How does aging influence object-location and name-location binding during a visual short-term memory task?

Raju P. Sapkota[1*], Ian van der Linde[1,2], & Shahina Pardhan[1],

[1]Vision & Eye Research Unit (VERU), School of Medical Science, Anglia Ruskin University, East Road, Cambridge, CB1 1PT, UK

[2]Department of Computing & Technology, Anglia Ruskin University, East Road, Cambridge, CB1 1PT, UK

Author Note

[*] Correspondence concerning this article should be addressed to Dr Raju P. Sapkota, Vision & Eye Research Unit (VERU), YST213, School of Medicine, Anglia Ruskin University, Young Street, Cambridge, CB1 1PT, UK. Phone number: 0044-8451962642

E-mail: raju.sapkota@anglia.ac.uk

Abstract

Objective

Age-related impairments in human visual short-term memory (VSTM) may reflect a reduced ability to retain bound object representations, viz., object form, name, spatial, and temporal location (so called 'memory sources'). Our objective is to examine how healthy aging affects VSTM in a battery of memory recognition tasks in which sequentially presented objects, locations, and names (as auditory stimuli) were learned, with one component cued at test.

Methods

Thirty-six young healthy adults (18-30 years) and 36 normally aging older adults (>60 years with no underlying health and vision issues) completed five VSTM tasks: 1. Object recognition for two or four objects; 2. Spatial location recognition for two or four objects; 3. Bound object-location recognition for two or four objects; 4. Object recognition with location priming for two or four objects; 5. Bound name (auditory)-location (cross-modal) recognition for four objects.

Results

Significantly lower performance for older adults was found in spatial location recognition [task 2, p=0.03, 2 (memory loads) × 2 (age groups) ANOVA], bound object-location recognition [task 3, p<0.001, 2 (memory loads) × 2 (age groups) ANOVA], object recognition with location priming [task 4, p=0.02, 2 (memory loads) × 2 (age groups) ANOVA], and bound name-location recognition [task 5, p=0.001, independent samples t-test] tasks. A significant age group-task interaction was found (p =0.02)

Conclusion

Performance for all tests except test 1 was impaired in older adults. Lower performance for older adults was most significant in VSTM tasks requiring object-location (visual only) or name-location (auditory and visual) binding. The findings are compatible with the 'memory source' model, demonstrating that age-related binding performance is influenced by spatial coding and location priming deficits.

Keywords: visual short-term memory, mild cognitive impairment, binding, dementia

Introduction

It is known that different features belonging to the same object, such as color, shape, name, and location, are processed in different brain areas (Rao, Rainer, & Miller, 1997; Ungerleider & Mishkin, 1982). Features like color, form (or shape), and name are thought to be processed via the 'ventral' route, whilst features like location, motion, and spatial location are said to be processed via the 'dorsal' route (Goodale & Milner, 1992; Ungerleider & Mishkin, 1982). Our brain is able to integrate these object features to create unified object percepts, a phenomenon commonly referred to as 'binding' in cognitive science (Wheeler & Treisman, 2002).

Binding in visual memory is crucially important in enabling us to remember the location and visual properties of objects in our physical environment, and guide our behavior during everyday tasks such as reading a road map, identifying the color of traffic lights, and remembering names of friends and acquaintances. Often our everyday environment involve interaction with the items encoded from the same or different sensory modalities, for example, remembering objects in a visual space (referred to as uni-modal) or learning by audio-visual presentation, i.e., hearing the words and seeing the visual information simultaneously (referred to as cross-modal).

Our ability to bind object features during a visual short-term memory (VSTM) task is thought to be supported by the hippocampi and the surrounding brain structures, including the entorhinal and perirhinal cortices (Hannula & Ranganath, 2008; Hartley, *et al.*, 2007; Sutherland & Rudy, 1989; Wheeler, 2000). These structures are known to deteriorate with age (Bäckman, Andersson, Nyberg, Winblad, Nordberg, & Almkvist, 1999; Mitchell, Johnson, D' Episito, Raye, & Mather, 2000; Murray & Richmond, 2001), and are believed to be affected early in the progression of Alzheimer's disease (Hampel, Burger, Teipel, Bokde, Zetterberg, & Blennow, 2008), a degenerative brain condition that affects memory and other cognitive functions and leads to dementia. As a result of the aging population and a proportionate increase in the occurrence of degenerative brain conditions (such as Alzheimer's) that affect memory performance, it is becoming increasingly important for us to understand age-related changes in VSTM performance.

A number of studies have improved our understanding of memory decline with advancing age (Borella, Carretti, & DeBeni, 2008; De Beni & Palladino, 2004; Fiore, Borella, Mammarella, & DeBeni, 2012; Gutchess & Boduroglu, 2018). These studies have shown that older adults are less adept at suppressing irrelevant information compared to young adults during memory retrieval, and consequently experience greater memory distraction. Memory distraction may occur due to confusion of the target item with other items held in VSTM, or with items stored in long-term memory that share a semantic resemblance with the target item (Sapkota, van der Linde, & Pardhan, 2015). In this study that employed VSTM object recall task, young and elderly participants were asked to report the name of the object presented at a given location. Errors rates wherein participants reported the names of objects that had been presented in the memory display but not at a given location (non-target errors) vs. objects that had not been presented at all in the memory display (non-memory errors) were compared. Significant effect of age on the occurrence of different object-recall error types (non-target vs. non-memory) was found. The findings of these studies support the postulation that memory performance decreases with age as a result of a general deterioration of older adult's ability to inhibit irrelevant visual information (Hasher & Zacks, 1988; Zacks & Hasher, 1994).

