Institute of Cognitive Science

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University of Colorado, Boulder

Temporal Dynamics of Visual Attention: An Examination Between Young and Older Adults

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Running Head: Age Differences in the Attentional Blink

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Abstract

We examined differences between young and older adults in the temporal dynamics of visual attention using the Rapid Serial Visual Presentation paradigm (e.g., Raymond, Shapiro, & Arnell, 1992). A common finding with this paradigm is a U-shaped function, referred to as the "attentional blink" (AB), in which there is a deficit in post-target processing of visual information when that information follows the target within a brief period of time (e.g., 200-500 ms). In the present study we found an AB that was longer for older adults (990 ms) than for young adults (330 ms) and a magnitude greater for older than young adults (384 vs. 223, respectively). Additionally, we examined age-related differences in task performance confidence ratings as well as in the use of three compensatory strategies that might be invoked when there is a perceived deficit in visual processing: (1) trade-off of target identification for probe detection, (2) increased 'yes' responses during identification / detection responses, and (3) report probe presence despite low confidence in detection accuracy. We failed to observe an age-related difference in the use of the three compensatory strategies. We also failed to observe an age-related difference in participant-assigned confidence ratings for target identification as well as probe detection. This failure to observe a difference suggests that older adults may have been overconfident in their probe detection performance relative to young adults.

To understand fully how the visual system processes information one must consider its limitations. One limitation is the amount of information that can be processed within a specified period of time (e.g., Chun, 1997); a limitation that may be due, in turn, to an attentional capacity limitation. Support for a capacity limitation was provided by Braun and Sagi (1990, 1991) who observed interference between two simple visual discrimination tasks when the tasks had to be performed simultaneously within a brief period of time. Limitations in attentional capacity may play an important role in a variety of phenomena such as the Attentional Blink (e.g., Raymond, Shapiro, & Arnell, 1992) and Repetition Blindness (e.g., Kanwisher, 1987). Another limitation is the rate with which the visual system can process information. As noted by Seiffert and DiLollo (1997), if the visual system is forced to process information at a rate faster than it can handle then the processing of that information will be degraded, if it is processed at all.

Limitations such as these are particularly relevant when the visual information processor is the older adult. Research has revealed several age-related changes in how the cognitive system operates. Illustrative are changes that occur in the ventral and dorsal processing streams as one ages (e.g., Grady, Maisog, Horwitz, & Ungerleider, 1994); increased difficulty in shifting attention as one ages (Kausler, 1994); age-related differences in working memory capacity (e.g., Cohen, 1988; Gick, Craik, & Morris, 1988; Kemper, 1988; Salthouse, Mitchell, Skovronek, & Babcock, 1989; Wingfield, Stine, Lahar, & Aberdeen, 1988); and a general slowing of the cognitive system in older adults (e.g., Cerella & Hale, 1994; Kail & Salthouse, 1994).

In terms of processing visual information we know that there are age-related differences in short-term (e.g., Schear & Nebes, 1980; Salthouse et al., 1988) as well as long-term memory (e.g., Denny, Dew, & Kihlstrom, 1992; Park, Puglisi, & Sovacool, 1983; Uttl & Graf, 1993) for spatial information with older adults showing poorer performance in both cases. We also know that there are age-related changes in the way visual attention is allocated when processing information. As suggested by Posner and colleagues (e.g., Posner, 1992; Posner & Deaene, 1994; Posner & Petersen, 1990) covert visual attention is comprised of disengagement, movement, and engagement of attention and with age there is increased difficulty in controlling attentional shifts. Two primary age-related changes in the processing of visual information are the ability to attend to different-sized regions of space and the ability to alter attentional scope (e.g., Kosslyn, Brown, & Dror, 1999). Finally, we know that the "perceptual window" (visual area in which information can be identified) shrinks with age (e.g., Cerella & Poon, 1981).

Our goal in the present study was to determine whether there are age-related differences in the processing of rapidly presented visual information when spatial characteristics are held constant but temporal characteristics vary. Additionally, we were interested in whether there are age-related differences in the use of compensatory strategies that might be engaged when there is a perceived deficit in the processing of visual information; a notion that is not novel. For example, Kline and Scialfa (1996) suggest that the older adults' narrowing of attention in processing visual is a compensatory strategy for the poorer quality of input from the eye (e.g., Hoyer & Plude, 1980). We suggest that older adults are more likely to engage compensatory strategies, relative to young adults, given that we know older adults have a propensity to doubt their memory abilities (e.g., Dixon & Hultsch, 1983). In the present study we gathered confidence ratings when participants reported target and probe items to determine if there were age-related differences in perceived competency when performing the visual tasks. We argue that there must be a perceived deficiency (veridical or not) before compensatory strategies are engaged.

We know that older adults can engage, when needed, compensatory strategies. For example, older adults compensate for age-related declines in basic encoding and retrieval processes when playing chess (e.g., more systematic searches of the problem space; Charness, 1981a, 1981b) and typing (e.g., increased eye-hand spans; Salthouse, 1984). The first strategy that we examined in the present study was whether there is an age-related difference in the degree to which participants trade-off target identification for probe detection. This strategy would result in poorer target identification but increased probability of correct probe detection. The second strategy that we examined was whether there is an age-related difference in the inclination to say "yes" to the presence of probes and whether this probability increases or decreases as participants gain experience with the RSVP task. That is, we were interested in whether there was an age-related difference in response bias. Clearly one can increase the frequency of "yes" responses and by doing so increase the hit rate on probe detection. The problem with this strategy is that there would also be an increase in false positives (FP; saying "yes" when the probe was absent).

The third and final strategy, related to the second strategy, is an increased inclination to report the presence of probes despite low confidence in the accuracy of the detection. One would not expect a change in this strategy as a function of probe position because, presumably, participants cannot know whether a probe will be present (on half of the trials a probe was present) until after the target was presented and presumably a commitment made, or not, to process the target. Further, we were interested in whether there were age-related differences in the use of this strategy.

To accomplish our goals we adopted the Rapid Serial Visual Processing (RSVP) paradigm (e.g., Broadbent & Broadbent, 1987); a task suitable for assessing perceptual as well as higher level cognitive processes (e.g., Potter, 1976). In the RSVP paradigm items are presented rapidly (e.g., 6-20 items per second) in the same location; thus, temporal information varies but spatial information is constant. In the majority of studies using the RSVP paradigm a "U" shaped function is observed such that detection is poorer when the probe item follows the target within a short period of time (e.g., 200-500 ms) relative to when there is a longer lag between target and probe. This period of visual disruption has been referred to as the "attentional blink" (AB; Raymond et al., 1992). As noted by Shapiro, Raymond, and Arnell (1994) the RSVP task can be viewed as a temporal analogue to the spatial search task in that the goal in both tasks is to search for targets embedded in a set of non-targets.

