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Original Research Report

Age-Related Deficits in Visuospatial Memory Are due to Changes in Preparatory Set and Eye–Hand Coordination

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Abstract

Objectives. Healthy aging is associated with a decline in visuospatial working memory. The nature of the changes leading to this decline in response of the eye and/or hand is still under debate. This study aims to establish whether impairments observed in performance on cognitive tasks are due to actual cognitive effects or are caused by motor-related eye–hand coordination.
Methods. We implemented a computerized version of the Corsi span task. The eye and touch responses of healthy young and older adults were recorded to a series of remembered targets on a screen.
Results. Results revealed differences in fixation strategies between the young and the old with increasing cognitive demand, which resulted in higher error rates in the older group. We observed increasing reaction times and durations between fixations and touches to targets, with increasing memory load and delays in both the eye and the hand in the older adults.
Discussion. Our results show that older adults have difficulty maintaining a "preparatory set" for durations longer than 5 s and with increases in memory load. Attentional differences cannot account for our results, and differences in age groups appear to be principally memory related. Older adults reveal poorer eye–hand coordination, which is further confounded by increasing delay and complexity.

Key Words: Aging—Attention—Corsi task—Eye movements—Hand movements—Motor control—Working memory

A cognitive mechanism that has generated great interest in the field of healthy aging is working memory (WM). First described by Baddeley and Hitch (1974), WM is a short-term memory system, which has limited capacity in the number of items held but represents an individual's ability to store, manipulate, and retrieve information. One component of the WM model is the visuospatial sketchpad, which is specialized for maintaining and storing visual and spatial information (Garden, Cornoldi, & Logie, 2002). Behavioral studies have demonstrated that spatial WM abilities decline (Elliott et al., 2011), especially from the age of 60 onward (Dobbs & Rule, 1989). This decline can have a detrimental effect on WM, which plays a central role in human cognition (Carpenter & Just, 1989). Several studies have also identified that healthy aging has a more detrimental effect on visuospatial working memory (VSWM) compared with other WM components such as verbal WM (Fiore, Borella, Mammarella, & Beni, 2012; Jenkins, Myerson, Joerding, & Hale, 2000; Tubi & Calev, 1989). Performance in older adults (OAs) demonstrates slower processing of spatial information (Meadmore, Dror, &

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Bucks, 2009) and reduced efficiency of encoding spatial stimuli when compared with the same in younger adults (YAs) (Hartley, Speer, Jonides, Reuter-Lorenz, & Smith, 2001). Aging can also result in a decline in VSWM maintenance compared with that in YAs, which shows a further decline with an increase in task demand (Kessels, Meulenbroek, Fernández, & Olde Rikkert, 2010), such as increase in set size (Chen, Hale, & Myerson, 2003; Plude, Hoyer, & Lazar, 1982) and delay (Gazzaley, Cooney, Rissman, & D'Esposito, 2005). Current literature suggests that OAs fail to preserve details in visual tasks over time, when compared with YAs (Sweeney, Rosano, Berman, & Luna, 2001).

Gazzaley (2011) proposed that the age-related decline in WM performance may be the consequence of impaired attentional processing. To address the effects of memory on motor performance and to control for possible attentional differences between age groups, the proposed study used a computerized version of the Corsi block-tapping (span) task (Corsi, 1972). This task is a popular approach for investigating spatial WM and involves remembering a series of blocks (targets) that have been touched by an experimenter. After a delay, participants are instructed to reproduce the same sequence of spatial locations (Corsi, 1972). Cross-culturally, OAs perform significantly worse in this task compared with YAs (Hedden et al., 2002; Myerson, Emery, White, & Hale, 2003). This study applied a computerized version of the Corsi span task that has been used previously in YAs (Burke, Allen, & Gonzalez, 2012). The performance of YAs in the study of Burke et al. (2012) revealed a significant decline with increasing target number (set size) and with sequential (position and order), compared with simultaneous (position only), target presentations. In addition, no delay between the target presentation and response resulted in a reduced reaction time (RT) of the hand. The attentional manipulation looked at color versus shape change for object identification, which was designed to induce easy versus more challenging detection, respectively; however, this manipulation had little effect on the movement parameters of both eye and hand in YAs (Burke et al., 2012).

In addition, there are also a number of motor changes, including balance and gait deficits, that occur as we age(for review, see Seidler et al., 2010). RT, in general, also increases across both eye and hand movements . When the goal of a motor response is known, the brain can prepare for this movement and facilitate the timing and accuracy of the movement. This gradual buildup of activity in the brain in anticipation of an oculomotor response is collectively known as "preparatory set" (Evarts, Shinoda, & Wise, 1984; Hebb, 1972). Although there is plenty of neurophysiological and behavioral evidence for the origin of this "preparatory set" and its relationship to the level of activity in the superior colliculus and frontal eye fields in monkeys and YAs (Connolly, Goodale, Menon, & Munoz, 2002; Everling & Munoz, 2000), little is known about how this mechanism changes with age or cognitive demand. Here, we compare the performance of YAs versus that of OAs in a computerized Corsi task to establish how the differences that emerge in cognition during healthy aging affect motor preparation and performance of the hand and the eye.