Other studies have suggested that age-related deterioration in VSTM also occurs due to a decline in our ability to access '*memory source*' (Mitchell *et al.*, 2000; Sapkota, van der Linde, & Pardhan, 2015). Memory source is often defined as memory for origin of when or where something (e.g., an object) was learned, and may be accessed by providing contextual cues such as an object's image or its position in space and time (Mitchell *et al.*, 2000). In this framework, when an bound object-location or name-location is considered as a *memory source*, providing one of the components (i.e., object image, name, location) as a test cue may benefit *memory source* retrieval due to the priming of its (bound) twin object feature stored in VSTM (*feature priming*), or the priming of the entire *memory source*, i.e., form-location or name-location unit (*binding priming*) (Sapkota, van der Linde, Lamichhane, Upadhyaya, & Pardhan, 2017). In patients with mild cognitive impairment, who are greater at risk of developing dementia (Gauthier *et al*. 2006; Petersen, Smith, Waring, Ivnik, Tangalos, & Kokmen, 1999), repeated use of stimulus locations is reported to prime memory sources to a lesser degree compared to age and education-matched healthy controls (Sapkota *et al*., 2017).

Previous studies theorize that visual and spatial working memories are not entirely dissociable (Jiang Olson, & Chun, 2000; Olson and Marshuetz 2005; Vergauwe, Barrouillet, & Camos, 2009); hence binding of object's visual and spatial components in VSTM is likely to be automatic. This is empirically supported by the finding that memory for one feature (such as appearance, color, or location) is enhanced when another (task irrelevant) feature is repeated from memory and test display (Hollingworth, 2007; Kahneman, Treisman, & Gibbs, 1992).

VSTM binding is thought to be supported by episodic buffer, a subsystem of the working-memory model proposed to integrate information from disparate sources (Baddeley, 2000). The impact of aging on memory binding of an object's name heard simultaneously with the presentation of its spatial location is unclear, and, furthermore, only a handful of studies exist that have examined how aging influences object-location binding (Chalfonte, & Johnson, 1996; Read, Rogers, & Wilson, 2016). Examining the effect of age on object-location or verbally spoken name-location binding is important because to recall the richness of sensory information available at any given moment, our brain that deteriorates functionally with age, has to extract meaningful information from both within and across the different sensory modalities (Hillock, Powers, & Wallace, 2011). To our knowledge, no previous study has examined the effect of aging on name-location binding using a location recognition task for auditorily presented object names.

In this study we examined how the performance produced during VSTM tasks for object memory, location memory, and memory for binding of object-location or name-location differed between normally aging older adults (defined as >60 years of age with no underlying health and vision issues, and no cognitive impairment for a given age) and young healthy adults (18-30 years of age) using a sequential stimulus display procedure. The use of the sequential display procedure ensured that any possible spatial crowding effects that may be produced by a simultaneous display (Flom, Weymouth, & Kahneman, 1963; Pelli, Palomares, & Majaj, 2004; Polat & Sagi, 1993) were avoided. It is a common practice in sequential memory literature to report the effect of recency of the target stimulus; if an item is examined more recently in a sequence, it is likely to be remembered better as a consequence of a reduced temporal window for decay, and also due to reduced opportunity to incur interference from non-target items (Gold, Murray, Sekuler, Bennett, & Sekuler, 2005; Irwin & Zelinsky, 2002; Makovski & Jiang, 2008; Sapkota, Pardhan & van der Linde, 2016; Zelinsky & Loschky, 2005). How recency effect is influenced by aging in VSTM tasks is not adequately understood.

We identified the effect of aging on uni-modal binding (in this case, object - location) and on cross-modal binding (in this case auditorily presented object name simultaneously with a spatial location), and tested the prediction that older adults' performance would differ significantly from the young adults in tasks that required memory binding. The findings will be useful in assessing the utility of these tests in detecting age-related cognitive decline, and will provide baseline data for differentiating changes in VSTM performance due to healthy aging from early dementia, as the brain areas known to deteriorate with age are also thought to be affected early in the progression of dementia (Hampel *et al.*, 2008).

Materials and Methods

Participants

Thirty-six normally aging older adults (mean age 69.2 years, *SD* 6.0; mean education level = 11.10 years, SD = 1.60) with no underlying health issues (self-report) and vision problems and 36 young healthy adults (mean age 22.1 years, *SD* 2.6; mean education level = 11.60 years, *SD* = 1.07) participated. All participants had a 'normal' cognitive score (> 27) on the mini-mental state examination (MMSE) test (Folstein, Folstein, & McHugh, 1975). Participant groups did not differ significantly in education level (p = 0.35). Participants gave their informed consent prior to taking part in the study. The study protocol was approved by the Faculty Research Ethics Panel, Anglia Ruskin University, Cambridge, UK. All participants were able to speak English fluently. Participants were treated in accordance with applicable ethical guidelines that followed tenets of the Helsinki Declaration. All participants had normal or corrected-to-normal vision and no hearing impairment (self-reported), and were able to give informed consent to take part in the study.

Stimuli

Stimuli comprised 180 line drawings of real world objects (Snodgrass & Vanderwart, 1980), each subtending 2.5˚ of visual angle at 57 cm. Stimuli belonged to one of 14 semantic categories (animal, article of clothing, flower, etc.). Example stimuli are shown in Fig. 1.

<<Figure 1>>

Nameable stimuli were used (rather than non-nameable novel objects) for ecological validity, and because, in some trials, our experimental procedure required cueing object locations by auditorily presented names (see *Procedure*). Furthermore, using only the line drawing of objects as stimuli rather than with their natural texture and color helped to minimize potential confounders from long term memory support. Stimulus presentation was controlled by MATLAB (Mathworks, Natick, MA) with the PsychToolbox/Video Toolbox extensions (Brainard, 1997; Pelli, 1997). Stimulus background was set to mid-gray.

