as demand characteristics. Participants were also presented with the category fluency test (Benton, 1968) and The Picture Sequence Memory Test from the NIH Toolbox for the Assessment of Neurological and Behavioural Functioning. The Picture Sequence Memory Test involved asking subjects to revert a sequence of recently learned pictures back to their originally presented order. This subtest from the NIH battery has a reported test-retest reliability of .77 for adults and a convergent validity of

.69 (Weintraub, Dikmen, Heaton, Tulsky, Zelazo, Bauer et al., 2013), which was normed against a fully representative sample of 476 individuals with ages ranging from 3-85.

4.2.2. Results

Figure 4.2 presents the recalled size as a function of the studied size (one point per item) averaged across participants and category. An inspection of this Figure shows that performance was reasonably good, with responses linearly related to studied sizes. Regression towards the mean can be seen by examining the difference between the diagonal line representing perfect performance and the best fitting lines included in the figure. As can be seen, items studied at smaller sizes tended to be remembered slightly bigger while the reverse was true of the larger items.

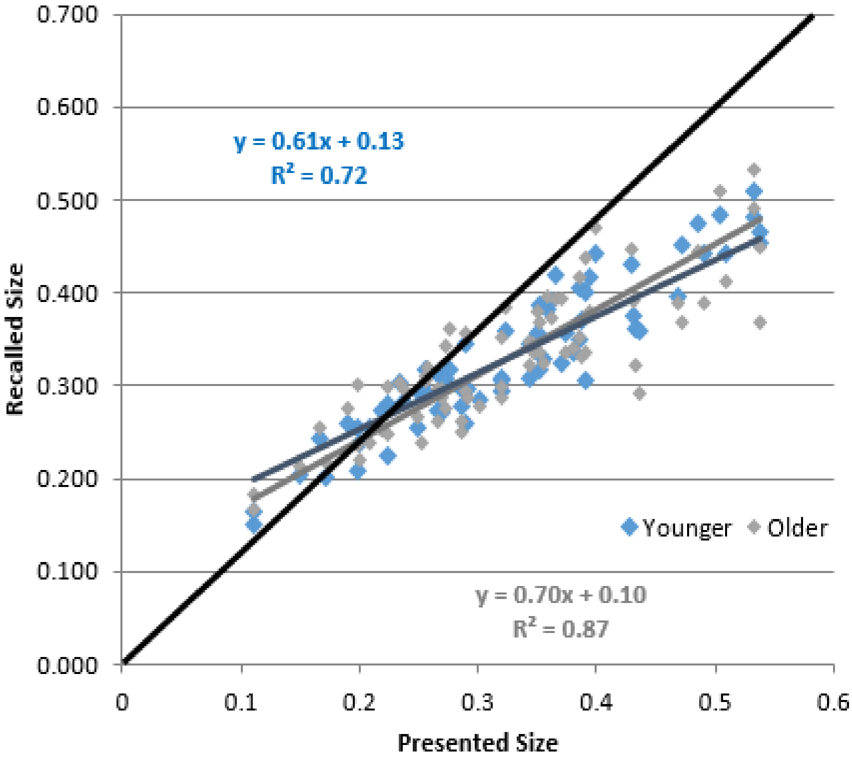

Figure 4.2. Reconstructed size as a function of studied size for older and younger adults.

Reconstruction error (reconstructed size minus studied size) as well as absolute error was used in the inferential statistics. In the first analysis, absolute error was examined instead of raw error to prevent positive and negative values cancelling each other out. The mean values are presented in Table 4.1.

Table 4.1. Means and SDs (in brackets) for absolute error for both younger and older adults.

	Familiar		Unfamiliar	
	Studied smaller	Studied larger	Studied smaller	Studied larger
Younger	.06 (.05)	.06 (.06)	.07 (.07)	.07 (.06)
Older	.08 (.09)	.07 (.07)	.08 (.09)	.11 (.09)

Group differences in the mean absolute error in each condition were assessed using a 2 (group; younger vs. older) x 2 (relative size; smaller vs. larger) x 2 (category; familiar vs. unfamiliar) mixed factor ANOVA. There was a main effect of category; *F*(1, 58) = 39.66, *p* < .001, with more error for the unfamiliar items. There was also a main effect of group; *F*(1, 58) = 10.45, *p* = .002 with more error for the older than the younger adults. These main effects were qualified by a

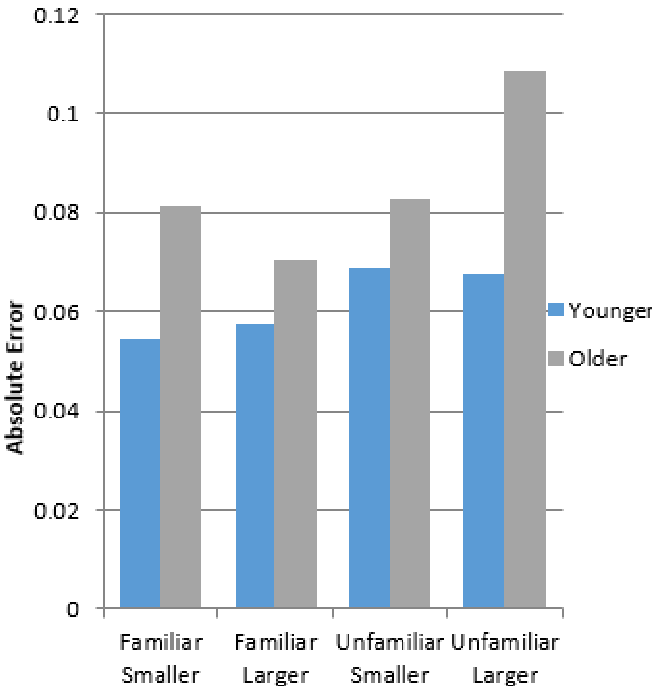

Figure 4.3. Absolute reconstruction error (reconstructed – studied size) per age group and category.

significant interaction between category and relative size, *F*(1, 58) = 16.48, *p* < .001. There was also a significant three-way interaction; *F*(1, 58) = 23.02, *p* < .001.

Planned contrasts with bonferroni corrections revealed no significant difference between smaller and larger familiar items for the younger participants; *t*(29) = .912, *p* = .369, nor for the unfamiliar items; *t*(29) = .023, *p* = .982. The older participants demonstrated no significant difference between larger and smaller familiar items, *t*(29) = -1.63, *p* = .115. However, there was a significant difference between items studied smaller and larger for the unfamiliar items; *t*(29) = 4.22, *p* < .001, with more error for the larger items (see Figure 4.3). This thus suggests that older adults show larger errors across the board, particularly so for the larger unfamiliar items (with the latter possibly being the source of the 3-way interaction).

Following Hemmer and Steyvers (2009), the effects of both object-level and superordinate-level prior knowledge were examined by analysing the raw error scores. Separate regression models were fitted for each participant and each category of stimuli (familiar and unfamiliar), examining how error was predicted by the relative size of the items (smaller or larger than the normative item size) and the actual studied size (see Figure 4.4 a-d for the results averaged across participants). Each regression thus involved three parameters; two intercept parameters corresponding to the smaller and larger relative sizes and one slope parameter relating studied and remembered sizes.

