Checking it Twice: Age-related Differences in Double Checking during Visual Search

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Abstract:

Visual search is an integral part of functioning in everyday life and a primary component of some occupational tasks. Older adults typically exhibit longer response times on visual search tasks compared to younger adults. Mechanisms proposed as explanations of these age-related differences include general slowing of the speed of information processing, amount of internal noise, attentional capacity, selective attention, and inhibition. This study evaluated the possibility that age-related differences in visual search may be partly due to older adults double checking to a greater degree than younger adults. Older adults did in fact double check more so than younger adults. Moreover, speed stress instructions reduced double checking behavior as well as age-related differences in double checking.

Keywords: visual search | double checking behavior | age-related differences | older adults | age-related slowing

Article:

INTRODUCTION

Visual search is a vital component of many tasks. For example, visual search is necessary for many everyday tasks, such as finding groceries in a supermarket, looking for signage and following in-vehicle navigation systems while driving, and interacting with computer interfaces. It is also an integral part of many occupations, such as transportation security screening (McCarley, 2009; McCarley, Kramer, Wickens, Vidoni, & Boot, 2004; Menneer, Barrett, Phillips, Donnelly, & Cave, 2006; Schwaninger, Hardmeier, & Hofer, 2005), medical X-ray reading (Doi, 2006), and quality control inspection in manufacturing and service industries (Drury, 1992; Tetteh, Jiang, Mountjoy, Seong, & McBride, 2008). Despite relying heavily on our visual search ability, visual search is a limited system and some factors, such as age, can impact its accuracy and speed.

Understanding the influence of aging on visual search is becoming more and more critical as people are living longer causing the older adult population to grow exponentially (Federal Interagency Forum on Aging- Related Statistics, 2008). More people are also remaining active in the workforce longer (Gendell, 2008). From a human factors perspective this demographic change translates into older adults becoming a larger and more relevant user group. Older adults have a unique set of limitations and capabilities that should be considered in the design process, including those related to visual perception.

Aging differentially influences visual perception abilities. With respect to visual search, research has confirmed some age-related declines. The extent of age- related declines in visual search depends on the type of search task. Age-related decrements are more likely (a) in difficult versus easy search tasks (i.e., conjunction versus single feature search) (e.g., Plude, & Doussard-Roosevelt, 1989); (b) as the number of distractors increase (e.g., Madden, Connelly, & Pierce, 1994); and (c) as heterogeneity of distractors increases (e.g., Madden, Pierce, & Allen, 1996). Moreover, many aspects of visual search remain stable with age (Humphrey & Kramer, 1997; Scialfa, Jenkins, Hamaluk, & Skaloud, 2000), including the kinematics of eye movements (Abrams, Pratt, & Chasteen, 1998) and marking of old objects (Kramer & Atchley, 2000). In addition, age-related differences in visual search effects may by minimized when older adults employ compensatory top-down processes (e.g., Hoyer & Ingolfsdottir, 2003).

Candidate explanations for age-related slowing in visual search include slowing in speed of information processing (e.g., Madden, 1990) amount of internal noise (e.g., Allen, Madden, Weber, & Groth, 1993), attentional capacity (e.g., Watson, Maylor, & Bruce, 2005), selective attention (e.g., Humphrey & Kramer, 1997), and inhibition (e.g., Connelly & Hasher, 1993; Humphrey & Kramer, 1997). This study evaluated the possibility that age-related differences in double checking contribute to age effects associated with visual search.