Apparatus

Stimuli were displayed using a Sony laptop computer (Sony Corporation, Model: PCG-71313M, Japan) with a screen resolution set at 1366×768 pixels and a refresh rate of 60

Hz. Viewing distance was set to be approximately 57 cm. Ambient light was held constant across trials and between participants.

Procedure

All eligible participants were tested on the VSTM tasks by author RS. Participants wore the spectacles where they were prescribed to correct their vision. Experimental procedures were preceded by a stimulus learning routine, during which all 180 stimuli were displayed sequentially in random order; participants were asked to name each stimulus in English (self-paced) as it appeared. When participants could not name/recognize a stimulus, the experimenter familiarized them with it by giving them a verbal prompt (its name). Next, stimuli that participants could not originally name were presented again one at a time, and participants were asked again to name them in English as they appeared. Out of the total, 11 participants (six older, five young) required re-presentation of one or more stimuli; nine (five older, four young) required re-presentation for only one stimulus (from a total of 170), and two (one older one young) required a re-presentation for two stimuli. There was no significant difference between the two groups ($p > 0.7$). All 11 participants were able to name all the stimuli correctly on their second attempt.

Detailed test procedures have been described elsewhere (Sapkota *et al.*, 2017), but are summarized below.

Test 1 (see Fig. 2, Test 1) measured participants' memory for object *only*. The following procedures were used: each trial began with a fixation-cross displayed at the screen center for 800 ms ensuring that all participants fixated upon a common screen position prior to the memory display. Next, either two or four line drawings of real-world objects (see *Stimuli*) were shown on to the computer screen sequentially (i.e., one at a time), each for 1000 ms, at random locations, which participants were asked to remember. We refer to this as the memory display. This was followed by the presentation of a two-digit number at the center of the display screen for 900 ms. Participants were asked to say this number aloud to discourage sub vocal rehearsal of stimuli during memory retention period (Baddeley, 1986; Todd & Marois, 2004). Using verbal load during memory encoding, wherein participants are asked to say aloud the two-digit number was not ideal in this study (mainly in test 4, see later, which would interfere significantly with the auditory presentation of the stimuli). Following this, a test display was presented in which either a previously shown object (*yes* trial) or a new object (*no* trial) was displayed at the center of the screen. Participants were required to identify whether the test object had been shown in the preceding memory display, and to give a yes/no verbal response. Responses were recorded by the experimenter using the left and right buttons of a computer mouse, for *yes* and *no*, respectively. The next trial commenced immediately after a response was submitted.

There were 16 trials in total. These were divided equally between the two memory loads, i.e., memory load 2 (ML2) and memory load 4 (ML4). For each memory load, there were an equal number of *yes* and *no* trials. In *yes* trials, the temporal positions used to present stimuli in the memory display were probed equally often (i.e., for ML2, each of the two temporal positions were tested twice; for ML4 each of the four temporal positions were tested once). Participants were instructed to concentrate on response accuracy rather than response speed.

Each participant completed a practice block of six trials before the experimental data were collected. Participants were permitted to rest whenever they wished by informing the experimenter, in which case the response they provided was withheld by the experimenter until they were ready for the next trial.

Test 2 measured participants' memory for location *only* (see Fig. 2, Test 2). Procedures were similar to test 1, except that here, in the memory display, an empty square box (2.5˚ × 2.5˚) was shown sequentially at two or four random spatial positions on the computer screen. In the test display, a spatial marker (2.5˚ × 2.5˚ empty square box) was shown either at one of the square locations cued in the memory display (*yes* trial), or at a new location not cued in the memory display (*no* trial). Participants were required to identify whether the location of the square box shown in the test display was cued in the preceding memory display, and give a yes/no verbal response. The number of trials across memory loads (i.e., ML2 and ML4) and temporal positions were distributed similarly to test 1.

Test 3 measured participants memory for object and location combined (i.e., object-location binding), see Fig. 2, Test 3. The experimental procedures, number and distribution of trials across memory loads were similar to test 1, except that here, in *yes* trials, the test object (selected randomly from the memory display) was shown at its original location. In *no* trials the test object was shown at a location occupied previously by a different memory object. Hence, memory for the binding of the target object (form) to its location was required to perform the task successfully.

Participants responded yes/no verbally to indicate whether they believed the location of the test object was the same or different to the location at which it had been shown in the preceding memory display.

Test 4 measured participant's memory for object with location priming (Fig. 2, Test 4). Stimulus locations were repeated from memory to test display, but unlike test 3, in *no* trials a new object not previously used in the memory display was shown in the test display. This enabled us to determine whether any responses in test 3 were driven by priming effects due to stimulus locations being repeated. Trials across memory loads and temporal positions were distributed similarly to test 3.

Test 5 measured participant's ability to bind an object's auditorily presented name to its location (cross modal binding for name-location), see Fig. 2, Test 5. Procedures were similar to test 3, except that, here, instead of showing object drawings in the memory display, empty square boxes were shown one after another at four random locations (i.e., only ML4 was used, as pilot data showed ceiling effects with ML2). While examining the empty boxes, participants also heard object names spoken (sufficiently loud to be heard clearly by all participants) by the computer in English, i.e., when they hear the word "shirt" they are required to encode the verbal component (the word "shirt"), and the concurrently displayed visual component (the location of the spatial marker). The presentation of auditory stimuli (object names) was synchronized with the presentation of the empty square boxes in the memory display. Participants were explicitly told to remember both the object name and the location of the empty square box presented concurrently. The test display comprised a line drawing of one of the objects named in the memory display. In *yes* trials, the test object was shown at the location at which its name was spoken when the square box had appeared at this location in the memory display. In *no* trials, the test object was shown at the location at which its name was spoken when the square box had appeared at a different location in the memory display. Hence, memory for binding of object name, presented auditorily, to its location was examined.