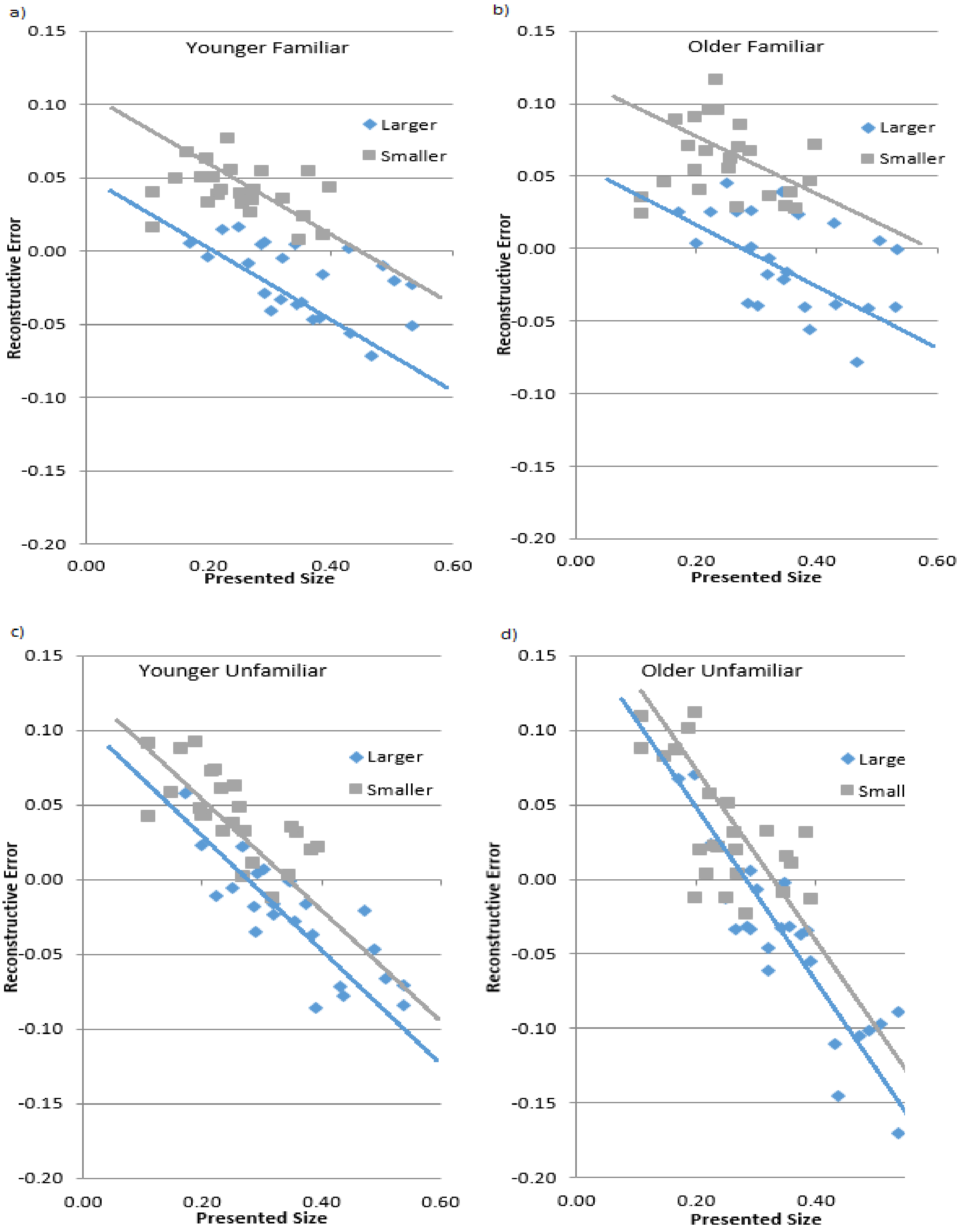

Figure 4.4 a-d. Figures a-b show reconstruction error for familiar items presented smaller or larger, for both age-groups.Figured c-d show reconsutrction error for unfamilair items.

The negative slopes in the figures illustrate a regression towards the overall mean for both the familiar and the unfamiliar items. Moreover, for the familiar items, both older and younger adults' exhibited two distinct regression lines for items studied smaller than their normative mean and items studied larger that their normative mean. This intercept difference is indicative of an object-level effect of knowledge. Surprisingly, there was an intercept difference for the unfamiliar items despite participants having little knowledge of the items, though the difference is smaller. The average slopes for each group are reported in Table 4.2.

Table 4.2. Mean Slopes and Intercepts by category and relative object size for each age group.

		Younger		Older	
		Familiar	Unfamiliar	Familiar	Unfamiliar
Slopes		-.099	-.275	-.106	-.434
Intercepts	Smaller	. 066	.114	.087	.143
	Larger	.015	.072	.029	.110

One-sample *t*-tests were used to confirm that the slopes were different from zero. Both younger (familiar: $t(28) = -2.89$, $p = .008$, unfamiliar: $t(28) = -5.04$, $p < .001$) and older adults (familiar: $t(28) = -2.19$, $p = .036$; unfamiliar: $t(28) = -5.97$, $p < .001$) showed significant slopes, indicating a regression towards the mean. To determine if any group differences emerged for the obtained slopes, a 2 (group; younger vs. older) x 2 (category; familiar vs. unfamiliar) mixed ANOVA demonstrated no group difference in terms of slopes, but did show a significant main effect of category; $F(1,56) = 35.48$, $p < .001$, with steeper slopes for unfamiliar than familiar items. The interaction was non-significant; *F*(1,56) = 3.63, *p* = .068 but approached significance. The older adults tended to show more regression towards the mean of the unfamiliar items than the younger adults.

Differences in intercepts were examined by running a 2 (group; younger vs. older) x 2 (category; familiar vs. unfamiliar) x 2 (relative size; smaller vs. larger) mixed factor ANOVA, which revealed a significant main effect of category; *F*(1,56) = 22.05, *p* < .001, with a larger difference for the familiar than the unfamiliar items. There was also an effect of relative size; *F*(1,56) = 144.80, *p* < .001, with a higher intercept for the smaller than the larger items. This was qualified by a significant category by intercept interaction; *F*(1,56) = 6.83, *p* = .012. Planned pairwise comparisons with bonferroni adjustments show a larger intercept difference between smaller and larger familiar; *t*(57) = 12.31, *p* < .001 than unfamiliar stimuli; *t*(57) = 6.81, *p* < .001. There was no group by relative size interaction; (*F*(1,56) = .077, *p* = .783), no group by category; *F*(1,56) = .358, *p* = .552) and no three-way interaction; *F*(1,56) = 1.33, *p* = .253).

4.2.2.1 Distribution of Responses

In an attempt to ascertain why older adults demonstrate more absolute error but similar patterns of bias to their younger counterparts, we obtained the average SD for each individual participant (based on their error scores) averaged across the familiar and unfamiliar items, presented both smaller and larger. Whilst the test of absolute error measured the participants deviations from the correct answer, the SD allows us to look at deviation away from the subjects own answer. A 2 (age group; younger vs. older) x 2 (category; familiar vs. unfamiliar) x 2 (relative size) mixed-factor ANOVA was conducted on the SD of each participants averaged responses. This revealed a significant main effect of group; *F*(1, 56) = 7.40, *p* = .009 with less error for the younger (*m* = .070, *SE* = .005) than the older adults (*m* = .095, *SE* = .005). There was also a main effect of category; *F*(1, 56) = 32.35, *p* < .001, with more error for the unfamiliar items (*m* = .091, *SE* = .003) than the familiar items (*m* = 0.74, *SE* = .004) and relative size; *F*(1, 56) = 9.33, *p* = .003, with more error for the larger (*m* = 0.088, *SE* = .003) than the smaller items (*m* = .077, *SE* = .004).

4.2.2.2 Further Analyses

Given the unexpected intercept difference for the shapes, we hypothesized that by presenting the tested items in relatively extreme groups (60% above and below object normative means), participants may have learned that there were two size categories that were tested. To test this hypothesis, we examined the responses from the first and last eight trials for each participant for the unfamiliar items. In order to test for learning effects, we compared the pattern of results at the beginning and at the end of the experiment and so we obtained separate estimates for each participant and each period. A 2 (group; younger vs. older) x 2 (relative size; smaller vs. larger) x 2 (period; first 8 vs. last 8) mixed-factor ANOVA was conducted to determine if the intercept difference changed as a function of period. This revealed a significant main effect of relative size; *F*(1, 56) = 38.58, *p* < .001, with a smaller intercept for the larger items than the smaller items (larger, *m* = -.135, *SE* = .031; smaller; *m* = .116; *SE* = .017). The size by period interaction approached significance; *F*(1, 56) = 3.78, *p* = .057, with the data suggesting a larger difference for the last 8 presented items (first 8; larger, *m* = -.083, *SE* = .043; smaller; *m* = .106; *SE* = .015 and last 8; larger, *m* = -.188, *SE* = .051; smaller; *m* = .127, *SE* = .026). This suggests that over the course of the experiment, the intercept difference became larger.

4.2.2.3 Recognition Response Analyses

To test whether there were any differences between the two groups for their confidence ratings, we conducted a between-samples t-test which found no difference;

t(56) = .986, *p* = .328. To test the relationship between the confidence ratings obtained (scaled from 0; no recollection to 8; remembered clearly) and recall performance, a 2 (group) x 2 (category) ANCOVA was conducted using absolute error, with the participants rankings of how clearly they remembered seeing the item used as a covariate (degree of recognition). This revealed significant main effects of group: *F*(1, 112) = 10.50, *p* < .001, with more error for the older adults, and category: *F*(1, 112) = 25.27, *p* < .001, with more error for the unfamiliar items, but a non-significant group by category interaction; *F*(1, 112) = 1.48, *p* = .225. When remembered response was entered into the model, this was found to be a non-significant covariate; *F*(1, 112) = .006, *p* = .940, suggesting that how well remembered an item was significantly affected absolute error but did not interact with the other variables.