We examined visual search in the noun-pair task. Participants are shown an array of noun pairs, referred to as a lookup table, and a probe pair (see Figure 1). Participants determine whether the probe pair of nouns are matched or unmatched in the lookup table (Ackerman & Woltz, 1994). On match trials the probe pair matches a noun pair (i.e., the target pair) in the lookup table (i.e., target-present); on nonmatch trials the left and right words of the probe pair are not paired together in the table (i.e., similar to a target-absent trial). When variably mapped (VM), the nouns are randomly paired across trials, which forces participants to scan the lookup table to determine whether each probe pair matches a noun pair. This task resembles many visual search tasks because it is necessary to search for words within a set of visually similar words. Moreover, the processes involved in completing the task may be generalized to other complex yet familiar stimuli. VM task data are consistent with an age-associated conservative speed-accuracy tradeoff criterion -- older adults typically demonstrate longer response times (RTs) and greater accuracy (e.g., Rogers & Gilbert, 1997). By varying speed-accuracy instructions, Strayer and Kramer (1994) showed that some of the age-related variance in visual search RT was due to older adults having a more conservative response bias.

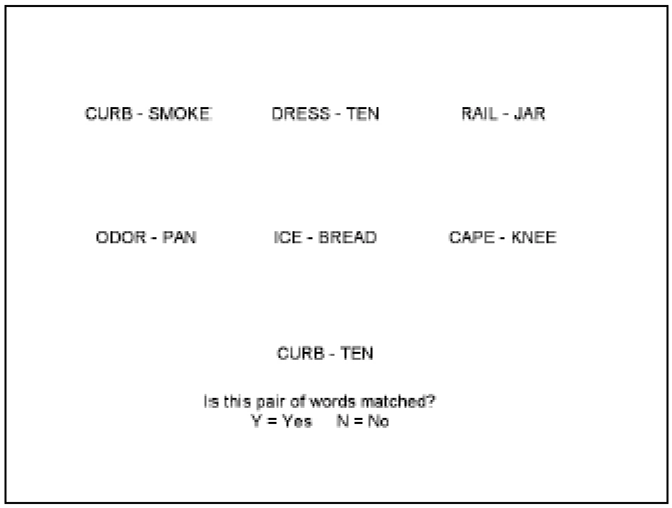

Figure 1. Sample trial stimuli screen for the noun-pair task. In this example, the correct answer would be "No."

We used eye movement data to further evaluate the processes that could generate the effects shown by Strayer and Kramer (1994). Previous eye-tracking research has demonstrated age-related differences in eye movements consistent with older adults' habitual use of conservative task strategies (e.g., Spieler, Mayr, & LaGrone, 2006). Watson and colleagues (2005) found older adults were more likely to engage in double checking behavior on an enumeration task, re-fixating items and locations. Others have also demonstrated that older adults are more likely to re-fixate items (Scialfa, Thomas, & Joffe, 1994; Veiel, Storandt, & Abrams, 2006) and make more regressions during reading (e.g., Kliegl, Grabner, Rolfs, & Engbert, 2004; Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006). Older adults appear to be more likely to seek confirming evidence after identifying relevant information in the search display.

We employed eye tracking to examine double checking behavior by younger and older adults in the VM noun-pair task. We hypothesized that older adults would have longer RTs and higher accuracy, and would be more likely to double check the match between the probe pair and target pair compared to younger adults. We also expected that trial type would impact verification; we expected more double checking on nonmatch trials, given that the left and right target words are presented in different locations. Moreover, we anticipated that if we found verification behavior using standard instructions, which emphasize speed and accuracy equally, it may be modifiable by instructional manipulation (e.g., Strayer & Kramer, 1994).

METHOD

Participants

Participants were 13 younger adults (*M* = 20; range: 19- 22 years of age) and 12 older adults (*M* = 66; range: 61-75 years of age). However, 2 younger adults and 4 older adults were excluded from the analyses because 10% or more of their eye tracking data were missing. Younger adults were recruited from Georgia Institute of Technology's psychology participant pool and older adults were recruited from a database maintained by the Human Factors and Aging Laboratory. Younger and older adults reported similar years of education ($M_{Younger}$ = 14, *SD* = .81; M_{Older} = 15, *SD* = 2) and all were native English speakers. Participants were screened to exclude those with uncorrected vision problems (i.e., acuity below 20/40 and cataracts) and health conditions that affect vision, such as diabetes and uncontrolled blood pressure.

