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SUPPORTING MEMORY FOR OBJECTS AND LOCATIONS IN AGEING: A SUBCOMPONENT ANALYSIS OF VISUO-MOTOR ENCODING.

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SUPPORTING MEMORY FOR OBJECTS AND THEIR LOCATIONS IN AGEING: A SUBCOMPONENT ANALYSIS OF VISUO-MOTOR ENCODING.

Abstract

The literature review examines current research indicating that memory for objects, locations and objects in their locations might be independent components, underpinned by different cognitive processes. These concepts are examined in relation to age-related and dementia-related decline. The review critically discusses the existing age-comparative literature and highlights several avenues for future research. One such avenue is how we might ameliorate decline in healthy and non-healthy older adults. A hypothesis of how to do this based on levels of processing theory (Craik & Lockhart, 1972) is developed and exemplified in relation to visuo-motor encoding. Conclusions are drawn about the clinical applications of subcomponent research and the amelioration hypothesis.

The empirical study examines whether object, location and object-location memory do in fact differ between younger and older adults. It also investigates whether these three types of memory differ depending on whether information has been learnt through visual and motor encoding, or visual encoding alone. The results indicate that location and object-location are impaired in ageing, but that object memory remains relatively intact under some circumstances. They also suggest that visuo-motor encoding does not confer an advantage over visual encoding. These results are discussed in terms of previous studies, motor processing in ageing, limitations of the study and avenues for future research.

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OBJECT-LOCATION MEMORY IN AGEING

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OBJECT-LOCATION MEMORY IN AGEING

Abstract

This literature review examines whether or not there is an age-related deficit in memory for objects, locations or these features bound together. It outlines early studies in this field that suggest that there is and outlines some limitations of this literature. It also considers visual processing, working memory, binding and object-location sub-processing theories that point towards the possibility of differential ageing effects for memory for objects, locations, and objects in their locations. This literature is combined with the levels of processing theory (Craik & Lockhart, 1972) in order to explore ways in which age-related or dementia-related decline may be ameliorated through deeper encoding. There is a particular focus on the possible benefits of physical interaction with stimuli at encoding. Future research in relation to sub-processing changes with ageing and visuo-motor learning in visual array tasks is discussed.

Keywords: differential deficits; motor amelioration; encoding; dementia.

Introduction

Memory for 'what' and 'where'

It is well established that visual information concerning the identity of objects and their spatial layout are processed by two functionally dissociable perceptual pathways (Coello, Richaud, Magne & Rossetti, 2003; Sala, Rama & Courtney, 2002). It is also thought this dissociation of 'what' and 'where' information is maintained in visual working memory (Schiavetto, Kohler, Grady, Winocur & Moscovitch, 2002). A number of studies have compared adults' recall and recognition memory for the identity of everyday objects and their positions in visual arrays. It has generally been found that older adults are impaired in this ability compared to younger adults but under certain circumstances, such as when information is presented in a meaningful context, age-related decline can be ameliorated (Park, Cerry, Smith & Lafronza, 1990; Simone & Baylis, 1997). This amelioration has been argued to be a result of task characteristics that enable more elaborate associations to be encoded when information is presented (Cherry & Park, 1993).

The theoretical importance of age-comparative studies

Measuring memory for objects and locations using items on a grid has face validity and is simple to administer. However, a growing criticism of many visual array studies to date is that they only measure 'bound' memory; that is memory for objects in their locations (Chalfonte & Johnson, 1996; Gulya et al., 2002). They do not also measure memory for objects and for locations as separate entities. Within the literature there is an emerging consensus that episodic memory for object and location information is the result of individual object and location feature processing activities, and a binding process that puts these two distinct features together in some way (Mitchell, Johnson, Raye, Mather & D'Esposito, 2000). Consequently, it has been recommended that future object-location memory studies should endeavour to measure memory for objects, locations, and objects in locations separately (Postma & de Haan, 1996). However, few studies comparing younger and older adults' object-location memory have been informed by recent subcomponent theories. Those that have, indicate location and bound object-location memory may be more greatly affected by ageing than object memory or individual feature memory (Chalfonte & Johnston, 1996). Therefore, there is a need to carry out age-comparative spatial array studies of object-location memory processing in order to inform theories of episodic memory for objects and locations.

The clinical importance of age-comparative studies

There is also a need to carry out age–comparative studies to inform clinical practice. Episodic object-location memory can deteriorate in older adulthood and with the progression of dementia (Erickson & Barnes, 2003). Healthy older adults as well as those with Alzheimer's or Parkinson's disease can have difficulty finding objects in their environment and using landmarks to navigate their way around familiar and unfamiliar places (Bucks & Willison, 1997). These difficulties can cause distress to individuals and their families, and can threaten independent living (Pearlin, Harrington, Powell-Lawton, Montgomery & Zarit, 2001). Improved standards of living and medical advances mean the western world is an ageing world (Simon, Walsh, Reignier & Krauss, 1992). Therefore, there is a growing need to devise strategies to support the learning of such information in ageing adults. Age comparative studies that separately measure memory for objects, locations, and objects in locations may lead to a better understanding of the cognitive processes underlying object-location memory over the human life cycle. In turn, this may make it possible to highlight avenues for ameliorating age-related decline, hence helping to ease distress and prolong independent living in an ageing population.

Additionally, a number of studies have shown that those with dementia are more greatly impaired on object-location memory tasks than healthy older adults (Tales, Muir, Bayer & Snowden, 2002; Giraudo, Gayraud & Habib, 1997). Hence, establishing an age-related normative baseline for each of the three visuo-spatial memory components may provide crucial clinical information. This information could be used for devising neuropsychological tests for the early detection of abnormalities, differential diagnosis and measuring treatment effects.

Ameliorating age-related decline

Craik and Lockhart's (1972) levels of processing theory suggests more elaborately encoded information is more memorable. This theory provides a well-established theoretical base from which interventions to ameliorate age and dementia-related impairment in object-location memory might be able to be devised. The theory implies that incorporating activities that facilitate the deeper processing of object and location information at encoding would promote better memory for the information learnt. For example, the visuo-motor literature suggests that performing a motor action with an object results in a deeper level of processing than simply looking at it. Also, motor learning and visual learning have different neural substrates (Brooks, Attree, Rose, Clifford & Leadbetter, 1999; Post, Welch, & Bridgeman, 2003). It is, therefore, hypothetically possible that incorporating visuo-motor encoding into object-location learning is one technique that could be used to support older adults or adults with dementia. Future research is needed to test what activities support object, location, and object-location memory in these populations.

Review outline

This review will endeavour to summarise and critically discuss the theories and future research issues outlined above. It begins by outlining current theories of perceptual processing and visual working memory, before going on to consider 'what' and 'where' binding theories and age-related object-location memory research. The review then suggests a number of ways in which age-related decline may be able to be ameliorated by manipulating the conditions under which object and location information is encoded. An emphasis is placed on how physically interacting with stimuli during learning may ameliorate age-related decline in object-location memory. It then hypothesises about how the amelioration hypothesis can be extended to apply to older adults with dementia. It concludes by summarising that more research is needed that measures the different sub-processes of memory for 'what was where' and how different activities at encoding affects each of these components.

The 'What'/'Where' Dissociation

Dissociable visual processing

Theories of visual processing distinguish between the processing of 'what' and 'where' information. A wide range of neuropsychological, neuroimaging and lesion studies suggest the perceptual processing of object identities and their locations is achieved by two domain-specific and anatomically discrete neural pathways (e.g. Halbig, Mecklinger, Schriefers & Freiderici, 1997; Mecklinger, 1998). The 'ventral' pathway projects from the occipital lobes in the visual cortex to the inferior temporal cortex. It processes feature information that enables objects to be identified such as colour, shape, patterns or texture (Chen, Myerson & Hale, 2002; Sala et al., 2002; Matios, Leung & Gore, 2000). The 'dorsal' pathway reaches from the occipital lobes in the visual cortex to the posterior parietal cortex. This processes objects' spatial features, such as their locations, spatial relationships, and goal directed movements towards them (Deco & Lee, 2002; Duebel & Schneider, 2001; Coello et al., 2003). The neuroanatomical interconnections between these two processing streams are abundant and both pathways go to both hemispheres (Merigan & Maunsell, 1993). Thus, the 'what'/'where' dissociation is not absolute and may be a product of processing efficiency rather than mutually exclusive potential (Alexander, Packard & Peterson, 2002). This becomes apparent in studies that have found dedifferentiation of 'what' and 'where' processing in normal ageing. Chen et al. (2002) found such a phenomenon when older adults showed a weaker functional distinction than younger adults in a series of visuo-spatial tasks designed to measure the functioning of dorsal and ventral pathways.

Dissociable visual working memory

Behavioural studies, neuroimaging research and lesion data indicate that the fractionation of what and where processing is maintained post perception, in the storage and maintenance of object and location information in episodic memory (e.g. Ruchkin, Johnson, Grafman, Canoune & Ritter, 1997; Bohbot, Kalina, Stepankova, Petrides & Nadel, 1998; Kessels, Postma, Kapelle & de Haan, 2000; Schiavetto et al., 2002). For example, a behavioural interference study by Tresch, Sinnamon, and Seamon (1993) found that working memory for object identities was impaired by a concurrent object interference task, but not by a spatial discrimination task. However, location memory showed the opposite vulnerability. The separation of 'what' and 'where' memory processing was also apparent in a study that measured cerebral blood flow whilst adults recognised either the identity or spatial features of previously learnt pictures (Moscovitch, Kapur, Kohler & Houle, 1995). The retrieval of identity information increased blood flow in the right inferior temporal lobe, whilst the retrieval of spatial information increased flow in the right posterior parietal lobe. An event-related potential study involving adults explicitly recognising the placement of drawings of familiar objects on a two-dimensional matrix, similarly suggested dorso-ventral delineations in object and location recognition memory (Mecklinger, 1998). Furthermore, it has been shown that patients with temporo-occipital lesions have difficulty recollecting object features but show no disadvantage on spatial tasks (e.g. Farah, Hammond, Levine & Calvanio, 1988). Patients with posterior parietal lobe lesions, however, show the reverse pattern (e.g. Perenin & Vighetto, 1988).

Thus, research has indicated the ventral prefrontal cortex is usually associated with object working memory (McCarthy, Puce, Constable, Krystal, Gore & Goldman-Rakic, 1996), and the dorsal prefrontal cortex is associated with spatial working memory (Courtney, Ungerleider, Keil & Haxby, 1997; Nystrom, Braver, Sabb, Delago, Noll & Cohen, 2000). However, these same studies have also found that both regions are often activated to some extent for object and for spatial working memory tasks. Thus, as with visual perceptual processing, memorial 'what' and 'where' dissociations are preferential as opposed to absolute. This conclusion is reinforced by evidence that memory for objects and locations is not only reliant on domain-specific structures; it also involves domain-general areas whose activation is dependent on whether information is being encoded or retrieved as opposed to whether 'what' or 'where' information is being processed. This was demonstrated by Kohler, Moscovitch, Winocur, Houle, and McIntosh (1998) who showed when young adults matched the location or identity of objects to drawings, different areas were activated during the perception, encoding and retrieval of spatial and identity information. Activation for spatial information occurred in the anterior inferotemporal cortex. Activation for identity information occurred in the posterior inferior parietal cortex. Activated domain-general areas were the bilateral superior temporal cortex regions during encoding and right prefrontal cortex, precuneous, and bilateral middle and inferior frontal gyri during retrieval.

Another similarity between memory for objects and locations and the perceptual processing of 'what' and 'where' information is that dedifferentiation occurs with ageing. This seems to occur in the form of domain-general anterior neocortical areas compensating for a reduction in the activity of domain-specific posterior processes. A recent PET study (Schiavetto et al., 2002) demonstrated that when encoding and retrieving information about object identity or location, older adults had lower cerebral blood flow in the domain-specific inferior temporal and inferior parietal cortices than younger adults. Also, older adults had higher activation in the domain-general right prefrontal and premotor cortices during encoding than during retrieval. Contrastingly, younger adults exhibited greater blood flow in the right extrastriate cortex during retrieval.

The involvement of the hippocampal region

The research above implicates the involvement of the prefrontal regions in object and location memory. Lesion studies have also highlighted the possible involvement of the temporo-hippocampal region in memory for objects and locations. Smith and Milner (1981, 1989) tested the ability of adults with right temporal lobe-hippocampal resections, left temporal lobe-hippocampal removals, or no neurological damage, to reconstruct spatial arrays of objects. Those with right temporal lobe resections that encroached onto the hippocampal and/or parahippocampal gyrus, could place the correct objects in the correct positions on immediate recall, but were impaired at delay. The disadvantage of these studies is that the lesions were not focal. Therefore, it is not apparent whether both temporal and hippocampal structures are implicated. More recent studies, that have used participants with more focal lesions, have shown the right-sided parahippocampal area is important, but the involvement of the temporal lobe is not crucial. Milner, Johnsrude & Crane (1997) compared the abilities of healthy controls, adults with left temporal resections with large hippocampal encroachment, those with selective left sided amygdalahippocampectomies and others with right-sided equivalent resections, to learn and replace objects on a visual array following a 2-minute delay. The performance of both groups with right-sided removals, was significantly poorer than left sided removal participants or controls. Crane (2002) then demonstrated that memory for the location of toys in a visual array was poor in adults with significant resections from the right hippocampal region, whether or not anterior temporal lobe removal was also present. Unfortunately, none of these studies compared individual feature memory with bound memory and so do not illuminate whether object and location processes are separated at the hippocampal level, or whether this region is only involved if recalling object and location information together. Kessels, de Haan, Kapelle, and Postma, (2001) shed some light on this issue in a meta-analysis of 27 studies on spatial memory disturbances in adults with hippocampal damage. Subsidiary analysis of a small proportion of studies which examined working memory for objects and locations using visual array tasks, showed adults with hippocampal damage are impaired in remembering occupied positions (location memory) and recall for 'what was where' (object-location memory). However, the effect sizes were larger for the former. This suggests different cognitive processes may support memory for locations and objects in locations.

Summary: The 'What'/ 'where' literature

The discovery of delineated 'what' and 'where' processing at the perceptual and working memory level suggests memory for objects and memory for locations are likely to be distinct entities. Hence, it could be argued that they should be measured separately in research as natural ageing, injury or neuropathology may differentially affect them. The finding that dedifferentiation of 'what' and 'where' processing occurs with ageing also indicates that it may be interesting to measure these aspects of visuo-spatial memory independently. This literature raises the question of whether memory for objects and memory for locations are affected in the same way by processing reorganisation.

Behavioural, neuroimaging and lesion studies indicate dorsal/ventral pathway structures which support perception, along with the prefrontal cortex and hippocampal circuitry, are important in episodic memory for objects and locations (e.g. Halbig et al., 1997; Kessels et al, 2001; Mitchell. Johnson, Raye, Mather, et al., 2000). Therefore, the 'what'/ 'where' literature also raises the issue of whether or not changes that might occur in these structures with normal and non-normal ageing have a detrimental effect on memory for objects and locations.

'What'/ 'Where' Binding

The role of the prefrontal cortex and hippocampus in binding

Researchers agree that memory for 'what was where' is complex. It involves 'binding' together individual feature information about the identity of an item and its location in space, then retrieving this bound information in order to complete navigational and placement tasks (Postma, Izendoorn & de Haan, 1998; Gulya et al., 2002). Visual tests of object-location memory require memory for individual features in terms of what was seen and what areas were filled, as well as processes that associatively bind these pieces of information together (Johnson & Chalfonte, 1994). Yet, little is known about how or when this binding process occurs, or its behavioural outcome at different stages in the human lifecycle (Reinitz & Alexander 1996; Mitchell, Johnson, Raye & D'Espisito, 2000). The nature of bound representations is also not yet known. It may be that features remain separate but associated. Alternatively, they may be combined into a new integral representation that is qualitatively different from the original feature representations (Chalfonte & Johnson, 1996).