4.2.2.4 Additional variables/ factors

We explored the impact of numerous additional variables. The effect of each individual familiarity rating for each vegetable was examined using a 2 (group; younger vs. older) x 2 (relative size; smaller vs. larger) ANCOVA for absolute error, though familiarity was a non-significant covariate; *F*(1, 56) = 3.3, *p* = .074. Moreover, we examined the level of interference during the delay task (the number of mathematical sums completed). An independent samples *t*-test indicated that younger adults (*m* = 7.64, *SD* = 3.5) completed more sums on average than the older adults (*m* = 4.62, *SD* = 1.62) [*t*(56) = 4.29, *p* < .001], which was found to be a significant covariate. When running an ANOVA for just group by error, there was a highly significant group difference; *F*(1, 56) = 35.53, *p* < .001. When delay was added as a covariate, although group remained significant, the *F*-value drastically decreased – *F*(1, 56) = 13.38, *p* < .001 and delay remained significant, *F*(1, 56) = 11.05, *p* < .001, indicating that the level of decay induced by the delayed task had a significant effect upon error. Moreover, once the level of delay was accounted for, the group differences declined, suggesting that the delay had a significant impact on the older adults' responses.

Furthermore, an independent *t*-test confirmed a significant group difference for the Picture Sequence Memory Test of episodic functioning; $t(57) = 5.8$ $p < .001$, with younger participants ($m = 22.62$, $SD = 7.58$) scoring higher than older ($m = 10.86$, $SD = 10.86$). Moreover, when analysing group differences in terms of absolute error, there was a significant group difference, $F(1, 56) = 8.56$, $p < .001$. However, when episodic visual memory capacity was added as a covariate, the group difference was no longer significant; $F(1, 56) = 1.22$, $p = .274$ and episodic functioning was marginally significant, $F(1, 56) = 4.3$, $p = .044$, thus indicating a potential causal explanation for the observed group differences. In terms of semantic capacity, there was also a significant group difference, with younger adults scoring lower ($m = 11.51$, $SD = 2.16$) than older ($m = 15.45$, $SD = 3.36$) [$t(49) = -5.0$, $p < .001$]. However, when run as a covariate against absolute error, it was found to be non-significant.

Lastly, the participants' responses were analysed to assess whether their responses were influenced by the size of the item shown at test by running a regression per participant determining whether test size was a significant predictor of participants' responses. Test size was a non-significant predictor for all participants bar three (one younger and two older), suggesting that test position had little systematic effect upon responses. These three participants possibly used the test position as an 'anchor' to influence their reconstruction response, but removing the participants made no overall difference to the model.

4.2.3 Discussion

The data for this study suggest that 1) older adults show more absolute error in their responses and 2) older and younger adults use prior knowledge to the same extent. We found that although prior knowledge led to more accurate reconstructions, with participants demonstrating less error for the familiar items than the unfamiliar items, accuracy declined with age. The older adults also demonstrated more variation in the responses (indicated by larger SD's for their responses), which we propose is indicative of noisier memory representations. The results thus showed that older adults made larger (and more varied) reconstruction errors despite both groups using object-level and superordinate category-level knowledge to the same degree. This suggests that greater memory error is not compensated for by a greater reliance on prior knowledge. The analyses suggest that the greater level of error for the older adults may have been affected by the delay, potentially due to greater interference between encoding and retrieval. Moreover, once episodic visual memory functioning was accounted for, the group difference was no longer significant, suggesting that this could have also been a causal factor in the observed level of error. To draw any substantial conclusions for our understanding of the mechanisms involving age differences, however, these factors would need further investigation.

The findings also suggest that both age groups learned categorical consistencies for the unfamiliar stimuli. This was demonstrated through the observed intercept difference for the unfamiliar items. This difference is typically attributed to object-level knowledge. It was thus surprising that in the current study, participants appeared to learn the underlying category structure of the presented items (the items tested in the current task were presented either smaller than the normative mean or larger) despite little knowledge of the items. It thus appears that this bi-modal presentation of the items caused participants to learn the two distinct categories.

Overall, therefore, our data suggests that older adults rely on prior knowledge to the same extent as younger adults, despite showing greater error. However, due to the surprising use of item-based knowledge for the unfamiliar items, we want to test our hypothesis for the effects of learning on memory reconstruction. Moreover, we wished to establish if the pattern of findings reported above was replicable (with a slightly different task). We aimed to determine whether the effects observed here still hold when we present items using a distribution approximating normal (i.e. most items presented at a value close to their respective normative means, rather than more extreme sizes) instead of a bi-modal distribution. We predict that in the absence of two distinct underlying categories (items smaller or larger than the mean), participants will show no effect of learning for the unfamiliar items. To test this, we designed a continuous recognition task which was much similar to Hemmer and Steyvers' (2009) original paradigm.

4.3 Experiment 6

In Experiment 6, therefore, we used a continuous recognition paradigm to examine the use of knowledge on episodic reconstruction in healthy ageing. The sizes of the presented and tested items in the current study were selected to approximate a normal distribution. As a result, we hypothesised that the data from this study would show no intercept difference for the unfamiliar items while the item-based knowledge effect would still be apparent for the familiar items.

4.3.1 Methodology

4.3.1.1 Participants

Participants comprised 100 adults (50 aged <30 and 50 aged >65) and were recruited via an existing database. This study was conducted online but participants were matched in the same way as the previous studies due to information obtained from the database.

4.3.1.2 Materials and Procedure

Materials and normative data for the mean size of each item were again obtained from Hemmer and Steyvers (2009) and comprised images of fruit and vegetables. The stimuli were used in a computer controlled continuous recognition task where participants were shown four sequences of 24 items. These were presented at a rate of one item every 2 seconds, though at test participants were given unlimited time to respond. Two of the sequences contained familiar fruit and vegetables objects and two contained random shapes. Within a list, each item was presented once, with 18 experimental stimuli and 6 dummy items which were not tested. During each sequence of 24 items, 9 tests were introduced (i.e. half of the experimental items were tested), so in total, 33 items were presented (including the test items).

Each experimental stimulus was paired with another item matched in size to enable each item to only be tested once (9 pairs of familiar items and 9 unfamiliar). Half (1 of each of the 9 pairs) of the experimental stimuli was tested in the first sequence and the corresponding 9 items were tested in the second sequence. Of each pair, one item was tested at a size smaller than its own normative mean (either 20%, 40% or 60% of the range between the normative mean and the minimum size) and the other was tested at a size greater than the mean (20%, 40% or 60% of the range between the normative mean and the maximum size). The items in a pair were tested at the same distance from the mean. Items were tested at 20% of the range between the normative mean and the maximum/ minimum size four times, at 40% of the range three times and at 60% of the range twice, so most values were presented around the normative mean. Within each list, 6 experimental items were presented relatively smaller than their normative mean, 6 items were presented as their normative means (average, not tested on that list) and 6 items presented larger than the normative mean. For the remaining 6 dummy items, two were presented smaller than the mean, two at the average size and two larger, though this was randomly allocated. The presentation, order and test size of the control shape stimuli was yoked to that of the fruit and vegetables.

The test conditions were interleaved between the presentations of the experimental stimuli, with the number of items between study and test varying between 2, 4 and 6 (three times per list). The order of the studied and tested stimuli was random, with one restriction - there was one set of all 3 lags within the first 12 items to ensure that the tests were not too clustered towards the end of the list. The function of the dummy items was to ensure that each lag could be used three times within each list, as including more items created additional presentation spaces for which the item and the test locations could be allocated.

When one of the items was presented again, it was at a different size. Above the presentation of the item on the screen was the question, “What was the size of this object when you saw it at study?” Participants were required to resize the item to replicate the size of the studied stimulus. This was done by using mouse-operated arrows which appeared at the bottom right of the screen. These items were measured on a scale of 0 to 1, with test items presented at a size of .2, .4, .6 or .8 (relative to the entire screen). The size of the test item was randomly determined independently for each participant with the constraint that each of the sizes was used equally often.

Following the size judgement, participants made a recognition judgement in the same way as the previous study.

4.3.2. Results

Figure 4.5 presents the recalled size as a function of the studied size. As in the previous experiment, the figure shows regression towards the mean. We then used reconstruction error and absolute error to analyse participants performance. The mean values for absolute error are in Table 4.3.