The task for participants in the Experimental condition of the RSVP paradigm is to identify targets and detect the presence of probes; an exercise that is, functionally, a dual task. Participants in the Control condition are to ignore targets and merely detect the presence of probes; an exercise that is, functionally, a single task. We know that dual task performance is more difficult for older adults than for young adults (e.g., Craik & McDowd, 1987; Macht & Buschke, 1983; Park, Smith, Dudley, & Lafronza, 1989). Given this we might expect older adults to have a more difficult time in the Experimental condition (e.g., misidentifying targets and/or missing probes) than in the Control condition. Which of the two, targets or probes, will not be processed efficiently is dependent upon experimenter-provided instructions, the viewer's perceptual goals, and whether the viewer believes there is a deficit in his/her processing of information.

Common to several accounts of the AB (see Jolicoeur, 1998 for a review) is a role for: (1) interference, (2) time utilization, and (3) engagement of cognitive resources. Interference may play a role in the Control condition where participants were asked to ignore targets. Despite this instruction participants' attention may be drawn to the target. Feasibly there will be age-related differences because older adults are not as efficient at inhibiting irrelevant information relative to young adults (e.g., Hasher & Zacks, 1988). Interference also may play a role in the Experimental condition where participants are asked to process target information that may then interfere with the processing of probe information.

In terms of time utilization a certain amount of time is required to process target information (e.g., Chun & Potter, 1995) and if this time is too long there may result less time being available for probe detection. If older adults process information slower than young adults (e.g., Cerella, 1990; Salthouse & Babcock, 1991) then we might expect older adults, relative to young adults to require more time to process targets (Experimental condition) and, consequently, miss more probes thereby producing a longer AB relative to young adults.

Finally, in terms of cognitive resources, we assert that resources are required to perform the RSVP; an assertion that is inherent in several models of the AB phenomenon (e.g., Chun & Potter, 1995). Illustrative is the Chun and Potter (1995) two-stage model where the first stage consists of a rapid detection of visual information that results in the formation of vulnerable representations and the second stage is comprised of a transformation of the vulnerable representations into more durable memory traces; a task that, according to Chun and Potter, is time consuming and effortful. If one assumes a relationship between effort and utilization of cognitive resources (e.g., working memory) one might argue that older adults, because they have reduced working memory resources (e.g., Cohen, 1988; Dobbs & Rule, 1990; Gick et al., 1988; Kemper, 1988; Salthouse et al., 1989; Wingfield et al., 1988), would not perform as efficiently as young adults on cognitive tasks that require substantial amounts of cognitive resources. Consequently, in the present study, we might expect that older adults would exhibit a deficit in processing stimuli; a deficit that would manifest as an AB that is longer, and the magnitude greater, for older adults than for young adults.

We made several predictions. First, we know that the use of compensatory strategies engages cognitive resources. Given that older adults have reduced resources (e.g., working memory), relative to young adults, we would expect overall performance by older adults to be poorer than that of young adults when strategies are engaged. Further, we would expect that when probes follow targets closely in time (where processing demands are heaviest) the likelihood of engaging compensatory strategies should be greatest. Thus, an age-related difference in probe detection would be greatest for probes that occur early in the presentation string. Second, to the extent that there are perceptual processing deficits, and these deficits are greater for older adults than for young adults, we would expect a greater propensity for older adults to engage a compensatory strategy. Thus, older adults might be more likely to trade-off target identification in an effort to improve probe detection accuracy (relative to young adults).

Our third prediction is that if participants engage a trade-off strategy we would expect poorer target identification relative to participants that don't trade-off identification. If older adults are more likely to use this strategy (based on the first prediction) then we would expect that they will exhibit poorer target identification relative to young adults. Our fourth prediction, to the extent that older adults do not process target information fully (relative to young adults) there would be a substantial number of target misidentifications (and not omissions). Fifth, to the extent that older adults in the Control condition find it difficult to inhibit the processing of target information we would expect poorer probe detection by older adults relative to young adults. Sixth, we expected to observe a longer AB for older adults relative to young adults particularly if older adults' cognitive resources are being tied-up for longer periods of time when processing target information. Finally, to the extent that there is a deficit in probe detection, and this deficit is greater for older adults than for young adults, we might observe older adults altering their response criterion as they gain experience with the RSVP task. That is, older adults might be more likely to respond "yes" to the presence of probes despite their absence (i.e., FP) and they wold be more likely to do this as they gain experience with the RSVP task (i.e., an increase in FPs across blocks).

METHOD

Participants

Twenty-six undergraduates (13 – Control; 13 – Experimental) enrolled in psychology classes at the University of Colorado at Colorado Springs participated for extra-credit. Twenty-six older residents (13 – Control; 13 – Experimental) from the Colorado Springs community (independent life styles) were compensated for their participation with a University of Colorado Memory and Aging logo coffee cup.

The average age of young adults was 20.23 (SD = 2.27) and of older adults 68.27 (SD = 7.87). Participants self-rated their health on a scale that ranged from 1 ("poor health") to 5 ("excellent health") with no difference in ratings between young and older adults (Ms = 4.39 and 4.15, respectively). Young adults had less education than older adults (Ms = 13.17 and 14.56, respectively), $t(50) = 2.51$, $SE = .55$, $p < .02$. All participants self-reported that they were native speakers of English and had normal or corrected-to-normal visual acuity. Additionally, a health questionnaire indicated that none of the participants had trouble seeing the stimuli.

Design

A 2 x 2 x 8 x 10 factorial design was used with Age (young vs. old) and Condition (experimental vs. control) as between-subjects variables and Blocks (1-8) and Probe Position (1-10) as repeated measures variables.

Stimuli and Apparatus

Stimuli were 1.5 cm wide and 2.0 cm high and subtended a visual angle of 1.83°. All stimuli were uppercase black letters except for target items which were uppercase white letters. All letters were presented in the center of a uniform gray field with each letter remaining on the monitor for 90 ms followed by an inter-stimulus interval (ISI) of 20 ms. Thus, stimuli were presented at approximately 9.09 letters per second. There were a total of 160 trials: all trials contained a target letter and half of the trials contained a probe. Across trials the total length of a sequence varied from 17 to 26 letters. Target letters were randomly selected from the alphabet, varied from trial to trial, and across trials could appear in serial positions 7 to 16; thus, the number of letters that could precede a target ranged from 6 to 15. Each sequence was constructed with the restriction that no letter could be repeated and across trials the probe could appear in any one of ten post-target positions with the probe occurring eight times across serial positions.

A Power Macintosh 7200 computer was used to present stimuli onto an Apple 17-in. (15.8 in. viewable area) color monitor (75 hertz vertical refresh rate / 49.74 kilohertz horizontal scan rate). Superlab[tm] (Cedrus Corporation, 1999) was used to program the experiment and to control stimulus presentation. Participants' responses were recorded in a response booklet by the experimenter. The experimental room was partially darkened and participants were seated approximately 47 cm from the screen.

Procedure

Participation was on an individual basis with each participant signing a consent form. Participants were seated in front of the computer and informed of the general procedure that was to be followed. Each trial was self-initiated by pressing the spacebar on the keyboard. After 500 ms a fixation point appeared in the center of the screen for 360 ms and then was followed by a sequence of letters.