More established is that the prefrontal and hippocampal regions are both important in the binding process (Johnson, Hashtroudi & Lindsay, 1993; Shimamura, 1994). It has been proposed that when encoding object-location memories, the prefrontal regions mediate reflective and organisational activities such as rehearsal, semantic judgements or imagery and the attentional working memory processes that trigger, monitor, coordinate and control the purpose of postperceptual binding processes (Gulya et al., 2002; D'Espisito et al., 1995). It is thought that the hippocampus combines different feature information that is coactive in working memory (Kroll, Knight, Metcalfe, Wolfe & Tulving, 1996).

There have been three main theories of the binding role of the hippocampus. The 'Cognitive Map Theory' (O'Keefe & Nadel, 1978, cited in Kessels, et al., 2001) proposed this region is specialised in constructing representational allocentric maps of spatial stimuli. The finding that those with hippocampal damage are impaired on allocentric but not egocentric spatial memory tasks provide support for this theory (Holdstock, Mayes, Cezayirli, Aggleton & Roberts, 1999; Holdstock, et al., 2000). Another proposal is that the hippocampal region is involved in short term working memory in general, rather than having a specialised role in spatial memory (Olton & Papas, 1979). This has received support from a study (Owen, Milner, Petrides & Evans, 1996) that found cerebral blood flow was significantly higher in the right anterior parahippocampal gyrus when adults recognised the position of representational drawings, than when they performed a less effortful task in which they recognised previously presented locations irrespective of the objects in those locations. These findings suggest the hippocampal region is important in the retrieval of bound place and item information in working memory. Further evidence for this viewpoint comes from hippocampal lesion studies in rodents. These have shown that rats are impaired on short term working memory spatial tasks but not long-term spatial memory tasks (e. g. Hunt, Kesner & Goldstein, 1995). A third, and more current explanation of the role of the hippocampal region in binding, is that it integrates separate contextual features of a scene or environment (Chalfonte, Verfaellie, Johnson & Reiss, 1996; Chun & Phelps, 1999; Eichenbaum, Schoenbaum, Young & Bunsey, 1996). In terms of object-location memory this means that identity and location information are processed separately in distinct pathways, then combined later (Johnson & Chalfonte, 1994; Mitchell, Johnson, Raye & D'Espisito, 2000). In this way the hippocampus is not essential for spatial memory that does not require information to be bound together. For example, tasks that only require the recognition of objects or solely the position of stimuli to be remembered would not rely heavily on this region.

Age-related decline in binding

Another fairly well accepted characteristic of binding is that it should show age-related decline. Both the hippocampal and frontal circuitry have been shown to deteriorate in normal ageing (Davis & Bernstein, 1992, Raz, 2000; Selkoe, 1992). Consequently, it has been hypothesised that binding is impaired as a result of disrupted reactivation and associative encoding processes (Chalfonte & Johnson, 1996; Johnson & Chalfonte, 1994). Also, a neuroimaging study by Grady et al., (1995) showed older adults did not show hippocampal activity when encoding faces, a task that could be considered to require the binding of identity and location feature information. However, this region was active when younger adults completed the same task. This study indicates binding may be disrupted at the encoding stage in ageing. This hypothesis was tested in a visual array task that examined younger and older adults' individual memory for object and location information and for combinations of these features (Mitchell, Johnson, Raye & D'Espisito, 2000). Older adults were as able as younger adults to recognise single individual object or location features. However, they showed a deficit in recognising two individual features (object and object, or location and location). Morover, they were even more impaired in memory for two combined features (object and location). The researchers concluded that these results indicated age-related interdimensional (location and object) binding difficulties that occur partly at encoding, alongside a general difficultly accessing or evaluating multiple features or alternatively, intradimensional (objects to objects, and locations to locations) binding difficulties. Interestingly, younger adults also showed a decrement in the intradimensional binding condition compared to two-feature memory. Based on Hasher and Zack's (1979) effortful processing theory, discussed more fully later in this review, this suggests binding is an effortful process that is affected by how people distribute their attentional resources.

Summary: binding with ageing

The literature indicates memory for 'what was where' is a composite of memory for objects and locations and that age-related changes in the prefrontal and hippocampal structures may lead to reflective and associative difficulties, thus detrimentally affecting it. However, considering binding research with the 'what/ 'where' dissociation literature introduces the concept that a person's memory for the object and location features that are to be bound together may contribute to their object-location memory. It is unclear whether memory for 'what was where' is a function of feature memory, binding, or both. Multi-processing accounts of object, location and object-location memory add weight to this issue. These will now be outlined.

Multi-component object-location memory theories

The working memory model

Research data indicating dissociable 'what' and 'where' processes in the perception, encoding and retrieval of object and location information along with binding literature, have resulted in multi-component theories of memory for objects and locations being advocated. The idea of multi-component memory is not new. Baddeley's (1992) working memory model is a classic example of theorists advocating the necessity of dividing memory into its subcomponent modules. This theory proposes the existence of dissociable storage modules for verbal and visual information (D'Espisito et al., 1995). Auditory phonological information is handled by the 'articulatory loop', whilst visuo-spatial information comes under the domain of the 'visuospatial sketchpad'. The information in both is co-ordinated, controlled and monitored by a separate 'central executive system' (Villa, Gainotti, De Bonis & Mara, 1990; Hartley, Speer, Jonides, Reuter-Lorenz & Smith, 2001).

Researchers have now begun to argue that models of working memory should subdivide the visual module further, into material specific subcomponents that independently handle object and spatial information (Postle, Jonides, Smith, Corkin, & Growdon, 1997; Smith, Jonides, Koeppe, Awh, Schumacher, & Minoshima, 1995). They have also begun to question how the nature of these subcomponents may alter with age (Schumann-Hengsteler, 1992). There are few studies that have compared age differences in visual working memory for object and spatial information. Those that have, use different stimuli to test these aspects of memory (e.g., Salthouse, 1995, Tubi & Calev, 1989), making valid comparison difficult. A notable exception was a matching study by Hartley et al. (2001), which moderated the instructions for the different tasks as opposed to the stimuli studied. They found that object and location systems were dissociable, to a lesser extent, in older than younger adults.

An object-location sub-processing theory

In keeping with the idea of subcomponent models of visual memory, Postma and colleagues (Postma, Meyer, Tuiten, van Honk, Kessels & Thijssen, 2000; Postma et al., 1998; Kessels, de Haan, Kapelle, Postma, 2002) outlined a multi-component theory of object-location processing in visual array memory tasks. They argued these tasks consist of several distinct sub-processes. One component is remembering the exact positions occupied in the visual display and thus, involves a process of 'positional reconstruction'. They proposed this process is generally tested by tasks that present the same objects in various locations in the display, and therefore, only require the participant to reconstruct locations. It is thought this component relies on the formation of metric spatial representations, in which absolute locations and the distances between them are encoded. Another component involves associating particular objects with various locations. This component was termed 'object-to-position assignment'. Postma et al. (2000) suggested this might rely on categorical processing of the variety 'the pen is above and to the right of the ball'. It is evident in tasks that present different objects in a display, then, require the allotment of objects to marked locations in the reconstruction phase. It was also speculated that there is a third 'integration' component, in which information about position and the identity of objects in those positions is brought together. This is theorised to occur in tasks in which multiple different objects are relocated in positions in unmarked space.

There is some preliminary evidence to support the separation of these hypothesised processes, although few studies have included older adults in their sample groups. Postma and de Haan (1996) examined the ability of undergraduate students to relocate objects, their positions, or both on a visual array. Increasing the number of objects in the display and articulatory suppression did not effect positional encoding, but detrimentally affected object-to-position assignment. In contrast, it has been shown that increasing the size of the relocation space detrimentally affects positional encoding but not object-to-position assignment (Postma & de Haan, 1995). Moreover, Kessels et al. (2000) found a double dissociation in adults who had intracranial tumour resections. Some were impaired at positional memory, others object-to-position assignment and others at an integration task. Support for at least two dissociable processes is also available from studies comparing gender differences of young adults on object-location tasks. It has been demonstrated that females perform equally as well as males on object-to-position assignment tasks and integrated object-position tasks, but perform less well on positional reconstruction tasks (Postma et al., 1998). It has also been shown that older children are better than younger children at remembering the positions of specific objects, but not at just remembering positions (Schumann-Hengsteler, 1992).

In light of multi-component visual memory and object-location theories, recent literature has begun emphasising the need for future visual array memory studies to measure memory for objects, locations and objects in their locations separately (Postma & de Haan, 1996; Gulya et al., 2002). The importance of such research will be considered in relation to existing age-related research of memory for objects and locations.

Ageing And Memory for Objects and Locations

Object-location memory decline with ageing

Normal ageing is associated with selective decline in different aspects of cognitive functions, including memory (O'Sullivan et al., 2001; Erickson & Barnes, 2003; Dror & Kosslyn, 1994). Explicit memory is particularly vulnerable to age-related decline (Kausler, 1994; Spencer & Raz, 1995).

Within this broad category, visual episodic memory tested by either recall or recognition paradigms, appears to diminish earlier and more rapidly than verbal episodic memory (Lezak, 1995). Visuo-spatial memory, in particular, declines with normal ageing (Glosser, Goodglass & Biber, 1989). Research that has directly examined the affect of ageing on memory for objects and locations is limited (Simon et al., 1992). Those studies that have measured this have done so in a number of ways. Although tasks used with older adults have largely required the reconstruction of the location of multiple different objects that were studied in a prior learning phase, methodological variations between studies make comparisons of their results difficult. Visual array studies have varied considerably in: the presentation times of arrays; the number of objects and locations presented together at one time; the total number of critical loci to be remembered; whether objects are line drawings, photos or actual objects; whether they test absolute spatial memory or categorical memory, and whether recall or recognition memory have been tested (Schumann-Hengsteler, 1992; Postma & de Haan, 1996).

As a general rule, early studies looking at explicit recognition or recall memory for objects and their spatial locations demonstrated age-related decline (e.g. Light & Zelinski, 1983; Cherry & Park, 1989; Pezdek, 1983). Visual array studies have shown object-location memory to be impaired in older adults if reconstruction is delayed. For example Flicker, Bartus, Crook, & Ferris (1984) found older adults were as able as younger adults to recall which room of a 25 room house was lit when recall was immediate, but were relatively impaired when a delay was introduced. Likewise, age-related impairment was discovered by Malec, Ivnik and Hinkeldey (1991) who asked adults aged 16 to 92 to learn the positions of different designs on a matrix and recall this information after a 30-minute delay. Older adults have also been shown to be impaired in object-location navigation tasks (e.g. Uttl & Graf, 1993; Wilkniss, Jones, Korol & Manning, 1997; Newman & Kaszniak, 2000). Uttl and Graf, (1993) compared the ability of 15 to 74 year olds to navigate their way through a museum and remember the layout of objects. They found age-related decline became apparent from age 60 onwards. Similarly, Newman & Kasniak (2000) found older adults were impaired relative to younger adults at remembering the location of it targets in a large tent construction.

Age-related object-location memory impairment has been demonstrated under both intentional and incidental learning conditions, although it is debated which of these conditions results in the greatest deficit. For example, Park, Puglisi, and Sovacool (1983) found that older adults memory for the section in which pictures of objects or names of objects had appeared on a screen was equally poor under both conditions. However, a meta–analysis of age-related spatial memory research (Spencer & Raz, 1995) concluded that object-location impairments are more pronounced under intentional learning conditions. There are, therefore, a number of studies that suggest older adults' memory for objects and their location in space is impaired.

Decline as a function of what is measured and how

Age-related decline in memory for objects and their locations has not always been found. Studies with more intricate designs have highlighted that age-related performance is a product of what is measured and how. This phenomenon is apparent in a large proportion of the early age-related literature that was concerned with the influence of context on memory for items in visual scenes. This body of research suggested the relationship between age and performance on object-location memory tasks is not as straightforward as one of general decline. Waddell and Rogoff (1981) showed that older adults experienced difficulties recalling object-location information when items were not meaningfully arranged, but that age-related differences were small when scenes were organised in a meaningful way. Similarly, Zelinski and Light (1988) found older adults' object-location memory was poor when measured using a blank background, but age-related decline was ameliorated when they learnt the location of items on 'maps' that were marked with streets. Both age groups were better at remembering the location of items on street maps. Performance was equal in this condition, but poorer for older adults in the non-context condition. Sharps and Gollins (1989) also found that age-related differences in the free recall of objects in space were reduced when contextual information was available. In this study, participants were presented items as a list so that no visual contextual cues were available, on a visually bland black and white map, or on a visually distinctive coloured map.

Contextual object-location studies, therefore, suggest deficits in older adults' object-location memory can be ameliorated under certain circumstances and may be influenced by working memory resources. Some have argued that findings of contextual amelioration support Craik and Lockhart's (1972) levels of processing (LOP) model. This argument is based on the reasoning that contextual cues enable a deeper level of processing for older adults (Hartley et al., 2001; Park, et al., 1990). It could also be argued that this phenomenon supports processing models that propose changes in attentional or working memory capacity, have the potential to negatively affect memory (Zacks & Hasher, 1988). In particular, lower retrieval capacity could make older adults more likely to rely on automatically activated association networks (Hess & Slaughter, 1990). These conclusions are tentative, however, since although age-related object-location memory deficit is normally demonstrated, contextual facilitation has not always been found. For example, Pezdek (1983) found contextual organisation benefited younger adults to a greater extent than older adults in recalling and accurately relocating pictured objects on a matrix. Also, Cherry and Park (1993) asked younger and older adults to reconstruct an arrangement of everyday objects that had been presented on a plain surface or in a three dimensional model. They found that distinctive context improved spatial memory equally in both groups. Individual differences in working memory accounted for a large proportion of the age-related variance in spatial location memory.

The models of processing influence

The effortful processing theory (Hasher & Zacks, 1979) and the level of processing theory (Craik & Lockhart, 1972) have both been influential in guiding and interpreting the object-location memory research reviewed above.

The effortful processing theory

Hasher and Zacks' (1979) theory of effortful processing has influenced most studies of memory for objects and locations, in some way. This theory categorises encoding activities into 'automatic' or 'effortful' processes based on the degree of cognitive or attentional resources necessary to encode available information (Zacks & Hasher, 1988). It was proposed that the performance of a task gets poorer the more cognitive effort it requires. The characteristics of an effortful task are that it: excludes the possibility of someone consecutively performing another effortful task; performance improves with practice; more specific instructions aid performance; there is an age or intelligence related impairment in performance; and, a variation in performance can be demonstrated across individuals (Giraudo et al., 1997). Object-location studies have distinguished between effortful and automatic processing by debating whether location is an automatically encoded feature of stimuli (e.g. Schumann-Hengsteler, 1992; Arias, 1999). In a study that directly set out to determine this, Shadoin and Ellis (1992) found the ability of undergraduates to relocate the photographs of objects in their studied positions decreased as the size of the matrix increased. Recognition of the photographs was unaffected. The researchers concluded this meant location memory was an effortful process.

In relation to ageing, Hasher and Zack's (1979) theory means that variations in people's memory for positional information would not show age-related decline. Rohling, Ellis and Scogin (1991) supported this conclusion, when they discovered that the ability of younger and older adults freely to recall and recognise the location of items in a picture book was similar. However, in a recent meta-analytic review of effect sizes in 72 independent samples that examined memory for spatial information, Arias (1999) found age significantly affected location memory, hence implying location encoding is effortful. Discrepant findings about the effort of encoding location may be a product of methodological differences. Furthermore, location memory has usually been tested when bound with object information and not in a pure manner. Thus, if object memory is an effortful process, the finding of whether or not location is an automatically encoded feature may rely on the degree to which object recall co-varies with location recall in the experimental task.

The levels of processing theory

Craik & Lockhart's (1972) levels of processing (LOP) theory proposes different types of processing at the time of encoding produce differences in subsequent memory performance. It postulates that episodic memory traces are records of processes that were executed to aid perception and comprehension and consequences of the elaborateness of cognitive processing activities. Processing activities range from initial sensory processes to later, more intricate, associative semantic and imagery processes (Vincent, Craik & Furedy, 1996). In parallel, the resultant durability of the encoded memory trace is an outcome of the 'depth' of processing of the learning event. Information about events and stimuli that are not fully attended to and only processed at a preliminary sensory level is stored in 'shallow' and fleeting memory traces. Stimuli that are fully scrutinized and enriched by semantic associations or images are encoded more deeply and are longer lasting (Craik & Tulving, 1975). Nyberg (2002) found support for this theory using functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET) technology. He demonstrated that some of the same sensory areas activated in initial perception were also activated at retrieval. Also, it was shown that activity in frontal and medial-temporal areas are related to the depth of processing, as indicated by the level of memory performance.

