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Short article

Age-related increase in top-down activation of visual features

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Previous research suggests that, during visual search and discrimination tasks, older adults place greater emphasis than younger adults on top-down attention. This experiment investigated the relative contribution of target activation and distractor inhibition to this age difference. Younger and older adults performed a singleton discrimination task in which either an E or an R target (colour singleton) was present among distractor letters. Relative to a baseline condition in which the colours of the targets and distractors remained constant, an age-related slowing of performance was evident when either the colour of the target or that of the distractors varied across trials. The age-related slowing was more pronounced in response to target colour variation, suggesting that older adults place relatively greater emphasis on the top-down activation of target features.

Several models of visual search share the assumption that there is an extraction of local differences among display items relatively early in the information-processing sequence, which influences the deployment of attention to the target item (Müller, Reimann, & Krummenacher, 2003; Treisman, 2006; Wolfe & Horowitz, 2004). In the guided-search model of Wolfe and colleagues, for example, visual features are processed in perceptual modules that are broadly tuned to values such as "upright", "tilted", or "red" (Wolfe, 1998; Wolfe, Butcher, Lee, & Hyle, 2003). As illustrated in Figure 1, the output of each module has a particular level of signal strength and noise. The output can be entirely the result of the bottom-up signal (i.e., local differences among display items), as in Panel A of Figure 1. The signal strength of one or more feature modules can be amplified by top-down attention, however, from a predefined representation of target features, as illustrated in Panel B. The output is summed across modules and passed on

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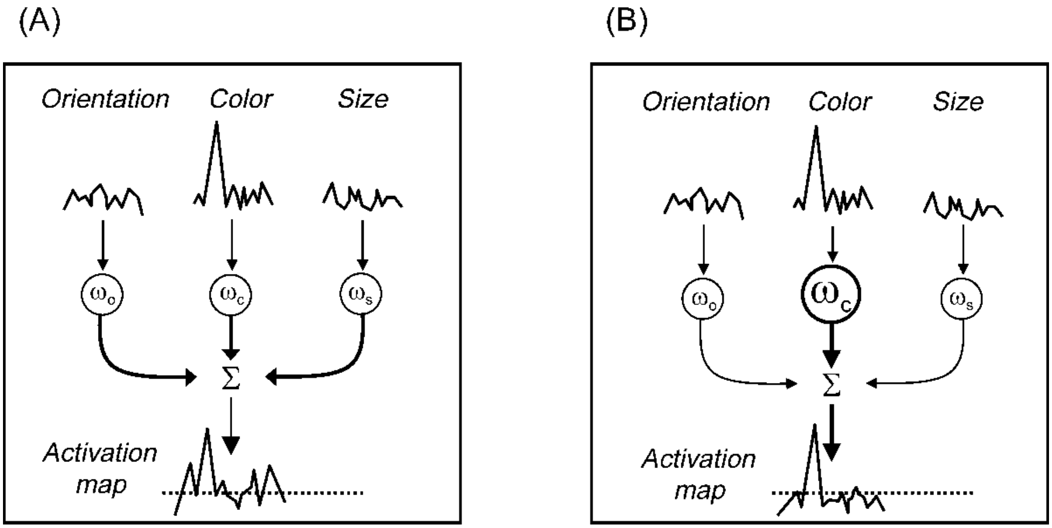

Figure 1. *A guided search characterization of visual feature processing. Information from separate feature modules is summated into a central activation map. When the observer has no basis for expecting a particular feature, as in Panel A, the outputs are weighted equally, and processing is entirely bottom-up. When the observer has a top-down expectation for a particular dimension (e.g., colour), the output of that module is weighted more heavily, as in Panel B, and the detectability of that feature in the activation map is enhanced. This figure is modified, with permission, from Figure 16 in "Changing your mind: On the contributions of top-down and bottom-up guidance in visual search for feature singletons", by J. M. Wolfe, S. J. Butcher, C. Lee, and M. Hyle, 2003,* Journal of Experimental Psychology: Human Perception and Performance, 29, *p. 498. Copyright 2003 by the American Psychological Association.*

to a more central representation in an activation map. The search for a target proceeds across the various sets of features activated within the map, beginning with the area of highest signal strength.