For each trial, participants in the Experimental condition were instructed to identify the white letter (target) and decide whether a black 'X' (probe) was present whereas participants in the Control condition were asked to ignore the target and focus on probe detection. Thus, all participants, irrespective of condition, saw the same letters. Participants were provided time at the end of each trial to report their response(s) to the experimenter who recorded them into a response booklet. The experimenter was unaware of the correct responses for all trials. After reporting a response(s) participants were asked to rate their confidence in the accuracy of that response(s) on a scale that ranged from 1 "unsure" to 20 "sure". Further, participants were instructed that a "1" value indicates a guess and that they should use the whole scale when making their decisions. After each block of 20 trials participants were provided an opportunity to rest (though neither young nor older adults used those opportunities). All participants were provided with ten practice trials.

RESULTS

Target Identification

Correct Identification. Correct identification (out of a possible 160) for participants in the Experimental condition ranged from 147 (91.88%) to 158 (98.75%) for young adults and from 131 (81.88%) to 155 (96.88%) for older adults. Young adults correctly identified more targets than older adults (Ms = 153.31 and 145.85, respectively), $t(24) = 3.24$, $SE = 2.30$, $p < .003$.

Participants in the Experimental condition were performing under dual-task conditions (i.e., target identification and probe detection). Thus, one might conclude that older adults did not perform as well as young adults on target identification because they were disadvantaged under dual-task conditions (e.g., Craik & McDowd, 1987; Macht & Buschke, 1983; Park et al., 1989). To examine this possibility we conditionalized target identification on correct probe detection. We reasoned that if probes are correctly detected then target identification must have completed, or at least to an extent such that resources were freed up, relative to a condition in which probes were missed. This analysis revealed no advantage for young over older adults (Ms = 96.10 and 94.33, respectively); $t(24) = 1.31$, $SE = 1.35$, $p < .202$. Thus, it appears that it is not the case that older adults, under all circumstances, perform more poorly than young adults under dual-task conditions.

Another approach to this dual-task issue is to determine how difficult participants found the task. To do this we examined target identification conditionalized on correct probe detection for the first five probe positions (where it might be more difficult to perform target identification and probe detection because probes occur within a short period after targets) and the last five probe positions (where it might be easier to identify targets and detect probes because a substantial amount of time has passed for target identification to complete its course). Thus, if older adults cannot perform as well as young adults under dual-task conditions then we would expect to see a difference between first and second halves in terms of target identification accuracy. On the other hand, to the extent that performance is similar for both halves we would conclude that dual task performance was not any more difficult for older adults than for young adults. An analysis, using percent correct target identification, conditionalized on correct probe detection, revealed no difference between halves for young adults (Ms = 96.75 and 96.08 for first and second halves, respectively; $t(12) = .51$, SE = 1.32, $p < .62$) nor for older adults (Ms = 94.54 and 95.35 for first and second halves, respectively); $t(12) = -.39$, SE = 2.07, $p < .70$.

To provide additional support for our assertion that older adults did not find the dual task condition more difficult than young adults we examined the relationship between target detection accuracy and the magnitude of the AB (defined as the difference between 100% and percent detection of a probe at each serial position for each participant and summed across participants; see Raymond et al., 1995). Our rationale was that to correctly identify targets effort must be engaged and this would be done at the expense of probe detection. Further, according to Raymond et al. (1992), probe detection should be "impaired" to the extent that targets are processed. Collapsing across age we found $r = -.66$, $p < .001$, one-tailed, $n = 26$; a finding that supports an assertion that target identification is effortful. When we examined correlations by age, we found a significant correlation for young adults, $r = -.51$, $p < .039$, one-tailed, $n = 13$ and a marginally significant correlation for older adults, $r = -.45$, $p < .063$, one-tailed, $n = 13$. Thus, for both age groups we obtained the expected pattern and there was no difference between young and older adults, $Z = -0.39$, $p < .35$; a finding that supports the assertion that young and older adults found the task equally demanding. Therefore, an argument that states poor dual-task performance is additive with the time course of the AB is weakened.

We suggest that probe detection failure is a function of the amount of time that cognitive resources are directed toward target identification and that upon reinstatement of resources (i.e., targets have been identified) probe detection is relatively accurate. Additionally, we argue that older adults' cognitive resources are engaged for longer periods during target identification than those of young adults. Consequently, older adults miss probes more frequently than young adults and are less accurate in their target identifications but that once resources are freed-up then probe detection accuracy is equivalent to accuracy levels of young adults.

A compensatory strategy that might be engaged to increase probe detection is to trade-off target identification accuracy. We found that young adults identified correctly more targets than older adults; thus, it is possible that older adults adopted this trade-off strategy. If older adults adopted this strategy then one would expect a decrease in correct target identification across trials. That is, we assert that as one gains experience with the task and, presumably, a more veridical assessment of one's visual processing capabilities, one would be more likely to engage a compensatory strategy, assuming of course that such a strategy is deemed necessary by the participant.

A 2 x 8 analysis of variance (ANOVA), with Age as a between-subjects variable and Block as a repeated-measures variable, using the number of correctly identified targets as the dependent measure, revealed an effect of Age, F (1, 24) = 10.51, MS_e = 4.30, p < .003 and an Age x Block interaction, F (7, 168) = 2.25, MS_e = 0.96, p < .03. One-way repeated-measures ANVOA's performed for each age group revealed that for young adults performance remained stable across blocks, F (7, 84) = 0.49, MS_e = 0.55, p < .84 whereas for older adults performance varied, F (7, 84) = 2.22, MS_e = 1.36, p < .04. The results of post-hoc tests revealed that older adults' performance was substantially lower than that of young adults in Block 1, t(24) = 3.49, p < .002, Block 2, t(24) = 3.21, p < .004, and Block 5, t(24) = 3.84, p <.001. There were no other effects.

Based on these findings it is reasonable to conclude that the older adults' poorer target identification performance, relative to young adults, did not result from the use of a trade-off compensatory strategy (unless one argues that older adults traded-off target identification early and then dropped the strategy later in the study). Again, we suggest that the opposite pattern (i.e., an increase in target misidentifications) would occur if participants were adopting a trade-off strategy.

Confidence Ratings. Obtaining confidence ratings permitted us the opportunity to determine whether there was a perceived deficit in the processing of visual information and more specifically, whether older adults might be poorer at monitoring their perceptual performance than young adults. If older adults were more likely to adopt a trade-off strategy (i.e., pay less attention to targets) then it would be somewhat difficult for them to rate their confidence in target identification accuracy. Such a scenario should result in confidence ratings being either lower or higher than the ratings of young adults. Further, if older adults were using such a strategy to compensate for a perceived deficiency in the processing of target information then the likelihood that this strategy would be engaged would be expected to increase across trials and consequently, we should observe a change in confidence ratings by older adults (decrease or increase) across trials.

Contrary to our expectation, a 2 X 8 mixed ANOVA, with age as a between-subjects variable and block as a within-subjects variable, revealed no age-related difference in assigned confidence ratings, F (1, 24) = 0.25, $p < .62$ nor was there an age x block interaction, F (7, 168) = .59, $p < .76$. There was a significant effect of block, F (7, 168) = 2.10, $p < .047$ such that participants' confidence ratings increased in strength from the first to the eighth block (Ms = 18.43 and 19.16, respectively).