LOP theory has been used as a framework for accounting for age-related memory decline by those who argue reflective encoding and retrieval processes are disrupted in older adults and so information is not processed as deeply as in younger adults (Kausler, 1994).

The new phase of age-related research

A growing criticism of the age-related studies reviewed, is that they do not adequately measure 'what' and 'where' components of memory (e.g. Chalfonte & Johnson, 1996; Gulya et al., 2002). In view of the 'what'/ 'where' and binding literature, plus multi-component theories of object-location memory, this would seem a valid criticism. A small number of studies show that when identity and location information are measured separately, age-related decline is not inevitable, even if impairment was apparent when they are tested in a bound (i.e. object-location) condition. In an effort to measure object and object-location memory separately, Park et al., (1990) examined the ability of younger and older adults to remember the names of 40 household objects arranged on a plain background, black and white schematic map, or three-dimensional coloured model. To examine object memory, participants freely recalled the names of items that had been pointed to by the researcher. Object-location memory was tested by asking participants to place objects on the backgrounds in the positions where they recalled the items being in the study phase. Object memory was poorer in the older adults in all conditions and comparatively better than object-location memory for both age groups. Both groups were facilitated by context in the object-location task. These results imply object and object-location memory are differentially affected by ageing and contextual elaboration. However, this conclusion is limited because the study did not compare individual object to location memory and both of these to object-location memory. A similar limitation is seen in a study by

Puglisi, Park, Smith and Hill (1985). This compared the ability of older and younger adults to remember the location of objects in an array (i.e. bound object-location memory) and location memory for the occupied and unoccupied spaces. Age-related decline was apparent on both location and object-location memory, but the study design was uninformative about how object memory compared to location or object-location memory.

Age-related studies that measure explicit memory for objects, locations and objects in locations are a relatively recent development. A pioneering study by Chalfonte and Johnston (1996) examined younger and older adults' recognition memory for the identity and location of drawings on a spatial array. It was found that older adults were significantly poorer than young adults at remembering location information, but memory for identity was similar. Also, object-location memory for which features go together was poorer than memory for individual features, in older participants. However, a study that directly compared object and location memory components did not find poorer location memory in older adults. Das and Agarwai (2000) contrasted the deterioration of memory for objects versus their locations using a self-report inventory. They found older adults were poorer at remembering specific objects, but were as able to remember the location of an object. Even though these results are contradictory, they indicate that older adults have separable deficits that differentially contribute to difficulties with complex memories. Therefore, they support the call for separating feature memory and binding in future research.

The limited multi-component research to date suggests it is possible that early studies that demonstrated the existence of a deficit in older adults' memory for objects and their positions (e.g. Light & Zelinski, 1983; Puglisi et al., 1985; Park et al., 1983; Pezdek, 1983) may have done so because of a binding deficit. However, they also suggest that impairment in memory for 'what was where' may also have been a result of feature memory deficits. Unfortunately, as with cross study comparisons in early object-location memory studies, methodological differences in later multi-component studies make firm conclusions about subcomponent functioning in ageing difficult. However, they still have the potential to influence our understanding of memory for objects and locations.

Summary: age-comparative studies

An overall view of the visual array literature suggests age-related differences might depend on both age and the characteristics of a task. Simone and Baylis (1997) suggested the findings of object-location memory studies might not be as contradictory as they first appear, if different aspects of the nature of the testing paradigms, and consequently, different aspects of processing are taken into consideration. Ageing is known detrimentally to affect attentional processing (D'Espisito et al., 1995) and possibly elaboration or self-initiated processing activities at encoding (Craik & Jennings, 1992; Park et al., 1990). Therefore, based on Hasher and Zack's (1979) processing theory, it has been argued that age-related memory deficits for objects and locations may be more apparent on tasks with high attentional demands, or which necessitate the effortful reconstruction of encoded materials during the test phase (Cherry & Park, 1993). In terms of ameliorating deficit, based on the LOP theory, introducing aspects to a learning task that intrinsically encourage elaborative processing without raising the effort of the task, might reduce age differences.

The research reviewed suggests that feature memory as well as combined object-location memory may be vulnerable to age-related decline. Given this literature it seems a statement by Gulya et al. (2002) that, "because explicit memory typically reflects a composite of different features, age-related changes in explicit memory will not necessarily correspond to the function for any single one" (pp. 276), is pertinent in relation to memory for 'what was where'. Future research is needed to tease apart the behavioural outcomes of ageing on the different components of memory for objects and locations and to establish whether apparent age-related deterioration is a result of impaired memory for individual features, the binding of these features, or both. Such issues could have a number of clinical implications, which will now be discussed.

Applying Age-Comparative Research

Clinical reasons for further age-comparative research

Intact explicit object-location memory enables us to navigate around our environment and to find objects in space (Alexander et al., 2002). If this cognitive function deteriorates markedly, for example with natural ageing or age-related illness, a person could encounter severe difficulties in finding their way around their own home or community, or may frequently misplace important items. Thus, complex memory for what is where is an important aspect of independent functioning in daily life that is threatened by ageing (Chalfonte & Johnson, 1996).

Future research looking closely at object and location feature memory versus bound memory in healthy and non-healthy ageing adults is, therefore, an important step towards better understanding the dissolution, and in turn the amelioration, of memory for where things are. Through a better understanding of the impact of ageing and age-related illnesses on each of these components, it may be possible to devise supportive interventions to overcome distressing object-location memory deficits that potentially threaten independent living in older adulthood. The idea of using supportive memory strategies with older adults to reduce the impact of difficulties on daily living is not unusual and commonly used in clinical practice (Wilson, 1997; Clare, et al., 2000).

The levels of processing paradigm may provide a solid base to work from when devising supportive learning strategies for object/location information. Based on this theory, if an activity that encourages more elaborative encoding can be incorporated into the learning of object and location information, then the memory trace will be more durable. In this way, memory for objects, spatial positions and objects in their locations may be improved. Furthermore, the literature reviewed suggests that 'what'/ 'where' processing becomes dedifferentiated with ageing and compensatory domain-general mechanisms are recruited during visuo-spatial tasks to bolster performance. Thus, it may be possible to incorporate activities at the learning stage that have a different neural base to compensate for deterioration of visual 'what' and 'where' structures. In this way domain-specific learning is bypassed and cross modality domain-general learning is introduced.

Amelioration through deeper encoding

Craik and Tulving (1975) tested the LOP prediction that greater semantic processing at encoding would confer an advantage over shallower processing in explicit retrieval tasks. In this study healthy adults made judgements about the meaning, sound, or physical characteristics of a word under both recall and recognition conditions. Judgements about meaning resulted in superior performance than sound judgements, which in turn conferred an advantage over physical judgements. Similarly, Hyde and

Jenkins (1976) found that processing the meaning of words resulted in better recall of a list of words than either processing their syntax or orthography. This finding of semantic supremacy over perceptual processing in explicit memory has been replicated many times since these early studies, and is viewed as the standard LOP effect (e.g. Bentin, Moscovitch & Nirhod, 1998; Bodner & Lindsay, 2003). Recent studies have also highlighted self-referent processing as promoting deeper encoding that is comparable to, or even better than, semantic processing. For example, Challis, Velichkovksy, and Craik, (1998) demonstrated this in a free recall and a recognition paradigm when they asked undergraduate students to encode words graphemically through a letter-search task, phonologically by counting the syllables in words, semantically by making living/non-living judgements, or with self-reference by judging their relevance to themselves. Performance was better in both paradigms under conditions of self-referent and semantic processing.

In terms of ameliorating object-location memory impairment in natural ageing or age-related illness, these studies imply that activities at encoding that result in semantic or self-referent processing could possibly bolster retrieval. There are many ways in which semantic or self-referent processing could be incorporated into object-location learning. For example, individuals could generate a description of its meaning, decide what context it should be categorised under, make judgements about the degree of pleasure an object brings them when they use it, or the usefulness of an object to them in their daily life.

Amelioration through motor encoding

The literature examining visuo-motor learning offers one interesting perspective from which to begin exploring the possibility of amelioration and compensation through the promotion of deeper encoding. Visuo-motor learning involves learning a motor response to a particular visual stimulus (Lezak, 1995). Although by definition it shares features with visual perception, it has been argued that it necessitates more extensive higher order processing than visual learning and has a different neural substrate (Senkfor, Van Peten & Kutas, 2002). To perform an action with a perceived object, additional features including devising action goals, generating appropriate action programmes and acting upon sensory feedback are necessary (Roche & O'Mara, 2003; Senkfor et al., 2002). In terms of the LOP theory this would mean that more elaborative encoding is achieved when the stimulus is processed through vision and motor modalities, resulting in a deeper and more durable memory trace being formed. If this concept is specifically applied to object-location memory, this could mean that learning the identity of objects and their spatial layouts through a goal directed visuo-motor task would be superior to learning them through visual perception alone.

Dementia-related implications

It is possible to extend the arguments developed in this review to some clinical populations. Object-location memory impairment is often very prominent in dementia-related illnesses, which commonly occur in older adulthood, including Alzheimer's and Parkinson's disease (Tales et al., 2002).

Those with Alzheimer's disease commonly misplace objects (Bucks & Willison, 1997), and have difficulty finding their way around familiar and unfamiliar places (Passini, Rainville, Marchand, Joanette & Lepage, 1997). Sahgal et al., (1992) found that Alzheimer participants in the moderate stages of the disease were significantly poorer at remembering the location of white squares on a screen than those in the mild stages. In turn, more mildly impaired participants were poorer than age-matched controls. Participants also tried to find tokens hidden behind squares to test positional reconstruction. The same deficit was found. These results suggest location and object-location memory deficits are apparent in the early stages of Alzheimer's disease and increase with the progression of the illness. Furthermore, it could be speculated that hippocampal damage in early Alzheimer's disease could result in object-to-position assignment difficulties, whilst later parietal damage could lead to difficulties with positional recognition (Nagy et al., 1999). However, because these studies did not measure the attention and concentration skills of participants, it is not possible to exclude the possibility that deficits in these areas were confounding object/location performance. Future research may benefit from better controlling for these factors or alternatively performing correlational analysis between attention/concentration and object/location dependent scores.

The main site of neuropathology in Parkinson's disease is the frontal lobes with the striato-frontal region, in particular the basal ganglia, being affected in the latter stages (Pillon et al., 1997). Therefore, those with Parkinson's disease could also show deficits in integrating location and object information. Giraudo et al. (1997) conducted one of only a few studies that has specifically measured memory for objects and locations in Parkinson's disease. They asked adults with Parkinson's disease, healthy older adults and younger adults to learn then reproduce the layout of places labelled on a map. They also learnt and reproduced the location of black dots. The participants with Parkinson's disease were less accurate than the other groups in the less effortful dot condition, and both groups of older adults were impaired in the map task compared to younger adults. These findings indicate location and object-location memory are impaired in those with Parkinson's disease.

It may be that memory deficits in Alzheimer's and Parkinson's disease are an amplification of the types of deficits that occur in normal ageing. The consequence of this would be that activities that are effective in ameliorating age-related decline might also be affective in ameliorating dementia-related decline. Alternatively, they may be a product of qualitatively distinguishable sub-processing changes. Hence, a different approach would be needed to support memory for objects and their locations in these clinical populations. More research is needed to investigate this. However, until we better understand normal age-related changes in the different components of memory for 'what was where' it is difficult to answer this question, as there is no established baseline with which to compare these changes.

If an age-related baseline of subcomponent performance was established, it may be possible to devise a clinically useful tool for the early detection of abnormalities, differential diagnosis, and measuring treatment effects. Visual array tasks that separately measure memory for individual features, as well as combined features, in younger and older adults may provide important information for producing such a baseline. Furthermore, if the theoretical underpinnings of memory for objects and locations was better understood, then memory tasks could be devised that have both good discriminate validity and are ecologically valid.

Currently available neuropsychological tests of visuo-spatial memory have been criticised for being too abstract, too verbal, and heavily reliant on good fine motor dexterity (Davies, 1996; Sahgal et al., 1992). It has also been argued that older adults, who are unlikely to previously have encountered standardised neropsychological testing formats, may view these tests as ridiculous, or as bearing little relation to their everyday problems of getting lost or losing important items (Crook, Youngjohn & Larrabee, 1990; Davies, 1996). It is likely to have been these problems that brought them to Psychology in the first place. Such a view is likely to undermine their motivation for testing, or invoke anxiety that may detrimentally affect the test results. Some have recognised these criticisms and made efforts to devise theoretically driven object-location tasks that do not require good dexterity and have good face validity, whilst being sensitive to brain dysfunction. The Location Learning Test (Bucks & Willison, 1997) and Misplaced Objects Test (Crook, et al., 1990) are two such examples. However, even these relatively user-friendly tasks only test memory for 'what was where' and, therefore, do not reflect the 'what'/ 'where' dissociation and binding literature or multi-component object/location theories. Visual array tasks that separately measure object, location and object-location memory have a certain degree of face validity, and hence may provide a format that could be used for neuropsychological testing. Future research would be needed to develop such tests that would also be reliable and have good discriminative validity.

Summary: clinical applications

Age-comparative multi-component research has clinical implications in terms of baseline measurement and treatment. Firstly, it may develop clinician's theoretical understanding of memory for objects and locations in normal ageing. This could be used to assess whether a client's presenting complaints or difficulties on visual array task are beyond what would be expected for their age and, therefore, require intervention. Secondly, theoretical advancement may highlight avenues for such intervention. The LOP theory and current visuo-spatial literature suggest one method may be to incorporate activities that encourage deeper encoding, such as goal-directed physical manipulation, into learning. These issues may be particularly pertinent to those with probable

Alzheimers' or Parkinson's disease, who have been shown to have difficulties with location and object-location memory.

Conclusion

This review examined the literature about the processing of object and location information and older adults' memory for such information. It also examined how apparent decline in this function may be ameliorated by facilitating more elaborative processing of object/location information at encoding, for example by incorporating motor movement into the learning paradigm. It then went on to discuss how future research of older adults' memory for objects, their locations, and objects in their locations could inform clinical practice with those with Alzheimer's or Parkinson's disease.

The review has highlighted the existence of dissociable 'what' and 'where' visual and working memory systems alongside evidence that these two types of information are somehow bound together by the fronto-hippocampal circuitry. The literature suggests: this circuitry becomes less efficient with ageing; that the 'what'/ 'where' dissociation is disrupted in older adults, and that there is behavioural evidence that older adults are impaired relative to younger adults at remembering objects in their locations on visual array tasks. Thus, it would seem at first glance that provided research orientated visual array tasks are valid predictors of object-location memory in everyday life, misplacing objects or losing the way in familiar environments is an inevitable consequence of cognitive decline with ageing, as is the distress and loss of independence that accompanies such deficits. However, the literature also indicates the presumption of object-location memory decline in ageing is possibly premature. This is suggested in: the call to separate visual working memory into object and spatial subcomponents; Postma and colleagues (Postma & de Haan, 1996; Postma et al., 2000) sub-processing theory of performance on visual array tasks; findings in the contextual literature that performance on object-location memory tasks is a product of the characteristics of the learning paradigm as well as age, and demonstrations that when memory for objects, locations and objects are tested separately they are differentially affected by age. Further research is needed to separate these components and consider their relationship with ageing. Such research would help establish a clearer theoretical understanding of the nature of memory for objects and locations and how this changes in the older adult. This, in turn, would provide a foundation for devising clinically informative neuropsychological tools for measuring object-location memory performance and for designing targeted interventions to ameliorate age-related decline in those areas worst affected.