The top-down guidance of attention can be implemented both explicitly, in terms of an observer's expectation for a particular feature value, and implicitly, as a result of repetition priming. Maljkovic and Nakayama (1994) proposed that virtually all of the effects of top-down attention could be attributed to repetition priming. These authors selectively repeated, across trials, either the colour of the target or the colour of the distractors in a singleton discrimination task (i.e., two-choice shape discrimination response to a colour singleton among homogeneously coloured distractors). This is a highly efficient form of search in which performance is not impaired significantly by increasing the number of distractors (display size). The results indicated that reaction time (RT) for the shape discrimination decreased (i.e., performance improved) across consecutive trials with a repeating colour. By the eighth trial, RT reached a level comparable to that occurring when the target and distractor colours were constant. That is, there was no additional contribution to target detection attributable to explicit top-down attention, beyond that associated with repetition priming.

Maljkovic and Nakayama (1994) reported significant priming for both target and distractor colour, but the priming magnitude was somewhat greater for target colour, suggesting a greater degree of priming for the activation of target features than for the inhibition of distractor features. Wolfe et al. (2003) also obtained greater priming effects for target colour than for distractor colour, in singleton discrimination. In contrast to Maljkovic and Nakayama, however, Wolfe et al. found that RT at the end of a priming sequence did not reach the level associated with constant target and distractor colours, which suggests that explicit top-down attention contributes to target detection independently of the implicit priming effects.

In a recent study, we examined adult age differences in top-down attention during colour singleton discrimination in a letter search task (Madden, Whiting, Spaniol, & Bucur, 2005). Consistent with Wolfe et al. (2003), we found that top-down attention has both explicit (expectation) and implicit (repetition priming) components. When either the colour of the singleton target or that of the distractors repeated for up to six trials, within an otherwise unpredictable sequence (i.e., a mixed condition), both younger and older adults exhibited some degree of repetition priming. That is, implicit top-down attention facilitated both target activation and distractor inhibition. When we compared performance in a baseline condition measuring the explicit top-down component (i.e., target and distractor colours constant) to the cumulative effect of priming (i.e., RT at the final trial of a priming sequence), we found that there was an additional decrease in RT associated with the explicit component, beyond that attributable to priming, for both target activation and distractor repetition. In addition, although the rate of priming for both targets and distractors was similar for younger and older adults, and both age groups exhibited some additional contribution of the explicit component, this latter contribution was greater for older adults than for younger adults. The Madden et al. (2005) results suggest that older adults may enhance the output of feature module(s), through explicit top-down attention.

In this experiment, we investigated whether the age-related increase in top-down attention is differentially greater for target activation or distractor inhibition. One limitation to the Madden et al. (2005) study is that the target and distractor colours were either both constant (in the baseline condition) or both varied (in the mixed condition). Thus, although the Madden et al. mixed condition included priming sequences for target and distractor colour separately, both types of display items varied in colour across trials, and the mixed condition consequently disrupted top-down attention to both target activation and distractor inhibition. In this experiment we also compared constant and varying colour during singleton discrimination, but we modified the mixed condition so that the colour of either the target or that of the distractors remained constant across trials, while the colour of the other type of display item varied. In addition, we eliminated the repetition priming sequences for the colour-varying items, so that implicit top-down attention did not contribute substantially to performance. Thus, we could measure the increase in RT associated with disrupting one component of explicit top-down attention, either target activation or distractor inhibition, while leaving the other component intact.