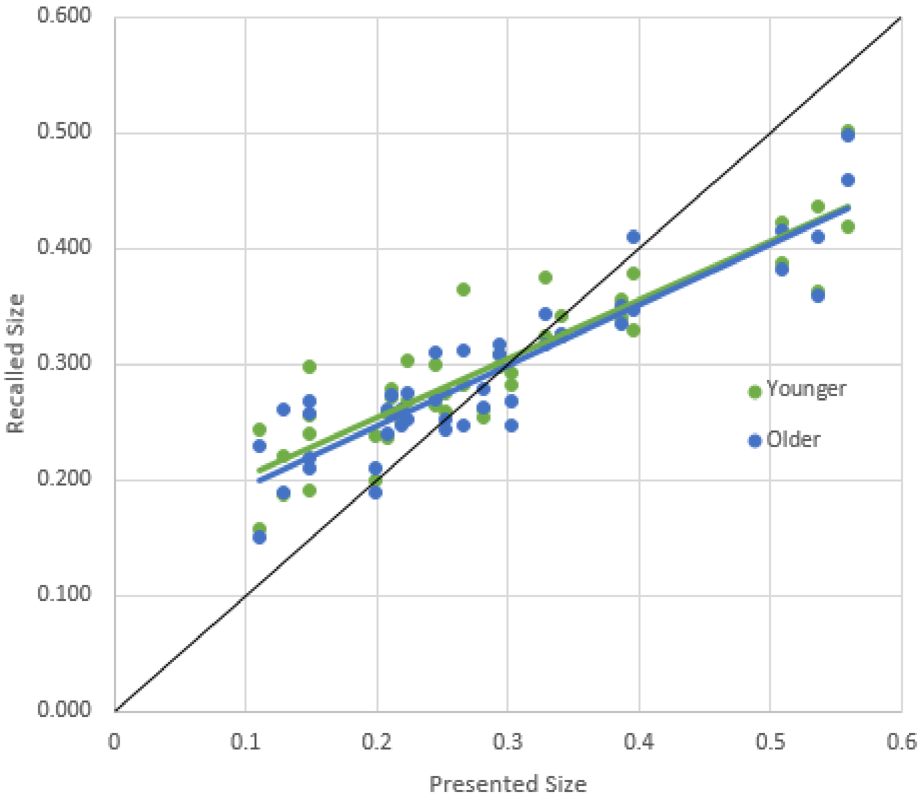

Figure 4.5. Recalled size as a function of studied size for older and younger adults.

Table 4.3. Means and SDs (in brackets) for absolute error for both younger and older adults.

	Familiar Smaller	Familiar Larger	Unfamiliar Smaller	Unfamiliar Larger
Younger	.07 (.06)	.07 (.06)	.10 (.08)	.11 (.09)
Older	.10 (.06)	.10 (.07)	.11 (.08)	. 10 (.09)

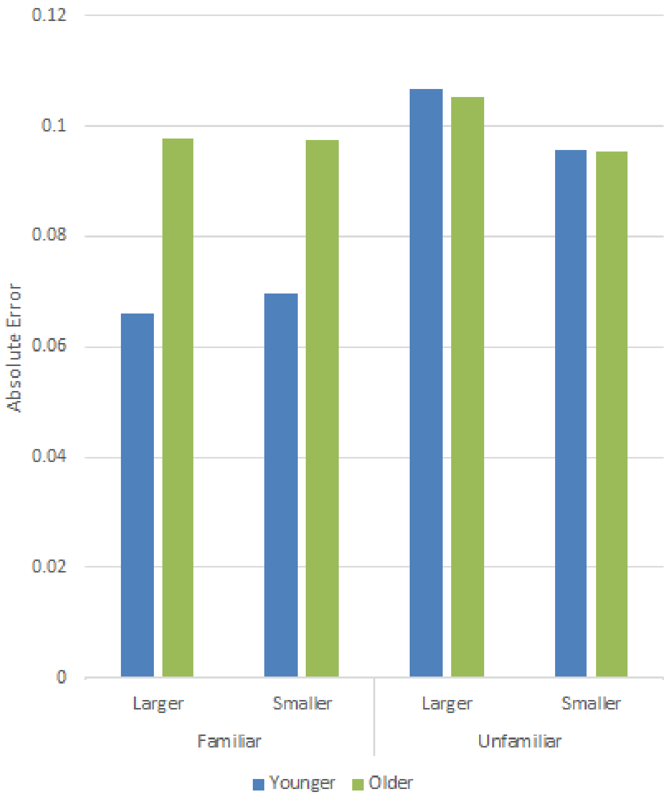

Figure 4.6. Absolute reconstruction error per age, category and relative size.

The absolute difference in error between older and younger participants was measured using a 2 (group; younger vs. older) x 2 (category; familiar vs. unfamiliar) x 2 (relative size; smaller vs. larger) mixed factor ANOVA. This revealed a significant main effect of category; *F*(1, 98) = 16.41, *p* < .001, with more error for the unfamiliar items. There was also a significant main effect of age group; *F*(1, 98) = 4.24, *p* = .042, with more error for the older than the younger adults. Lastly, there was a significant group by category interaction; *F*(1, 98) = 11.62, *p* = .001. There was no interaction for group by size; *F*(1, 98) = .033, *p* = .856, category by size; *F*(1, 98) = 2.16, *p* = .145 and no 3-way interaction; *F*(1, 98) = .096, *p* = .757

(see Figure 4.6). Post-hoc analyses for the group by category interaction showed a significant group difference for the unfamiliar items; *t*(198) = -3.84, *p* < .001, with more error for the older (*m* = .11, *SD* = .128) than the younger adults (*m* = .092, *SD* = .070). There was no difference for the familiar items; *t*(198) = -.140, *p* = .889.

To examine the effects of the superordinate and object-level knowledge on episodic reconstruction, we fitted separate regression models for each participant and each stimulus material (familiar and unfamiliar), examining how error was predicted by the relative size of the items (smaller or larger than the norm) and the studied size (see figure 4.7 a-d). Once again, we have negative slopes for both the familiar and unfamiliar items and so bias towards the central tendency of the presented stimuli. The two regression lines for the familiar items showed the influence of prior object knowledge, yet the two regression lines for the unfamiliar items were superimposed, indicative of no prior object knowledge effects. As the sizes of the unfamiliar items were yoked to those of the vegetables, the difference cannot be attributed to studied size. The average slopes and intercepts for each group are reported in Table 4.4.

Table 4.4. Average slopes and intercepts by category and relative object size for each age group.

		Younger		Older	
		Familiar	Unfamiliar	Familiar	Unfamiliar
Slopes		-.28	-.65	-.30	-.57
Intercepts	Smaller	.10	.20	.10	.17
	Larger	.08	.20	.07	.17

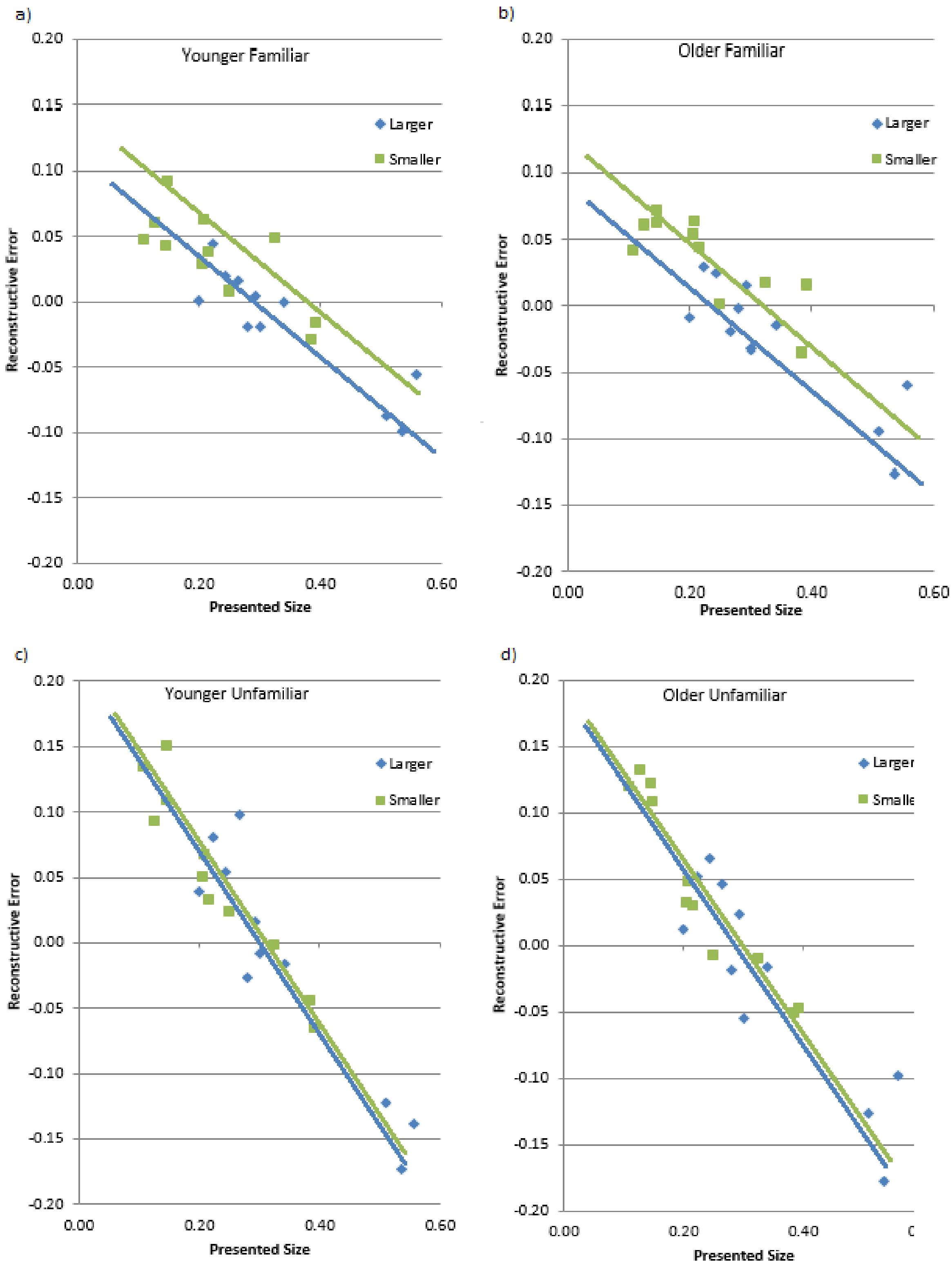

Figure 4.7 a-d. Figures a-b show reconstruction error for presented size of familiar items presented smaller or larger, whilst figures c-d show reconstruction error for the unfamiliar items