Method

Participants

Sixteen healthy YAs aged between 20 and 26 years (mean age: 22.8 ± 2.8 years; 8 women) and 16 healthy OAs aged between 60 and 79 years (mean age: 69.8 ± 6.8 years; 9 women) were recruited. All participants were right handed, had no known neurological disorders or color blindness, and had normal or corrected-to-normal vision. All participants completed consent forms prior to the experiment and performed a visual acuity test. Only the OAs answered a shortened but validated 9-item version of the Mini-Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975; Schultz-Larsen, Lamholt, & Kreiner, 2007) to rule out any abnormal age-related deficits in memory. The authors received ethical approval for this study from the University of Leeds.

Materials

A "MagicTouch" USB touch screen (Keytec Ltd.) was connected to a 19-in. CRT monitor (Iiyama, 1,024 × 786 resolution, 75 Hz) and linked with an EyeLink 1000 (SR Research Ltd.)-tower-mounted eye-tracking system via Experimental Builder software (SR Research Ltd.). Participants were seated comfortably 37 cm away from the CRT monitor with their chin and head on padded rests to minimize head movements. We recorded eye movements at 1,000 Hz and touch responses at 75 Hz throughout the experiment. A frequency of 75Hz translates to a display timing precision of 13 ms, which is much smaller than any of the effects we subsequently describe in the following study. Experiment Builder software was used to create the experimental stimuli, whereas Data Viewer was used to analyze the experiment (both by SR Research Ltd.).

Stimuli and Design

Our experimental design included four main conditions: color (C), color change (CC), shape (S), and shape change (SC), with three delays: 0, 5, and 10 s and four set sizes: 2, 3, 4, or 5 targets. Each of the four experimental conditions were presented in blocks of 24 trials (24 × 4 = 96 trials in total for each participant), resulting in eight repetitions of each delay and six repetitions of each set size for each block. The four main conditions (C, CC, S, and SC) were pseudorandomized among participants to avoid order effects.

For all conditions, each trial started with a fixation point placed on a black computer screen for 1,000 ms, prior to the appearance of 12 blue squares (60 × 60 pixels or 22-mm^2 box on the screen) in fixed positions across the monitor (Figure 1). After 1,000 ms, a number (between two and five) of these squares either (1) changed color (red) or (2) changed shape (circle) and did so either (a) in simultaneous presentations (duration in seconds = 1 × number of targets) or (b) sequentially (with a 1-s pacing between each change in target position). After a time delay (0, 5, or 10 s), the 12 blue squares reappeared and the participant was required to touch the remembered locations of the changed items either in the right order (1b and 2b) or in any order (1a and 2a). During the show of the recall screen, a "beep" and brief disappearance of the touched target indicated that participants had met the necessary requirements of placing their touch responses exactly within the boundaries of the blue square. Touch responses required to be placed within boundaries of the blue square for the program to accept it as a true response. This signaled to the participants that their responses had been recorded.

For the color conditions (C and CC), some of the blue squares changed from blue to red, an obvious difference requiring low attention, whereas the shape conditions (S and SC) saw some of the blue squares change to circles, a less-salient difference demanding higher levels of attention. Target presentations obligated participants to remember the target changes either in the specific temporal order that they were presented in (CC and SC) or just the location (C and S) (Figure 1).

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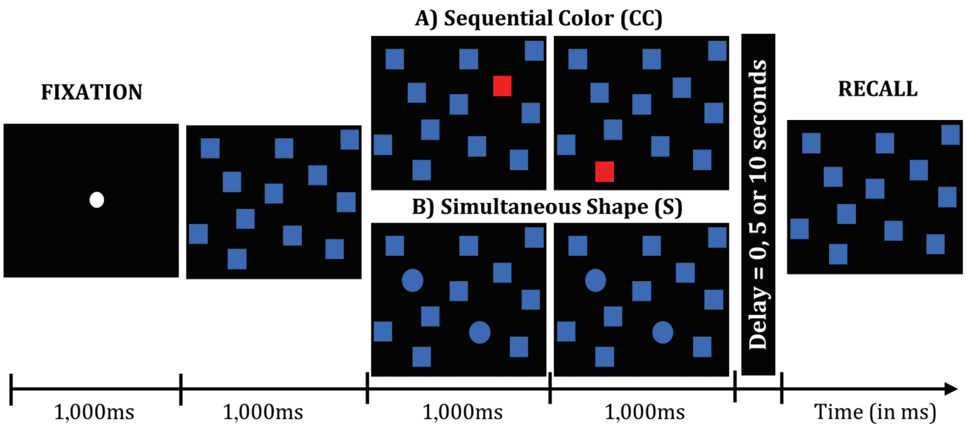

Figure 1. A diagrammatic representation of two of the four possible conditions: a sequential color condition (A) and a simultaneous shape condition (B) in which two items changed color or shape, respectively. Participants initially fixated a central fixation target before 12 blue squares appeared and either (i) change color one by one (CC) or display all the changed targets together (C) or (ii) change shape sequentially (SS) or simultaneously (S). Each target change was presented for 1 s and therefore if three items changed sequentially or together, the total duration would be 3 s. After target presentation, the blank delay screen appeared for 0, 5, or 10 s prior to the recall screen, wherein participants made their touch responses to the remembered locations.

Participants could take short breaks between blocks of 24 trials, to reduce fatigue and minimize dark adaptation. All recorded eye and touch data, alongside any touch errors, were collated for offline analysis.