Varying the colour of either the target or distractor items is a source of noise that is more likely to be distracting for older adults than for young adults (Hasher, Zacks, & May, 1999; but cf. Kramer, Humphrey, Larish, Logan, & Strayer, 1994). We interpret differences between the target-varying and distractor-varying conditions, relative to a baseline condition with target and distractor colours constant, as evidence for the type of top-down attention that occurs within the baseline condition. If the age-related increase in explicit top-down attention reported by Madden et al. (2005) relies more heavily on the activation of target features, then the age-related increase in RT should be greater in the target-varying condition than in the distractor-varying condition. Conversely, a greater age-related increase in RT in the distractor-varying condition than in the target-varying condition would suggest an increased reliance on top-down distractor inhibition. These two effects are not mutually exclusive and may both contribute to the previously reported age-related increase in the explicit top-down component.

We hypothesized that older adults would place relatively greater emphasis on the top-down activation of target features. Previous studies of spatial cueing effects, for example, suggest that older adults are generally as successful as younger adults in using advance information regarding specific target features to improve search performance (Kramer & Madden, in press). Thus, we predicted that the age-related slowing of search performance associated with varying target colour would be greater than that associated with varying distractor colour.

Method

Participants

Participant characteristics are presented in Table 1. The research procedures were approved by the Institutional Review Board of the Duke University Medical Center, and all participants gave written informed consent. There were 24 younger adults (12 women) between 18 and 28 years of age and 24 older adults (12 women) between 63 and 79 years of age. The younger adults were students who received compensation in the form of course credit. The older adults were community-dwelling individuals who were compensated for their participation. All participants demonstrated corrected near visual acuity of at least 20/40, normal colour vision of at least 12 points on the Dvorine pseudo-isochromatic plates (Dvorine, 1963), and a score of at least 27 (maximum 30) on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975). Participants were in addition screened for current major health problems (e.g., stroke, Parkinson's disease) and the use of psychotropic medications.

Apparatus and stimuli

Presentation of the visual displays and measurement of participants' RT and accuracy were controlled by a 2.0-GHz processor, Pentium 4 microcomputer with a 19-in., flat-panel, liquid-crystal display. The task was the same as that used by Madden et al. (2005): a two-choice version of singleton discrimination in which the target letters were E and R. Participants viewed a series of displays, each containing either four or six letters, one of which was a target. The target letter was always a colour singleton relative to the nontarget (distractor) letters, which were all the same colour (e.g., a red E among grey distractor letters). At the appearance of each display participants made an E/R response regarding the identity of the singleton target, by pressing one of two buttons on a response box. Participants rested their left and right index fingers on the response buttons throughout the experiment, and the assignment of target letters to responses was counterbalanced across participants.

The character space for each display position was approximately 1.21° wide by 1.52° high, at a viewing distance of 60 cm. The display items were arranged in a six-position circle with a diameter of 6.06°, and the midpoints of these positions were arranged to be equidistant from fixation at clock positions 12, 2, 4, 6, 8, and 10 o'clock. The

Table 1. *Participant variables by age group*

	M		*SD*	
	Younger	*Older*	*Younger*	*Older*
Age (years)	19.33_a	70.42_b	2.10	5.42
Education	13.04_a	16.54_b	1.23	2.80
Acuity	15.00_a	24.58_b	0.00	9.77
Colour vision	13.95_a	13.63_b	0.20	0.58
Vocabulary	64.17_a	64.08_a	3.52	3.88
Digit Symbol Acc	98.15_a	97.39_a	1.86	2.22
Digit Symbol RT	$1,235.04_a$	$1,911.42_b$	184.51	364.22
MMSE	29.75_a	29.33_b	0.53	0.82

Note: $N = 24$ per age group. Vocabulary = raw score (maximum of 70) on the Wechsler Adult Intelligence Scale–Revised (Wechsler, 1981). Acuity = denominator of the Snellen fraction for corrected near vision. Colour vision = raw score (maximum of 14) on the Dvorine colour plates (Dvorine, 1963). Digit Symbol Acc and Digit Symbol RT = percentage correct and reaction time (ms), respectively, on a computer test of digit symbol coding (Salthouse, 1992). MMSE = raw score (maximum 30) on the Mini-Mental State Examination (Folstein et al., 1975). Means in the same row that do not share subscripts differ by *t* test at $p < .05$.