Participants responded yes/no verbally to indicate whether the image of the test display object was shown at the cued location at which its name was spoken in the memory display. Each participant completed six practice trials, followed by 16 experimental trials. There were an equal number of *yes* and *no* trials. In *yes* trials, the temporal positions used to cue locations in the memory display were probed equally often (i.e., each of the four temporal positions were tested twice).

Test order was randomized for each participant rather than counterbalanced. It took approximately 20 minutes for each participants to complete all tests, including completing the MMSE test.

<< Figure 2>>

Data were categorized into hits, misses, false alarms and correct rejections. Memory performance was analyzed in terms of percent correct responses. For comparison purposes with our previous studies and other studies, we preferred to use % correct responses as performance measurement. Hit rates across temporal positions were used to interpret recency (or order) effects. Since test stimuli in non-match trials were not presented in any of the temporal positions in the memory display (owing to the nature of the task used, i.e., yes-no recognition), only the hit rates were used (i.e., correct responses from match trials) to examine recency effects. Hit rates relative to the n-back position of the target stimulus in the memory display (which ranged from 1 to 2, where 1 = earliest and 2 = latest for ML2, and from 1 to 4, where 1 = earliest and 4 = latest for ML4) were analyzed using a one-way repeated measures ANOVA with temporal position as a within-subjects factor; a similar approach has been used in previous studies (Sapkota, Pardhan, & van der Linde, 2011; Zelinsky & Loschky, 2005). Response biases was calculated using the formula from Macmillan and Creelman (1991) as following, response bias = - [Z(HR) + Z(FAR)]/2. Between-group participant data were analyzed using 2 (participant groups) × 2 (memory load) mixed ANOVAs, or independent sample t-tests, as required. To examine the effect of memory source and prime source a 2 (location vs. object) x 2 (location vs. object) design repeated ANOVA was used for each participant group. One factor would be the source of a prime (location vs. object form) and the other would be the source of the memory (location vs. object form).Where the assumption of sphericity was violated (identified using Mauchly's test), degrees of freedom were adjusted using the Greenhouse-Geisser procedure. Cohen's *d* and partial eta square (pη^2) were used to report effect size for the *t*-test and the ANOVA test, respectively

Results

Fig. 3 shows overall performance (% correct responses) averaged across memory loads for tests 1-5. Overall higher performance was found in test 1 compared to the rest of the tests. This may be because test 1 was relatively easier to perform producing near-celling effects.

<<Figure 3>.

Mean % correct responses for individual memory load (for each participant group) for tests 1-5 are shown in Table 1.

<<Table 1>>

For object *only* memory (test 1) a 2 (young, older; age groups) ×2 (2, 4 stimuli; memory loads) mixed ANOVA showed that overall memory performance did not differ significantly between the age groups (Table 1). Although, paired samples *t*-tests showed a significantly lower performance (mean % correct response) for ML4 than ML2 for each age group individually (Table 2), independent samples-*t* tests showed that memory performance did not differ significantly between the age groups for either memory load (Table 1). Recency effects were not significant, except for with young adults at ML4 [p =0.05].

For location *only* memory (test 2) a 2 (age groups) ×2 (memory loads) mixed ANOVA showed a statistically significant difference between the age groups (Table 1). Similarly to test 1, a paired samples *t*-test showed a significantly lower performance for ML4 than ML2 for each age group individually (Table 2), and an independent sample-*t* test showed that memory performance differed significantly between the age groups for ML2 only (Table 1). This is an interesting finding which we aim to explore in detail in future. One possible explanation may be that at low memory load, in young adults, VSTM resources for location are shared more congruently compared to the older adults, producing higher performance; while at high memory load, VSTM resources for location are shared randomly in both the young and the older adults.

Older participants showed significant recency effects at lower memory load [ML2, $F(1,35)$ =7.35, p =0.01, d =0.70], and the young adults showed a significant recency effect at higher memory load [ML4, $F(2.18,76.33) = 5.65$, $p = 0.004$; $p\eta 2 = 0.14$]. It is possible that the at higher memory load, older adults may have used a deliberate memorization strategy, in which they memorized only the first few items in a sequence, and/or the most recently presented few items, i.e., not necessarily reflecting primacy and recency effects (Sapkota, Pardhan & van der Linde, 2016).

In test 3 (object-location binding), which required participants to explicitly remember objects and their locations combined, significantly lower performance for the older participants compared to the young participants was found using a 2 (participant groups) × 2 (memory loads) mixed ANOVA ($p < 0.001$, Table 1). The difference was significant at both high and low memory loads (Table 1). These results, combined with the non-significant difference found between the participant groups for object *only* (test 1) memory, and relatively, a weaker significant difference between participant groups for the location *only* (test 2) memory, suggest that older adults are relatively less adept at binding object to its location in VSTM when compared to young adults. The data suggest that age-related impairments in object-location binding are influenced to a greater degree by deficits in memory for location than for object itself. Paired samples *t*-test showed significantly lower performance for ML4 than ML2 for test 3 (Table 2). An independent samples-*t* test showed that memory performance differed significantly between the participant groups at both high and low memory loads in test 3 (Table 1). Significant recency effects were observed only for older adults at ML4 [$F(3,105) = 3.90$, $p = 0.01$, $p\eta 2 = 0.10$].

In test 4 participants performed an object recognition task in which the locations used to present stimuli in the preceding memory display were reused in the test display in both *yes* and *no* trials (allowing the effect of location priming by its repeated presentation to be examined). A significant difference in performance between participant groups was found using a 2 (participant groups) × 2 (memory loads) mixed ANOVA (Table 1). This suggests that the significant differences observed between the participants groups in test 3 could have been influenced by the use of locations between memory and test displays. Furthermore, we examined whether controlling for priming effects by using regression analysis (test of mediation, Sobel test) would render performance differences between age groups in test 3 to be non-significant; this was not found (p =0.04). The results suggest that age differences in test 3 (object-location binding) occurred above and beyond any age differences in priming.