Identification Errors. More misidentifications (excluding omissions) were made by older adults (n = 176) than by young adults (n = 81), t(24) = -3.25, SE = 2.25, $p < .003$. We assert that target identification errors were not random, not the result of inattentiveness, nor were they pre/post-target items retrieved from the visual short-term memory store (e.g., Shapiro et al., 1994; Shapiro & Raymond, 1994). In support of these assertions we found that 12.35% (10 out of 81) of the target misidentifications by young adults were pre/post items and only 5.68% (10 out of 176) of the misidentifications by older adults were pre/post items.

We assert that for older adults there is a greater likelihood that the transformation process (i.e., recoding visual input into more durable memory traces) will be disrupted by subsequent items in the visual stream; an assertion based on the observation that there were more visual errors (e.g., "R" reported instead of "B"; "P" instead of "F"; "C" instead of "G"; "N" instead of "V") by older adults than by young adults. These data support a hypothesis that it takes older adults more time to transform visually presented information into durable memory traces (e.g., acoustical) than young adults and that prior to being encoded the trace is fragile and susceptible to loss. This conclusion ties in with our previous conclusion that older adults take longer to process target information than young adults.

Confidence Ratings for Misidentified Targets. We failed to observe an age-related difference in confidence ratings assigned to incorrectly identified targets ($Ms = 12.32$; $SD = 5.09$ and 12.69; $SD = 3.88$ for older and young adults, respectively), $t(24) = .21$, $SE = 1.78$, $p < .84$. We also observed that confidence ratings were weaker when incorrect identifications were made relative to when correct identifications were made by young adults [($Ms = 12.69$ and 18.72, respectively), $t(12) = 7.32$, $SE = .32$, $p < .001$] and older adults [($Ms = 12.32$ and 18.94, respectively, $t(12) = 4.90$, $SE = 1.35$, $p < .001$]. These patterns support an assertion that there is little age-related difference in the ability to assess one's perceptual processing performance under conditions in which visual information is presented at a rapid rate.

Probe Detection

Correct Detection. Correct probe detection for young adults ranged from 61 to 78 in the Control condition and 53 to 65 in the Experimental condition. For older adults correct probe detection ranged from 58 to 80 in the Control condition and 32 to 61 in the Experimental condition. Collapsed across conditions and serial position we found that young adults correctly detected more probes than older adults ($Ms = 66.62$ and 58.54, respectively), $t(50) = 2.33$, $SE = 3.47$, $p < .02$.

A 2 (Age: young vs. old) X 2 (Condition: Experimental vs. Control) X 9 (Serial Position: positions 2, 3, 4, 5, 6, 7, 8, 9, and 10) mixed ANOVA with Age and Condition as between-subjects variables and Serial Position as a within-subject variable, using the number of correctly detected probes as the dependent measure, revealed a main effect of Age such that more probes were detected correctly by young adults ($M = 6.70$) than by older adults ($M = 5.90$), $F(1, 48) = 23.65$, $MS_e = 3.16$, $p < .001$. There was also a main effect of Condition such that participants in the Control condition (M = 7.34) correctly detected more probes than participants in the Experimental condition (M = 5.27), $F(1, 48) = 159.06$, $MS_e = 3.16$, $p < .001$. There was a main effect of Serial Position such that the number of correctly detected probes increased from serial position two (M = 4.92) to serial position ten (M = 7.15), $F(8, 384) = 58.85$, $MS_e = .967$, $p < .001$.

Additionally, there were several two-way interactions involving Age and Serial Position, $F(8, 384) = 2.00$, $MS_e = 0.97$, $p < .045$, Age and Condition, $F(1, 48) = 18.41$, $MS_e = 3.16$, $p < .001$, and Serial Position and Condition, $F(8, 384) = 42.24$, $MS_e = 0.97$, $p < .001$. Finally, there was a triple interaction involving Age, Condition, and Serial Position, $F(8, 384) = 2.62$, $MS_e = 0.97$, $p < .008$. To uncover the nature of these interactions, we conducted a separate 2 (Age: young and old) x 9 (Serial Position: positions 2, 3, 4, 5, 6, 7, 8, 9, and 10) mixed ANOVA on the experimental and control conditions. The results showed that the effects of Age, $F(1, 24) = 35.89$, $MS_e = 3.67$, $p < .001$, Serial Position, $F(8, 192) = 73.39$, $MS_e = 1.32$, $p < .001$, and their interaction, $F(8, 192) = 2.97$, $MS_e = 1.32$, $p < .004$, were significant for the experimental condition. However, for the control condition, we only found a marginally significant effect of Serial Position, $F(8, 192) = 1.91$, $MS_e = 0.62$, $p < .06$.

Because of the triple interaction we examined age-related differences between participants in the Experimental and Control condition separately as a function of Serial Position with planned comparisons. Using percent correct probe detection as the dependent measure, we found that for older adults differences between the experimental and control conditions were significant at lags of one, $t(24) = 7.28$, $p < .000$, two, $t(24) = 17.84$, $p < .000$, three, $t(24) = 8.30$, $p < .000$, four, $t(24) = 5.65$, $p < .000$, five, $t(24) = 4.82$, $p < .000$, six, $t(24) = 3.02$, $p < .006$, seven, $t(24) = 5.14$, $p < .000$, eight, $t(24) = 4.23$, $p < .000$, and nine, $t(24) = 3.01$, $p < .006$. In contrast, for young adults differences between the experimental and control conditions were significant at lags of one, $t(24) = 6.07$, $p < .000$, two, $t(24) = 9.12$, $p < .000$, and three, $t(24) = 4.40$, $p < .000$. Based on these analyses we determined that the length of the AB for young adults was 330 ms (approximates that found by others; e.g., Raymond et al., 1992) and for older adults 990 ms. Further, the magnitude of the AB was greater for older adults ($M = 383.65$) than for young adults ($M = 223.08$), $t(24) = -5.24$, $SE = 30.66$, $p < .001$. AB magnitude was quantified using a procedure outlined in Raymond et al. (1995); the difference between 100% and percent detection of the probe at each serial position for each participant and summed across participants. The magnitude calculation was based on serial positions 2-10 as in Raymond et al. (Experiment 2, 1992) and Raymond et al. (Experiment 1, 1995). The AB magnitude found for young adults in the present study ($M= 223.08$) approximates magnitudes reported for young adults in Raymond et al. (1992; $M= 231.60$) and Raymond et al. (1995; $M = 248$).

A compensatory strategy that participants might use if they believe that they were missing probes is to increase the frequency with which a "yes" response is emitted. If participants were using such a strategy there would be an increase in FPs. As can be seen in Table 1 there was no change in FP rates across blocks for either young or older adults. This observation was confirmed with a 2 x 8 ANOVA, using age as a between-subjects variable and block as a repeated-measures variable. The effect of age was not significant, $F(1, 24) = 1.64$, $MS_e = 1.55$, $p < .21$, nor was the effect of block, $F(7, 168) = 1.00$, $MS_e = 0.53$, $p < .43$ nor the Age x Block interaction, $F(7, 168) = 0.99$, $MS_e = 0.53$, $p < .44$. Thus, it appears that individuals did not adjust their response criteria as a function of experience with the RSVP paradigm.