separation between the edges of adjacent characters was approximately 1.91°. The distractor letters for each display were selected without replacement from the set F, H, K, N, P, S, T, and X. For the four-letter displays, the remaining two display positions were each filled with an asterisk placeholder (presented in the distractor colour), and these two items were always diametrically opposite each other (e.g., 12 o'clock and 6 o'clock).

The target and distractor colours were red, green, blue, and grey, matched for luminance at 41 cd/m^2 with the OptiCAL 3.7 (Colorvision, Inc., Lawrenceville, NJ) colorimeter. The letter displays were presented against a black background. The red–green–blue (RGB) and Commission Internationale de l'Eclairage (CIE) values were the following: red (RGB = 255, 25, 25; CIE $x = 0.61$, $y = 0.34$), green (RGB = 13, 150, 13; CIE $x = 0.29$, $y = 0.59$), blue (RGB = 0, 122, 255; CIE $x = 0.18$, $y = 0.21$), and grey (RGB = 117, 117, 110; CIE $x = 0.34$, $y = 0.36$).

Design and procedure

There were three task conditions, associated with separate trial blocks: baseline, target varying, and distractor varying. In the baseline condition, the colours of both the target and distractors remained constant within a trial block. In the target-varying condition, the colour of the singleton target varied across trials, while the distractor colour remained constant. In the distractor-varying condition, distractor colour varied across trials, while the colour of the target was constant. Participants performed 432 test trials across six blocks of 72 trials, with two blocks for each of the three task conditions. Each block contained 18 trials for each combination of the E/R targets and two display sizes. Across these 18 trials, the target occurred at each of the six display positions three times. Within the four-letter displays, the asterisk placeholders were located in each of the three pairs of diametrically opposite display positions six times. During the trial sequence within each block, there were no more than four successive trials with a particular target letter or display size and no more than three successive trials with the target in the same display position. Three colours were used for the colour-varying items within each trial block (e.g., a red target among blue, green, or grey distractors), and no repetition of any given colour across adjacent trials was allowed.

The testing session began with three blocks of 24 practice trials, comprising one block for each of the three task conditions. Participants then performed the six blocks of test trials, arranged in two sets of the three task conditions, with no repetitions of conditions (e.g., ABCABC). We used six orders of the test trial blocks, which counterbalanced the block sequence so that each task condition occurred once in each serial position. Across these six block orders, we counterbalanced the assignment of the four colours to target and distractor sets and the target–response mappings.

The experimenter encouraged the participants to respond as quickly as possible while still maintaining a high level of accuracy. At the beginning of each block of trials, an instruction screen described the upcoming task condition. Each trial began with a 500-ms fixation cross. Following this interval, the display remained on the screen for a maximum of 2 s but was terminated by the participant's response if it occurred before 2 s. A 500-ms feedback interval occurred at the offset of the display. This interval was blank for correct responses; the computer sounded a beep during the feedback interval if the participant either responded incorrectly or failed to respond within 2 s. A yellow question mark also appeared on the screen during the feedback interval if there was no response to the display. The display for the next trial appeared following this interval.

Results

Error rate

The older adults failed to respond on 0.14% of the trials (15 trials total); there were no failures to respond in the younger adult group. Following an arcsin transformation, analysis of variance (ANOVA) of the error rates (Table 2) yielded a significant effect of age group, $F(1, 46) = 8.50$, $MSE = 0.035$, $p < .01$, reflecting an overall higher error rate for younger adults (3.13%) than for older

Table 2. *Mean percentage error rates*

		M		*SD*	
Condition	*Display size*	*Younger*	*Older*	*Younger*	*Older*
Baseline	4	2.99	1.17	3.16	1.92
Baseline	6	3.01	1.05	3.66	1.45
Distractor varying	4	3.30	1.68	3.54	2.05
Distractor varying	6	3.65	1.00	4.15	1.61
Target varying	4	2.66	0.87	3.22	0.99
Target varying	6	3.18	1.85	3.79	2.19

adults (1.27%), but no main effect or interaction involving task condition or display size.