The LOP literature suggests a number of activities at encoding could promote better memory for objects and their locations. For example, the visuo-motor literature suggests that motor learning has a different neural basis to visual learning and necessitates higher order and thus deeper processing.

Therefore, the 'active' learning of objects and their spatial arrangements may be superior to 'passive' visual learning, because this would result in more elaborative encoding of identity and spatial information. If this were found to be the case it may be possible to use this knowledge clinically to ameliorate age-related or even dementia-related difficulties in remembering where things are. However, this amelioration hypothesis is speculative. Thus, future research is needed to validate its predictions.

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AGEING, MOTOR ENCODING AND MEMORY FOR OBJECT LOCATIONS

Shortened title: Ageing, encoding and object locations

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AGEING, MOTOR ENCODING AND MEMORY FOR OBJECT LOCATIONS

Abstract

This study examines whether younger and older adults' memory for objects, locations and objects in their locations differs. It also compares these types of memory when information is learnt through visual and motor modalities (active encoding), and visually only (passive encoding). It uses visual arrays of everyday objects to test memory for objects and locations. The results indicate that generally both object recognition and location recall were better when learnt as individual features and not in combination. With regards to ageing, younger adults object memory is superior to older adults when learnt as an individual feature and when bound with location information. Younger adults recall of locations is also better than older adults whether it is learnt as an individual feature or bound with object information. It was found that visual encoding was either superior or equal to visuo-motor encoding for all memory components, although visual encoding supremacy was more apparent for younger adults under some circumstances. There were no interactions between age, memory task and/or encoding condition. These findings are discussed in relation to previous studies of memory for objects and locations and theories of visual and motor processing. Limitations of the study are also highlighted and areas for future research outlined.

Keywords: differential deficits; binding; amelioration; visual arrays.

Introduction

Object-location memory

Object-location memory is memory for what object was where (Postma & de Haan, 1996). It is often measured by asking people to remember the location of different items on a visual array (e.g. Gulya et al, 2000; Mecklinger, 1998; Crane, 2002; Postma, Izendoorn & de Haan, 1998). In daily life, it enables someone to navigate their way around their environment or find objects (Alexander, Packard & Peterson, 2002; Kessels, de Haan, Kapelle & Postma, 2001). Thus, if it deteriorates markedly, for example through natural ageing or age-related illness, a person could experience severe difficulties finding their way around their own home or community, or may frequently misplace important items (Bucks & Willison, 1997). Such problems can be distressing and threaten independent living (Pearlin, Harrington, Powell-Lawton, Montgomery & Zarit, 2001).

'What' and 'where'

The perceptual system processes information about 'what' an object is through a 'ventral' pathway. This projects from the occipital lobes in the visual cortex to the inferior temporal cortex (Sala, Rama & Courtney, 2002; Deco & Lee, 2002). Spatial 'where' information and goal directed movements towards objects, is processed separately by the 'dorsal' pathway, which projects to the posterior parietal cortex (Coello, Richaud, Magne & Rossetti, 2003; Duebel & Schneider, 2001). However, this dissociation appears to become dedifferentiated with ageing, with this phenomenon having been explained in terms of reduced pathway efficiency and neuronal compensation (Chen, Myerson & Hale, 2002; Alexander, Packard & Peterson, 2002).

Behavioural, lesion and neuroimaging studies indicate the delineation of 'what' and 'where' processing is also apparent post-perception in visual episodic working memory (Tresch, Sinnamon & Seamon, 1993; Mecklinger, 1998; Kessels, Postma, Kappelle & de Haan, 2000). However, as with perceptual processing, de-specialisation occurs with ageing; cortical activation becomes less domain-specific, with domain-general compensation occurring through the prefrontal and premotor cortices (Schiavetto, Kohler, Grady, Winocur & Moscovitch, 2002).

The 'what'/'where' literature, therefore, suggests object and location memory are independent material specific components whose nature of processing probably changes with ageing (Postle, Jonides, Smith, Corkin, & Growdon, 1997; Schumann-Hengsteler, 1992). This raises the question of whether such changes are reflected in older adults' ability to remember objects or locations. There has been little age-comparative behavioural research directly comparing memory for objects versus locations. Two studies that exist agree that at least one of these types of memory is impaired, but disagree on which (Chalfonte and Johnson, 1996; Das & Agarwai, 2000). This may be a result of methodological differences. Although relative ability between object and location memory cannot be established by these studies, they do suggest that different cognitive processes underlie these two types of memory. The majority of research on memory for objects and locations has focussed on measuring the impact of ageing on memory for 'what was where' (e.g. Malec, Ivnik, Hinkeldey, 1991; Cherry & Park, 1993; Cherry & Park, 1989); that is, object and location feature information that has been combined.

'What was where'

Memory for 'what was where' (object-location memory), involves the binding together of separate 'what' and 'where' information, probably at encoding (Gulya et al., 2000). It is thought the hippocampal and prefrontal regions are heavily involved in this process (Crane, 2002; Milner, Johnsrude & Crane, 1997). Both these regions deteriorate in normal ageing, and also with the progression of some dementia-related illnesses (Raz, 2000; Selkoe, 1992; Nagy et al., 1999; Pillon et al., 1998). Consequently, it has been hypothesised that binding, and hence object-location memory, should be impaired in older adults (Chalfonte & Johnson, 1996; Johnson & Chalfonte, 1994). This is supported by visual array studies that have generally demonstrated normal age-related decline in object-location memory (e.g. Flicker, Bartus, Crook & Ferris, 1984; Light & Zelinski, 1983; Malec et al., 1991). Deficits on object-location memory tasks have also been found in participants with Alzheimer's and Parkinson's disease (Sahgal et al., 1992; Giraudo, Gayraud & Habib, 1997).

However, it is unclear whether memory for the features to be bound together ('what' and 'where' information) contributes to the proposed object-location binding deficit in older adults. The 'what'/ 'where' literature and findings that older adults are impaired at recognising two individual but unbound features (object and object, or location and location) as well as bound features (Mitchell, Johnson, Raye, Mather & D'Espisito, 2000) suggest this could be the case.

Multi-component research to date

Despite the 'what'/ 'where' dissociation and feature binding literature, few age-comparative studies have measured object and location memory in their own right and compared them to bound memory. This shortfall has resulted in a plea for research that measures all three types of memory separately (Gulya et al., 2000; Schumann-Hengsteler, 1992). However, this call has gone largely unanswered. Furthermore, there have been no studies comparing the effect of healthy and non-healthy ageing on these different components of memory.

The multi-component age-comparative studies that do exist have tended to measure only one type of feature memory (object or location) and compared it with object-location memory. Hence, the conclusions that can be drawn from them are limited. However, together they indicate that: object-location memory is impaired in older adults, as is location memory to a lesser degree;

object memory is possibly less impaired in ageing than location memory, and feature deficits (i.e. impaired object or location memory) are not inevitable even when object-location memory is impaired (Park, Cherry, Smith & Lafronza, 1990; Puglisi, Park, Smith & Hill, 1985; Chalfonte & Johnson, 1996; Das & Agarwai, 2000).

These initial studies indicate that object-location memory impairment in older adulthood is likely to be more complex than a simple binding-deficit theory suggests. It seems it may be a result of some degree of feature impairment as well as binding difficulties. Multi-component research that uses a methodology that enables direct comparisons to be made between all three components is needed to explore this possibility further. This assertion is strengthened by the development of a sub-processing theory of visual array tasks by Postma and colleagues (Postma, Meyer, Tuiten, van Honk, Kessels & Thijssen, 2000; Kessels, de Haan, Kapelle & Postma, 2002). In keeping with the 'what'/'where' distinction and binding theory, it proposes that three distinct processing components are involved. One process is 'positional reconstruction'. This involves remembering the exact metric positions occupied in space (location information). Another process is 'object-to-position assignment'. This involves the relational association of particular objects in the form the pen is below and to the right of the ball (object information). The third process is 'integration' of the other two (object-location information). This involves the binding together of information about positions and the identity of objects in those positions. However, this theory has been developed through studies involving younger adults (e.g. Postma &

de Hann, 1996; Postma et al. 1998). Hence, future research is needed to establish its applicability to older adults.

Clinical applications

Future age-comparative research separately measuring object, location and object-location memory in healthy adults may make it possible to establish a normative age-related baseline for use in detecting abnormalities in ageing, aiding differential diagnosis, and monitoring treatment effects. Also, it could be investigated whether visual array tasks are flexible and reliable enough to have diagnostic utility. Furthermore, object-location memory deficits in Alzheimer's and Parkinson's disease may be an amplification of the types of deficits that occur in normal ageing. Consequently, activities that are effective in ameliorating age-related decline might also be effective in ameliorating illness-related decline. Alternatively, they may be a product of qualitatively distinguishable sub-processing changes and, hence, a different approach would be needed. However, until we better understand normal age-related changes across these different memory components, it is difficult to answer this question.

Ameliorating decline

If, as the limited current research suggests, the three aspects of object/location memory may be differentially impaired in older adults, a related issue is how we might ameliorate decline in each of them. This is an important question in terms of easing distress and promoting independent living. Age-comparative research examining the influence of context on object-location memory provides some insight on this matter (e.g. Sharps & Gollins, 1989; Zelinski & Light, 1988). This research suggests if the characteristics of a task can be manipulated to enable a deep level of processing at encoding, then age-related object-location impairment can be attenuated (Hartley, Speer, Jonides, Reuter-Lorenz & Smith, 2001; Park et al., 1990; Kausler, 1994). This explanation is consistent with Craik & Lockhart's (1972) levels of processing (LOP) theory. This postulates that information is better remembered if it is processed more deeply at encoding. Deeper encoding is characterised as involving a high degree of elaborate semantic and imagery processing (Vincent, Craik & Furedy, 1996; Craik & Tulving, 1975). Studies testing the predictions of the LOP theory have supported its claims (Bentin, Moscovitch & Nirhod, 1998; Bodner & Lindsay, 2003). They have also found that generally self-referent processing can produce durable memory traces (Challis, Velichkovsky & Craik, 1998).

With regards to age-related or dementia-related decline in memory for objects and locations, the contextual and LOP literature suggests amelioration might be achieved by learning this information through activities that promote a high level of semantic and/or self-referent processing. The visuo-motor literature offers one interesting perspective from which to explore this possibility.

Amelioration through motor encoding

The visual and motor systems share a common input from early vision, but have different neural substrates, with the motor system not relying heavily on the hippocampal region (Coello et al., 2003; Jeannerod, 1994). This neural distinction has been supported by lesion studies demonstrating that motor learning and preparations for object manipulation can remain intact even when visual learning and object recognition are compromised (e.g. Goodale, Milner, Jakobson & Carey, 1991). Hence, compensatory domain-general processing on episodic object-location tasks may be possible by using motor modalities to by-pass compromised domain-specific visual learning.

Also, although visuo-motor learning shares features with visual perception, it necessitates greater higher order processing than visual learning. To perform an action with a perceived object additional features, including devising action goals, generating appropriate action programmes and acting upon sensory feedback are necessary (Roche & O'Mara, 2003; Senkfor, Van Peten & Kutas, 2002). Therefore, it seems a greater degree of semantic and self-referent processing is undertaken when objects and locations are processed through visual and motor modalities, as opposed to visual means alone. Hence, it would be expected that memory should be superior under these circumstances.

Debating visuo-motor supremacy

There has been no research examining whether visuo-motor encoding is more advantageous than visuo-perceptual encoding for any aspect of memory for objects and locations. The motor-amelioration in ageing hypothesis is therefore appealing, but speculative.

The hypothesis is supported by a small number of object recognition and virtual environment navigation studies with young adults. These studies demonstrated that memory for objects and for a spatial layout is improved if an element of self-performed interaction with the to-be-remembered information occurs at the learning phase (e.g. Lawrence, Cobb and Beard, 1978; Brooks, Attree, Rose, Clifford and Leadbetter, 1999). These advantages were explained by the authors in terms of active learning providing more elaborative information and leading to a deeper level of processing. Unfortunately, there have been no studies of a similar nature with older adults and so these findings should be generalised to this population with caution.

The hypothesis is disputed, however, by emerging evidence that the perception or maintenance in working memory of information about objects that can be manipulated, activates common neural mechanisms to action generation. For example, under such circumstances activation occurs in the left ventral premotor cortex and anterior intraparietal suclus, which are thought to mediate the conversion of object properties that inform appropriate movement to and with them into hand activities (Mecklinger, Gruenewald, Besson, Magnie & Von Cramon, 2002). Furthermore, imagined and performed actions both produce brain activity in the premotor, supplementary motor areas (SMA) and inferior parietal cortex, although the primary motor cortex is involved to a lesser extent in imagined actions (Binkofksi et al., 2000; Rizzolatti, Fadiga, Gallese & Fogassi, 1996; Cunnington, Iansek, Gradshaw & Phillips, 1996). Such findings indicate that incorporating actions into object/location learning may not improve performance. This would be because visual processing alone may lead to motor representations or programmes for manipulation, even when there is no actual physical interaction with the to-be-remembered information (Grezes & Decety, 2001). Again, however, this research has focused on younger adults and should, therefore, be applied to the motor-amelioration in ageing debate with caution.

Some age-comparative literature does exist that has a bearing on the debate. However, it opposes the argument that visuo-motor encoding will confer an advantage over visual learning. Even on simple motor tasks, older adults show different patterns of activation to younger adults in the sensorimotor regions (e.g. Mattay et al., 2002). This may reflect the compensatory redistribution and reorganisation of processing such that they recruit supplementary cortical and subcortical areas to perform the same task (Sailer, Dichgans, & Gerloff, 2000). If older adults are already compensating and recruiting additional processing resources on motor tasks, incorporating motor encoding into object/location learning may be unhelpful. This is because it may make the task too demanding. This viewpoint would be consistent with capacity-limited models of processing such as that of Hasher and Zack's (1979). This theory argues that 'effortful' tasks are those that require a high degree of attentional or cognitive resources to encode the available information, and the more effortful a task is, the poorer performance becomes.

Summary

In summary, there has been insufficient research to establish whether ageing differentially affects object, location and object-location memory. It could also be questioned whether performing a motor action with an object at encoding would result in improved memory for objects, locations or objects in their locations. If these questions could be answered then their response may have clinical implications for the older adult population in terms of supporting navigation and people's memory for where they put important items. Research in this area would also be beneficial in terms of moving towards establishing a normative baseline for healthy ageing in these three aspects of memory, and developing visual array tasks that can reliably and validly measure them. Such a baseline and assessment tools would have clinical value for detecting abnormalities in ageing, differential diagnosis and monitoring treatment effects.

Study aims

This study examines the effect of healthy ageing and motor encoding upon memory for objects, locations and objects in their locations. It aims to consider the differences between healthy younger and older adults object, location, and combined object-location memory and the effect of visual and visuo-motor encoding, as well as age/encoding interactions.

The study was approved by the University of Southampton Department of Psychology Ethics Committee (see Appendix B for letter of approval for research).

Method

The study used a mixed experimental design. Three experimental tasks: Object Recognition (Object); Location Recall (Location), and Combined Object Recognition and Location Recall (Object-location) were completed by younger and older adults under conditions of active and passive motor encoding.

Participants

Participants were community dwelling adults. Thirty-two younger adults (YA) aged 18 to 30 (YA: *M* 24.67, *SD* 4.26) and 32 older adults (OA) aged 65 to 80 (OA: *M* 69.78, *SD* 4.17) were recruited through friends, family, and a wide range of community clubs and societies (e.g. sports clubs, church groups, coffee groups, recreational clubs) following piloting (see Appendix C for details). Sample sizes of 32 were chosen because significant age-related differences have been found in comparable studies (i.e. studies with similar age groups, methodologies and data analysis techniques) using group sizes of between 10 and 24 (e.g. Hess & Slaughter, 1990; Giraudo et al, 1997), hence indicating samples above this size would have sufficient power to detect between group differences in this study. Participants were informed of the details of the study in writing via a participant information sheet (see Appendix D) and gave written consent (see Appendix E for consent form). Participants had no current or past neurological or psychiatric illness that would affect their ability to complete the experimental tasks and were not complaining of memory difficulties, as determined by a brief background questionnaire (see Appendix F). Older adults were screened for general cognitive level on the Mini Mental State Examination (MMSE: Folstein & Folstein, 1975). All scored 26 or above. Participants all reported normal or corrected to normal vision and were able to point to and name three objects similar to those used in the testing scenario. Thirty-one younger adults and 30 older adults were right handed. The average years of education completed was higher for younger than older adults (YA: *M* 14.44, *SD* 2.58; OA: *M* 10.7, *SD* 1.55). However, there was no significant difference on predicted full scale IQ (YA: *M* 105.16, *SD* 8.89; OA: *M* 104.16, *SD* 9.55; t (62) = 0.43, p = 0.67) using the Revised National Adult Reading Test (NART: Nelson & Willison, 1991), with both groups predicted full scale scores falling within the average range. Participant groups were matched on gender distribution, with 15 females and 15 males in each age group.