One-sample *t*-tests were used to confirm that the slopes were different from zero. The younger participants confirmed that this was the case for both familiar and unfamiliar items (familiar; $t(49) = -8.81$, $p < .001$, unfamiliar; $t(49) = -15.36$, $p < .001$), as did the older participants (familiar; $t(49) = -9.34$, $p < .001$, unfamiliar; $t(49) = -16.97$, $p < .001$). To determine if any group differences emerged for the obtained slopes, a 2 (group; younger vs. older) x 2 (category; familiar vs. unfamiliar) mixed factor ANOVA was conducted. This revealed a main effect of category; $F(1, 98) = 144.04$, $p < .001$, with steeper slopes for the unfamiliar items. However, there was no group effect; $F(1, 98) = .920$, $p = .340$ or group by category interaction; $F(1, 98) = 2.61$, $p = .109$.

Differences in intercepts were examined by running a 2 (group; younger vs. older) x 2 (category; familiar vs. unfamiliar) x 2 (relative size; smaller vs. larger) mixed factor ANOVA, demonstrating main effects of both category; $F(1, 98) = 168.51$, $p < .001$, with a larger intercept difference for the familiar items than the unfamiliar and a main effect of relative size; $F(1, 98) = 13.93$, $p < .001$, with a larger intercept value for the smaller than the larger items. There was also a significant interaction between category and relative size; $F(1, 98) = 27.58$, $p < .001$ and group by category; $F(1, 98) = 4.00$, $p =.048$. Planned contrasts with bonferroni adjustments demonstrated that for the familiar items, those presented smaller had a larger intercept than those presented larger, $t(99) = 5.92$, $p < .001$ but for the unfamiliar items there was no significant difference, $t(99) = .255$, $p = .800$. Moreover, an independent-samples t-test demonstrated no group difference for the familiar items; t(198) = .156, p =.876 but there was a group difference for the unfamiliar items; t(198) = 2.54, p = .012. The difference was in where the regression lines crossed the ‘y’ axis, which was slightly higher for the younger adults. As can be seen in Table 4.4, the intercept for the unfamiliar items is .2 for the younger adults and .17 for the older adults.

4.3.2.1 Distribution of Responses

As before, in an attempt to ascertain why older adults demonstrate more absolute error but similar patterns of bias to their younger counterparts, we obtained the average SD for each individual participant (based on their error scores) averaged across the familiar and unfamiliar items, presented both smaller and larger. Whilst the test of absolute error measured the participants deviations from the correct answer, the SD allows us to look at deviation away from the subjects own answer.

A 2 (age group; younger vs. older) x 2 (category; familiar vs. unfamiliar) x 2 (relative size) mixed-factor ANOVA was conducted on the SD of responses per position. This revealed a significant main effect of group; *F*(1, 97) = 4.00, *p* = .048 with less error for the younger (*m* = .068, *SE* = .003) than the older adults (*m* = .080, *SE* = .003). There was also a main effect of category; *F*(1, 97) = 17.59, *p* < .001, with more error for the unfamiliar items (*m* = .080, *SE* = .003) than the familiar items (*m* = .067, *SE* = .004). There was no significant interactions.

4.3.2.2 Recognition/ confidence ratings analyses

To test whether there were any differences between the two groups for their confidence ratings, we conducted a between-samples t-test which found no difference; *t*(98) = .253, *p* = .801. To test the relationship between the confidence ratings obtained (scaled from 0; no recollection to 8; remembered clearly) and recall performance, a 2 (group; younger vs. older) x 2 (category; familiar vs. unfamiliar) ANCOVA was conducted using absolute error, with the participants rankings of how clearly they remembered seeing the item used as a covariate (degree of recognition). Without ‘degree of recognition’ entered into the model, there was a significant main effect of category: *F*(1, 196) = 64.79, *p* < .001 and a significant group by category interaction;

F(1, 196) = 15.2, *p* = .001, with more error for older participants and the unfamiliar items. When remembered response was entered, this was found to be a significant covariate; *F*(1, 196) = 69.90, *p* < .001, suggesting that items memorability significantly affected absolute error. This caused the main effect of category to reduce in significance to *F*(1, 196) = 92.91, *p* < .001, suggesting that remembered response had some moderating effect on absolute error between the familiar and unfamiliar items.

4.3.3 Discussion

The data in this study clearly demonstrates the effects of knowledge on memory reconstruction, with object-level prior knowledge available for the familiar but not the unfamiliar items. Moreover, when the presented and tested stimuli approximate a normal distribution, there was no effect of object-level knowledge for the unfamiliar items. This supports our hypothesis that the bimodal distribution of target item sizes in the previous two studies facilitated session-based learning of the item statistics. Lastly, older and younger adults demonstrated the same level of knowledge-based bias, though younger adults exhibited less error than the older adults.

4.4 General Discussion

The overall aim of the current research was to systematically examine the influence of pre-existing knowledge in healthy ageing. In this paper, by testing older and younger adults' memory for the size of familiar and unfamiliar items, we found that 1) older adults showed larger reconstruction error than the younger adults and 2) both age groups appeared to rely on both object-level and superordinate category knowledge to the same degree for both the familiar and the unfamiliar items. Both of these points will be discussed in more detail below.

In both studies, prior knowledge was found to consistently improve accuracy, with participants demonstrating less error for the familiar items than the unfamiliar items. However, memory precision was found to consistently decline with age, with older adults demonstrating more error and more variation in their responses than younger adults. Across the board, better episodic recall for the younger adults was supported by evidence of greater reconstruction variability for the older participants. This was interpreted as evidence of noisier episodic representations of the studied items (e.g. Noack et al., 2014). Despite this, we found no evidence that the hypothesized increased variability in representations for older adults led to under- or over-reliance on prior knowledge. This suggests that both age groups capitalise on the same resources to inform their memory reconstructions.

Surprisingly, however, we found evidence of item-based knowledge for both familiar and unfamiliar items, with both age groups implicitly learning the underlying distribution of the presented unfamiliar items to the same extent. In Experiment 6 we demonstrated that when the presented stimuli were approximating a normal distribution, there was no intercept difference for the unfamiliar items. When the underlying distribution in Experiment 5 was presented as two separate categories, these regularities were learned. This is in line with research in younger adults, such as that by Chong and Treisman (2003) and Utochkin and Tiurina (2014). They showed that by presenting stimuli as an approximation of a bi-modal distribution (items presented at extreme sizes with no intermediate presentation sizes), the larger and smaller items were not grouped as a single distribution. Reconstruction of these items thus reflected the two groups of distinct sizes separately. In the current study, however, we demonstrate that older adults also show this pattern of response and so they adapt to statistical regularities just as much as younger adults.

In the current paper, we tested episodic memory which demonstrates more robust declines with ageing, and used more difficult tasks, yet the data supports out previous study investigating knowledge in VSTM. We did note earlier, however, that Experiment 5 and Experiment 3 were conceptually identical, yet the item representation in Experiment 5 would have suffered the effects of interference. Despite this, across all of the experiments, the data suggests that reliance upon object-level and superordinate category knowledge is equivalent across the two age groups. In our previous experiment of VSTM, we visually illustrated these two levels of influence on reconstruction in the figure below (Figure 4.8). The figure depicts both the superordinate (overall) and the object-level knowledge influence, which we suggest equally influence both age groups. The specific representation of the studied item was also depicted visually as a distribution of uncertainty (error) around the presented value. This hypothetical distribution was depicted by a dashed line for the older adults and a solid line for the younger adults.