Although, paired samples *t*-test showed a significantly lower performance for ML4 than ML2 for both participant groups (Table 2), an independent samples *t*-test showed that memory performance differed significantly between the participant groups for ML4 only (Table 1). Recency effects were not significant for either participant group for either memory load ($p \geq 0.10$).

In test 5, participants' memory for the explicit binding of object locations to their auditorily presented names was measured. Older adults' performance was significantly lower than for young adults (independent samples t-test, Table 1). Significant recency effects were observed for both participant groups [older adults, $F(2.43,85.03) = 6.72$, $p <$ 0.001, $p\eta^2 = 0.16$; young adults, $F(3, 105) = 3.23$, $p = 0.03$, $p\eta^2 = 0.08$], implicating global recency effects (Gold, Murray, Sekuler, Bennett, & Sekuler, 2005).

Each of the four temporal positions in ML4 in tests 1-4 were probed only once (and twice in test 5, see below). Consequently, the robustness of recency effects examined within each participant group may be limited. However, it should be noted that the overall aim of this study was to compare average performance (% correct response) between participant groups for each memory load; eight trials were collected from each participant for each memory load, except for test 5, in which testing was done *only* with ML4 and thus comprised 16 trials.

Response bias was not found to differ significantly between participant groups for any test 1-5 (all $p \geq 0.50$).

A concerning issue may be that in test 5, an auditory label is presented at encoding and a visual object is presented at test. Thus, Test 5 not only mixes the modality presentation that differs with the other experimental condition, but also leads to a mix of modalities between encoding and test. To address this concern, we collected additional data (from 18 healthy young and 18 healthy elderly participants) for test 5 by presenting the exact stimulus type (auditory) in both the memory and the test display (test procedures were otherwise identical to test 5), and also added another test condition that measured memory for auditorily presented names *only* (using a yes-no recognition task). While the performance differences between the age groups were not significant for the auditorily presented names only condition, the differences were significant in binding the simultaneously presented auditory (in our case object name) and location information, $t(34) = 5.49$, $p < 0.001$, $d = 1.83$.

Age (2 groups) x tests (5 conditions) mixed ANOVA was conducted to identify whether the overall performance across tests differed between the age groups and any interactions occurred between age groups and test conditions. Since in test 5 only one memory load (comprising four items) was used, performance in test 1-4 had to be averaged across memory loads for the analysis. A significant main effect of age [$F(1,70) = 21.75$, $p < 0.001$, $p\eta^2 = 0.24$], and a significant interaction between age and test conditions [$F(4.280) = 3.08$, $p = 0.02$, $p\eta^2 = 0.04$] was found, suggesting that age impacted differently in our different VSTM tests.

In responding to a reviewer's comments we also examined the main effect of memory source (location vs. object form) and prime source (location vs. object form) using as a 2 x 2 design for tests 1-4 (Table 3). A significant main effect of prime source but not of memory source was found for both age groups [young participants $F(1,35) = 71.78$, $p < 0.001$, $p\eta^2 = 0.67$, older participants, $F(1,35) = 166.78$, $p < 0.001$, $p\eta^2 = 0.83$). Significant main effect of prime source was also observed when memory source for visual object was replaced by auditory (verbally spoken name) memory source (test 5).The interaction between the prime source and memory source was not significant for either participant group ($p > 0.10$). In addition to, we also re-plotted/analyzed data using a 2 (age) x 2 (display size) x 2 (prime source) x 2 (memory source) design (Fig. 3). Overall, a greater memory performance was observed for both the age groups when the memory source was a visual form/location, compared to when the memory source was visual form-location or auditory-location ($p < 0.05$). Furthermore, a significant main effect of prime source was found. A four-way interaction between source type x prime type x age group x memory load was found ($p = 0.04$), suggesting that effect of age on memory prime in influenced by the type of memory source and the size of memory load in tests 1-4.

Discussion

In this study we examined the VSTM performance using five different tests in two age groups: normally aging older adults and young healthy adults. In tests 1 and 2 our memory task did not require participants to bind object to its location. In tests 3 and 5, explicit memory binding was required for object-location and name-location respectively. In test 4 memory binding was not required to perform the task successfully, but because in '*yes*' trials the test object was always shown at its original location from the memory display, there was a possibility that participants could bind object to its location implicitly. Also, as one of the locations used to present items in the memory display was always re-used in the test display, i.e., regardless of whether a trial was '*yes*' or '*no*' trial, test 4 enabled us to examine potential age-related deficits in location priming arising due to its repeated use to present stimuli between the memory and the test display during a VSTM task.

Significantly lower performance was found for older adults at both high and low memory loads (i.e., sequence lengths) where participants were required to remember an object's and its location combined (test 3). Lower performance was also found for older adults in retaining an object's name and its location combined, compared to young adults (test 5). An overall performance difference across memory loads was also observed between participant groups in tests 2 and 4. However, the performance decline in tests 3 and 5 for older adults compared to the young adults was of greater statistical significance than in tests 2 and 4. Earlier study on patients with mild cognitive impairment in which the same set of tests were used suggest that tasks measuring unimodal (object-location) and cross-modal (name-location) binding performance appear to be particularly effective in detecting early cognitive changes in those at higher risk of developing dementia

(Sapkota *et al.*, 2017). The results of the present study in conjunction with the findings from that study (Sapkota et al., 2017) suggest that VSTM binding performance is affected both in early dementia and aging process, but the effect is likely to be more obvious for early dementia. Furthermore, our data suggest that age-related decline in visual and auditory binding occur when the memory sources are auditory and visual, or auditory and visuo-spatial. The findings are potentially useful in understanding memory complaints in complex environments where stimulus information from different modalities (visual, auditory, visuo-spatial) are present simultaneously. Within the visual modality older adults are reported to consistently demonstrate poorer recognition memory for bound object features compared to individual object features such as color, shape, and location, especially when these visual features are acquired intentionally (Chalfonte & Johnson, 1996).