Apparatus and stimuli

Participants' object and location memory under different encoding conditions was measured using visual array learning tasks that did not require fine motor control, drawing skills, verbal recall, or complex instructions. Similar visual array tasks have been used to measure object-location memory in younger and older adults' both in research and in clinical settings (e.g. Bucks & Willison, 1997; Postma & deHaan, 1996).

Grids measuring 45 cm by 45 cm were divided into 25 squares (5 by 5), each measuring 9 cm by 9 cm. These formed the backgrounds of the visual arrays. Sixteen arrays were used; 12 learning arrays, 3 practice arrays and 1 blank test array. For both the learning and practice arrays, the to-be-remembered (target) objects were photographed from a canonical viewpoint using a digital camera (Canon Powershot G3 digital camera), such that their scale relative to each other was maintained. These photographs were transposed onto 10 squares of the learning arrays and five squares of the practice arrays (see Appendix G, figure, for a photograph of examples of the apparatus and stimuli used in the study).

The different permutations of occupied squares for each array were devised pseudo-randomly under the restrictions that: each square should be used approximately the same number of times when their frequency of use was summed across the series of 15 arrays (Appendix G, figure 2, for array layout totals); the highest frequency counts did not consistently fall on the corner squares; there should not be any more than three sets of two objects next to each other either vertically or horizontally on any one array, and when this did occur at least one of the pairs should be of a different orientation to the other two. These restrictions were put in place to reduce the effect of anchoring cues on performance outcomes, thus maximising the person's reliance on position-to-position memory. Within these constraints, the number of instances in which obvious patterns such as crosses or lines appeared on the grids was also minimised.

The study used a total of 225 everyday man-made objects commonly found around the home, work place or recreational settings (e.g. peg, scissors, ball); 120 were target objects, 80 were distractors, and 25 were practice objects. The objects selected for inclusion were small enough to fit on an array square leaving at least a 1cm border between its extremities and the edges. As many different types of objects as possible were used, however, due to the large number of objects required there was some duplication in items. To minimise the effect of intrusion errors on performance outcomes, where this occurred, objects selected for inclusion were very different in appearance; differing on aspects such as colour, dimensions, materials from which they were constructed and texture. Objects were assigned randomly to the target and distractor categories and then pseudo-randomly to arrays, under the restriction that the same type of object did not occur twice on the same array, nor in the target and the distractor group for the same array.

In the testing phase, participants used round wooden markers to indicate locations on an array. A screen, measuring 45cm by 32cm, was used by the researcher in passive trials whilst preparing the learning arrays to shield the array from the view of the participant. An instruction booklet was used by the researcher to ensure that all participants completed the screening and experimental tasks in the correct order and with the same wording of instructions (see Appendix H for an example of an instruction booklet used for a participant).

Procedure

Participants met the researcher for approximately 70 to 90 minutes to complete: screening; the experimental tasks; a feedback questionnaire about the study (see Appendix I for the feedback questionnaire) and debriefing (see Appendix J for debriefing statement).

Before each task was administered a practice trial was undertaken, with either active or passive encoding, to familiarise the participant with the requirements of the subsequent trials. Practice arrays had only 5 objects in order to minimise the demand practicing placed on participants.

The order of the 15 trials was pseudo-random. The Object-location task trials were always last, due to the repeated measures design of the study. However, the order of the Object and Location tasks was counter balanced, as was the order of active and passive trials across tasks. The order of the arrays within tasks was determined using a Latin square design, and these orders assigned to tasks such that no two participants within the same group had them in the same order.

All the experimental tasks involved participants studying objects on a grid. In Active trials, participants created the arrays themselves by placing the objects on the grid in the places denoted by photographs. They were given 30 seconds to place all the objects before the array was removed. In passive trials, 10 objects were placed on the grid by the researcher in locations denoted by the photographs. The array was then revealed to the participant for 30 seconds before it was removed. Although these procedural aspects were held constant across all tasks, instructions varied in the study phase and test conditions also differed.

Object task

Participants were instructed to learn the objects presented on the array and not to learn their locations. Although it is possible that participants still encoded location information in the form of a gestalt of the array the use of explicit instructions that location information was not important should have helped control for this. When the array was removed following the 30-second learning time, participants were provided with the objects that had been on the grid mixed with 10 distractor objects. They were then asked to select the original objects from the distractors. They were allowed as much time as they wished to do this and were allowed to exchange objects until they were satisfied with their response.

Location task

Participants were explicitly instructed to learn the location of the objects on the array but not their identity. Following the removal of the array, participants were provided with a blank grid, along with ten wooden markers. They were instructed to place the markers on this grid where they thought there had been objects in the array they had just learnt. They were allowed as much time as they wished to do this and were allowed to move markers, once placed, until they were satisfied with their response.

Object-location task

The procedural formats of the Object and Location tasks outlined above were integrated by asking participants to learn both the objects and their locations. During testing participants were provided with a blank grid and the original objects mixed with ten distractors. They were instructed to select the objects they thought they had seen in the array they had just learnt, and place them in their correct locations.

Scoring

Object task

In the Object task, the number of correctly recognised items, i.e. 'true positives', was scored, as well as the number of incorrectly chosen items, i.e. 'false positives'.

The ability of participants to accurately discriminate between targets and distractors, i.e. 'discrimination index', and the degree to which they were biased towards identifying an object as a target object when they were unsure, i.e. decision 'bias index', were then measured. The use of such scores as the basis for measuring recognition memory has been recommended in the literature (Snodgrass & Corwin, 1988). The reasoning for using discrimination and bias indices is to help overcome the potential problem of participants having perfect recognition of targets and imperfect recognition of distractors by simply saying yes to everything. Such a problem could occur if using 'true positives' as the dependent recognition score, as this is affected by guessing.

The 'discrimination index' and 'bias index' scores were based upon two measures of recognition performance; 'hit rate' (HR) and 'false alarm rate' (FAR). The 'hit rate' was the conditional probability of a participant correctly recognising an object from amongst the target objects (HR = ('true positives' + 0.5) / (targets + 1)). The 'false alarm rate' was the conditional probability of a participant incorrectly recognising an object from amongst the distractors (FAR = ('false positives' + 0.5)/(distractors + 1)). Equations for calculating 'discrimination index' (DI) and 'bias index' (BI) scores were: DI = HR – FAR, and BI = FAR / (1-DI) respectively. The 'discrimination index' and 'bias index' scores were used as the dependent recognition scores for data analyses.

Location task

In the Location task, the number of correctly recalled grid positions, i.e. 'correct locations', were scored. Incorrectly recalled positions were scored in the form of a 'displacement' score, i.e. the number of squares away from the nearest correct location which had not been recalled. This was calculated using vertical and horizontal movements only; that is, moves were calculated as a knight moves on a chessboard by adding the number of horizontal movements to the number of vertical movements that would be necessary to reach the nearest correct location that had not been recalled.

Object-location task

In the Object-location task the performance scores described above were calculated. In addition, the number of correct objects placed in their correct locations, i.e. 'true location', and the displacement of incorrectly positioned objects from their correct positions, i.e. their 'true displacement' were scored. The 'true location' and 'true displacement' scores only included the placement of 'true positive' objects. Thus, between subjects comparison would have been confounded by the relative ability of participants correctly to recognise objects. To overcome this difficulty, 'proportional location' and 'proportional displacement' scores were calculated that were a function of the number of objects correctly recognised. The 'proportional displacement' score was calculated by dividing the 'true location' score by the 'true positive' score. The 'proportional location' score was calculated by dividing the 'true displacement' score by the 'true positive' score. Proportional scores were used in the data analyses.

All the data were inspected visually using box and whisker plots. No outliers that were more than 2 SD were identified and so all the data were included in the analysis. Analysis was conducted using SPSS version 11.0.01 (SPSS, 2001). An alpha level of .05 was used throughout and all tests were two-tailed.

Results

Tables K1 and 1 give the descriptive statistics for the NART and the analysed dependent scores for younger and older groups in the Object, Location and Object-location tasks. They indicate that scores were better for passive tasks and for younger adults on most measures. These scores are discussed in more detail below in relation to the data analyses.

Insert table 1 about here.

The NART predicted full scale IQ (calculated from conversion tables for NART error scores in Nelson & Willison, 1991) and all the dependent scores used for analyses were examined for normal distributions using One-sample Kolomgorov-Smirnov tests (see Appendix K, table K1, for z scores and p values).

NART predicted full scale IQ scores, and all the location scores were normally distributed for both participant groups (all $z > 0.42$; all $p > .20$). All the object scores differed significantly from the normal distribution for both groups (all $z < 1.37$, all $p < .04$), apart from Active 'discrimination index' scores in the Object-location task ($z = 1.17$, $p = .13$) which were significantly different from the normal distribution for the younger adult group only.

Examination of the raw scores indicated that scores that differed significantly from the normal distribution did so because of a ceiling effect on the Object task. A large number of participants obtained high scores on this task, thus the data were too skewed for transformation to be possible. Therefore, data that did not have a normal distribution were analysed using non-parametric techniques.

Location recall in the Location task

The effect of Age (YA/OA) and Encoding (active/passive) on 'correct location' scores in the Location task was explored using a mixed ANOVA.

The main effect of Encoding was not significant (F (1,62) = 1.68, p = .20). The main effect of Age, however, was significant (F (1,62) = 48.83, p = <. 01). Examination of the means suggested this was due to more 'correct locations' being recalled by younger than older adults. There was, however, no significant interaction between Encoding and Age. (F < 1).

The effect of Age and Encoding on 'displacement' scores in the Location experimental task was also explored. In this analysis, both the main effect of Encoding (F (1,62) = 6.74, p = .01) and Age (F (1,62) = 51.48, p = < .01) were significant. Comparison of the means indicated higher 'displacement' occurred in the active encoding condition and there was lower 'displacement' by younger adults. However, the Encoding by Age interaction was not significant (F (1,62) = 3.53, p = .07).

These results suggest that younger adults performed better than older adults overall. Participants performed similarly across Encoding conditions when recalling 'correct location' but Encoding had an effect on 'displacement' such that it was higher in the active condition. There was insufficient evidence to conclude that the Encoding manipulation affected the two groups differently, although there was a strong trend to suggest that younger adults were more greatly disadvantaged than older adults in terms of 'displacement' when encoding locations actively.

Location recall in the Object-location task

A mixed ANOVA was also used to investigate the effect of Age (YA/OA) and Encoding (active/passive) on 'proportional location' scores in the Object-location task. The main effect of Encoding was significant (F (1,62) = 5.14, p = .03), due to higher 'proportional location' scores in the Passive condition. The main effect of Age was also significant (F (1,62) = 57.00, p = .00), with higher 'proportional location' scores achieved by younger than older adults. The Encoding by Age interaction was, however, not significant (F (1,62) = 0.13, p = .72).

The effect of Age and Encoding on 'proportional displacement' scores was also examined. In contrast to 'proportional location', the main effect of Encoding for 'proportional displacement' was not significant (F (1,62) = 3.91, p = .05). As in 'proportional location' Age was significant (F (1,62) = 32.39, p = < .01), with examination of the means highlighting lower 'proportional displacement' by younger than older adults, but the interaction was not (F (1,62) = 1.03, p = .32).

Taken together, these results indicate that passive encoding conferred an advantage, and younger adults were superior to older adults. However, both groups responded similarly to the Encoding manipulation.

Comparison of location recall across tasks

A mixed ANOVA of Age (YA/OA) and Encoding (active/passive) by task type (Location/Object-location) were conducted for 'correct location' and 'displacement'.

For 'correct location' there was no main effect of Task (F (1,62) = 3.70, p = .06), nor Encoding (F (1,62) = 5.50, p = .02). There was, however, a significant main effect of Age (F (1,62) = 91.50, p = < .01) in that younger adults recalled more 'correct locations' than older adults. However, the Task by Age Encoding by Age, and Task by Encoding interactions were not significant (all F < 1). Neither was the three-way interaction between Task, Encoding and Age (F (1,62) = 0.00, p = .95).

For 'displacement' the main effects of Task (F (1,62) = 8.66, p = .01), Encoding (F (1,62) = 12.48, p = .00) and Age (F (1,62) = 87.93, p = < .01) were all significant. Comparison of the means suggested participants showed greater 'displacement' in the Location task than in the Object-location task, when the location of objects had been learnt actively, or they were older. However, the Task by Age (F < 1), Encoding by Age (F (1,62) = 1.29, p = .26) and Task by Encoding (F < 1) interactions were not significant. Neither was the three-way interaction between Task, Encoding and Age (F (1,62) = 2.42, p = .13).

Overall, the effect of Age on 'correct location' and 'displacement' was such that younger adults performed better irrespective of task. The Encoding conditions had no effect on 'correct location', but affected 'displacement' irrespective of task. Task had an effect on 'displacement' scores only. However, both Age groups were similarly affected by Task and Encoding conditions both for 'correct location' and 'displacement'.

The effect of Age on Object recognition

Mann-Whitney U tests were used to investigate whether younger and older adult's 'discrimination index' and 'bias index' scores differed significantly in the Object and Object-location tasks, both for active and for passive Encoding.

For 'discrimination index' in the Object task there was a significant difference in the active Encoding condition (U = 357.00, N_{YA} = 32, N_{OA} = 32. $p < .01$). Examination of the group medians showed both groups had similar 'discrimination index' scores, although the group means indicated younger adults had higher 'discrimination index' scores (YA: M = .93, SD = .14; OA: M = .90, SD = .09). However, there was no significant difference in the passive Encoding condition (U = 497.000, N_{YA} = 32, N_{OA} = 32. p = .74).

There was no significant difference in either the active (U = 496.00, N_{YA} = 32, N_{OA} = 32. p = .32) or the passive Encoding condition (U = 511.50, N_{YA} = 32, N_{OA} = 32. p = .98) between younger and older adults' 'bias index' scores in the Object task.

In summary, Age only had an effect on the ability to discriminate between target and distractor objects when objects were learnt through active

Encoding. There was no effect of Age on decision bias under any Encoding conditions.

Similarly to the Object task, there was a significant difference in the active condition (U = 231.00, N_{YA} = 32, N_{OA} = 32. $p < .01$) between younger and older adults' 'discrimination index' scores on the Object-location task. The group medians showed younger adults had higher scores. In contrast to the Object task, however, there was also a significant difference in the passive condition (U = 315.00, N1 = 32, N2 = 32. $p = .01$). Again this was such that younger adults had higher 'discrimination index' scores.

Whether younger and older adults' 'bias index' scores differed significantly was also examined. In this analysis, the results were the same as in the Object task; there was no significant difference in the active (U = 512.00, N_{YA} = 32, N_{OA} = 32. $p = 1.00$) or passive condition (U = 496.50, N_{YA} = 32, N_{OA} = 32. $p = .57$).

These results indicate Age had an effect on the ability to discriminate between target and distractor objects, irrespective of the Encoding condition, but had no effect on decision bias.

The effect of Task on object recognition

Wilcoxon tests were carried out to explore whether either 'discrimination index' or 'bias index' scores differed across the Object and

Object-location tasks, irrespective of Encoding and Age. Active and passive scores were collapsed across both age groups. There was a significant difference in 'discriminative index' scores ($z = -4.77$, N – Ties = 48, $p < .01$). Examination of the collapsed medians suggested this was due to higher 'discrimination index' scores being achieved in the Object task (Object task: median = 0.98, range = .54 - .98; Object-location task: median = 0.88, range = .59 - .98). However, there was no significant difference between 'bias index' scores ($z = -.11$, N – Ties = 6, $p = .92$).