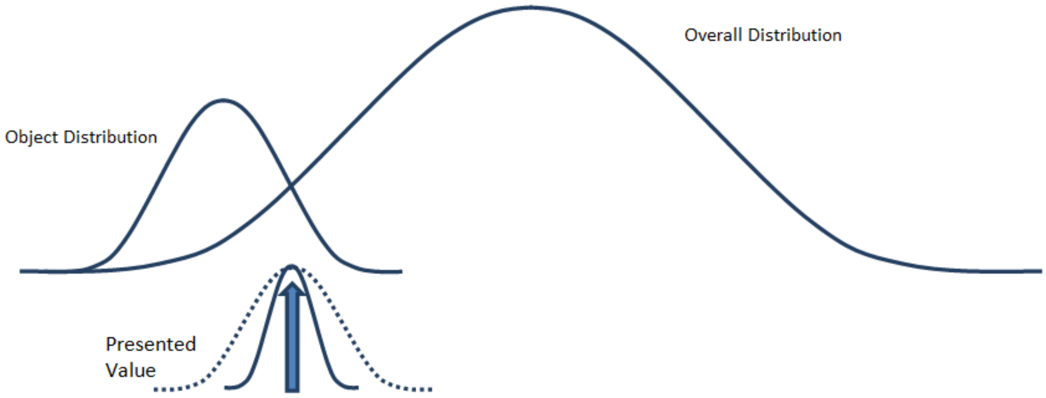

Figure 4.8. A visual illustration of the distributions of the various influences in memory reconstruction.

The implication is that older adults produce more widely distributed representations/ more variable responses than the younger adults. Thus, knowledge biases the older adults' responses in the same way as the younger adults, but the distribution of remembered sizes was noisier. We hypothesised that when using raw error as a measurement, estimates for smaller items are overestimated and for larger items are underestimated and so these values cancel each other out. When using absolute error as a measure we observed age-related differences. These hypotheses thus also seem to be applicable to the current experimental data and so we suggest that noisier representations in older age can lead to the same effects of knowledge in both VSTM and episodic memory. In line with our task of VSTM, therefore, the current data indicates that the use of knowledge is comparable for both age groups, but older adults have fuzzier/ more widely distributed memory representations.

Overall, therefore, the data obtained in this paper 1) extended the findings of our previous data which examined the use of knowledge in visual immediate/ STM (Daniel & Poirier, submitted) to reconstruction in episodic memory (or from a task with a clearer to a task with a fuzzier item representation), 2) reproduced the main findings of Hemmer and Steyvers (2009) but with a somewhat different continuous recognition task, as well as a delayed reconstruction task, 3) demonstrated that prior knowledge improved episodic recall and 4) showed that statistics for tested distributions can be learned for both familiar and unfamiliar stimuli.

Chapter 5: General Discussion

It is well established in the literature that our prior expectations about the environment influence our memories (e.g. Hemmer & Steyvers, 2009; Huttenlocher et al., 1991, 2000; Persaud & Hemmer, 2014). By calling upon a model of categorical learning, I conducted a series of experiments to examine the use of categorical knowledge in memory reconstruction for both familiar and unfamiliar faces, as well as for the sizes of various familiar items. This was examined in the case of immediate memory, over the very short-term, as well as over a longer timeframe through various episodic tasks. The findings consistently demonstrated the hierarchical use of prior knowledge, where the item and category-related statistics biased recall; both the overall category mean and item-level prior knowledge had an impact on performance.

What was novel about the current approach was the use of these models to systematically examine how categorical prior knowledge interacted with memory reconstruction in healthy older adults. I wanted to explore if and how these two systems interacted and how they changed as a function of age. I first consider a summary of the key findings within three broad themes, namely the level of bias/ knowledge in reconstruction, age-related differences in absolute error and the effects of learning on memory reconstruction. These will later be discussed within the broader context of memory in healthy ageing.

5.1 Knowledge levels in reconstruction

One of the main aims of the current research was to shed light on how reliance on knowledge – in the context of a memory task— might change with age. I systematically explored age-related differences in memory reconstruction with designs where the effect of multiple levels of knowledge could be assessed. This ranged from more generic, broader knowledge for the non-familiar face stimuli to more specific knowledge for the familiar faces. I also measured knowledge for just the ensemble statistics of the unfamiliar random shapes relative to strong pre-existing knowledge for the size of fruit and vegetable items. I found that at the superordinate category level, both age groups demonstrated a regression towards the overall category mean (e.g. Huttenlocher et al. 1991; 2000, Brady & Alvarez, 2011; Neumann, Schweinberger & Burton, 2013). In the case of the fruit and vegetables, for example, this meant that large items (i.e. a pineapple) were underestimated, whilst small items (i.e. a raspberry) were overestimated. The same trend was observed for the unfamiliar random shapes, despite the fact that these less familiar items are not associated with prior knowledge. This propensity to rely upon the central tendency when reconstructing from memory was the same for both age groups throughout, indicating that older adults relied on this superordinate categorical knowledge to the same extent as younger adults for both familiar and unfamiliar items.

Moreover, both age groups consistently demonstrated the same level of object-level bias. Again, in terms of the fruit and vegetables, this suggests a clear pattern of bias towards the mean of each individual fruit and vegetable item. They also showed bias towards familiar/famous faces, again demonstrating a bias linked to item-level knowledge. This was displayed consistently, even when I tested participants using a difficult continuous recognition paradigm or in a task including a filled-delay (designed to alter the interaction between memory and knowledge). There was some indication from previous research that the inclusion of a filled delay could be more detrimental to older adults due to a greater susceptibility to interference (e.g. Haaland, Price & LaRue, 2003; Troyer et al., 1994). In light of this, I predicted that if older adults were going to depend upon prior knowledge to a greater extent, it would be in this context. However, there was still no significant age difference in the level of bias. In terms of my hypotheses, therefore, I systematically demonstrated age-invariance when hierarchical prior knowledge was available.

From a more theoretical perspective, I earlier discussed the literature examining how knowledge and memory interact in advancing age; I have thus given some consideration to how my data fits into this general literature. There is a considerable amount of research which indicates that ageing declines have been alleviated or even eliminated by prior knowledge; some literature even demonstrates that prior knowledge benefits older adults to a greater extent than younger adults (e.g. Matzen & Benjamin, 2013; Umanath & Marsh, 2012; Verhaeghen, 2003). Conversely, in some circumstances, this adaptive use of prior knowledge can lead to more bias and errors in the recall of older adults (e.g. Dalla Babba et al., 2010; Rhodes & Kelley, 2005). However, my data is in line with the literature that suggests age-invariance in the use of available prior knowledge (e.g. Badham et al., 2012; Castel, 2005; Naveh-Benjamin, Hussain, Guez & Bar-on, 2003). Despite different types of stimuli and various manipulations, the findings showed that older adults used prior knowledge to the same extent as younger adults.

The current data thus appears to contrast with the literature that suggests that prior knowledge leads to more bias in the responses of older adults; I want to consider why this might be the case. There are two main ways of considering this type of literature. The first is that older adults are more susceptible to false memories (i.e. in the Deese-Roediger-McDermott paradigm, DRM, related items are deliberated excluded from highly associated lists and older adults are more prone to recalling them). The current data shows no evidence of this; however, it is unlikely that my studies really tapped into this type of memory. Most theories suggest that age-related susceptibility to false memories are a type of conceptual source memory problem where older adults are more likely to misattribute the source of a presented item (e.g. Dodson, Koutstaal & Schacter, 2000; Piguet, Connally Krendl, Huot & Corkin, 2008; Schacter, Norman & Koutstaal, 1998). According to this idea, the activation of an item would be misconstrued as indicating a recent encounter. In the current tasks, this would mean that the older adults would have had to misattribute the size of an item across trials due to the multiple presentations and tests of the same item. However, it is also likely that the older adults (and presumably younger adults, due to no age-effects in the use of knowledge) misremembered the features of the most recent items due to factors such as averaging the presented items or remembering another item instead. To alleviate the potentiality of misattributing the source of a presented item, in my last study, each item was only studied (and thereby tested) once. The data still revealed the same pattern of bias across age-groups, indicating that in the current tasks conceptual source memory was not a problem.

The second area to consider is where older adults show greater susceptibility to remembering details in line with their prior knowledge. In some instances, older adults demonstrate a propensity towards mis-remembering more recently presented information, such as recalling the features of an adapted version of a famous fairy-tale to be more in line with the details of the original version (Dalla Babba et al. 2010). In the current data, conversely, there is some evidence to indicate that the older adults remembered the items just as well as the younger adults (obtained from their confidence judgments/ memory ratings provided after each trial). It is not clear how much I can rely on these ratings to maintain that the older adults remembered the items to the same extent as the younger adults, especially as my data also indicates more variable representations for the older adults (more absolute error). However, as it stands, the overall pattern of data indicates that the items were generally not forgotten or inaccessible but that the older adults just had fuzzier representations (this will be discussed in more detail below). The results might have been different if the older adults were failing to remember the items or if I had used a design where I deliberately manipulated the stimuli/ environment to promote error (i.e. deliberately not presenting an associated lure in a series of related words; Tehan, 2010). It is thus possible that in some instances older adults do generate more error or bias in their responses. However, within the paradigms called upon here, where there was no deliberate manipulation of the environment to try to create more error and when support from the task was available, older adults used their knowledge to the same extent as younger adults.

