Primbing of Pop-out in Visual Search: A Comparison of Young and Old Adults

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ABSTRACT

An experiment examined potential age-related differences in priming of pop-out (Maljkovic & Nakayama, 1994, 1996, 2000; McPeek, Maljkovic & Nakayama, 1999), an implicit, memory-based phenomenon that facilitates repeated gaze or attention shifts between visually similar stimuli. Older and younger adults performed a visual search task requiring them to judge the orientation of a color singleton target. Trial-to-trial repetition of target color and/or target position primed attentional selection for both age groups, producing faster and more accurate responses. Age-related increases in the strength of priming by target color appeared to arise from generalized slowing in older observers, but marginal age-related increases in the strength of priming by target position remained even after transformation to account for generalized slowing.

Everyday visual behavior is densely interspersed with movements of attention, overt and covert. Inspecting a scene, an observer will commonly make as many as 3–4 saccades per second, while an individual performing even a very simple visual-manual task will typically precede each reach with a shift of gaze to the same location (Epelboim et al., 1997). Eye movements and attention shifts often occur even where it is not obvious they are necessary, as when observers re-attend information after very short intervals, trading the cost of additional attention shifts for the benefit of not having to hold the details of previously inspected stimuli in explicit memory (e.g., Ballard, Hayhoe, & Pelz, 1995; Wolfe, Klempen, & Dahlen, 2000).

Adaptive behavior thus entails the constant acquisition and re-acquisition of visual information, making the ability to efficiently select informative stimuli as attentional and saccadic targets vital. Beffittingly, intensive research has been devoted to the study of visual search and control of visual attention, and elaborate models have emerged (e.g., Itti & Koch, 2000; Treisman & Sato, 1990; Wolfe, 1994). A number of models have converged on a framework that explains visual search as resulting from the interaction of bottom-up mechanisms, driven purely by stimulus characteristics, with top-down mechanisms, driven by the observer’s knowledge of target/distractor properties and task goals. Low-level feature maps encode the distribution of rudimentary stimulus characteristics such as color, orientation, and depth across the visual field. Salience signals, generated by localized contrast between values within a stimulus dimension, feed forward from these feature maps to converge on a master salience map, wherein peaks in activation mark

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the locations whose contents are most likely to be behaviorally relevant. When the properties (e.g., color, orientation) of a target item are pre-specified, knowledge-driven, top-down processes are presumed to modulate the signals fed forward from the feature maps, biasing salience map activation in favor of signals which match the target template (Treisman & Sato, 1990; Wolfe, 1994).

Recent evidence has suggested that such models should be modified to incorporate an alternative, implicit form of top-down attentional guidance. A series of reports by Maljkovic, Nakayama, and colleagues (Kristjánsson, Wang, & Nakayama, 2002; Maljkovic & Nakayama, 1994, 1996, 2000; McPeek et al., 1999) has detailed evidence for a role of unconscious short-term memory in the control of visual attention. This evidence has come from experiments demonstrating effects of trial-to-trial priming in visual search. Observers performed a search task requiring them to make a subtle shape judgment of a color singleton target – a uniquely colored item among a pair of homogeneously colored distractors (e.g., a green target among red distractors). While the target item could be selected on the basis of its unique color, therefore, focal attention was necessary for the shape judgment on which the response was based. Target and distractor colors reversed unpredictably from trial to trial, and target position varied randomly.

Of interest was the finding that RTs for shape discrimination were reliably shorter when either target color or position was repeated across trials. That is, repetition of color or location appeared to prime attention shifts toward the target (Maljkovic & Nakayama, 1994, 1996). Such priming appeared to be implicit (i.e., non-conscious or non-verbalizable), and outside of volitional control; strength of priming was uncorrelated with observers’ ability to verbally report the color of the target on the priming trial (Maljkovic & Nakayama, 2000), and effects of priming persisted even when observers were forewarned of upcoming changes in target color (Maljkovic & Nakayama, 1994). The strength of priming showed no decline over intervals of 1–3 s between trials, suggesting that “forgetting” might result from the encoding of subsequent visual events, rather than from passive decay (Maljkovic & Nakayama, 2000). Similar effects of priming have been found in search for a spatial frequency singleton (Maljkovic & Nakayama, 1996, 2000), and in search for a target defined by a conjunction of features (Hillstrom, 2000; Kristjánsson et al., 2002). Maljkovic, Nakayama and colleagues (Chun & Nakayama, 2000; Kristjánsson et al., 2002; Maljkovic & Nakayama, 1994, 1996, 2000) have suggested that such trial-to-trial priming reflects the operation of an implicit memory store existing to facilitate repeated attention shifts between visually similar stimuli or between a small set of locations, an endogenous attentional control mechanism that is not goal-driven but stimulus-triggered. They have termed the effect priming of pop-out (PoP).