Overall, Task affected 'discrimination index' scores but not 'bias scores' when measured irrespective of Encoding and Age.

The effect of Encoding on object recognition

Wilcoxon tests were also carried out to examine whether 'discrimination index' scores differed across Encoding, irrespective of Task and Age. Object and Object-location scores were collapsed across both age groups. There was no significant difference in either 'discrimination index' ($z = 1.04$, N – Ties = 43, $p = .30$) or 'bias index' scores (z = - 1.29, N – Ties = 48, p = .20).

These results indicated there was no effect of Encoding on 'discriminative index' and 'bias index' scores when measured irrespective of Age or Task.

Discussion

This study responded to a call within the literature for research to measure object, location and object-location memory as distinct entities (Gulya et al., 2000; Postma & de Haan, 1996). It used an age-comparative approach to examine whether the nature of these aspects of explicit visuo-spatial memory, when measured separately, changed with ageing. It also explored whether they differed depending on whether information was encoded through visual and motor modalities or via visual modality alone. Its main findings were that age-related differences were apparent to some extent on all three aspects of memory, and visuo-motor encoding did not confer an advantage over visual learning alone. These findings are now discussed more fully.

Memory for objects

Generally, participants' ability to distinguish between objects that had and had not been on the visual array was better when they had been instructed only to learn the identity of objects (Object task), than when they had been told to learn the identity *and* location of objects (Object-location task). This ability was similar whatever encoding had been used to learn object information. The tendency for participants to identify an object as having been on the array when they were unsure was also similar across encoding conditions, as well as across tasks. With respect to age, in the Object task, younger adults' performance was superior to older adults' when object feature information was learnt through visual and motor modalities, but not when learnt via visual encoding alone. In contrast, in the Object-location task, younger adult's discrimination ability was superior whatever encoding had been used to learn the information. Age did not affect either younger or older adults' decision bias.

These findings suggest that, although adults' recognition memory for objects is generally poorer when bound with location information at encoding and this is not affected by additional motor encoding, this pattern is age sensitive. This sensitivity is such that if object information is bound with location information or learnt separately, but through visual and motor modalities, an age-related deficit becomes apparent.

Object-location sensitivity is consistent with previous studies that have found object-location memory deficits in older adults (e.g. Malec et al., 1991; Cherry & Park, 1989). It also supports researchers who advocate that binding is likely to be impaired at the encoding stage in older adulthood due to hippocampal and prefrontal degeneration (Johnson & Chalfonte, 1994; Chalfonte & Johnson, 1996). Furthermore, it is comparable with initial studies of object versus object-location memory that have shown object memory to remain relatively intact in older adults compared to bound memory (Park et al, 1990; Chalfonte & Johnson, 1996). Therefore, this finding upholds the argument that these aspects need to be measured as separate entities to better understand human memory for objects and locations.

Encoding sensitivity is consistent with the literature examining the influence of context on memory for visual scenes that suggests memory performance is a function of what is measured and how (e.g. Sharps & Gollins, 1989; Cherry & Park, 1993; Zelinski & Light, 1988; Hartley et al, 2001). Age-related Object deficit in this study was a function of the encoding characteristics of the task, rather than a global impairment in memory for object information. Thus, it seems that memory for object features can be affected by the conditions under which the information was learnt, and poorer performance is not an inevitable consequence of age-related generalised decline.

The finding that older adults' performance was poorer under conditions of active encoding, however, was not of the nature predicted by the motor-amelioration hypothesis. This envisages that encoding object information through visual and motor modalities should confer an advantage over visual encoding alone by promoting deeper semantic and self-referent processing. Feedback from participants via the questionnaire at the end of testing highlighted that older adults found the active tasks more difficult than passive tasks. This is understandable in light of the literature indicating that older adults need to recruit supplementary cortical and subcortical processing resources to maintain performance levels on motor tasks (Mattay et al., 2002; Sailer et al, 2000). Although the 'what'/ 'where' dissociation literature suggests compensation occurs in visual learning with age (Schiavetto, Kohledr, Grady, Winocur & Moscovitch, 2002; Alexander, Packard & Peterson, 2002), if older adults were also compensating for impaired motor learning on the active tasks, it is likely visuo-motor learning was more effortful than visual learning in terms of the demands it paced on individual's processing resources, especially as to some extent the active task could be argued to be a multi-tasking paradigm. In keeping with Hasher and Zack's (1979) effortful processing theory, this would in turn lead to poorer performance under this condition.

Memory for locations

When instructed to learn location feature information only, younger adults' ability to recall positions that had been occupied on a visual array was superior to that of older adults'. Also, when younger adults incorrectly recalled an unoccupied space as being occupied, the recalled location was nearer to a location that had been occupied, but not recalled, than incorrect locations recalled by older adults. Moreover, for both younger and older adults, encoding the locations of objects using motor and visual modalities, as opposed to visual modality alone, increased the degree of 'displacement' from a correct location. Interestingly, the strong trend for an Age by Encoding interaction for suggests this apparent disadvantage of visuo-motor encoding may be stronger for younger adults when measuring recall in terms of 'displacement'.

These findings support the minimal amount of previous research that has measured location memory in its own right and found an age-related deficit (e.g. Puglisi et al, 1985; Chalfonte & Johnson, 1996). When considered in conjunction with the finding that object memory was also impaired in some circumstances, this study suggests ageing can affect both types of feature information memory. It therefore adds to the growing body of evidence that indicates different cognitive process underlies them and the need to separately measure and compare these aspects of memory.

In terms of the motor-amelioration debate, a conclusion similar to that for memory for objects can be drawn; that active encoding, in the format tested, may be so effortful that it actually hampers performance. Interestingly, a disadvantage on this type of encoding was not restricted to older adults for location memory as it was for the Object task. 'What' and 'where' dissociations in visual processing (e.g. Chen et al, 2002; Bohbot, Kalina, Stepankova, Petrides, & Nadel, 1998; Kessels et al, 2000), and object-location memory sub-processing theory (Postma et al, 2000; Postma et al, 1998) indicate this may be due to location and object memory being underpinned by different cognitive processes. It also indicates that Postma and colleagues theory, although developed through research with younger adults, is applicable to older adults. Thus, comparison of the results of the Encoding manipulation in the Location and Object task further reinforces the earlier conclusion, that it is worth further exploring the similarities and differences between object and location memory in ageing.

Comparing the ability of all participants correctly to recall locations across the Location and Object-location memory tasks revealed that performance across both tasks was similar, whatever modalities were used to learn location feature information. It also showed younger adults' recall of occupied positions was superior to older adults'. There were no Age or Encoding by Task interactions. Comparing 'displacement' across tasks, however, highlighted that it was larger when location feature information was learnt separately from object information, when it was learnt through visual and motor modalities, and in older adults. Again, there were no interactions between Age, Encoding or Task.

These findings suggest an age-related deficit in memory for occupied positions exists, which is independent of whether location feature information is learnt in isolation, or in combination with object feature information. It also seems this age effect is independent of the modality through which locations were learnt. This supports the limited multi-component research suggesting that both location and object-location memory are impaired in ageing (Puglisi et al, 1985; Chalfonte & Johnson, 1996). It also, possibly, supports the argument that adding a motor component to visual encoding does not improve performance because, if an object can be manipulated, simply maintaining information about those objects in working memory is sufficient to build motor representations and programmes. It is also feasible that even though passive encoding did not involve any actual motor movement with objects, participants used motor imagery techniques to learn locations. Research findings that imagined and performed actions produce similar cortical activation (e.g. Binofski et al, 2000; Rizzolatti, Fadiga, Gallese & Fogassi, 1996) suggest that if participants were using such a strategy this could negate any advantage of active encoding, as effectively, both conditions would be visuo-motor. Feedback from participants, however, indicated that this had not occurred.

Thus, an effortful processing explanation seems more appropriate. This could be verified by future research that replicated the location and object-location tasks of this study, but with objects that can and cannot be manipulated.

The finding that location memory was relatively impaired compared to object-location memory when 'displacement' but not when 'correct location' is measured is interesting in terms of the argument that performance on memory tasks depends on what is measured and how. On the one hand this difference suggests that, even within the same component of memory there may be sub-divisions in processing. However, it could also be advocated that 'correct location' is merely a less sensitive measure of performance than 'displacement' and hence differences are a product of methodology rather than true differences in ability.

Memory for objects in their locations

In keeping with the findings for object and location memory age-related decline and superior performance under conditions of visual learning was apparent when the ability of younger and older adults to recall the correct object in the correct location was measured. However, although age-related difficulties were evident, whether object-location information was learnt through visual or visual and motor modalities was only an important factor in determining displacement performance. Active encoding was poorer than passive encoding even for younger adults.

As with other results of this study, these findings are in agreement with previous research that has highlighted age-related decline in object-location memory and hold up the argument that binding becomes impaired with normal ageing (e.g. Grady et al, 1995; Mitchell et al., 2000). However, they do not support the motor-amelioration hypothesis.

Methodological and conceptual limitations of this study

This study was the first of its kind. Thus, there was little literature upon which to base its methodology. Consequently, the study was exploratory and had some methodological limitations that future research may benefit from addressing.

This discussion has raised the issue that the active encoding condition may not have ameliorated age-related deficits because it was too effortful. This is supported by feedback from participants whom reported that they found placing objects on the arrays themselves a distraction from learning. This was consistent with observations that many participants commonly placed the objects on the array quite quickly and used the remaining time to learn the grid visually. The intention of the study was that participants should use goal-directed movement as a vehicle for learning. However, it appears this may not have been what actually occurred in some cases. Rephrasing the active instructions may over-come this in future research. An instruction such as "use the placement of objects to learn…" may better test the motor-amelioration hypothesis. A related issue is that due to the size of the two sample groups, it was not possible to create age-clustered sub-groups within the younger and older sample groups that would be of sufficient size, and hence have adequate discriminative power, to perform age-related subsidiary analysis to highlight within group differences. Subsidiary analysis may have been informative in terms of ascertaining whether the disadvantage of active encoding had a greater impact on the older members of the two groups for example. Secondly, the neuropsychological literature has criticised current object-location memory tasks used with older adults for being too heavily reliant on writing, fine motor and verbal skills (Davies, 1996; Saghal et al., 1992). Therefore, the recognition paradigm was designed to enable completion without high-level literacy, naming or expressive language abilities. It was also based on a visual array approach to allow comparison with previous research. Moreover, the paradigm was created in a form that could be used in the Object and Object-location task. This enabled valid comparisons to be made between scores in the two tasks. However, these design constraints led to ceiling effects in recognition performance. Consequently, non-parametric analysis had to be conducted to compare 'discrimination index' and 'bias index' scores. Therefore, the probability that small, but significant effects of age, task, or encoding would not be detected was increased. The procedure was piloted before the main data collection phase to minimise the probability of such an occurrence, but participant's range of scores did not highlight this difficulty. In retrospect, the piloting sample may have been insufficient to provide a representative level of performance and therefore a ceiling effect was not highlighted on this task.

Future research could use larger arrays to overcome this effect, although this somewhat limits the practicality of the task in terms of its use as a diagnostic tool. Array size would also need to be increased in the Location task to control for difficulty across tasks and maintain comparability, which may result in a floor effect. To prevent this the Location task may also need to become a recognition paradigm. The need to make the Location task a recognition rather than a recall task is further supported by the finding that as a general rule, recognition memory is superior to recall memory, even in older adults (Lezak, 1995). Thus, it could be argued that in this study, between task differences were confounded by the fact that different categories of memory had been tested.

Finally, the motor-amelioration hypothesis is heavily based on the level of processing theory. There is an element of circularity to the depth of encoding argument. As there is no measure of 'depth' it is possible to claim that any well-remembered event has been deeply processed (Vincent, Craik & Furedy, 1996). Thus, even if visuo-motor learning had ameliorated age-related decline in any of the three aspects of memory tested, then claiming it was due to deeper encoding may have been premature. In future, using neuroimaging techniques to monitor processing during the manipulation of encoding conditions may help to elucidate this debate. This study may also be complemented by neuroimaging research that takes up the challenge of separately measuring cortical activation in object, location and object-location memory tasks. Such research may be able to shed light, for example, on whether impaired binding performance is in fact due the degeneration of the hippocampal and prefrontal regions.

Conclusion

This study has found that the ageing process detrimentally affects location and object-location memory, whereas memory for objects remains relatively intact under some circumstances. Thus it seems that, as with most categories of explicit memory, global impairment is not inevitable (Davies, 1996). It appears that age-related impairment in memory for where things are may be a product of impairment in the features to be bound together and the binding process. Therefore, this study has moved towards creating a better understanding of how object, location and object-location memory alter with ageing. It has also begun to take a step towards establishing a normative baseline that could be used for clinical purposes. Furthermore, this study has shown that it is indeed possible to measure object, location and object-location memory as separate entities using visual array tasks. Therefore, it appears that such tasks may be useful as neuropsychological assessment tools in the clinical setting.

However, it was found that, where impairment does exist, it is unlikely to be ameliorated by encouraging supplementary motor encoding in the form tested. Thus, it is doubtful whether the motor-amelioration hypothesis, as it stands, could be clinically applied to support older adults with navigation difficulties or who frequently lose items. However, variations on its theme, such as using repeated action or pairing action with visualisation, might prove useful. Based on participant feedback and current processing and motor encoding literature, the lack of amelioration could be due to trying to use a compensatory modality that is already compromised in ageing, thus making too large a demand on processing resources.

The findings of this study would, however, need to be replicated and further variations of active encoding explored before firm conclusions could be drawn about the therapeutic utility of the motor-amelioration hypothesis in ageing. Research would also need to occur that compared clinical and non-clinical populations.

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Table 1: Descriptive statistics for active and passive scores in younger and older participant groups

		Younger adults	Older adults
		M, (*SD*), range Median, mode, range *	*M*, (*SD*), range median, mode, range *
Object task:	***Active***		
	Discrimination index	0.95, 0.95, .19 - .95 *	0.95, 0.95, .48 - .95 *
	Bias index	0.50, 0.50, .50 - .50 *	0.50, 0.50, .05 - .50 *
	Passive		
	Discrimination index	0.95, 0.95, .48 -.95 *	0.95, 0.95, .75 - .95 *
	Bias index	0.50, 0.50, .05 - .50 *	0.50, 0.50, .25 - .50 *

Location task:	***Active***		
	Correct location	15.63, (2.69), 10.00 – 20.00	11.50, (2.96), 7.00 – 20.00
	Displacement	6.81, (4.49), 0.00 –20.00	11.03, (3.50), 0.00 – 16.00
	Passive		
	Correct location	16.00, (3.88), 0.00 – 20.00	12.22, (2.49), 7.00 – 17.00
	Displacement	4.28, (3.25), 0 .00- 11.00	10.63, (3.50), 3.00 – 16.00
Object-location task:	***Active***		
	Discrimination index	0.85, 0.95, .76 - .95 *	0.83, (0.09), .67 - .95
	Bias index	0.50, 0.50, .50 - .50 *	0.50, 0.50, .50 - .50 *
	Correct location	16.28, (2.37), 12 .00– 20.00	11.94, (2.83), 11.00 – 7.00
	Displacement	4.75, (3.28), 0.00 – 12.00	10.65, (3.19), 3.00 – 17.00

Proportional location	0.75, 0.15, 0.45 – 1.00 *	0.46, (0.19), 0.12 – .95
Proportional displacement	0.49, (0.37), 0.00 - 1.40	1.14, (0.61), 0.11 – 2.31
Passive		
Discrimination index	0.95, 0.95, .48 - .95 *	0.86, 0.86, .38 - .95 *
Bias index	0.50, 0.50, .05 - .50 *	0.50, 0.50, .05 - .50 *
Correct location	17.19, (2.88), 9.00 – 11.00	12.78, (2.81), 6.00 – 18.00
Displacement	3.63, (3.67), 0.00 – 12.00	9.19, (3.65), 3.00 – 18.00
Proportional location	0.81, (0.23), 0.42 – 1.00	0.52, (0.17), 0.24 - .89
Proportional displacement	0.42, (0.43), 0.00 - 1.71	0.96, (0.54), 0.00 – 2.40

Note: * Median, mode, range reported for non-parametric scores

APPENDICES

Appendix A: Notes for contributors to Neuropsychologia

Guide for Authors

1. Papers submitted for publication should be sent to either of the Editors-in-Chief, Professor A.D. Milner (Europe) or Professor M. Moscovitch (Rest of the World), and marked 'Neuropsychologia' on the address label.