Data Analysis

The eye movement parameters investigated included (a) region of interest (ROI) analysis: how long participants spent looking at the targets that changed color or location during the trial as a percentage of overall trial length (excluding delay time), to provide an estimate of encoding time on targets, (b) eye start RT: the time taken from the onset of the recall screen to the onset of the first saccade, and (c) eye pacing interval: the mean time that participants fixated within a 1-cm window (~2° of visual angle) on the recall screen before a saccade was made to another location on the screen. This fixation was determined using a predefined velocity and acceleration algorithm from EyeLink (SR Research Ltd., Canada) to define saccade onset (Stampe, 1993). For the touch response, the following parameters were investigated: (a) Touch start contact time: time taken for participants to touch the first target after the onset of the recall screen; (b) Touch pacing interval: mean time between touches on targets on the screen from finger touchdown to next finger touchdown, after the first target had been touched (as in a); and (c) Touch errors: number of touch responses that were not made to the correct target as a percentage of overall number of presented targets.

Single repeated measures analysis of variance was used for all the eye movement parameters, and the results were separated into the following factors: (a) age (young and old participants), (b) condition (C, CC, S, and SC), (c) delay (0, 5,000, or 10,000 ms), and (d) set size (two to five targets). The same was done for the touch responses. Multivariate main effects and interactions among variables were evaluated with Bonferroni corrected post hoc tests. A significance level of $p < .05$ was established for all statistical analyses.

The data were further segregated into (a) results in which an error was made and (b) results where the response was correct (i.e., hits vs. misses) for eye and hand RTs and pacing intervals. Due to the small number of errors made by the YAs, data were collapsed across set size and the attentional manipulation of color and shape, leaving the comparison of simultaneous versus sequential conditions only for each age group and for hits versus misses. A 2×2 × 2 repeated measures analysis was performed for age (young vs. old), correct (hit vs. miss), and condition (simultaneous vs. sequential) to establish whether errors were due to the differing fixation strategies used and whether this strategy differed between the age groups.

Table 1. Means and Standard Deviations for All 32 Willing Participants With Regard to Age and the Scores for Visual Acuity and in the MMSE

	Mean		STD	
	Young	Old	Young	Old
Age (years)	22.81	69.80	1.83	6.81
Visual acuity (arc/min)	1.58	1.31	0.34	0.34
MMSE		12.5		0.82

Results

The visual acuity task and MMSE scores (Table 1) were recorded prior to the experiment to ensure that participants reached the minimum requirement. All recruited participants achieved a score of ≥10 on the scale (mean: 12.5) out of a maximum score of 13. Table 2 reports all main effects and interactions found in this study.

Eye Movement Results

Regions of interest

No significant difference between age groups in the mean amount of time spent looking at ROIs (targets that changed color or shape) as a percentage of overall trial time (excluding the delay) was found. However, both age groups revealed a significant difference between conditions ($F_{(3,15)} = 12.03$, $p < .001$, $\eta^2 = 0.706$), which was mainly driven by color versus shape change comparisons ($p = .01$), with all participants spending longer within the relevant targets in the shape change condition. A significant effect of delay ($F_{(2,7)} = 27.29$, $p = .001$, $\eta^2 = 0.886$) was observed, with the pairwise comparison revealing that all delays were significantly different ($p < .05$) and that people spent longer looking in the ROI with increasing delay duration. Finally, a small effect of set size was observed in both age groups ($F_{(3,6)} = 5.67$, $p < .05$, $\eta^2 = 0.739$), which was mainly driven

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Table 2. Significant Main Effects and Interactions (With *p* Values) Are Shown for All Parameters of Interest, Alongside a Description of the Direction of the Observed Effect

	Main effects	Statistics	Description
Eye			
Region of interest (ROI)	Condition	$p < .001$	More time spent looking at color targets than shapes
	Delay	$p < .01$	Increase in time spent looking at ROI with increasing delay
	Set size	$p < .05$	More time spent looking at targets when four items were displayed instead of two
Reaction time	Age × Delay	$p < .05$	Older adults revealed slower reaction times after a delay, compared with the condition when there was no delay
Pacing interval	Condition	$p < .001$	Shape change had longer fixations than changes in color or shape only
	Age × Condition × Set size	$p < .05$	The younger group spent longer time fixating during sequential presentations compared with simultaneous presentation
Touch			
Contact time	Age	$p < .05$	Older participants took significantly longer to touch the first target on the screen
	Delay	$p < .001$	Participants took longer touching the first target after a 10-s delay
	Set size	$p < .05$	Remembering five targets resulted in significantly longer first-touch time
	Age × Condition × Delay	$p < .05$	Older participants took longer to touch the first target after the 10-s delay during the sequential tasks compared with the young participants
Pacing interval	Age	$p < .001$	Older participants took longer between touches
	Delay	$p < .005$	Participants took longer between touches when there was a 5- or 10-s delay
	Set size	$p < .001$	More items to remember increased duration between touches
	Age × Set size	$p < .005$	Set-size effect was only observed in the older-age group
% correct	Age	$p < .001$	Older participants were less accurate
	Condition	$p < .001$	Shape change was less accurate than shape-only and color change tasks
	Set size	$p < 0.001$	Increasing errors with increase in set size
	Age × Set size	$p < .005$	Older adults revealed a decrease in accuracy with increasing set size
	Condition × Set size	$p < .001$	Shape change was more significantly affected by set size than color change, and this effect was even smaller in the color and shape condition.