Stimulus Materials and Apparatus

The lookup table was composed of six noun pairs. Stimulus words ranged in length from three to five letters and were taken from Hertzog, Kidder, Powell-Moman, and Dunlosky (2002). We created ten lists of 12 semantically unrelated words and randomized list order across participants. On each trial, words were randomly paired together and pairs were randomly assigned to six possible display locations, such that word pairings and locations were variably mapped. Participants performed the task under standard instructions emphasizing speed and accuracy equally and speed stress instructions emphasizing speed over accuracy. Participants were presented with 80 trials per condition.

Stimuli were presented and RT and accuracy data were obtained using E-Prime (2000). Stimuli were presented in Arial typeface (mean size for letters was approximately 0.50°) and in white color on a black background to maximize contrast. An Applied Science Laboratories eye tracker (Model 504 with remote pan/tilt optics) was used with a sampling rate of 60 Hz.

Procedure

After participants provided informed consent, they were seated in a chair with a chin and headrest facing a computer monitor and a 9-point calibration of the eye tracking system was conducted. The experiment was composed of two blocks of practice trials, followed by ten blocks each of standard and speed stress trials. Each trial began with a 1000 ms centrally located fixation point, followed by the presentation of the stimuli. Participants responded by pressing keys labeled "yes" or "no." The probe pair was matched in the lookup table for half of the trials. Participants were presented with their mean RT and accuracy as well as condition-specific feedback following each block. After the experiment, participants completed a post-task survey and were debriefed.

RESULTS

Areas of interest (AOIs) were categorized to a rectangular area surrounding each noun pair including a three degree margin of error. If pupil diameter was recorded as zero for 12 or more consecutive data fields, that data sequence was considered a blink and excluded. Data samples outside of the AOIs were also excluded (9.7% of the raw data). In addition, RTs greater than six seconds and less than 100 milliseconds were considered outliers and were excluded from the analyses.

Fixations were defined as two consecutive sampled eye position points within an AOI. Gazes were defined as beginning at the onset of a fixation within an AOI and ending with the offset of the last fixation within that AOI. That is, gazes were computed by summing sequential fixations within each AOI. All analyses (excepting comparisons of accuracy data) included correct trials only. Given that we had a small sample size we performed one- tailed (directional) *t* tests for all a priori hypotheses. We also report Cohen's *d* (Cohen, 1988) to provide effect size estimates.

Standard Instructions

RT and accuracy. As expected with standard instructions, older adults had significantly longer RTs compared to younger adults, M_{Older} = 2689 ms and $M_{Younger}$ = 1892 ms, $t(17) = 5.20$, $p < .01$, $d = 2.55$. Also as anticipated, nonmatch trials had longer RTs compared to match trials, for younger adults, $M_{Nonmatch}$ = 1997 ms and M_{Match} = 1788 ms, $t(10) = 3.05$, $p < .05$, $d = 1.92$, and for older adults, $M_{Nonmatch}$ = 2883 ms and M_{Match} = 2496 ms, $t(7) = 2.29$, $p < .05$; $d = 1.73$. Both age groups demonstrated high levels of response accuracy, M_{Older} = 96 and $M_{Younger}$ = 96, $p = .38$. We did not find a trial type effect for older adults, $p = .84$. Younger adults, however, were more accurate on nonmatch than match trials, $M_{Nonmatch}$ = 98% and M_{Match} = 93%, $t(9) = 3.17$, $p < .05$, $d = 2.11$. This result is consistent with a speed-accuracy tradeoff; younger adults had longer RTs and higher accuracy on nonmatch trials compared to match trials.