In the present study we investigated potential age-related differences in PoP. Over the past 20 years a substantial number of studies have been conducted to examine visual search performance across the lifespan (see Hartley, 1992; McDowd & Shaw, 2000; for reviews of this literature). Many of these have focused on the influence of various aspects of the visual display and stimuli on search performance. For example, a number of experiments have found that both young and older adults are able to benefit from perceptual grouping on the basis of stimulus properties such as color, form and motion, as they search through displays for a pre-defined target (Humphrey & Kramer, 1997; Madden, Gottlob, & Allen, 1999; Plude & Doussard-Rossevelt, 1989), although older adults do not always benefit to the same extent as younger adults (Folk & Lincourt, 1996; Madden, Pierce, & Allen, 1996). Other studies have found age-equivalence in the ability to use temporal information about when a target will occur to enhance visual search with stationary (Kramer & Atchley, 2000), but not moving objects (Watson & Maylor, 2002).

Other research has examined the effects of learning in consistently mapped search paradigms. In these studies subjects have been trained for thousands of trials on search tasks in which one set of objects always serves as targets while another set of objects always serves as distractors. With adequate practice, search performance in young adults appears to become automatized; RTs
become insensitive to the number of objects in the display, and large disruptions in performance occur when the role of targets and distractors is reversed. Evidence for such automatized search in older adults is mixed. A series of studies by Rogers, Fisk, and colleagues (Fisk, Rogers, Cooper, & Gilbert, 1997; W.A. Rogers, 1992; W.A. Rogers, Fisk, & Hertzog, 1994) found that even after substantial practice older adults failed to achieve flat RT functions in a consistently mapped search task, and further that older adults showed no large performance disruptions when targets and distractors switched roles. Other research has found age-equivalence on these measures, at least in paradigms in which targets and distractors are defined by simple visual features (e.g., color and orientation) (Ho & Scialfa, 2002). The visual search tasks used to demonstrate trial-to-trial priming effects, however, differ in a number of ways from the paradigms used to examine automatization of search. First, feature search paradigms are usually used in the PoP research while conjunction search tasks are often used in the automatization research. Second, the priming stimuli do not cue a specific response in the PoP tasks as they do in studies of automatization. Finally, and perhaps most importantly PoP appears to be the result of implicit memory while target-distractor relations are explicit in the automatization research.

It is well documented that older adults show significantly more sparing of implicit than explicit memory (e.g., Hay & Jacoby, 1999; Jennings & Jacoby, 1997; Light & Singh, 1987; Light, Singh, & Capps, 1986) (see Light, 1996 for review). Measures of priming often show little if any age-related decline, even in circumstances where conscious recognition and recall differ dramatically between young and older subjects. Moreover, some data suggest that implicit memory for perceptual information might be especially robust in the face of aging (Jelicic, Craik, & Moscovitch, 1996; though see Pilotti, Meade, & Gallo, 2003). In light of these findings, it seems reasonable to expect that PoP will be relatively age-invariant, suggesting that an endogenous component of attentional control could be used effectively to enhance visual search across the adult lifespan. We tested this hypothesis by asking young and old adults to indicate the orientation of a color singleton target among distractors. Target orientation, location, and color were chosen randomly and independently every trial. To explore the possibility of age-related differences in the strength of PoP, we measured the influence of trial-to-trial repetitions of target location and color on the speed and accuracy of young and elderly observers' responses. To examine potential age differences in the time course of priming, we also assessed the effects of the response-to-stimulus interval (RSI) separating trials.

**METHOD**

**Observers**

Observers were 20 young adults (7 female), and 20 older adults (14 female), recruited from the community of the University of Illinois at Urbana-Champaign. Mean age of the younger observers was 25.48 years, SD = 5.47. Mean age of the older observers was 71.55 years, SD = 6.20. Mean self-reported level of health, on a 1–5 scale with 5 the best, was 4.95, SD = .51, for younger observers, and 4.20, SD = .62, for older observers. All observers had fair and near visual acuity of 20/30 or better.

**Apparatus and Stimuli**

Figure 1 illustrates the stimuli and sequence of events within a typical series of trials. Stimuli were presented on a 21 in. monitor with a refresh rate of 100 Hz. Displays were viewed from a distance of approximately 55 cm, with viewing distance controlled by a chinrest. Stimuli comprised a set of four squares, 1.1° x 1.1°, centered 5.8° from a central fixation mark on the corners of an imaginary diamond. Stimuli were presented against a gray background. Each trial, three squares were of one color (black or white) relative to the background, while the remaining square was of the alternative color. Thus, one square each trial was a color singleton. All four squares contained a gap, 7°, on either their left or right side. One of the non-singleton squares was always gapped on the same side as the singleton square. The remaining non-singleton squares were gapped on the opposite side. The fixation mark was a red .3° x .3° square. Manual responses were made via a response box (Cedrus, Inc.) with timing accurate to the millisecond.