2. *Neuropsychologia* considers for publication papers dealing with the neural bases of cognition and behaviour and having the following types of format: (a) Research Reports (up to 20 printed pages) and Notes (up to 10 printed pages). These should describe new and original observations in various fields of the behavioural and cognitive neurosciences, whether in humans (normal or brain damaged) or in animals, and should afford significant contributions to neuropsychological theorization; (b) Reviews and Perspectives (up to 30 printed pages). These should provide critical accounts and comprehensive surveys of topics of major current interest within the scope of the journal. Historical notes and purely theoretical papers will be considered for publication only exceptionally.

3.(a) Submission of a paper to *Neuropsychologia* is understood to imply that it is an original paper which has not previously been published (except in the form of an abstract or preliminary report), and that it is not being considered for publication elsewhere.

(b) A certain proportion of submitted papers will be given fast-track processing in a new 'rapid publication' section of the journal whenever they are judged by the Editors in Chief as being particularly important and timely.

(c) Papers will be published as quickly as possible after acceptance and, subject to space being available, should appear in the issue following the receipt of the author's corrected proofs.

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4. 25 reprints will be sent free of charge to the corresponding author. Additional reprints may be ordered on the reprint order form which will accompany the proofs sent to the author. Reprints may also be obtained after publication of the paper at a somewhat higher cost.

5.(a) Papers will be accepted in English only.

(b) The title page should include: the name(s) of the author(s); the name of the department and institution where the study was carried out; the institutional affiliation of each author; the name, the postal and email address and the telephone and fax number of the corresponding author; a running head of not more than 50 letters. A shortened title (a caption of no more than 5 words) to appear on the front cover of *Neuropsychologia* should it be chosen.

(c) Abstracts should be less than 250 words, and should be followed by a list of up to six keywords (which do not appear in the title) to be used for indexing purposes.

(d) Research Reports and Notes as a rule should include an Introduction, a section on Methods, a section on Results and a Discussion. The description of methods and results should be sufficiently detailed so as to allow a critical assessment of their appropriateness and validity.

(e) The section on Methods of research reports, footnotes and the whole text of notes will be printed in small type. Authors may mark other passages which may also be printed in small type.

(f) Four double-spaced typewritten copies of the manuscript should be submitted in all cases, along with an electronic copy of the manuscript (on disk or as email attachment), preferably in *Word* or *Wordperfect*. A manuscript must be in the correct format, i.e. doubled-spaced, references in correct format, and top-quality figures or it will be returned to the author. Only one side of each page should be used, allowing generous margins. Manuscripts of rejected papers will not be returned to the authors. Always keep a backup copy of the electornic file for reference and safety.

(g)**On-Line Submission**: Authors can also upload their article as a LaTeX, Microsoft (MS) Word, WordPerfect, PostScript or Adobe Acrobat PDF document via Author Gateway page of this journal, where a detailed description on its use will also be found. The system generates an Adobe Acrobat PDF version of the article which is used for the reviewing process. It is crucial that all graphical and tabular elements be placed within the text, so that the file is suitable for reviewing. Authors, Reviewers and Editors send and receive all correspondence by e-mail and no paper correspondence is necessary. Note: compuscripts submitted are converted into PDF for the review process but may need to be edited after acceptance to follow journal standards. For this an editable file format is necessary. See the Guide to On-Line Submission and the further general instructions on how to prepare your article below.

(h) On acceptance, in order to expedite publication, authors are required to submit the final version of their paper on disk. The instructions for preparing electronic documents will be communicated to the authors in the final letter of acceptance of their paper. Two final paper copies plus disks and a complete set of original figures must be returned to the Editor and not directly to the Publishers.

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References should be given in the following form:

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Baron-Cohen, S. (1995). *Mind-blindness: an essay on the psychology of autism.* Cambridge, MA, MIT Press

Kinsbourne, M. (1993) Orientational bias model of unilateral neglect: evidence from attentional gradients within hemispace. In I.H. Robertson & J.C. Marshall, *Unilateral neglect: clinical and experimental studies* (pp.63-86). Hove, UK: Lawrence Earlbaum

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Appendix B: University of Southampton Ethics Committee approval letter

University of Southampton

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Telephone +44 (0)23 8059 5000
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9 May 2002

Andrea Burrow
Clinical Psychology
University of Southampton
Highfield, Southampton
SO17 1BJ

Dear Andrea,

Re: Ageing and spatial memory processing: A sub-component analysis

The above titled application - which was recently submitted to the departmental ethics committee, has now been given approval.

Should you require any further information, please do not hesitate in contacting me on 023 8059 3995. Please quote reference CLIN/2002/16.

Yours sincerely,

Kathryn Smith
Ethical Secretary

cc. Janet Turner

Appendix C: Summary of piloting

Piloting was conducted in order to investigate the construction of the test before any data collection began. The pilot study examined the effect of three independent variables in each condition, namely: Age (younger or older adult); Encoding (passive: in which the to be remembered objects were placed on the arrays, or active: in which the participant placed the objects themselves) and Difficulty (low difficulty: in which 5 to be remembered objects were on the array, or high difficulty: in which 10 objects were on the array). Each participant completed 6 low difficulty (3 passive and 3 active) and 6 high difficulty trials (3 passive and 3 active) in each experimental task. Thus, completing a total of 36 scored trials. They also completed 6 practice trials; a passive and an active trial in each experimental task, therefore, making an overall total of 42 trials including practice trials.

Piloting demonstrated that this design was extremely lengthy and very demanding upon participants. It was felt this would result in recruitment difficulties or participants dropping out before testing was complete. Piloting also showed that the low difficulty condition had a ceiling effect in both age groups and the high difficulty condition had a ceiling effect in the younger age group. Consequently, the study was modified by: removing the easy trials; reducing the number of hard trials to 2 per encoding condition; reducing the number of practice trials to three (such that only a passive or an active trial was practiced for each experimental task with this being the same as the mode of encoding of the first scored trial in each task), and decreasing the time allowed to learn a array from 60 to 30 seconds. Re-piloting showed these changes overcame difficulties with the identified ceiling effects and condensed the total time demands on the participants to between 70 and 90 minutes. This modified design was used in the main data collection phase.

Appendix D: Participant information sheet

UNIVERSITY HEADED PAPER

Participant Information Sheet

Now where did I put that?

Memory for objects and locations

You are being asked to take part in a research study with the University of Southampton. Before you decide if you will take part, it is important for you to know why the research is being done and what you will be asked to do. The information below is to help you with this. We will contact you within the next two weeks to see if you are willing to take part and to arrange a time that you can do so.

Thank you for reading this.

Why is the study being done?

We are trying to find out how young and older adults' memory for objects is similar and differs. We want to know how people's ability to remember the identity and location of everyday objects changes with ageing. This information may prove useful in helping some older people live independently, for longer, in their own homes.

Why have you been chosen?

You have been asked because this study is designed for older and younger adults without memory difficulties who are representative of those living in the community, like yourself.

What are the possible risks of taking part?

You may find remembering things harder than you expect. This may be disappointing for you, but we do not expect you to remember all the things we show you. We encourage you to guess when you are unsure.

What are the benefits of taking part?

There are no direct benefits to you for taking part beyond the fact that many people find these types of tasks enjoyable. However, for taking part you will be paid for your travelling expenses. More importantly information you give in the study will help us to better understand how memory for objects and their location in the environment changes with age. Your effort is crucial in learning what to expect of people's memory for where they have put objects, as they get older. You will show us what is 'normal'. Then we can go on to understand what happens when people become ill.

Do you have to take part?

It is your choice if you take part. If you do, you can withdraw at any point and do not need to give a reason.

What will I be asked to do?

You will be asked a few brief questions about yourself and then to complete a number of short tests. In these tests you try to remember what objects have been put on a grid of squares, and what square they were on. This should take about 1 and a half hours.

Will anyone be told about what I say or my scores on the tests?

Anything you say and your scores on the tests are strictly confidential. Your name, address or any other identifying information will be removed from the results and your scores pooled with others who choose to take part. No individual will be identifiable from the results.

What will happen to the results of the study?

A report will be written about the study, and a summary of the results made available upon request. We hope to share the results with our colleagues through publication in scientific journals.

Who is organising and funding the research?

The study is being organised and funded by the Department of Clinical Psychology at the University of Southampton.

Who has scrutinised the study?

The study has been reviewed and approved by the Department of Psychology Ethics Committee, University of Southampton. If you have any concerns about this study you can contact the chair of the Ethics Committee, Department of Psychology, University of Southampton, Highfield, Southampton, S017 1BJ. Telephone: 023 80593995

Contact for further information

If you have any questions, or wish to request a summary of the results please contact either:

Andrea Burrow (Trainee Clinical Psychologist) or Romola Bucks (Senior Lecturer)

at: The Department of Clinical Psychology
University of Southampton
Highfield
Southampton

S017 1PN
Telephone: 023 8059 5321

Thank you for your help in learning more about memory with ageing so that we can begin to better support those with memory difficulties.

Andrea Burrow
Trainee Clinical Psychologist

Tel: 023 8059 5321

Appendix E: Consent Form

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Now where did I put that? Memory for objects and locations
Consent Form

Information

I am Andrea Burrow, a trainee clinical psychologist at the University of Southampton. I am requesting your participation in a study regarding people's memory for the identity and location of objects. This will involve answering some brief questions about your self and trying to remember what objects are placed where on a series of grids. This should take about one and a half hours in total. Personal information will not be released to or viewed by anyone other than researchers involved in this project. Results of this study will not include your name or any other identifying details.

Your participation is voluntary and you may withdraw your participation at any time. If you have any questions please ask them now, or contact me (Andrea Burrow) through the Department of Clinical Psychology at the University of Southampton (023 8059 5321).

Signature: Date:

Statement of Consent

I ________________________ have read the above informed consent form.

I understand that I may withdraw my consent and discontinue participation at any time without penalty or loss of benefit to myself. I understand that data collected as part of this research project will be treated confidentially, and that published results of this research project will maintain my confidentiality. In signing this consent letter, I am not waiving my legal claims, rights, or remedies. A copy of this consent letter will be offered to me.

I give consent to participate in the above study. Yes / No

Signature: Date:

I understand that if I have questions about my rights as a participant in this research, or if I feel that I have been placed at risk, I can contact the Chair of the Ethics Committee, Department of Psychology, University of Southampton, Southampton, SO17 1BJ. Phone (023) 80 8059399

Appendix F: Background Questionnaire

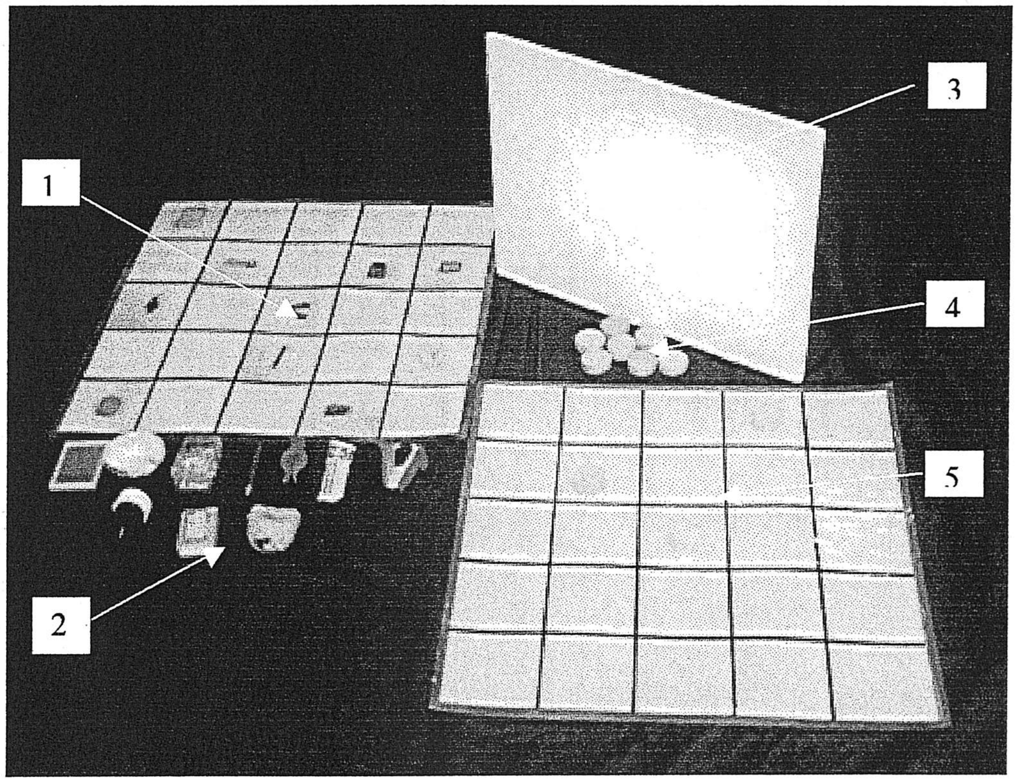
Please fill in this form. If you have any questions please do not hesitate to ask for assistance.

Name	
Date of Birth	
Age	
Do you have normal vision? (corrected vision with glasses/contact lenses is considered to be normal).	Yes / No
Are you right or left handed? (please circle)	Right / left
Gender (please circle)	Male / Female
Years of education (e.g. 5yrs old –14 yrs old = 9 yrs education)	
Are you currently on any medication? (if yes, please specify)	
Are you currently suffering from any illnesses? (if yes, please specify)	
Have you ever been treated for depression or any other mental health difficulties? (if yes, please specify)	
Has any member of your family ever suffered from memory difficulties? (if yes, please specify)	

Appendix G: Apparatus and stimuli used in the study

Below is a photograph (see figure 1) of a study array with its target objects, the wooden markers used for recall in the location task, the blank grid used for the location and object-location task and the screen used in passive trials.

Figure 1: Examples of the grids and objects used in the study



Key: 1 = study grid

2= target objects for study grid

3 = screen

4 = wooden markers

5= blank test grid

Figure 2: Array layout totals

Numbers indicate the frequency with which each square was occupied by an object across the test arrays.

4	3	4	4	4
3	4	3	4	4
4	4	3	3	4
4	4	4	3	4
3	4	3	3	3

Appendix H: An instruction booklet used for a participant

PARTICIPANT_____TESTING LOCATION__________TESTING DATE__________

Introduction

Hello, my name is Andrea. I'm a trainee clinical psychologist at Southampton University. Thank you very much for agreeing to take part in this research. We will be exploring people's ability to remember the identity and location of everyday objects.

I will need about 1 and a half hours of your time today. If you want to stop at any time let me know. You are not obliged to continue if you do not wish to. Any information you give me is confidential. This means I will be the only person who knows what you have personally told me, and no particular individuals results will be identifiable.

Unfortunately I won't be able to discuss the results of the tasks you do today because I need time to score them afterwards.

Outline of testing

I'm going to ask you to do a series of 15 short memory tasks, which take a few minutes each. These look at your skills for remembering what objects are placed where on a square grid. Don't worry if you think your memory is not very good, you are not expected to remember everything perfectly. Just do the best you can.

Consent

Have you any questions about the research? (Answer the questions that have been asked)

Before we begin the memory tasks, if you are happy to continue could you sign this consent form for me please. This is to say you wish to take part in the research, are aware of your rights to confidentiality and to withdraw at any stage, and that I have explained what is being asked of you. (Sign consent form)

** If the person wishes to withdraw:
Thank you for taking the time to find out more about this study. Deciding not to participate today does not mean you cannot participate in this study in the future. Here is a contact address in case you change your mind about participating.