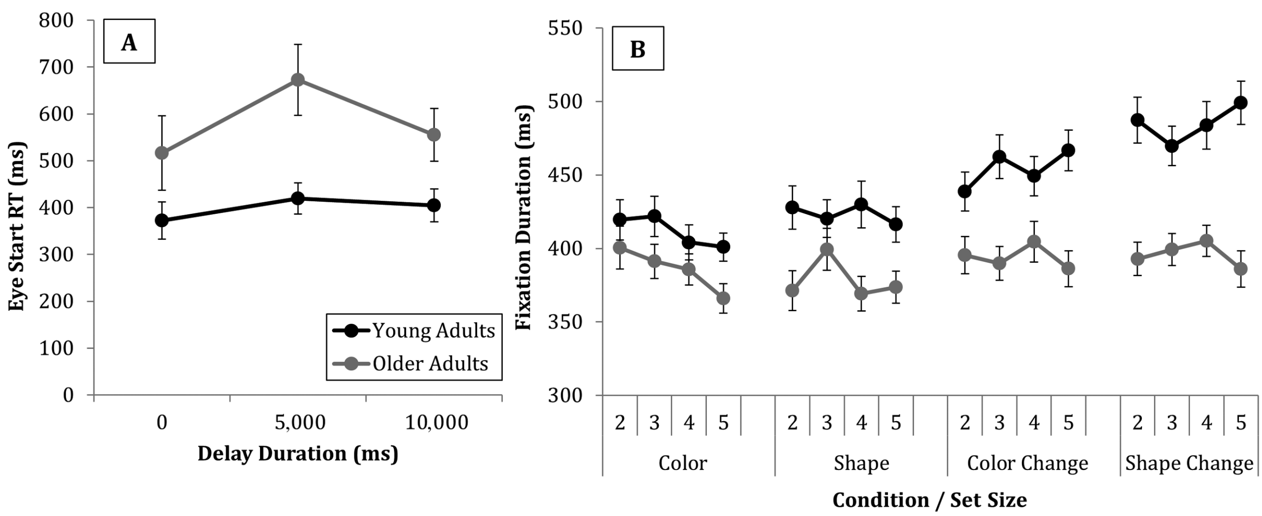

Figure 2. The graph on the left (A) shows the age × delay interaction (Table 2), with mean initial reaction time (Eye Start RT) of the eye to the recall screen along the *Y* axis and each delay (0, 5, and 10 s) along the *X* axis. The black circles display mean results for the data on younger participants, and the gray circles show the results for the older participants, with error bars denoting the standard error from this mean. The graph on the right (B) shows the age × condition × set-size interaction observed in the mean fixation duration during recall. Fixation duration is presented in milliseconds on the *Y* axis, with condition and set size along the *X* axis.

by the two targets versus the four target comparisons ($p = .011$) across all conditions.

Eye RT

The time taken for the eye to look toward the first target from recall screen onset was measured and termed the eye RT (Figure 2A). A significant interaction for age × delay ($F_{(2,23)} = 5.305$, $p < .05$, $\eta^2 = 0.316$) showed that there was a significant difference in eye RT between the no-delay and the delay conditions in the OAs ($p < .001$ for both 5- and 10-s comparisons with 0-s observation), but no effect was observed in the younger group. OAs took longer to initiate the first saccade when a 5- or 10-s delay was implemented. Further analysis of the hits versus misses revealed that all participants, regardless of age or complexity of the task (i.e., both simultaneous and sequential), made faster initial eye RTs with a subsequent "miss" ($F_{(1,6)} = 23.03$, $p = .003$, $\eta^2= 0.795$) than with a "hit."

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Eye pacing interval

Eye pacing interval between saccades and standard error (in ms) during recall are illustrated in Figure 2B. A significant effect of condition ($F_{(3,15)} = 12.03$, $p < .001$, $\eta^2 = 0.706$) was found, which showed that shape change had significantly longer fixation durations than color and shape when they did not change ($p < .005$ and .001). An interaction for age × condition × set size ($F_{(9,9)} = 4.37$, $p < .05$, $\eta^2 = 0.814$) suggests that the differences in condition were entirely driven by the younger group fixating longer during the sequential conditions (CC and SC) when compared with fixating during the simultaneous conditions ($p < .05$ for all comparisons).

Figure 3 reveals that eye pacing interval is generally longer for "misses" than for "hits" ($F_{(1,5)} = 18.77$, $p = .007$, $\eta^2 = 0.790$) and that there are differences between the age groups in eye pacing interval ($F_{(1,5)} = 23.97$, $p = .004$, $\eta^2 = 0.827$), with the young showing longer fixations. The interaction between the age groups and the condition (simultaneous vs. sequential) revealed a trend ($F_{(1,5)} = 5.294$, $p = .070$, $\eta^2 = 0.514$) in that the younger group had differing eye pacing intervals for the simultaneous and sequential tasks, whereas older groups revealed the same interval for both. We suspect this latter effect did not reach significance due to power issue with the low number of errors made by the younger group.