Confidence in Probe Detection. Presented in Figure 2 are the confidence ratings as a function of serial position, condition, and age. It appears that the confidence ratings for older and young adults were approximately the same for participants in the Experimental and Control conditions. Further, a visual comparison between Figures 1 and 2 reveals that confidence ratings roughly paralleled the probability of probe detection for older as well as young adults.

A 2 (Age: young vs. old) x 2 (Condition: Experimental vs. Control) x 10 (Serial Position: 1-10) ANOVA , using Age and Condition as between-subjects variables and Serial Position as a within-subjects variable, revealed no effect of Age $F(1, 48) = .001$, $MS_e = 16.15$, $p < .980$; a significant effect of Condition $F(1, 48) = 9.46$, $MS_e = 16.15$, $p < .003$; a significant effect of Serial Position $F(9, 432) = 24.26$, $MS_e = 2.75$, $p < .000$; no Age x Condition interaction, $F(1, 48) = 1.91$, $MS_e = 16.15$, $p < .174$; no Age x Serial Position interaction, $F(9, 432) = 0.81$, $MS_e = 2.75$, $p < .604$; a significant Serial Position x Condition interaction, $F(9, 432) = 15.30$, $MS_e = 2.75$, $p < .000$; and no triple interaction of Serial Position x Age x Condition $F(9, 432) = 1.00$, $MS_e = 2.75$, $p < .437$.

We examined the Serial Position x Condition interaction in more detail with post-hoc tests (adjusted $\alpha = .005$). The analyses revealed significant differences at lags one $t(50) = 4.50$, $p < .000$, $SE = 0.96$; two $t(50) = 5.43$, $p < .000$, $SE = 0.75$; and three $t(50) = 2.93$, $p < .005$, $SE = 0.76$. There were no other differences between individuals in the Experimental and Control groups at subsequent serial positions. An analyses of changes in confidence levels as a function of age and block (Table 1) revealed no age-related differences in the ratings as a function of block except for the first block ($p < .05$) where older adults were substantially less confident in the accuracy of their responses than young adults.

To determine whether participants were adopting a compensatory strategy in which they said "yes" more often than they should we examined the number of reported FPs. FPs occur when individuals report the presence of a probe and the probe was actually absent. A high FP rate is indicative of a less lenient response criterion. A 2 x 2 ANOVA, using Age and Condition as between-subjects variables, and number of FPs as the dependent measure, revealed no significant effects. In addition to examining FP rates we examined a response bias measure referred to as c (cf., See, Warm, Dember, & Howe, 1997). The value of c is zero when FP rates equal misses [1 – p(hit)]. c becomes positive when FP rates are lower than misses and conversely, c becomes negative when FP rates exceed misses. Positive c values indicate conservative bias whereas negative c values indicate a more liberal bias. A 2 x 2 ANOVA, using Age and Condition as between-subjects variables, revealed an effect of Condition, $F(1, 48) = 11.45$, $MS_e = 0.29$, $p <.001$. However, the effects of Age, $F(1, 48) = 0.23$, $MS_e = 0.29$, $p <.63$ and the Age x Condition interaction, $F(1, 48) = 1.48$, $MS_e = 0.29$, $p <.23$ were not significant. These results revealed that participants in the experimental group were more conservative ($M = 0.82$, $SD = .50$) than participants in the control group ($M = 0.32$, $SD = 0.58$). However, contrary to what we expected, we found that older adults ($M = 0.53$, $SD = 0.63$) were not more conservative than young adults ($M = 0.61$, $SD = 0.58$).

DISCUSSION

We found that the length and magnitude of the AB was longer and greater for older adults than for young adults. We also found an age-related difference in correct target identification such that young adults were better at the task than older adults but this conclusion must be tempered with the finding that there was no age-related difference when target identification was conditionalized on correct probe detection. Further, we observed no age-related difference in either target identification or probe detection confidence ratings. Thus, it appears that young and older adults were equivalent in assessing their ability to process target and probe information. An examination of probe confidence ratings as a function of block, which provides an indication as to whether there was a change in information processing strategies as a function of experience, revealed an age-related difference in the first block (20 trials) such that older adults were substantially less confident in the accuracy of their responses than young adults. Finally, the data suggest that participants in the Experimental condition were substantially less confident in their probe detection in the first 330 ms relative to participants in the Control condition. Thus, it appears that all participants provided confidence ratings that paralleled their probe detection performance.

We failed to observe age-related differences in the use of the three compensatory strategies that were examined in the present study. We found that older adults were poorer at target identification that young adults but an analysis of performance across blocks revealed an increase in target identification accuracy for older adults, a pattern opposite to what would be expected if one adopted a trade-off strategy. We also failed to observe an age-related difference in the propensity to report "yes" to probes when probes were not present. This latter conclusion is based on analyses in which the number of FPs and a response bias measure (c) were used as dependent measures. We observed that participants in the Experimental condition (irrespective of age) were more conservative in their reporting of probes than participants in the Control condition. This failure to observe an age-related difference provides additional support for the assertion that older adults' poorer target detection performance was not the result of a compensatory strategy whereby they traded-off target identification in an effort to increase the probability of correct probe detection. Finally, we observed that both young and older adults reported the presence of probes despite having a low level of report confidence. This conclusion is drawn from a comparison of confidence level reports and probe item reports (figures one and two).

An initial reaction to the present findings is that the length and magnitude of the AB was greater for older adults than for young adults because older adults had greater difficulty in processing the visual stimuli presented in the RSVP stream. If this was the case then one would expect to find an age-related difference in probe detection for participants in the Control condition but we failed to observe such a difference. Further, if older adults were having a more difficult time seeing the letters then it should make no difference if we conditionalized target identification accuracy on correct probe detection. Yet, we found that conditionalizing altered the results for older adults; target identification accuracy was equivalent to that of young adults. Finally, data collected from the health questionnaire revealed that neither older nor young adults reported any difficulty in seeing the stimuli.

Alternatively, one might argue, given that older adults do not perform as well as young adults under dual task conditions (e.g., Craik & McDowd, 1987; Macht & Buschke, 1983; Park et al., 1989) that the poorer target identification that we observed for older adults in the Experimental condition is additive with the time-course of the AB. We suggest that this explanation is weakened on several counts. First, we observed that older adults were poorer than young adults in overall target identification but when we conditionalized on correct probe detection we failed to find an age-related difference. Second, it has been reported in the literature that poorer performance by older adults, relative to young adults, under dual-task conditions occurs when the tasks are relatively complex (e.g., driving in traffic and listening to a conversation simultaneously). When the tasks are not complex then older adults perform as well as young adults under dual-task conditions (e.g., Somberg & Salthouse, 1982). We suggest that the reason why older adults did not do as well as young adults in detecting probes is that the older adults' cognitive resources were tied-up for longer periods of time during target identification than those of young adults.