5.2 The effects of learning

I also observed the role of learning in the current data. In their experiments, Hemmer and Steyvers (2009) used a distribution of tested sizes approximating normal (most items presented around their respective normative means, with few extreme presentation sizes). Conversely, in the first immediate memory (Chapter 3, Exp. 3) and the first episodic tasks (Chapter 4, Exp. 5), items were presented at a size either smaller or larger than their respective normative means, effectively creating a two category distribution. As a result, it appears that participants learned the two separate distributions for the unfamiliar items. Their responses thus reflected a pattern of bias similar to that of the familiar items, where relatively larger unfamiliar items were underestimated and items presented smaller than the normative mean were overestimated. In an attempt to clarify this hypothesis of learning, I replicated the immediate resizing study but with a distribution of tested stimuli approximating normal; it is suggested that if participants were learning the bi-modal distribution of the tested stimuli in the first task, then this effect would be eliminated when the items were presented as one continuous distribution. The data shows that that just as in Hemmer and Steyvers' original data, there was no intercept difference between the regression lines of the unfamiliar items. The familiar items, conversely, continued to demonstrate an intercept difference as this reflected pre-existing knowledge for the items.

This finding thus suggests that the shape of the distribution of the presented stimuli influenced retrieval; presenting stimuli in the form of a two-peak distribution caused participants responses to reflect two separate and distinct distributions which represent the two sizes separately (e.g. Chong & Treisman, 2003; Utochkin & Tiurina, 2014). The current data supports research demonstrating that younger individuals are sensitive to regularities within the environment. Such sensitivity allows for accurate predictions and adaption to ones surroundings (e.g. Brady & Alvarez, 2011; Brady & Oliva, 2008; Knowlton & Squire, 1993), as well as more efficient encoding of items and thus the retention of more items in memory (Brady et al., 2009). However, to my knowledge, this data is the first to systematically compare how the learned ensemble statistics of a distribution differ between older and younger adults. The data showed that both the younger and older adults relied upon session-based learning to the same extent. The current data thus demonstrated that both older and younger adults are sensitive to the structure of the environment and so older adults are able to implicitly learn the underlying distribution of presented stimuli just as efficiently as the younger adults.

5.3 Age-related differences in absolute error

Moreover, the data clearly demonstrated the facilitative use of prior knowledge for correcting erroneous memory traces and improving overall accuracy. Both groups of participants consistently exhibited less error for familiar relative to unfamiliar stimuli.

However, the older adults repeatedly demonstrated a greater level of absolute error than the younger adults in all conditions, despite no age-related difference in terms of categorical bias. This was supported by differences in the data which showed that older adults exhibited more overall variation in their responses. The data showed that the responses of the older participants had larger standard deviations than the younger adults, indicating that their responses were more varied around the tested value; I interpreted this to mean that the older adults demonstrated more widely distributed memory representations. I thus suggest that the older adults maintained fuzzier representations in memory than the younger adults.

I propose that this offers support for the well-established findings that older adults demonstrated a reduction in both working/ immediate (e.g. Backman, Small & Wahlin, 2001; Hartley, Speer, Jonides, Reuter-Lorenz & Smith, 2001; Park, Lautenschlager, Hedden, Davidson, Smith & Smith, 2002) and episodic memory (e.g. Davidson & Glisky, 2002; Mitchell, 1989). It is possible to argue, however, that these differences did not emerge because all participants had noisy representations of roughly equal strength but because a minority of the older participants had noisier representations than normal, with most elderly participants having “normal” levels of noise. A closer examination of the frequency distribution analyses in each experiment were important for resolving this issue. An examination of the standard deviations and the histograms for each group separately showed no difference, indicating that the older adults were no more variable than the younger adults.

To rule out any potential confounding or moderating variables which may have led to these inflated levels of error for the older adults, I checked the influence of numerous other variables. In the VSTM and delayed memory tasks, I measured the effect that familiarity for each individual item had on the level of absolute error.

However, this was found to have no moderating effect on absolute error. I did surprisingly find significant group differences in a measure of semantic capacity (the category fluency test), with older adults demonstrating greater functioning than the younger adults. This group-difference was somewhat unexpected considering that previous research typically demonstrates that age negatively influences category fluency (e.g. Crossley, et al., 1997; Troyer, 2000). However, other research suggests that such deficits only really occur after the age of 80 or that it is level of education which moderates age-related declines (e.g. Bank et al. 2000; Brucki & Rocha, 2004; Crossley et al. 1997). This finding would thus need further clarification, though it was not explored any further in the current research because it was not found to co-vary with the degree of absolute error in participants' responses and so had no influence on memory reconstruction in the current study.

There was, however, an observed group difference in episodic functioning, where the younger adults showed better episodic performance. This was also found to be a significant covariate (measure obtained from the NIH toolbox). This is somewhat expected considering that I measured episodic memory; it's not surprising that another measure of episodic memory correlates. However, the variable representations around the studied values are easy to conceive of as episodic representations; this would be in line with my interpretation of the variability in error.

One of the key aims of this research was to determine if knowledge and memory interact in a comparable way in both young and older adults. I have already established that older adults use their prior knowledge for familiar items to the same extent as the younger adults, despite making more absolute errors than the younger adults. It is thus unclear why the older adults did not compensate for their fuzzier representations through greater reliance on prior knowledge.

To explain this, I suggested that older adults have more widely distributed/ noisier memory representations of the tested item than the younger adults. As mentioned before, I have some evidence to indicate that the older adults felt that they remembered the item just as well as the younger adults. This suggests that it was not a case of the older adults just simply not remembering the size of the item but that their representations were fuzzier. This can be observed in the figure below which has been reproduced to prevent an attempt to locate said figure in previous discussions (see Figure 5.1). This figure depicts the various categorical influences which make up memory reconstruction. It shows the overall, superordinate category distribution of all of the presented items, as well as the object-level influence of the individual stimulus. It also reflects the distribution of the representation of the tested item; the depicted item was studied at the value represented by the blue arrow. This arrow demonstrates that the object was studied larger than the mean for the object distribution (that is, an item that is studied at a size that is larger than the normative mean) but was small relative to the overall superordinate distribution.

The findings of this dissertation suggest that this latter distribution is wider for the older than the younger adults (the dashed line represents the distribution of the older adults and the solid line represents the younger adults). The purple arrows correspond to the maximum values of the ‘episodic distribution’ around the studied value for the younger adults (arrows positioned around the distribution of remembered values), whilst the red arrow depict the values for the older adults. I postulate that when using raw error to estimate the participants’ responses, this age-related difference is cancelled out (reconstruction of smaller and larger items cancels out values to zero). This indicates why there is only an age difference when absolute error is used as an estimate. I thus postulate that knowledge biases the responses of the older adults just as much as the younger adults, but the memory representations of the older adults are noisier.

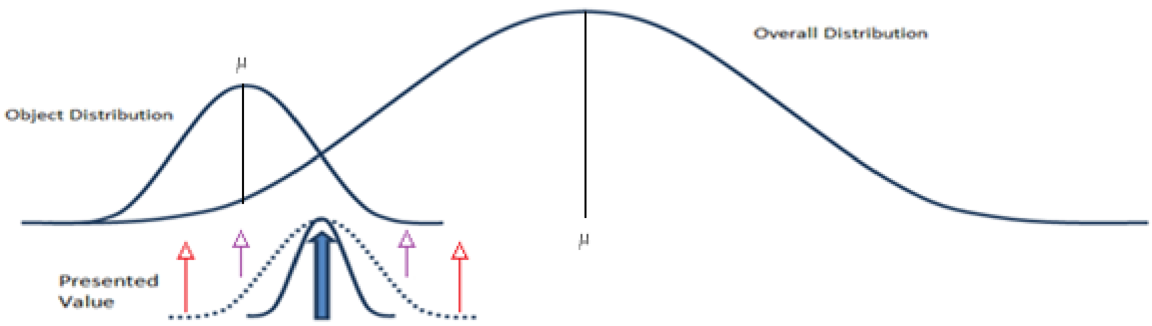

Figure 5.1: The three distributions assumed to contribute to the reconstructive response. This includes the superordinate (overall) distribution, the object-level distribution and the distribution representing each participant's representation of the studied value (the depicted item was studied at the value represented by the large blue arrow).

Overall, however, the current data suggests age-invariance in the use of knowledge at the object-level and superordinate category levels. These conclusions were supported by simulations of the data (see Chapter 3), where the data from Hemmer and Steyvers's (2009) model was manipulated to quantitatively predict how this affected the data when responses were more variable. I thus inputted fuzzier representations for the older adults' (based on the idea that the distribution of presented items changes with age, with a wider distribution for the older adults), without changing the weight to see if this gave more dispersion. My data presented no clear evidence that the weight of the prior knowledge had changed but suggests that the memory representation is less strong. These simulations supported the observed data; increased noise in recording/ storing the presented size of the item for the older adults relative to the younger adults leads to the pattern seen in the data. I have discussed the implications of these results within the context of other research examining the effects of prior knowledge on memory in age. However, I also want to explore how the results fit with other broader theories of memory in ageing.