Touch Responses

Touch start contact time

A significant difference in the touch responses to the first target between the age groups was found ($F_{(1,15)} = 8.0$, $p < .05$, $\eta^2 = 0.35$), revealing that OAs had a significantly longer initial RT when making their first touch to a target on the recall screen (Figure 4A). The delay revealed a significant difference ($F_{(2,14)} = 15.286$, $p < .001$, $\eta^2 = 0.69$) that was principally driven by differences between the 10-s and the other delay conditions ($p < .001$). A main effect of set size ($F_{(3,13)} = 5.11$, $p < .05$, $\eta^2 = 0.54$), where remembering five targets resulted in longer touch RT than remembering two, three, or four targets (all $p < .05$), was also observed. These main effects, however, are better explained via the interactions that we found for age × delay ($F_{(2,14)} = 8.49$, $p < .005$, $\eta^2 = 0.55$), condition × delay ($F_{(6,10)} = 9.02$, $p < .005$, $\eta^2 = 0.84$), and age × condition × delay ($F_{(6,10)} = 4.03$, $p < .05$, $\eta^2 = 0.71$). This revealed that in the 10-s delay during sequential tasks (SC and CC), the OAs had significantly longer RTs to touch the first target than YAs. We found a significant interaction between age and the correct responses versus the incorrect responses ($F_{(1,6)} = 17.0$, $p = .006$, $\eta^2 = 0.739$) in that both groups were slower during miss trials, but this difference was much greater among the OAs.

Touch pacing interval

Looking at the touch pacing interval, we found a number of significant main effects, including a clear difference by age ($F_{(1,28)} = 122.89$, $p < .001$, $\eta^2 = 0.814$), whereby OAs took significantly longer between touches than YAs (Figure 4B). A significant effect of delay was found ($F_{(2,27)} = 7.24$, $p < .005$, $\eta^2 = 0.35$), whereby participants took longer between touches during the 5- and 10-s delay compared with the no-delay condition ($p = .002$ and .028, respectively). Finally, increasing the set size resulted in a significant difference ($F_{(3,26)} = 8.53$, $p < .001$, $\eta^2 = 0.496$) in which remembering three, four, or five items resulted in a significantly longer duration between touches when compared with remembering only two items ($p = .008$, $p = .001$, and $p < .001$, respectively). We also observed a significant interaction between age and set size ($F_{(3,26)} = 6.55$, $p < .005$, $\eta^2 = 0.43$), which was observed only in the OAs ($p < .05$ for all set-size comparisons, apart from that between 2- and 3-item sets, wherein $p = .91$). There were no significant effects between hits and misses in the touch pacing responses between age groups.

Percentage correct response

The percentage of correct responses to the targets revealed significant main effect differences between age groups ($F_{(1,31)} = 44.77$, $p < .001$, $\eta^2 = 0.591$), condition ($F_{(3,29)} = 36.0$, $p < .001$, $\eta^2 = 0.788$), and set size ($F_{(3,29)} = 34.7$, $p < .001$, $\eta^2 = 0.782$). OAs produced more errors in touching the targets than YAs. Across all participants, a reduction in accuracy was observed with shape change versus the accuracy

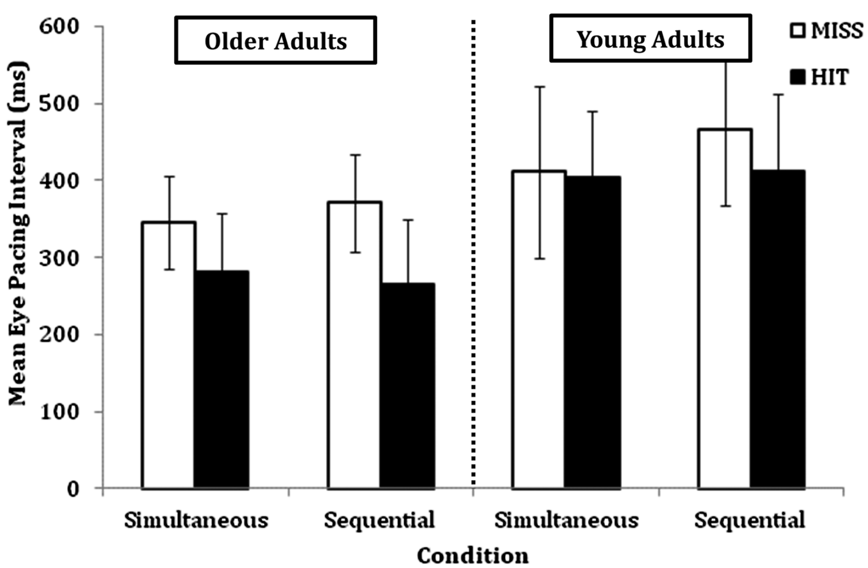

Figure 3. Mean eye pacing interval for all participants for correct (hit; black bars) versus incorrect (miss; white bars) trials, along with standard deviation. Older adults reveal longer eye pacing intervals for misses versus hits in both simultaneous and sequential conditions. Younger adults show a trend for demonstrating a greater difference in eye pacing interval for sequential tasks than for simultaneous task conditions.