We outlined three characteristics implicated in accounts of the AB: interference, time utilization, and engagement of cognitive resources. We examined age-related differences in the interference component by examining the ability to inhibit the processing of target information (Control condition) and the interfering effect that target processing might have on probe detection (Experimental condition). According to Yantis and Hillstrom (1994) the appearance of a novel perceptual object elicits a shift in attention (toward the object) and the function of this shift is to create an episodic perceptual representation. According to Egeth and Yantis (1997) this process may be "hard-wired", that is, attention may be "drawn" toward the object despite instructions to ignore it. Participants in the Control condition of the present study were asked to ignore (or inhibit) targets and to focus their attention on probe detection but their attention may have been "automatically" drawn to the targets. Thus, participants must inhibit the processing of white letters in the Control condition (where participants were instructed to ignore that information).

We expected that older adults would have a more difficult time at this given that the efficiency with which older adults can inhibit irrelevant information is poorer relative to young adults (e.g., Hasher & Zacks, 1988) and that the process of inhibiting information requires effort and cognitive resources (e.g., Hasher & Zacks, 1988). Difficulty in inhibiting targets might be reflected in poor probe detection because resources are drawn away from detection in an effort to inhibit target processing. Contrary to our expectation, we failed to observe an age-related difference in the probability of probe detection for participants in the control condition. Thus, it appears that there was little age-related difference in the ability to inhibit irrelevant information (i.e., targets). Our failure to observe 100% probe detection by young and older adults might be due to, as noted by Eriksen and Eriksen (1974), the difficulty that even young adults have in attentional selectively; it is difficult to eliminate completely the effects of extraneous variables.

We examined age-related differences in time utilization by adopting a speed-of-processing interpretation. If we accept the assumption that older adults process information at a slower rate than young adults (e.g., Cerella, 1990; Salthouse & Babcock, 1991) then it is reasonable to expect older adults to take longer to identify targets (i.e., attentional resources would be used for longer periods of time) and consequently less time and resources would be available to detect probes. Such a scenario would result in an AB that is longer than that of young adults; a pattern that was observed in the present study. Related to this is a finding by Hoyer and Familant (1987; Experiment 2) where it was observed that cueing helped younger and older adults in a visual search task but that the cue was not effective for older adults unless the stimulus-onset-asynchrony (SOA) between cue and displayed information was greater than 750 ms.

According to Raymond et al. (1992), the AB results from a state of confusion: a target and a post-target is held together in the visual short-term memory and the cognitive system attempts to conjoin the correct color with the correct identity (the color white with the letter and the color black with the 'X'). Thus, from this perspective, it may be that a greater amount of time is required for older adults to conjoin information than young adults and this idea is supported by the observation that older adults made more visual errors in the present study when identifying targets than young adults. Related to this is whether transforming visual information into more durable memory traces (e.g., acoustical) takes longer for older than for young adults. There may be an intimate relationship between the length of the AB and such a transformation process. In support of this we observed a greater number of misidentifications that were visual in nature by older adults than by young adults (94.32% vs. 87.65%, respectively).

Additionally, we observed that the majority of misidentifications were not pre/post-target items in the visual stream as might be expected if one adopts the Similarity Theory (e.g., Jolicoeur, 1998) where it is argued that matched templates are placed into visual short-term memory (VSTM) with varying weights. According to proponents of this theory items that enter VSTM early are postulated to have heavier weights than items that enter later and assigned weights determine what is reported to the experimenter (e.g., heavier weighted items are reported first).

Finally we examined resource limitations and how these might differ between young and older adults in processing rapidly presented visual information. Several accounts of the AB have stressed the role of cognitive resources. For example, according to the Delay-of-Processing account (e.g., Seiffert & DiLollo, 1997), anything that makes it difficult to process targets will result in greater ABs. Illustrative is the masking of targets. Such masking would make it more difficult to process targets and, therefore, should result in a relatively large AB as was found by Seiffert and DiLollo (1997). If this account is accurate then we would infer that the age-related difference that we observed in the present study resulted in older adults having more difficulty with the processing of targets than young adults. To examine this possibility we calculated the correlation between correct target identification and the AB magnitude. We found a negative correlation between the probability of correct target identification and AB magnitude for older adults (r = -.51) as well as for young adults (r = -.45) suggesting that identifying targets required more "effort" and that, at least in the present study, there appears to be little age-related difference in how difficult the participants find the task.

Another important resource issue related to amount of cognitive resources is the capacity available for engaging tasks. Jolicoeur (1998) argues that larger ABs are observed when participants are required to report targets immediately after they occurred, in contrast to the standard procedure of waiting until the whole string of letters is presented. Jolicoeur (1998) suggests that resources are used for identifying targets and this results in fewer resources being available for processing probes. We know that older adults have a reduced working memory resource pool (e.g., Cohen, 1988; Gick et al., 1988; Kemper, 1988; Salthouse et al., 1989; Wingfield et al., 1988). Thus, one might expect that older adults would have more difficulty in identifying targets and detecting probes (Experimental condition) if one assumes that more working memory resources would be required to engage a dual-task (e.g., target identification and probe detection).

Chun and Potter (1995) suggest that more effort is required during the second stage of their two-stage model of visual information processing. The primary function of the second stage of their model is to transform visual information into more durable memory traces. Further, according to Chun and Potter, the second stage is a limited capaicity system. We know that older adults have a more difficult time, relative to young adults, when a cognitive task requires effort and that they have reduced working memory resources (which could be tied to reduced system capacity). Thus, we might expect a longer AB for older adults because of the limited resource pool available to the older adult. Further, if one assumes such a limited capacity system then one might also suggest that when information is not fully processed there will result processed information that is similar in visual aspects to the to-be-processed information (i.e., visual errors); an explanation that can account for several of the age-related differences we observed in the present study.

As a final issue we turn to possible age-related differences in the use of compensatory strategies. If the perceiver believes that there exists a deficiency in their processing of visual information then one might expect these individuals to engage in some sort of compensatory strategy to help improve efficiency with which they process visual information. The first compensatory strategy that we examined was the trading-off of target identification for probe detection. If one is not detecting probes as well as one should then an obvious solution would be to free-up resources in order to increase the quality of probe detection and one way of accomplishing this is to direct fewer resources to the processing of targets. We found that older adults identified fewer targets than young adults; a finding that is suggestive of a trade-off strategy. However, for several reasons we believe that this pattern is not the result of an adopted compensatory strategy. First, in the extreme, one could completely ignore targets in an effort to maximize probe detection; a situation that would result in no targets being identified. An examination of Table 1 reveals that mean percent target identification was relatively high for older (91.16%) as well as for young adults (95.82%). Thus it appears that such an extreme strategy was not adopted. Second, one might expect a decrease in the probability of correct target identification across blocks as one gains experience with the RSVP paradigm and their assessment of information processing becomes more veridical. Again, an examination of Table 1 reveals that this did not occur. In fact, we observed an increase in the likelihood of correct target identification across blocks.

Third, if older adults were trading-off target identification for probe detection then confidence in target identification would be low relative to a condition in which participants were not trading off target identification for probe detection. Further, confidence in probe detection would be relatively high because more resources would be directed toward the task of detecting probes. We failed to find an age-related difference in assigned target identification confidence levels nor did we observe an Age X Block interaction. With respect to probe confidence ratings, we found no age-related difference and more importantly, no interaction between Age and Serial Position. In conclusion, it appears that older adults did nothing different, in terms of trading-off target identification, than young adults when processing probes.