Eye movements. We hypothesized that age-related increases in RT might be partly due to double checking the match between the probe pair and target pair prior to making a response. Double checking was operationally defined as additional gazes made to the probe pair contingent on having made a gaze to the target pair on match trials or either of the target words on nonmatch trials. Both age groups demonstrated double checking behavior, and older adults did so significantly and substantially more, $M_{Younger} - M_{Older} = 0.28$ (a 20% difference), $t(17) = 2.44$, $p < .01$, $d = 1.19$ (see Table 1). Younger adults were more likely to double check on nonmatch trials compared to match trials, $t(9) = 3.95$, $p < .01$, $d = 2.49$. Consistent with our hypothesis, older adults engaged in more double checking compared to younger adults. We also expected nonmatch trials to elicit significantly more double checking compared to match trials given that two locations could be checked to verify response accuracy. Only younger adults demonstrated this sensitivity to trial type suggesting that older adults verified both match and nonmatch trials.

As expected, our results demonstrated that older adults had slower RTs, however the typical age effect for accuracy was not found. Rather, both age groups maintained a high level of accuracy. As predicted, we also found that older adults exhibited more double checking behavior relative to younger adults. Although older adults' double checking behavior may contribute to their slower RTs, this specific effect cannot fully explain the age-related differences in RT on the noun-pair task.

Table 1

Means and Standard Errors for Double Checking

	Double Checking	
	M	*SE*
Standard		
Younger adults		
Nonmatch	1.32	.12
Match	1.11	.08
Older adults		
Nonmatch	1.58	.14
Match	1.39	.09
Speed stress		
Younger adults		
Nonmatch	1.32	.11
Match	1.31	.17
Older adults		
Nonmatch	1.56	.12
Match	1.17	.19

Speed Stress Instructions

RT and accuracy. Next we explored whether an emphasis on speed reduced age-associated differences. With speed emphasis instructions age-related differences remained significant with younger adults faster than older adults, $M_{Younger} = 1521$ and $M_{Older} = 2280$, $t(16) = 3.94$, $p < .01$, $d = 1.98$. The trial type effect was not significant for either age group, $p_{\text{Younger}} = .40$ and $p_{\text{Older}} = .30$. That is, though younger adults remained faster than older adults, they reduced their RTs for nonmatch trials in the speed condition to the extent that the trial type effect was no longer significant as it had been in the standard condition.

Though age-related differences in RT remained, we examined whether either age group reduced their RTs to a significant extent relative to the standard condition. For both older and younger adults, RTs were significantly faster in the speed condition compared to the standard condition, $M_{Older\ Standard\ -Speed} = 409$ and $M_{Younger\ Standard\ -Speed} = 371$, $t(7) = 1.64$, $p < .05$, $d = 1.23$ and $t(9) = 3.69$, $p < .01$, $d = 2.33$, respectively. These results demonstrate that not only did older adults reduce their RTs, younger adults did as well, hence the residual age-related effect.

Whereas younger and older adults demonstrated similar levels of accuracy in the standard condition, younger adults were significantly less accurate compared to older adults in the speed condition, $M_{Younger} = 78\%$ and $M_{Older} = 89\%$, $t(16) = 2.90$, $p < .01$, $d = 1.45$. To examine whether participants followed the instruction to sacrifice accuracy for speed we conducted instruction condition comparisons. All participants lowered their response accuracy as instructed: $M_{Younger\ Standard\ -Speed} = 18\%$ and $M_{Older\ Standard\ -Speed} = 7\%$, $t_{\text{Older}}(7) = 2.49$, $p < .01$, $d = 4.86$ and $t_{\text{Younger}}(9) = 5.93$, $p < .01$, $d = 3.95$. These results suggest that both age groups increased their speed and reduced their accuracy in the speed condition, yet younger adults did so to a greater extent.

Eye movements. We predicted that an emphasis on speed would minimize double checking behavior and reduce age-related differences. Indeed, whereas we had found significant age-related differences in the standard condition for double checking, younger and older adults engaged in double checking to similar extents in the speed condition, and $p = .36$, $d = .17$, respectively.

Overall, the speed emphasis instructions appear to have reduced age-related differences in RT and eliminated age- related differences in double checking. The speed emphasis instructions were also associated with an increase in age- related differences in response accuracy. We expected age- related differences driven by verification would be reduced with an emphasis on performing the task as quickly as possible. Our results demonstrate that double checking behavior was modifiable in this manner through instruction.