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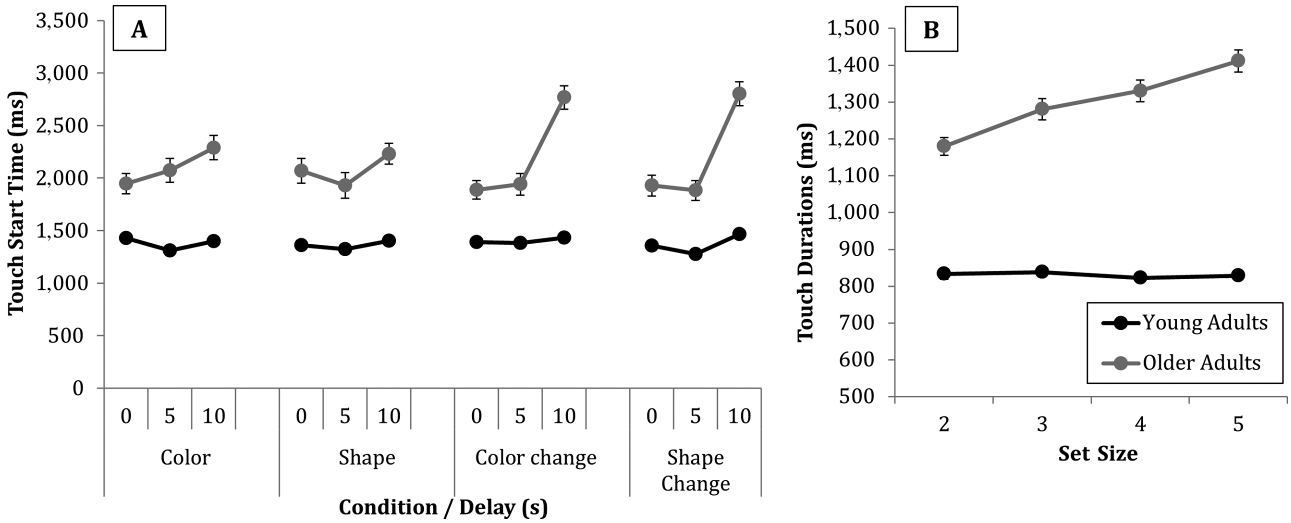

Figure 4. (A) The significant interaction for age × condition × delay for the initial touch start time (i.e., the time taken to touch the first target on recall screen). Age groups are plotted separately, with black and gray denoting younger and older participants, respectively, and error bars showing the standard error from the mean. The mean touch durations (i.e., pacing intervals between touches) highlighting the significant interaction for age × set size are shown in graph (B).

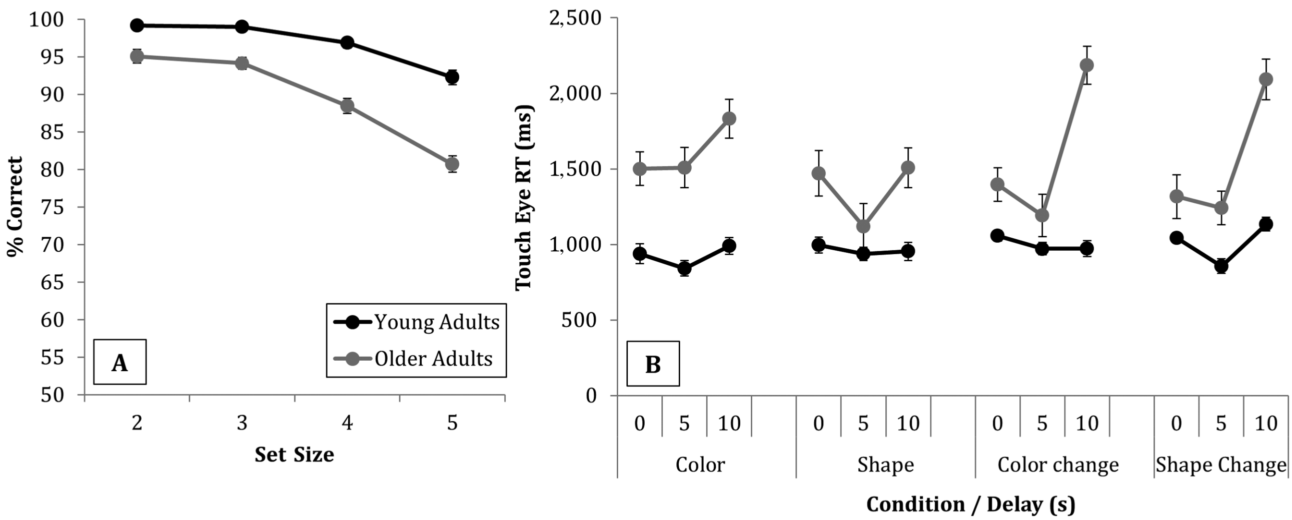

Figure 5. (A) The mean percentage of correct touch responses (to the targets/ROIs) for the younger (black) and older (gray) participants, highlighting the age × set-size interaction observed. All conventions used in the graph are the same as those in previous figures. (B) The mean lag time of the hand behind the eye to the recall screen for each age group in response to each condition and delay. Results are calculated by subtracting the start of the first saccade from the initial contact of the finger to the recall screen (Touch RT – Eye RT). As shown earlier, error bars are used to denote standard error.

under all other conditions ($p < .001$), and more errors were made with increasing set size ($p < .001$ for all comparisons apart from two- versus three-item comparisons wherein $p < .05$). Significant interactions were observed for age × set size ($F_{(3,29)} = 6.45$, $p < .005$, $\eta^2 = 0.4$) (Figure 5A), whereby OAs revealed increasing errors with increasing set size. We also found a condition × set size ($F_{(9,23)} = 14.9$, $p < .001$, $\eta^2 = 0.85$) effect for both age groups, which revealed significantly poorer accuracy with set size in the color change and shape change conditions, when compared with the color- and shape-only conditions. This effect was highly significant ($p < .005$) in all but one comparison (2 vs. 3 set size) in both age groups ($p > .05$). In general, all participants found sequential tasks more difficult compared with simultaneous tasks and the shape task to be harder than the color task (increasing order of difficulty = C, S, CC, and SC).