5.4 Wider implications for memory and ageing

Older adults have generally been shown to have more difficulty with tasks that are effortful, strategic and complex; I want to ascertain how this research fits into theories of ageing. Craik (1986; 1994) proposed an account which characterises age-related declines in memory tasks as dependent on the level of demand. When there is minimal environmental support and so the task is more dependent upon self-initiated processing, older adults show greater declines. According to this view, if the task is ‘stimulus driven’ and provides sufficient environmental support for retrieval (e.g. relevant cues or a reinstatement of the encoding conditions at test), age-related declines will be minimised (Craik & Schloerscheidt, 2011). If the task does not provide adequate cognitive support, processing is self-initiated and so age differences will be large. As discussed earlier, the advantages of support are most apparent at retrieval when comparing tests of recognition against tests of recall. In contrast to cued recall and recognition tasks where cues passively aid recall, tasks of free recall have minimal external context to guide retrieval and so require a substantial amount of self-initiated processing, making age-related performance comparatively poorer (e.g. Craik, Byrd & Swanson, 1987; Craik & McDowd, 1987; Dunlosky & Hertzof, 1998). In this series of studies, I employed a unique set of paradigms where the to-be-remembered items were presented again at the point of recall and participants were required to remember a specific feature of the item (i.e. size of the item or a particular face). It is thus arguable that providing the item at retrieval acted as a cue which supported retrieval.

However, older adults did show greater error/ more variation than the younger adults. In the paradigms used, despite reinstating the item at retrieval, participants were required to recall a precise, context-bound feature of the most recent presentation of the item within the experiment. There is evidence to suggest that older adults demonstrate difficulties recalling the specific contextual features in which the item was presented (e.g. Hess & Pullen, 1996; Kessels, Hobbel & Postma, 2007). This may explain why they show more variable representations and thus greater absolute error. The data thus suggests that older adults show no problem with the coarser details of an item (i.e. when they can rely on prior knowledge/ can use cues to prompt recall) but show more difficulties for the more fine-grained details.

This is in line with the premises of the fuzzy-trace theory (Brainerd & Reyna, 2001; Reyna, 1992; Reyna & Brainerd, 1995). This framework is based on the idea that level of memory error varies with the relative accessibility of the gist (categorical) and the verbatim (exact) information. Specific recollection, as required in the current series of studies, is contingent upon dependence on the verbatim information, rather than the gist trace. However, older adults are found to demonstrate more error for the verbatim than the gist traces (e.g. Brainerd, Reyna & Howe, 2009). This could potentially explain why older adults can use their coarser, pre-existing knowledge to guide reconstruction but their recall of the specific context-dependent sizes of the studied items shows declines and thus leads to greater error.

There are also other key theories of memory decline in cognitive ageing. Proponents of the processing speed account suggest that ageing is characterised by a general slowing of cognitive processing, leading to declines in other cognitive functioning, such as memory (e.g. Birren, Woods, & Williams, 1980; Cerella, 1985). As the speed of processing slows, it has been suggested that deficits appear because time-limited processes cannot be effectively completed within a given time frame (the limited time mechanism). It has also been proposed that the necessary outcomes achieved by earlier processing may not be retrievable at the time of later processing, referred to as the simultaneity mechanism (e.g. Salthouse, 1992; 1996; Verhaeghen, Cerella, & Basack, 2006).

Using large psychometric studies and path analyses, Salthouse (1991; 1996) proposed that after controlling for lower speed, the independent contribution of age to memory decline is relatively weak and so age is only an indirect factor. In one demonstration of this, Salthouse (1996) asked older and younger participants to make perceptual comparisons as quickly as possible for whether two letters were in the same or different fonts or for whether two pictures matched. There was a consistent advantage for younger over older adults in terms of reaction times. Speed of performance was also found to predict performance on numerous other tasks, with older adults who were faster for the perceptual comparisons task also performing better for tests of WM and episodic memory.

In the current study, I am able to rule out the effect of slowing at retrieval as participants were given unlimited time to recall the feature of the item. However, at encoding, the to-be-remembered items were shown for only a short period of time and this was equivalent for both age groups. It is possible that if older adults had been given more time to encode the items, less variation in responses would have been observed.

Moreover, according to the Processing Resources Framework, the level of attentional resources (or mental energy) available for cognitive processing declines with age (Craik, 1983; Craik & Byrd, 1982; Craik & Simon, 1980). This restricts the capacity to perform numerous concurrent activities, with greater effects on difficult tasks which require more resources than simpler tasks (e.g. Cowan, 2010). Due to reduced processing resources, older adults would be less likely to execute effortful and resource-demanding memory processes (e.g. Craik, 2006) or to engage in more demanding cognitive strategies, such as elaborate encoding (e.g. Craik & Byrd, 1982; Salthouse, 1982). Rabinowitz, Craik and Ackerman (1982) found that older adults are more likely to encode information in a more general, automatic fashion and are less likely to encode specific contextual details about items, leading to poorer retrieval. Other experiments have also shown deficits in memory for contextual information when younger adults are performing under divided attention conditions (e.g. Troyer & Craik, 2000; Troyer, Winocur, Criak & Moscovitch, 2000), suggesting that a reduction in available attentional resources may underlie age-related memory deficits.

In the current studies, it is possible that greater error or variation in the older adults' responses were the result of reduced attentional resources leading to greater difficulties recalling the specific contextual details of the particular presented item. However, there is no direct measure of this and so I cannot infer whether this was the case. Furthermore, another line of enquiry casts some doubts on this interpretation. Naveh-Benjamin, Guez, Givati and Marom (2001) demonstrated that older adults demonstrated a greater decline in memory performance for associative information relative to item information. However, they also examined the performance of younger adults in a divided attention condition; under these conditions, the younger adults showed deficits in both associative and item information. This suggests that the division of attention does not show the patterns of impairment observed in the older adults and so casts doubt on the idea that declines in memory are the result of attention. Instead, it is possible that the greater level of observed error in the current series of tasks may be the result of difficulties combining information of the particular item with a specific feature (e.g. a particular item and its size or a particular variation of a specific face).

More generally, with particularly relevance to the broader memory literature, is the linkage of tasks to memory systems. In some instances, the tasks employed in this dissertation tap into different memory systems – short-term (immediate) memory and episodic (delayed) memory. These different systems have been treated separately throughout the course of this dissertation. However, despite this, the same pattern has emerged across all of the tasks. Such a categorisation allows for the possibility that a single memory system (and knowledge) underpins all cognitive tasks; this is line with various unitary models of memory (e.g. Brown, Neath & Chater, 2007; Nairne, 1990; Nairne & Dutta, 1992). Furthermore, the design of the tasks within this dissertation are based on the assumption that performance, particularly with reference to the contribution of knowledge, is under strategic control; this suggests that deficits in one area can be compensated for by use of other areas. If this was the case, then I would expect that the older adults would rely on prior knowledge to a greater extent than the younger adults. However, this was not observed and so it is plausible that the integration of semantic knowledge happens at a more automatic level as one might fine is memory is just a single system. The data in the current study, therefore, contributes towards the literature which suggests that short-term (immediate) and longer-term (delayed) memory systems are not architecturally separate systems but rely largely on the same representations.

5.5 Conclusions

Overall, therefore, I present a compelling series of experiments across a range of memory domains, with different kinds of stimuli. The current data shows that both age groups consistently produce the same level of bias, with the use of item-specific knowledge for familiar items leading to more accurate reconstructions for both younger and older adults. I thus present evidence which suggests that whilst there are declines in some areas, other areas are relatively well preserved. By capitalising upon the capacities which are maintained, it may be possible for older adults to develop effective strategies for profiting from their memories. It may also reduce some of the negative stereotypes associated with ageing (e.g. Hess, Auman, Colcombe, & Rahhal, 2003; Hess, Emery, & Queen, 2009; Thomas & Dubois, 2011). It is thus important that research is systematically challenging this negative stereotype.

In terms of theoretical contributions, therefore, this data clearly suggests age-invariance in the use of available prior knowledge. Moreover, even when prior knowledge is not available, both older and younger adults are able to implicitly learn the underlying distribution of the presented stimuli to the same extent, though older adults appear to rely upon the overall statistics of the distribution when their representations are fuzzier. However, despite the same level of bias in memory reconstruction between both age-groups, memory precision tends to decline with age, with older adults generating more absolute error and more variation in their responses than younger adults. In terms of my initial hypotheses, therefore, older and younger adults use prior knowledge to the same extent but older adults do not capitalise upon their knowledge to compensate for more error in their memory representations.

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