Background Information

Before we start the memory tasks I would like to ask you some questions about yourself and your health. Please could you complete this form? Feel welcome to ask for advice if you are unsure what it is asking you or you are having difficultly reading the form

Screening

MMSE:

I am going to ask you some brief questions. Answer them as best you can. (Administer MMSE)

NART:

I want you to read slowly down this list of words starting here. (Indicate Ache). After each word please wait until I say next before reading the next word. I must warn you that there are many words that you probably wont recognise, in fact *most* people don't know them, so just have a guess at these, O.K? Go ahead. (Administer NART)

VISUAL ACUITY:

Now I just need to check you will be able to see and recognise the types of objects we will be using for the memory tasks. You can wear glasses if you need to (Place 3 eye test objects in a line in front of the person).

Please can you point to each object in turn and tell me what they are. Start on your left. (Remove objects when completed). Thank you.

Visuo-spatial memory tasks

You have given me all the background information I need so we are ready to begin the memory tasks. We will do lots of brief tasks, which may seem repetitive, but you are asked to do the same tasks several times so that brief lapses in concentration don't affect the results. Also, although the tasks seem similar I am going to change slightly what I ask you to do. So please listen carefully to the instructions I give you before each task. (Administer memory tasks in order in this booklet)

Practice location

		Wplg 1	Bead 1	
Comb 1				
		Trch 1		Tssl 1

We will be doing 4 tasks in which I will ask you to learn where objects are on a grid, like this (show example of a grid). What the objects are will not important, just where they are. Sometimes *I* will put the objects on the grid and sometimes I will ask *you* to put them on yourself. If I put the objects on you will have thirty seconds to look at the grid and learn where there are objects. When you put the objects on yourself you will have 30 seconds to place the objects as well as learn where you have placed them. After 30 seconds the grid you have been learning and the objects that were used will be removed. Then you will be asked to put markers, like these (show a marker) on a blank grid in the places where you think you had put objects. Lets have a practice. In this practice your performance won't be scored its just so you can learn how to do the task, and there are only 5 objects. In the scored tasks there will be 10 objects to remember the location of (set up practice trial). If you do not know what any of the items are then please ask

(Practice in passive or active according to whether the scored task that follows is in the passive or active condition)

Passive :
I will place some objects on the grid. I want you to learn where I put them, what they are is not important..just where they are. You will have 30 seconds to learn this before I take the grid away and replace it with a blank one.

Please put the markers where you think there were objects

Active :
I would like you to place these objects on the grid on the squares that have their pictures on and learn where you put them, what they are is not important..just where they are. You will have 30 seconds to do this before I take the grid away and replace it with a blank one.

Please put the markers where you think you placed objects. **Now you have had a practice lets begin the four scored tasks that look at your memory for locations**

Active V1H7 (location-1st)

	Pclp 1	Ctbd 1		Dice 1
Cork 3				
	Nail 1		Sltp 1	
Gftg 2			Hrrl 3	
		Ctwl 1		Tmsr 3

I will give you 10 objects and a grid with pictures on it. You will have 30 seconds to put *all* the objects on the grid in the locations shown by the pictures *and* to learn which squares you put objects on. Do not learn what the objects are-that is not important, just learn *where* you put them

(Reveal grid for 30 seconds then remove. Put the blank grid in front of the participant. . Give the participant 10 markers)

You have the same number of markers as objects you just put on the grid. Place the markers on the squares that you put objects on. You should place *all* the markers on the grid.

Active V1H8 (location-2nd)

Cflm 4		Shkl 1		Cbow2
Krng 1		Bckl 3		
				Pspn 4
Syrg 1		Cpeg 1	Dfls 2	
	Nbrs 2			

Place the objects on the their squares and learn *where* you put the objects. What the objects are isn't important, just where they are. You have thirty seconds (show grid for 30 seconds then remove).

(Replace with blank grid and 10 markers). Place the markers on the squares where you put objects. Use all the markers.

Passive V2H10 (location-1st)

Spls 2			Thmb 2	Ersr 2
	Bell 1	Bolt 3		Phok 2
Lstk 3			Pltr 1	
	Bpnr 3		Vsln 2	

(Put up screen. Lay out grid by matching objects to the pictures)

I have put 10 objects on a square grid. You can look at them for 30 seconds. I want you to learn which squares have objects on them. Do not learn what the objects are-that is not important, just learn *where* they are.

(Reveal grid for 30 seconds then remove. Put the blank grid in front of the participant. Give the participant 10 markers in a line between the participant and the grid)

Passive V2H11 (location-2nd)

Kkey 4		Clck 1		
	Ecup 3		Inkp 1	
Jpot1			Mcst 1	
	Soap 4	Cpad 4		Tppx 2
			Slce 1	

Look at the objects I have placed on the grid and learn *where* they are. What the objects are isn't important, just where they are. You have 30 seconds (show grid for 30 seconds then remove)

(Replace with blank grid and 10 markers) Place the markers on the squares where there were objects. Use all the markers.

Practice object

			Pcrd 1	
	Akey 1			
	Stmp 1		Hchf 1	
Chan 1				

We will be doing 4 tasks in which I will ask you to remember *what* objects are on a grid, like this (show example of a grid). Where the objects are will not important, just what they are. Sometimes *I* will put the objects on the grid and sometimes I will ask *you* to put them on yourself. If I put the objects on you will have thirty seconds to look at the grid and learn what the objects are. When you put the objects on yourself you will have 30 seconds to place the objects as well as learn what you have placed on the grid. After 30 seconds the grid you have been learning and the objects that were used will be removed. Then you will be asked to pick out the objects that were on the grid from amongst other objects that were not on the grid. Lets have a practice. In this practice your performance won't be scored its just so you can learn how to do the task, and there are only 5 objects. In the scored tasks there will be 10 objects to remember the identity of (set up practice trial). If you do not know what any of the objects are then please ask. (Practice in passive or active according to whether the scored task that follows is in the passive or active condition)

Passive :
I will place some objects on the grid. I want you to learn what objects I put on the grid, where they are is not important..just what they are. You will have 30 seconds to learn this before I take the grid away and replace it with a blank one.

(mix the objects with the distractors) Please pick out the objects you think were on the grid from amongst those that you think were not on the grid

Active :
I would like you to place these objects on the grid on the squares that have their pictures on and learn what objects you place, where they are is not important..just what they are. You will have 30 seconds to do this before I take the grid away and replace it with a blank one.

(mix the objects with the distractors) Please pick out the objects you think were on the grid from amongst those that you think were not on the grid **Now you have had a practice lets begin the four scored tasks that look at your memory for objects**

Active WH4 (object-1st)

	Btry 2		Nfle1	
	Swkt 2			Nclp 1
Ebnd 1		Hsld 3		
		Brct 4		Scrs 3
Dmmy 2			Strg 3	

I will give you 10 objects and a grid with pictures on it. You will have 30 seconds to put *all* the objects on the grid in the locations shown by the pictures *and* to learn what objects you put on the grid. Do not learn where you put the objects-this is not important, just learn *what* they are

(Reveal grid for 30 seconds then remove. Give the participant 10 objects and 10 distractors mixed together)

Here are the same 10 objects that you just put on the grid. They are mixed in with an equal number of objects that you did not put on the grid. I want you to pick out the objects you think you put on the grid, leaving those you think you did not.

Active WH5 (object-2nd)

	Wire 1			Cndl1
			Ptop 1	
	Cflm 2			Wshr 1
Tpck 4		Lblb 3		Etmr 1
	Stpl 3		Ppen	

Put the objects on their squares on the grid and learn *what* they are. Where they are is not important. You have 30 seconds (show grid for 30 seconds then remove)

(Replace with objects and distractors mixed together)

Pick out the objects you think you put on the grid.

Passive XH4 (object-1st)

			Coin 2	
Lblb 1	Ball 5			Erng 1
			Bttn 2	
	Ring 4		Bttl 4	
Cndl 3		Swts 5		Clgt 4

(Put up screen. Lay out grid by matching objects to the pictures)

I have put 10 objects on a square grid. You can look at them for 30 seconds. I want you to learn what objects are on the grid. Do not learn where the objects are-that is not important, just learn *what* they are.

(Reveal grid for 30 seconds then remove. Give the participant the 10 objects and 10 distractors mixed together)

Passive XH5 (object-2nd)

Bdge 4	Scrw 1			Cskr 3
		Sdvr 3		
	Bkcs 4		Bclp 4	
Ccup 3			Spch 1	
	Phot 1	Stpr 1		

Look at the objects I have placed on the grid and learn *what* they are-where they are is not important. You have 30 seconds (show grid for 30 seconds then remove)

(Replace with objects and distractors mixed together)

Pick out the objects you think were on the grid.

Practice location + object

Foil 1				
				Rkey 1
		Cpop 1		
	Tdsc 1		Awpe1	

We will be doing 4 tasks in which I will ask you to learn *what objects are where* on a grid, like this (show example of a grid). Both where the objects are and what they are is important. Sometimes *I* will put the objects on the grid and sometimes I will ask *you* to put them on yourself. If I put the objects on you will have thirty seconds to look at the grid and learn where and what the objects are. When you put the objects on yourself you will have 30 seconds to place the objects as well as learn where and what you placed on the grid. After 30 seconds the grid you have been learning and the objects that were used will be removed. Then you will be asked to pick out the objects that were on the grid from amongst other objects that were not on the grid and put them back on the grid in their correct positions. Lets have a practice. In this practice your performance wont be scored its just so you can learn how to do the task, and there are only 5 objects, in the scored tasks there will be 10 objects to remember (set up practice trial). If you do not know what any of the items are then please ask. (Practice in passive or active according to whether the scored task that follows is in the passive or active condition)

Passive :
I will place some objects on the grid. I want you to learn what objects I put where on the grid, both where they are and what they are is important. You will have 30 seconds to learn this before I take the grid away and replace it with a blank one.
(mix the objects with the distractors) Please pick out the objects you think were on the grid from amongst those that you think were not and place them where you think they were on the grid you just learnt

Active :
I would like you to place these objects on the grid on the squares that have their pictures on and learn what objects you place where on the grid, both where they are and what they are is important. You will have 30 seconds to do this before I take the grid away and replace it with a blank one.
(mix the objects with the distractors) Please pick out the objects you think were on the grid from amongst those that you think were not and place them where you think they were on the grid you just learnt **Now you have had a practice lets begin the four scored tasks that look at your memory for objects and their locations**

Active YH4 (object + location-1st)

	Kpin 1		Hnge 3	
Pctr 3			Clgt 3	
Ssht 4		Bclp 4		
	Ndle 1		Ntpd 1	
Hbnd 2				Sbrs 1

I will give you 10 objects and a grid with pictures on it. You will have 30 seconds to place all the objects on the grid in the locations shown by the pictures and to learn *which squares you put what on.* Both the *identity and the location* of the objects are important

(Reveal grid for 30 seconds then remove. Give the participant 10 objects and 10 distractors mixed together)

Here are the same 10 objects that you just put on the grid. They are mixed in with an equal number of objects that you did not put on the grid. I want you to pick out the objects you think you put on the grid, leaving those you do think you did not, then put them on the squares you think they were on in the grid you just learnt. So you are remembering *what* objects you saw *and where* you saw them.

Active YH5 (object + location – 2nd)

Drbt 1		Plst 1		
		Twhk 4		Dlck 1
	Ktmr 1			Wstl 3
Hpip 1				
	Crng 1		Spls 1	Erng 2

Put the objects on their squares on the grid and learn *where they are and what* they are. Both are important. You have 30 seconds. (show grid for 30 seconds then remove)

(Replace with objects and distractors mixed together)

Pick out the objects you think you put on the grid and put them on the squares you think they were on.

Passive ZH4 (object + location-1st)

			Twzr 1	
Rbbn 3		Dfls 1		
Btck 1			Swch 1	Mold 1
	Eplg 4			
Pfrm 2		Ppot 1		Pspn 1

(Put up screen. Lay out grid by matching objects to the pictures)

I have put 10 objects on a square grid. You can look at them for 30 seconds. I want you to learn where the objects are on the grid *and* what they are. Both the *location and the identity* of the objects is important.

(Reveal grid for 30 seconds then remove. Put the blank grid in front of the participant. Give the participant 10 objects and 10 distractors mixed together)

Here are the same 10 objects that were on the grid you just looked at. They are mixed in with an equal number of objects that were not on the grid. I want you to pick out the objects you think were on the grid leaving those that were not, then put them on the squares you think they were on in the grid you just learnt. So you are remembering *what* objects you saw *and where* you saw them.

Passive ZH5 (object + location-2nd)

Mirr 1				
	Plst 3		Pill 1	Mtch 1
Cpeg 5		Stpl 1		
		Pncl 2		Bcks 2
Prbn 3			Dpin 5	

Look at the objects I have placed on the grid and learn *what* they are *and where* they are. Both are important. You have 30 seconds. (show grid for 30 seconds then remove)

(Replace with a blank grid and objects and distractors mixed together)

Put the objects you think were in the grid on the squares you think they were on.

Administer feedback questionnaire

Administer debriefing

Appendix I: Feedback questionnaire

FEEDBACK QUESTIONNAIRE

Before we finish I would just like to ask you a few short questions

How did you find doing this study?

How did you find the tasks when you put the objects on yourself and when I put them on? How did you do each of these sorts of task?

How did you find doing the three tasks (when I asked you to remember where things were, what things were, or both what and where things were)? How did you do each of them?

Sign here to say that you have been debriefed: Date:

Appendix J: Debriefing statement

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Now where did I put that? Memory for objects and location

Debriefing Statement

The aim of this research was to explore similarities and differences in younger and older adults' memory for objects and locations. It is expected that there will be some similarities and some differences and that these will be affected by the way in which the information was learnt to begin with. Your data will help our understanding of human memory and in what ways memory changes or stays the same as we get older. It is then intended to use this understanding to go on to explore ways in which people with dementia differ from healthy adults. In this way we hope to find ways in which we can better support people who have dementia. Once again, results of this study will not include your name or any other identifying characteristics. The experiment did not use deception. If you have any further questions or wish to have a summary of the research findings once the project is complete, please contact me (Andrea Burrow) through the Clinical Psychology Office at the University of Southampton (023 80 595321).

Thank you for your participation in this research.

Signature ______________________________ Date ________________

Name Andrea Burrow

If you have questions about your rights as a participant in this research, or if you feel that you have been placed at risk, you may contact the Chair of the Ethics Committee, Department of Psychology, University of Southampton, Southampton, SO17 1BJ. Phone: (023) 80593995.

Appendix K: Table K1: One-sample Kolmogorov-Smirnov test results

			Younger adults	Older adults
			z, significance.	*z*, significance.
NART predicted full-scale IQ			0.64, .80	0.65, .79
Object task:	**Active**			
		Discrimination index	2.92 , .00**	1.87, .00**
		Bias index	†	3.05 , .00
	Passive			
		Discrimination index	2.73, .00**	2.78, .00**
		Bias index	3.05, .00**	3.05, .00**

Location task:	**Active**			
		Correct location	0.65, .80	0.86, .45
		Displacement	0.61, .85	0.68, .75
	Passive			
		Correct location	0.94, .37	0.55, .92
		Displacement	0.89, .41	0.64, .80
Object-location task:	**Active**			
		Discrimination index	2.21, .00**	1.17, .13
		Bias index	†	†
		Correct location	0.81, .53	0.58, .89
		Displacement	0.84, .48	0.65, .80
		Proportional location	0.42, .99	0.68, .75
		Proportional displacement	0.81, .53	0.70, .72

Passive		
Discrimination index	1.92, .00**	1.37, .04*
Bias index	3.03, .00**	3.05, .00**
Correct location	0.98, .29	0.71, .70
Displacement	0.97, .31	0.52, .95
Proportional location	0.87, .44	0.52, .95
Proportional displacement	0.93, .35	1.07, .20

Note: * = $p < .05$; ** = $p < .01$; † = insufficient variance to calculate z score and significance level