One might posit that the observed differences between participant groups in object-location binding tasks may have been driven by differences in priming effects arising from the repeated use of the same locations between the memory and test displays. To address this, in test 4, memory stimulus locations were primed in the test display (in both *yes* and *no* trials), but participants were not required to explicitly remember both the object and its location (since the memory task required object recognition only). A significant performance difference was found between participants groups at high memory load only, suggesting that the impairment found for older participants for object-location binding at high memory load may be driven by differences in location priming effects. Clinical data have also shown a significantly lower location priming effects in VSTM in a color-shape binding task in patients with both early onset familial Alzheimer's disease (caused by E280A mutation of *presenilin*-1 gene), and late onset sporadic Alzheimer's disease (Mitchell & Schmitt, 2006; Parra, Abrahams, Fabi, Logie, Luzzi, & Sala, 2009).

One influential model proposes that age-related differences in VSTM occur due to a decline in our ability to access object's spatial and temporal features (so called '*memory sources*') due to advancing age (Mitchell *et al*., 2000; Sapkota, van der Linde, & Pardhan, 2015). Access to those sources supports the binding of spatial and temporal features in VSTM. In this framework, when we consider object-location or name-location binding as a *memory source*, the provision of one of its components (object, name, or location) as a test cue may benefit *memory source* retrieval. Our data suggest that age-related decline in VSTM binding may occur due to a deficit in *feature priming* (in which a test cue primes the representation of its (bound) twin object feature stored in VSTM or *binding priming* (in which a test cue primes the representation of the entire *memory source*, i.e., an object -location or name-location bound unit (Sapkota *et al*., 2017). Older adults were found to have an impaired ability to prime the *memory source* compared to young adults.

Following limitations should be noted: (i). As hearing performance was not measured objectively, it is possible that age differences in test 5 performance may have been due to decreased hearing in addition to binding deficits. However when participants were trained in our pilot tests, none of them expressed any problems with their recognition of the auditory stimuli; (ii). Our categorization of normally aging older adults was based on participants' self-report of having no underlying health issues and also their normal performance on established and recognized memory tests; however it is possible that participants may not always know if they have any underlying health issues and unless sophisticated brain imaging is carried out, it is difficult to know exactly. This was beyond the scope of our study (iii). It may be possible that participants were visualizing a version of the object when the auditory label was presented during the memory display, or that they could have represented only the auditory component during encoding. Hence, the relative influence of the individual modality type (auditory vs. visual) on information being bound together is not distinct; (iv). Since memory was tested in the lab using line drawings of objects, it is possible that performance may be vary a bit when using stimuli in their natural environments. This needs to be investigated under very controlled conditions.

To summarize, our data show that older adults exhibit greater impairment in VSTM tasks that require object-location and name-location binding. More importantly, overall aging was found to affect the location memory task. Age-related decline in VSTM performance is influenced by impairments in spatial coding and location priming. According to a previous model, attention shifts to the location where the stimulus appears to create spatial codes; if the same location is reused, spatial codes serve to facilitate memory recognition task (Nicoletti & Umilta, 1994). The findings are useful in gaining a more complete understanding of age-related cognitive decline, and are expected to provide baseline data in delineating early cognitive decline due to dementia from normal age-related changes.

Disclosure

All the authors have read the manuscript and have agreed to be listed as authors. We declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Figure 1. Example stimuli.