DISCUSSION

Visual search behaviors have been investigated in relation to several occupations, such as transportation security screening (McCarley, 2009; McCarley, Kramer, Wickens, Vidoni, & Boot, 2004; Menneer, Barrett, Phillips, Donnelly, & Cave, 2006; Schwaninger, Hardmeier, & Hofer, 2005), medical image reading (Doi, 2006).), and quality control inspection in the manufacturing and service industries (Drury, 1992; Tetteh, Jiang, Mountjoy, Seong, & McBride, 2008). Outside of the workforce, visual search is involved in many everyday tasks, such as driving (Recarte & Nunes, 2003) and interacting with computers. Given the growing aging population and more people delaying retirement, it is becoming more important to understand age-related differences during visual search tasks.

In the current study, younger and older adults performed the VM noun-pair task, producing a typical age- related increase in RT (e.g., Rogers et al., 2000). Although differences in low-level cognitive abilities may contribute to such age-related differences in performance, higher-level strategic differences may also be implicated. Our primary hypothesis was that older adults would demonstrate double checking behavior to a greater degree than younger adults. Consistent with previous research (e.g., Watson et al., 2005), we found age-associated differences in search performance were influenced by older adults double checking more frequently relative to younger adults. These findings add convergent evidence to previous research demonstrating older adults’ tendency to engage in eye- movement-based behaviors that are consistent with verification (e.g., Scialfa, et al., 1994; Veiel et al., 2006).

Both age groups showed the expected effect of trial type for RT; longer RTs for nonmatch trials. Younger adults were also more accurate on nonmatch trials. Younger adults demonstrated more double checking for nonmatch trials as well. The increase in double checking for nonmatch trials is likely a contributing factor to younger adults’ higher accuracy and longer RTs for nonmatch trials. These data suggest younger adults approached nonmatch trials more conservatively, in general, and thus were more accurate and required more time to complete nonmatch trials.

A secondary hypothesis was that double checking behavior may be modifiable with a change in instructions. Following instructions to respond quickly, both groups significantly reduced their RTs and response accuracy as compared to the standard condition. Moreover, age-related differences in double checking were eliminated. Our findings demonstrate that older adults are capable of adjusting their search behavior to reduce double checking to a comparable extent as younger adults.

It is still an open question whether the verification we observed reflects a direct influence of response conservatism on age-related differences in search RT. The age-associated increase in RT typically found on visual search tasks is correlated with age-related differences in cognitive abilities, including perceptual speed and working memory (e.g., Rogers et al., 2000). Age-related declines in cognition could also influence eye movements. For example, older adults may make more gazes and double check more to compensate for working memory declines, as suggested by the results of Kemper and colleagues (Kemper, Crow & Kemtes, 2004; Kemper & Liu, 2007), as an inefficient “risky” reading strategy (Rayner et al., 2006), or due to perceptual (e.g., Laubrock, Kliegl, Engbert, 2006) and attentional declines, such as reduced UFOV (Sekuler, Bennett, & Mamelak, 2000). However, Stephens (2005) found that double checking behavior was not significantly related to age-associated declines in digit- symbol performance, suggesting that working memory declines alone do not induce double checking.

For occupations that heavily rely on visual search, our results suggest that older workers may be slower and double check more so than younger workers to maximize their performance accuracy. Our findings also demonstrate that older workers may be able to reduce their double checking behavior while maintaining a high level of accuracy if a time pressure is imposed. It is possible that experience could mitigate these age-related effects. Future research is needed to investigate whether occupational expertise decreases double checking behavior.

The age-associated differences in double checking identified in this study should be considered especially when designing interfaces with timed visual displays. Not only may older adults need longer display times, they may also be inclined to revisit previously presented parts of the display. In certain contexts, such as an older adult using an in-vehicle navigation system, lack of consideration for older adults’ tendency to double check could cause usability difficulties with serious consequences.

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