Reaction time

We conducted ANOVA of participants' median RTs for correct responses, with age group as a between-subjects variable and task condition (baseline, target varying, distractor varying) and display size (4, 6) as within-subjects variables. The means of these median RTs are presented in Figure 2. All three main effects were significant. Mean RT was 157 ms higher for older adults than for younger adults, $F(1, 46) = 123.20$, $MSE = 14{,}449$, $p < .0001$, and ranged from 564 ms in the baseline condition to 584 ms and 571 ms in the target-varying and distractor-varying conditions, respectively, $F(2, 92) = 17.30$, $MSE = 536$, $p < .0001$. Responses to six-item displays were 6 ms slower than those to four-item displays, which was significant, $F(1, 46) = 15.22$, $MSE = 142$, $p < .001$.

The only interaction that was significant was the Age Group × Condition effect, $F(2, 92) = 8.00$, $MSE = 536$, $p < .001$. The effect of condition was significant for older adults considered separately, $F(2, 46) = 16.89$, $MSE = 751$, $p < .0001$, but not for younger adults, $F(2, 46) = 2.70$, $MSE = 320$, $p = .077$. Bonferroni-corrected

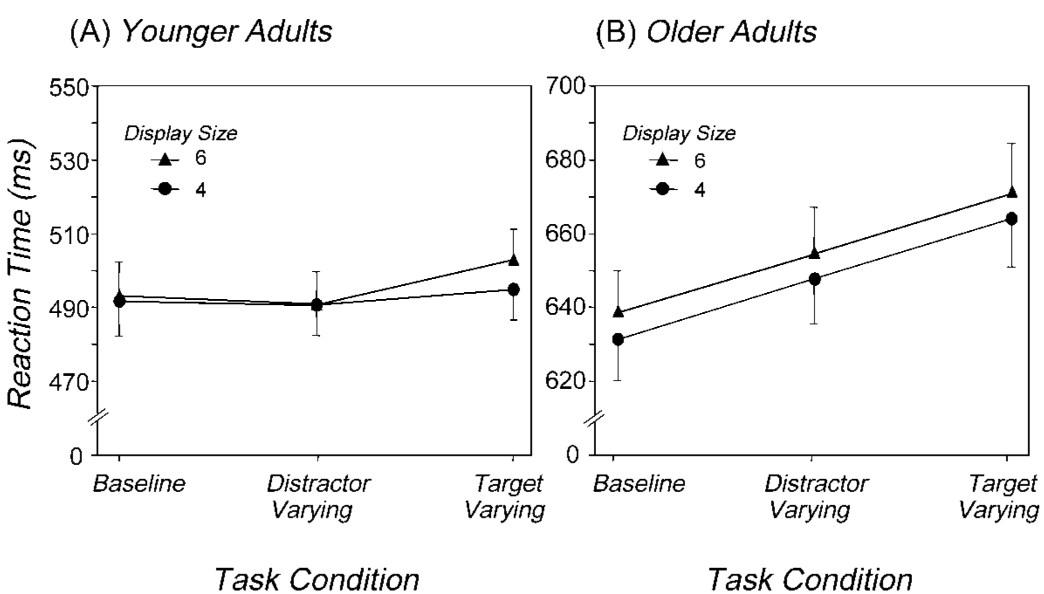

Figure 2. *Reaction time as a function of task condition, display size, and age group. Error bars represent 1 SE.*

paired comparisons among the task conditions, for older adults, indicated that at alpha = .05, the minimum difference in RT required for significance was 14 ms. By this criterion, all of the paired comparisons were significant for the older adults. That is, older adults' mean RT in both the target-varying and distractor-varying conditions was higher than that in the baseline condition, and RT in the target-varying condition was higher than that in the distractor-varying condition. For younger adults, the minimum RT difference for significance with the Bonferroni comparison was 9 ms, but none of the comparisons among the task conditions for younger adults exceeded this value.