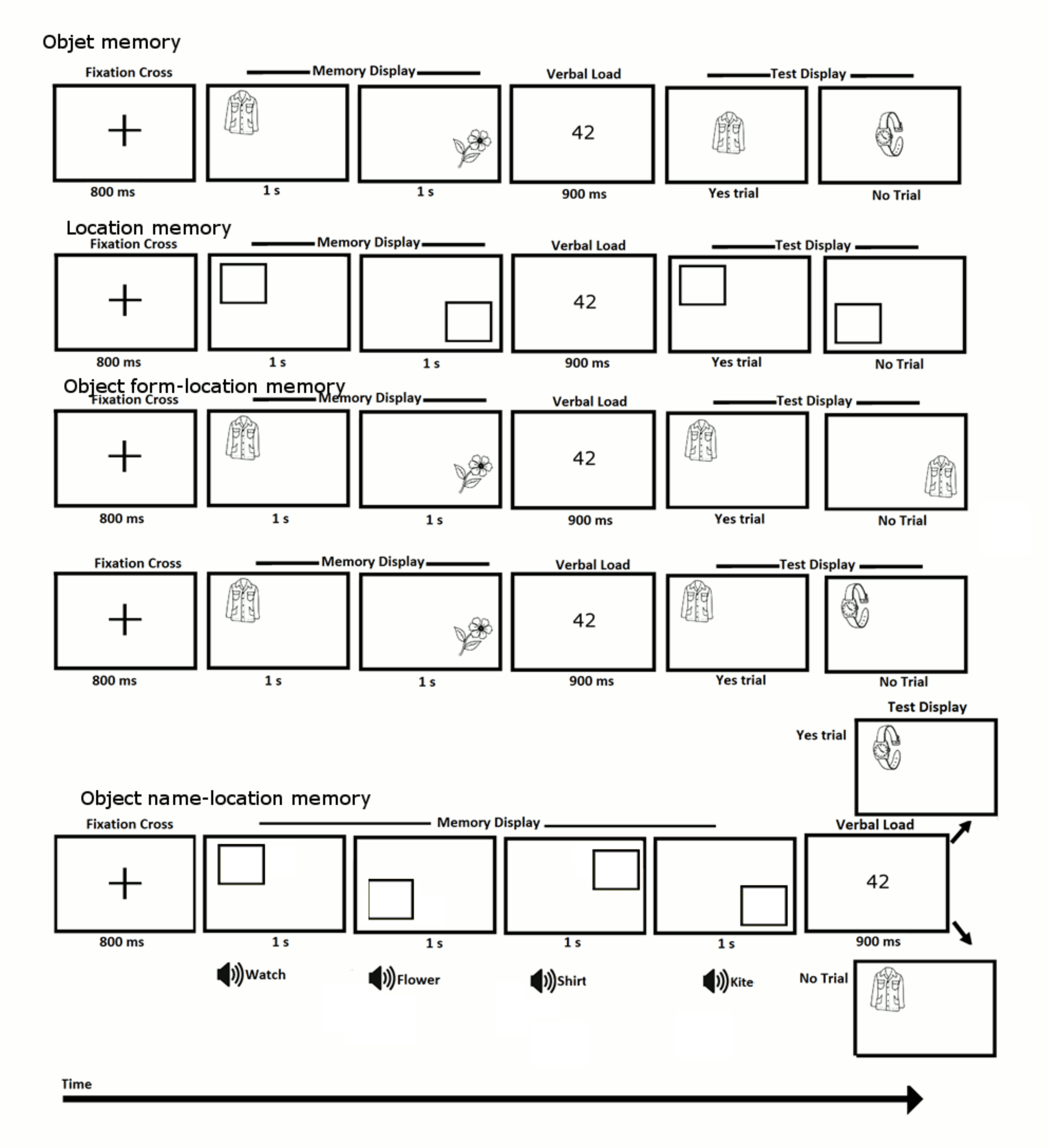

Figure 2. Schematic diagram (not-to-scale) of trial sequence used. For tests 1-4 only memory load 2 is represented. For test 5 memory load 4 is represented. In test 5 🔊 represents the presentation of an auditory stimulus simultaneously with the presentation of a spatial marker in the memory display.

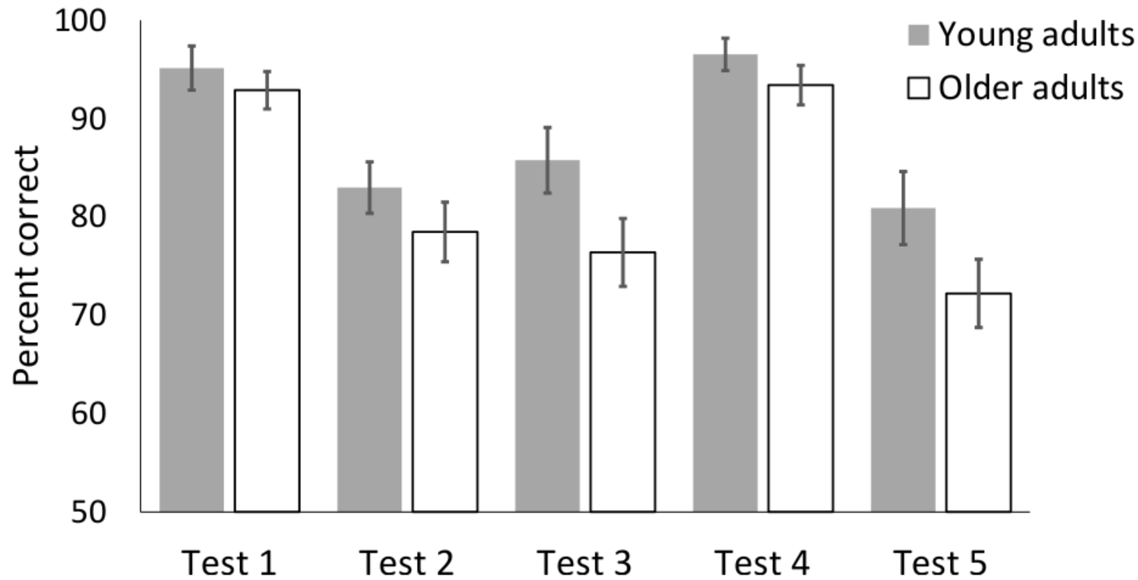

Figure 3. Overall percent correct response for young and older adults for tests 1-5 (test 1-object recognition for two or four objects; test 2-spatial location recognition for two or four objects; test 3-bound object-location recognition for two or four objects; test 4-object recognition with location priming for two or four objects; test 5-bound name-location recognition for four objects). Error bars represent ±1.96SE.