The second compensatory strategy that we examined was change in response criterion. Specifically, we examined whether there was an increase in the number of "yes" responses to the presence of probes. Such a strategy would increase the probability of correct probe detection but at a cost; there would be an increase in FPs (i.e., reporting a probe when it was absent). Further, we might expect that for young, as well as older, adults the use of such a strategy would increase across blocks; as one gains experience with the RSVP task one's assessment of how well one is detecting probes would become more accurate and, presumably, the propensity to respond "yes" should increase as one realizes that probes are being missed. Further, in particular, if older adults were having a difficult time detecting probes then we might expect older adults to adopt such a strategy because their performance on probe detection was somewhat poorer than that of young adults. An analysis revealed no age-related difference in the number of reported FPs. Further, as can be seen in Table 1, and as the analyses in the present study revealed, there was no change in the rate of FPs by young and older adults across blocks. In addition to examining FP rates we examined a response bias measure referred to as c (cf., See et al., 1997) and failed to observe an age-related difference in response bias. Thus, it appears that individuals, irrespective of age, did not adjust their response criterion during the RSVP task.

Finally, an examination of the third strategy, reporting presence of probes despite low confidence ratings, suggests that neither young nor older adults adopted this strategy. As can be seen in Figure 2, both young and older adults felt uncertain about their probe detection performance when probes occurred shortly after targets. Despite the relatively low confidence participants continued to report probes. When we examined confidence ratings as a function of block, which provides information as to whether there was a change in information processing strategies as a function of experience with the RSVP task, we only found an age-related difference in the first block (20 trials). It appears that individuals in the Experimental condition (where, functionally, a dual task was being performed) were significantly less confident in their probe detection in the first 330 ms relative to individuals in the Control condition.

We failed to find differences between young and older adults in the use of these strategies. There are two post-hoc explanations. First, participants may not have perceived a deficiency in their visual information processing. The failure to observe age-related differences in participant assigned ratings supports this possibility. Thus, if there was not a perceived deficit in the processing of information then participants would have no need to engage a compensatory strategy. A second explanation is that participants were unaware of the compensatory strategies that were available to them. We suggest that the first conclusion, relative to the second, follows from our failure to observe age-related differences in participant-assigned confidence ratings.

Future directions:

We conclude by suggesting that more research is necessary to understand what sorts of compensatory strategies might be engaged when there is a perceived deficiency in the processing of visual information. There is little research that has examined compensatory strategies in general and even less in terms of age-related differences in the use of such strategies. In the present study we attempted to shed light on the use of compensatory strategies when individuals must process information at a rapid rate.

Related to this issue is the difficulty participants might have in "releasing" attention from the processing of targets (Experimental condition). We know that older adults require more time to shift their visual attention from one area of the visual field to another (Hartley, Kieley, & McKenzie, 1999) and that automatic "capture" effects are larger for older adults than for young adults (Lincourt, Folk, & Hoyer, 1997). We also know that damage to the parietal lobe results in an impaired ability to disengage attention from targets especially when they occur on the side opposite the lesioned hemisphere (e.g., Posner, Walker, Friedrich, & Rafal, 1987). Thus, it may be that deterioration in the parietal lobes accompanies the aging process just as the prefrontal cortex deteriorates with age (e.g., Haug, Barmwater, Eggers, Fischer, Kuhl, & Sass, 1983; Raz, Gunning, Head, Dupuis, McQuain, Briggs, Loken, Thornton, & Acker, 1997; Shimamura, 1994). If older adult's propensity for visual capture is mediating the present findings then the thalamus may be playing an important role. It has been suggested by Lincourt et al.(1997) that the superior colliculous and thalamus play an important role in the automatic capture of attention with the thalamus playing a particularly important role in the disengagement of attention from target items. We are currently examining this possibility.

The present findings raise the issues as to whether the amount of working memory resources affects the length and magnitude of the AB. Related to this is whether an intact prefrontal cortex is required to efficiently process visual information that is presented at a rapid rate. These issues are relevant in attempting to account for the present findings because we know that there are age-related differences (favoring young adults) in working memory resource capacity (e.g., Cohen, 1988; Gick et al., 1988; Kemper, 1988; Salthouse et al., 1989; Wingfield et al., 1988) and in frontal lobe functioning (e.g., Raz, Gunning, Head, Dupuis, McQuain, Briggs, Loken, Thornton, & Acker, 1997).

In conclusion, the present findings are important for several reasons. First, it shows that older adults require a substantially greater amount of time to process visually presented information (when that information is presented at a rapid rate) than do young adults. These findings also suggest that older adults may be overconfident (relative to young adults) in their ability to process rapidly presented visual information. Further, it is not at all clear what strategies, if any, individuals might use when there is a perceived deficiency in the processing of visual information. This is an area that needs a substantial increase in research efforts, a sentiment that has been voiced by others (e.g., Kausler, 1994).