Age group differences in RT measures can occur as a result of age-related slowing of elementary perceptual speed, which tends to magnifying RT differences among task conditions for older adults relative to younger adults, regardless of specific task demands (Madden, 2001; Salthouse, 1985). To assess the potential role of generalized age-related slowing to the present results, we performed a linear regression analysis in which the six task condition mean RTs for younger adults were used as a predictor of the older adults' means (Brinley, 1965). This analysis did not yield a significant linear effect, $r^2 = .49$, $p < .12$, indicating that the present data are not well explained by a linear form of age-related slowing. Similarly, when we performed an ANOVA on log-transformed RT (thus treating absolute differences in RT as proportional differences), all of the effects that we had observed for mean RT remained significant.

Discussion

The goal of this experiment was to determine whether the activation of target features or the inhibition of distractor features contributed differentially to the age-related increase in explicit top-down attention observed by Madden et al. (2005). We compared younger and older adults' singleton discrimination performance in task conditions that varied either the colour of the singleton target or that of the distractors. Our assumption was that increases in RT in these conditions, relative to a baseline condition in which the colours were constant, would represent the selective disruption of target activation and distractor inhibition processes. The critical result was the Age Group × Task Condition interaction (Figure 2), which occurred because variation in either the target colour or the distractor colour led to slower responses, relative to the baseline condition, for older adults, but not for younger adults. In addition, the increased RT was greater in magnitude for variation in target colour than for variation in distractor colour. Thus, although top-down emphasis on both target activation and distractor inhibition was more pronounced for older adults than for younger adults, the greater contribution was from target activation.

These findings are consistent with previous reports of a contribution from explicit top-down activation of target features during highly efficient search (Wolfe et al., 2003), in contrast to the proposal that top-down effects are driven entirely by repetition priming (Maljkovic & Nakayama, 1994). Although the 6-ms increase in RT from the four-item and six-item displays was significant statistically, this effect translates to a search rate of 3 ms per item, which is highly efficient and close in absolute magnitude to the limit defined by a zero-slope criterion.

Surprisingly, the variation in target and distractor colours did not lead to significant increases in RT for younger adults. Previous studies of singleton discrimination, conducted with younger adults, typically find that the introduction of variation in target or distractor features leads to increased RT (Maljkovic & Nakayama, 1994; Wolfe et al., 2003). The present experiment is similar in general design to that of these previous studies, which also required a two-choice response to a singleton target. In the previous experiments, however, the display items were shapes, and identification of the singleton was necessary prior to the discrimination response (e.g., the presence or absence of a white dot on a bar). In this experiment, the display items were letters, and participants could in theory perform the discrimination response (identification of the E/R target) independently of the colour singleton. Variation in task-relevant features clearly influenced older adults' performance, but additional confirmation would be valuable with a version of singleton discrimination leading to significant task condition effects for younger adults.

In terms of the model of visual search illustrated in Figure 1 (Wolfe et al., 2003), it appears that when a task-relevant feature is constant, older adults enhance the output of the relevant feature module in a top-down manner, through both target activation and distractor inhibition. The activation of target features, however, receives greater emphasis. The age-related increase in top-down attention may represent a compensatory response to age-related decline in the efficiency of bottom-up visual processing (Madden, 2006). As a result, the level of signal is increased, and accompanying noise is decreased (Carrasco, Penpeci-Talgar, & Eckstein, 2000; Kastner, 2004), facilitating the discrimination of target identity.

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