Coordination between eye and touch responses

In order to assess coupling (coordination) between the eye and the hand for each condition, we subtracted eye RT from touch RT and calculated a mean difference between the eye movement onset and the touch movement onset for each participant. The results show a highly significant effect of age ($F_{(1,29)} = 11.26$, $p = .002$, $\eta^2 = 0.28$), condition ($F_{(3,27)} = 3.37$, $p = .033$, $\eta^2 = 0.27$), delay ($F_{(2,28)} = 12.75$, $p < .001$, $\eta^2 = 0.48$), and set size ($F_{(3,27)} = 6.81$, $p = .001$, $\eta^2 = 0.43$). We also found an interaction for age × condition × delay ($F_{(6,24)} = 3.29$, $p = .017$, $\eta^2 = 0.45$), whereby OAs revealed a larger difference between the eye and the hand RTs with the 10-s delay condition. This larger difference was most pronounced in the shape change and color change conditions when the complexity of the task was greater, and the effect was principally observed in the response of the hand (Figure 5B).

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Discussion

Effects of Age on Eye Movement Parameters

This study focuses on the comparison between Oas' and YAs' performances of the eye and the hand, in response to manipulations of both memory and attention. This novel approach for age group comparisons has provided new evidence to suggest that YAs use differing eye movement strategies depending on task complexity and take longer between fixations with increasing attentional and memory demands. The OAs revealed a different fixation duration strategy to the YAs, in which similar fixation durations were implemented across all attentional and memory manipulations (Figure 2B). Further analysis into these fixation strategies suggested that longer fixation durations resulted in more errors in the YAs. The overall amount of time spent looking at the targets was equivalent for both age groups as the ROI analysis revealed, but the OAs exhibited more saccades. This ultimately resulted in poorer retrieval, with OAs showing a decrease in percentage of correct responses (Figure 5A). Our findings are in agreement with a number of studies that reported that OAs have longer, but fewer, fixations than the YAs (Ho, Scialfa, Caird, & Graw, 2001; Williams, Zacks, & Henderson, 2009). Furthermore, the longer fixation durations reported for the OAs in these previous studies are in line with the ranges reported here, which provides further support for a more automatic approach to processing. Based on these findings, we suggest that YAs adopt longer fixation strategies to aid in retrieval dependent on the task (i.e., when the task is more complex), whereas OAs appear to use a common strategy independent of the task demand (Figure 5). This suggestion is supported by the further analyses on the eye pacing interval for correct versus incorrect trials. We found that older participants tend to show shorter fixations for correct versus incorrect trials in both simultaneous and sequential tasks. YAs show a substantially longer eye pacing interval for misses with sequential tasks, but no difference was observed in simultaneous tasks, indicative of the use of differing encoding strategies.

We found that OAs were slower to initialize their first saccade to the targets on the recall screen and that they were even slower when a delay (5 or 10 s) was introduced between the presentation and recall screen. This slower RT in the eye movements of OAs is a common finding (Abel, Troost, & Dell'Osso, 1983; Cerella, 1985; Warabi, Kase, & Kato, 1984) and is thought to be principally due to changes in the efficiency of the neuron firing and a shift in brain activity from posterior to more frontal brain regions during aging (Raemaeker, Vink, van den Heuvel, Kahn, & Ramsey, 2006). Recent evidence suggests that deterioration of the corpus callosum during aging also contributes to longer RTs due to lack of inhibition in the non-dominant hemisphere (Langan et al., 2010). In our task, only the OAs revealed an increase in RT with the increase in delay duration, possibly indicating issues with maintaining a "preparatory set" (A preparatory set can be considered equivalent to holding a motor plan in WM until the response is required.). Connolly, Goodale, Goltz, and Munoz (2002) found a relationship between the frontal eye field activity and RT, with higher activity resulting in a shorter RT. This area (alongside other frontal areas) is thought to be vital in "preparatory set" activity for generation of saccadic eye movements (Nagel et al., 2008). Thus, our results suggest that the deficits observed in frontal activity during healthy aging could account for problems in maintaining a preparatory set during a delay and hence comprise the cause of the increase in RT of the eye with increasing delay.

Effects of Age on Touch Parameters

Differences in touch responses to the recall screen, between our age groups, were clear in all behavioral measures. The contact time for making the first touch to the recall screen was significantly increased in the OA group when a delay was introduced. This delay in RT could be due to the decline in inhibitory control with aging because poor inhibition can result in the revoking of a prepared or initiated motor response (Coxon, Van Impe, Wenderoth, & Swinnen, 2012) (an effect also observed in the RT of the eye). Furthermore, initial touch contact time was further increased in the sequential task when compared with the contact time during simultaneous presentation in this older cohort during the 10-s delay. We show that OAs took longer to react to the recall screen when the delay between encoding and recall reached 10 s (Figure 5A). We found that during this longer delay, remembering both order and position (CC and SC) further amplified this effect in the OA group. This effect was also observed in the RT of the eye, with an age × delay interaction. It has been suggested that OAs are more cautious and require more time to think about their answers (Veiel, Storandt, & Abrams, 2006). Others have found that storage or capacity problems may result in more recall errors (Peich, Husain, & Bays, 2013), but this may not explain the longer response times. Therefore, increasing task difficulty may increase uncertainty in performance and ultimately increase their time to respond. In line with this finding, we found that the touch pacing interval was significantly longer in the OAs, with additional increases in duration between touches with increasing set size and delay duration. Both findings, interpreted together, provide further evidence that OAs have problems maintaining a preparatory set for both the eye and the hand when delays are introduced. Slower initial responses to the recall screen, with increasing delay in both the eye and the hand, demonstrate this effect clearly. Furthermore, we found that OAs show a much greater increase in touch RT when they subsequently miss the target compared with the RT when they are correct. Thus, longer preparation times (or RTs) are also associated with worse performance. The increase in self-pacing interval observed in the hand with increasing set size supports the notion that OAs need more preparation time in between touches to accurately select the correct targets when more targets are introduced, suggesting that creating the preparatory set may also be problematic. This issue with preparedness is in agreement with an earlier study (Lahtela, Niemi, & Kuusela, 1985), wherein participants needed to turn either a right or a left switch to identify target appearance. However, in contrast with the findings presented here, Lahtela and colleagues (1985) found a reduction in RT in the OA group with increasing delay. This former study used three randomly presented interstimulus intervals (2, 4, and 6 s), which could suggest that shorter delay intervals may initially improve RT in some tasks. Our study finds that OAs have most difficulty in maintaining a preparatory set when the delay reaches 10 s. Our novel approach has also provided new evidence that a delay interval of 10 s significantly amplifies the touch start times in complex tasks (SC and CC) in OAs. Although the effect is present in more simple tasks (S and C), it is not as robust.