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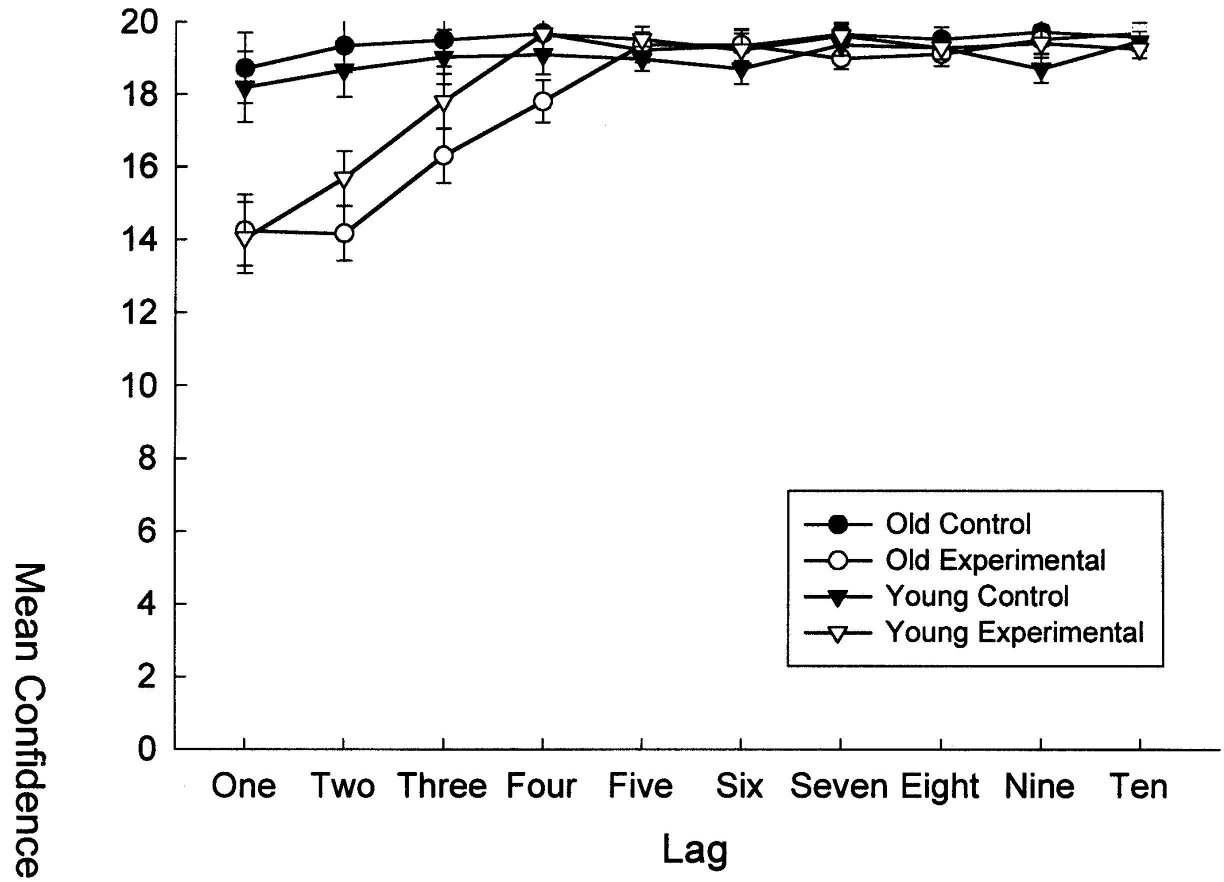
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Old Experimental
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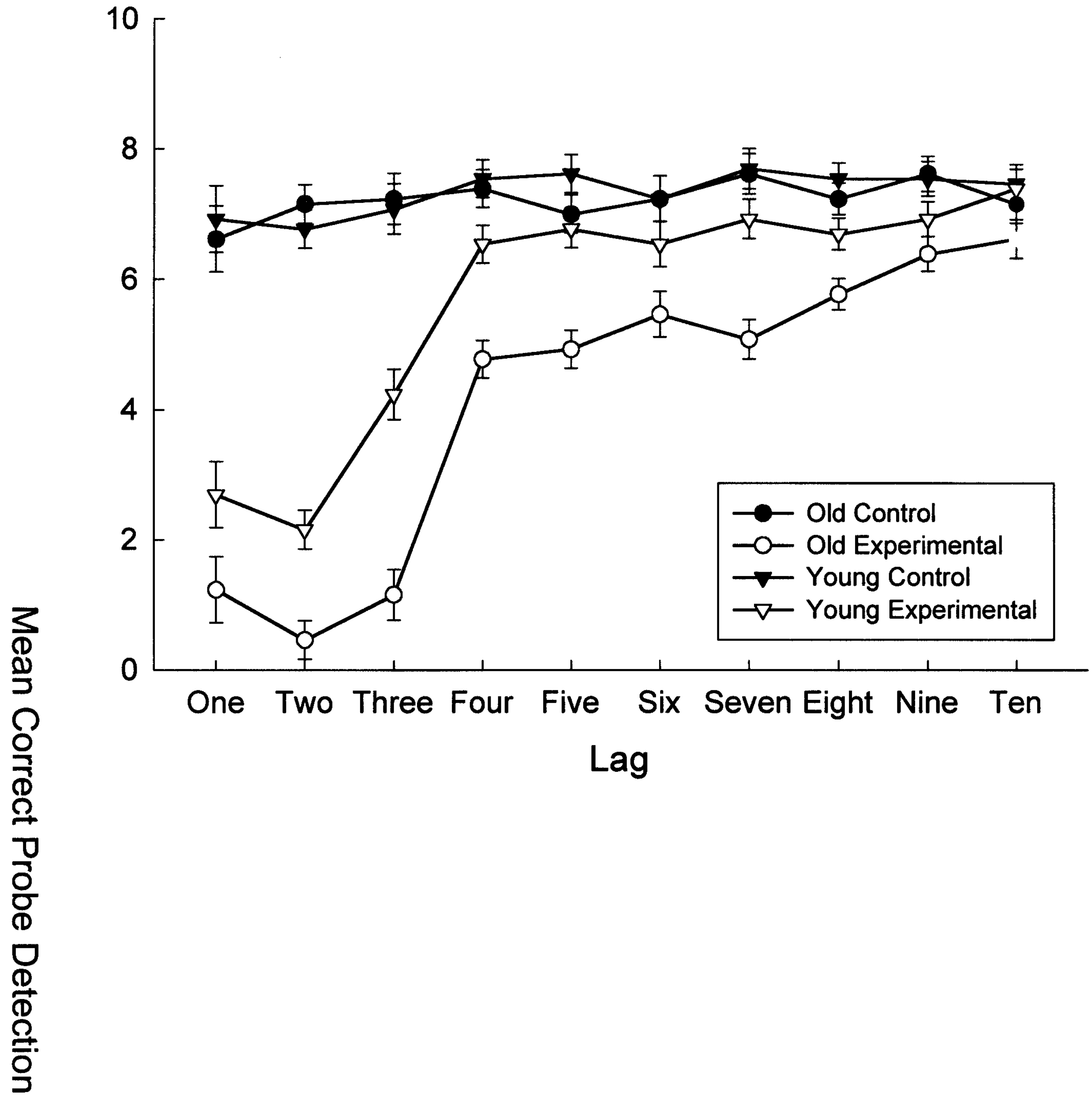

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Mean Correct Probe Detection

Figure Captions

Figure 1. Mean percent (and standard errors of the mean) probe detection as a function of serial position, age, and condition.

Figure 2. Mean confidence rating (and standard errors of the mean) as a function of serial position, age, and condition.

Table 1

Target Identification, Probability of Probe False Positives (FPs), and Probe Confidence as a Function of Block and Age for Individuals in the Experimental Condition

Block	Target Hits		Target Confidence**		Probe FPs		Probe Confidence**	
	Young	Old	Young	Old	Young	Old	Young	Old
1	19.23	17.62***	18.87	18.43	.85	.62	19.51	17.40***
2	19.31	17.69***	17.92	18.54	.15	.39	18.59	19.27
3	19.00	18.38	19.06	18.71	.15	.85	18.98	18.92
4	19.08	18.62	19.34	18.98	.23	.54	19.44	18.91
5	19.23	17.69***	18.64	18.72	.31	.62	17.97	19.11
6	19.00	18.62	19.07	18.76	.54	.46	18.87	18.99
7	19.38	18.46***	18.76	18.91	.23	.39	19.08	19.43
8	19.08	18.77	19.16	19.03	.23	.62	19.01	18.41

*Each block contained 20 trials. **Confidence ratings were conditionalized on correct target identification and probe detection. ***Significant at $p < .05$.

Table 2

Probe Detection

Condition	Mean Number Hits	Mean Number Correct Rejects.	Mean Number False Positives	Mean Number Misses
Experimental Old	45.46 (7.82)*	75.46 (4.35)	4.54 (4.35)	34.54 (7.82)*
Experimental Young	59.54 (3.73)*	77.00 (2.67)	3.00 (2.67)	20.46 (3.73)*
Control Old	72.15 (7.80)	75.77 (5.35)	4.23 (4.92)	7.84 (7.81)
Control Young	73.69 (4.46)	76.38 (5.34)	3.62 (5.34)	6.31 (4.46)

*Significant at $p < .05$