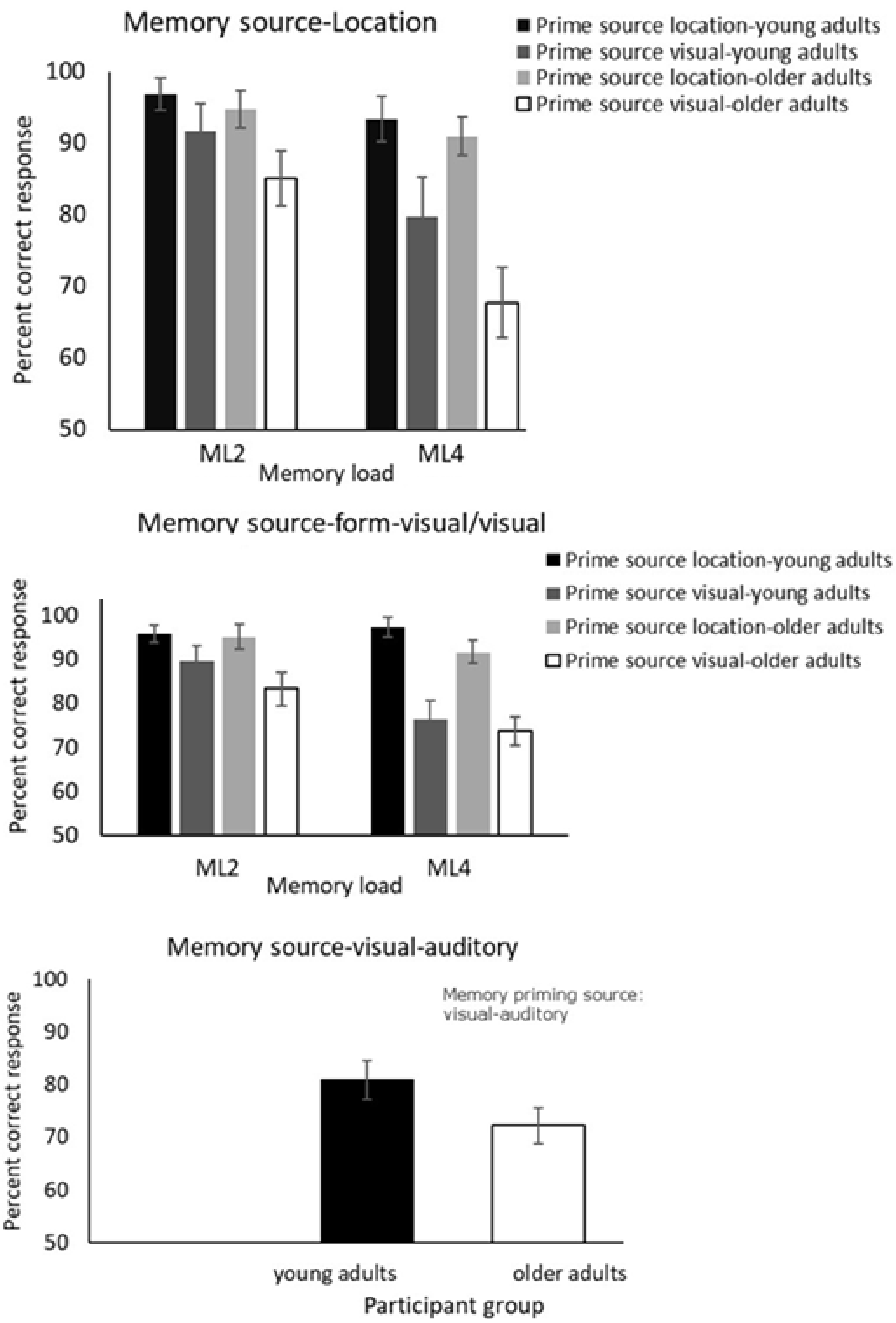

Figure 4. Summary of percent correct response data for different memory source and prime source types.

	MEMORY LOAD 2			MEMORY LOAD 4			
	Older adults	Young adults	Independent samples t-test	Older adults	Young adults	Independent samples t-test	**ANOVA Results**
TEST	Mean (SD)	Mean (SD)	Older vs.Young adults	Mean (SD)	Mean (SD)	Older vs. Young adults	2 (age groups) × 2 (memory loads)
1	94.79 (±8.11)	96.88 (±6.93)	t(70) =-1.17, p =0.25, *d* =0.28	90.97 (±8.24)	93.40 (±9.68)	t(70) =-1.15, p =0.26, *d* =0.28	F(1,70) =2.27, p =0.14, $p\eta^2$ =0.03
2	83.33 (±11.95)	89.58 (±10.98)	t(70) =-2.31, p =0.02*, *d* =0.54	73.61 (±9.81)	76.39 (±13.29)	t(70) =-1.01, p =0.32, *d* =0.24	F(1,70) =4.90, p =0.03*, $p\eta^2$ =0.03
3	85.07 (±11.88)	91.67 (±11.95)	t(70) =-2.35, p =0.02*, *d* =0.55	67.71 (±15.05)	79.86 (±16.44)	t(70) =-3.27, p =0.002*, *d* =0.20	F(1,70) =14.66, p <0.001*, $p\eta^2$ =0.18
4	95.14 (±6.45)	95.83 (±5.98)	t(70) =-0.40, p =0.69, *d* =0.55	91.67 (±7.91)	97.22 (±6.76)	t(70) =-3.21, p =0.002*, *d* =0.76	F(1,70) =5.55, p =0.02*, $p\eta^2$ =0.07
5				72.22 (±10.61)	80.90 (±11.37)	t(18) =3.35, p =0.001*, *d* =0.76	

Table 1. Mean (±SD) and results of independent samples t-tests (between memory loads), and 2 × 2 mixed ANOVAs on percent correct response for tests 1-5. The shaded areas for test 5 indicate that only memory load 4 was used. Effect size are represented by Cohen's *d* and partial eta square ($p\eta^2$) for the t-tests and the ANOVA tests, respectively

	Young adults	Older adults
Test number	ML2 *vs*. ML4	ML2 *vs*. ML4
1	t (1,35) =2.14, p =0.04, d =0.41	t(35) =1.99, p =0.05, d =0.47
2	t(35) =4.30, p <0.001, d =1.01	t(35) =5.02, p <0.001, d =0.89
3	t(35) =3.50, p =0.001, d =0.82	t(35) =6.14, p <0.001, d =1.28
4	t(35) =2.52 p =0.02, d =0.22	t(35) =5.59 p <0.001, d =0.42

Table 2. Results of paired samples *t*-test between memory loads within each participant group for test 1-4. Test 5 has not been included as only ML4 was used.

		Prime source	
		Location	(Visual) object form
Memory source	Location	Is this a location presented in one of the displays? (Test 2)	Is this object form in its correct location? (Test 3)
	(Visual) object form	Is this the correct object form in this location? (Test 4)	Is this an object presented in one of the displays? (Test 1)

Table 3. Categorizing tests 1-4 according to the memory source (location vs. object form) and the prime source (location vs. object form). Test 5 is identical to test 4, except that visual object form memory source is replaced with an auditory object form memory source.