Unlike previous studies, we also have details of self-pacing intervals between touches, which further provide opportunities to interrogate how the memory capacity (set size) and retention intervals affect this measure. Increasing the number of targets to be remembered slows the pacing interval in OAs in both eye and hand, suggesting that longer motor preparation is needed between each touch when compared with the process in YAs. This effect of cognitive load on contact time is now well established in the literature and has been

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found to be dependent on the amount of information to be processed (Norman & Bobrow, 1975). In line with this, we found the number of errors to targets on the recall screen was significantly greater for the OAs (Figure 5), particularly with increasing set size. Thus, our data provide evidence that as we age, our preparatory set becomes more sensitive to both the amount of information that needs to be stored and the retention interval. We suggest that accuracy is sacrificed, rather than timing, with an increase in memory capacity (set size) in OAs, whereas an increase in the retention period (delay) principally affects the RT of the response (i.e., timing). We found no effects specific to our attentional manipulation of color versus shape, indicating that attention for color or shape is not significantly altered during healthy aging.

Eye–Hand Coordination During Healthy Aging

To investigate the temporal link between eye and hand in our task, we looked at the lag of the hand behind the eye to the recall screen after the 0-, 5-, or 10-s delay. Overall, we found a longer lag between the eye and the hand in OAs. This difference was significantly increased with the 10-s delay in the sequential tasks. The difference between the first eye movement and the subsequent first touch movement was ~1,000 ms in the YAs, whereas OAs revealed a longer difference between the eye and the touch (~1,600 ms). This indicates that additional motor delays are observed in OAs when translating responses downstream into a hand response compared with the same in YAs. We suggest that OAs are adversely affected in coordinating the eye–hand axis during tasks with higher cognitive demands (i.e., sequential task and memory delay), which results in an increased rise in lag. Optimal RT differences between the eye and the hand to aid coordination have been found to be around 200 ms (Wilmut, Wann, & Brown, 2006) during saccadic tasks and around 75–120 ms in tracking tasks (Miall & Reckess, 2002). Our lag time of 1,000 ms in the YAs is considerably longer than these but is comparable with the time in other studies using time to contact (Warabi, Noda, & Kato, 1986) instead of time to initiation of movement (RT). Our task included a greater cognitive (memory and attention) component, which inevitably would also contribute to longer processing and recall times (see Lavie, 2005 for a review). These results suggest that, although we have noted a number of cognitive effects between age groups, some of the differences can be attributed downstream in the processing of the hand movement. Increasing complexity of the task results in a longer temporal gap between the eye and the hand (i.e., a decrease in coupling between modalities), negatively affecting performance. This can be interpreted as a reduction in coordination between these modalities. Interestingly, we find that coordination between eye and hand significantly deteriorates with increasing cognitive effort in the OAs, but not in the YAs. This could indicate a competing resource issue as both the cognitive demand of the task and the motor demand for eye–hand coordination require memory, motor, and attention circuits in the brain (Crawford, Medendorp, & Marotta, 2004). We suggest that increasing the cognitive effort consequently increased the amount of mental resources required, which ultimately negatively affected hand–eye coordination in OAs. It is clear that OAs have a smaller mental resource pool and hence their capacity is more easily exceeded, resulting in a decline of performance that is not observed in the YAs (Levitt, Fugelsang, & Crossley, 2006).

Conclusions

This study contributes to our understanding of changes in motor preparedness or "preparatory set" during healthy aging. The increases in RTs of the eye and the hand in OAs when a 10-s delay was introduced demonstrates issues in maintaining/retaining a "preparatory set" for these modalities. Additionally, increases in durations between fixations and touches and the decreasing accuracy with increasing set size provide further evidence that OAs may have problems in accessing these preparatory sets during recall, creating uncertainty in their responses. We find that complexity of the task plays a factor in the initial hand RT, but only when in conjunction with long delays. It is interesting to note that manipulations made in delay durations affected the initial timing of the eye and the hand responses (i.e., RT), whereas capacity manipulations (set size) affected accuracy measures, suggesting that the storage of temporal and spatial information are segregated mechanisms in the brain and are differentially affected by age. Finally, our results show that eye–hand coordination significantly deteriorates with increasing cognitive demand in elderly participants and that OAs fail to adjust fixation strategies to compensate for higher cognitive loads.

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