**Procedure**

The observers' task was to indicate the orientation of the singleton item, hereafter referred to as the target,
with a manual response, pressing a button with the left hand to indicate a left-facing target and pressing a button with the right hand to indicate a right-facing target. Target orientation, location, and color were chosen randomly every trial. Stimuli appeared at trial onset, and remained visible until the observer’s response. Trials were force-paced, separated by an RSI of either 1000 ms or 3000 ms, with RSI held constant within a block and alternated between blocks. The fixation mark remained visible throughout a block. Observers were asked to keep their gaze on the fixation mark as they performed the task, and to make responses as quickly as possible while maintaining high levels of accuracy. Between blocks, they were encouraged to rest as long as they wished. Each observer completed two practice blocks of 20 trials each, then 10 experimental blocks of 50 trials each.

Unsurprisingly, younger observers’ mean RTs were shorter overall than those of the older observers, $F(1, 38) = 19.282$, $p < .001$, $MSE = 404739.746$. As demonstrated by a reliable main effect of RSI, RTs were also shorter following a 3000 ms RSI than a 1000 ms RSI, $F(1, 38) = 18.357$, $p < .001$, $MSE = 17427.150$, indicating a preparatory benefit accruing during the inter-trial delay. A reliable interaction of age and RSI indicated that this benefit was larger for older than for younger observers, $F(1, 38) = 8.253$, $p = .007$, $MSE = 17427.150$. As expected, RTs were significantly shorter following a between-trials repetition of either target color, $F(1, 38) = 126.360$, $p < .001$, $MSE = 6385.059$, or target position, $F(1, 38) = 36.254$, $p < .001$, $MSE = 3969.400$, replicating past evidence that the deployment of attention is primed by repetition of either the target-defining feature value or target location. Most importantly, the effects of this priming were modulated by age; reliable interactions of age by target color, $F(1, 38) = 9.779$, $p = .003$, $MSE = 6385.059$, and age by target position, $F(1, 38) = 36.254$, $p < .001$, $MSE = 3969.400$, revealed that the effects of priming by either characteristic were significantly larger for elderly observers. Within-subject analyses conducted separately for each age group revealed that the effect of priming by target color was reliable

RESULTS

Figure 2 Top presents mean RTs as a function of age group, RSI (1000 ms vs. 3000 ms), target color relative to that of the priming trial (same vs. switched), and target position relative to that of the priming trial (same vs. switched). For omnibus statistical analysis, data were submitted to a mixed ANOVA with age as a between-subjects variable and with RSI, target color relative to that of priming trial, and target position relative to that of the priming trial as within-subject variables.
for both older and younger observers, $F(1, 19) = 67.843, p < .001, MSE = 9714.690$, and $F(1, 19) = 68.788, p < .001, MSE = 3055.427$, respectively, but that the effects of priming by target position were statistically significant only for the elderly participants, $F(1, 19) = 45.694, p < .001, MSE = 4229.293$, $F(1, 19) = 2.463, p = .133, MSE = 3709.5061$ for younger participants.\(^1\) Contradicting the results of previous studies (Maljkovic & Nakayama, 2000), the present data showed reliable interactions of RSI by target color, $F(1, 38) = 13.400, p = .001, MSE = 4094.355$, and RSI by target position, $F(1, 38) = 7.603, p = .009, MSE = 2495.352$, indicating that the effects of priming by color and by position decayed as a function of the temporal interval between trials. Non-reliable three-way interactions of RSI by target position by age and RSI by target polarity by age, $F_s < 1$, suggested that this decay was similar across age groups.

Data thus indicate an age-related increase in the magnitude of trial-to-trial priming produced by repetition of the target-defining feature and target position in visual search. A common explanation for many of the cognitive changes manifested with age is a general slowing of older observers’ perceptual and information processing speed (Salthouse, 1996), and it is possible that such slowing might account for the age-related

\(^1\)Given that earlier studies involving only young adult subjects have demonstrated clear effects of priming by target location (e.g., Maljkovic & Nakayama, 1996), the non-significant main effect of target position in the young observers’ data seems likely to reflect a lack of statistical power rather than a true absence of priming. Further, reliable effects of priming by position were evident in the young observers’ error rate data.
effects seen here. A proportionate increase of RTs for primed and non-primed trials, that is, would produce a proportionate increase the RT difference between primed and non-primed trials. This change alone, absent any circumscribed or specific changes in the mechanisms responsible for PoP, might account for the increased magnitude of priming seen in older adults. We tested this hypothesis using a procedure described by Madden, Pierce, and Allen (1992). The logic of this technique is to test for age-related changes not attributable to generalized slowing by searching for interactions of age by manipulation that remain significant after the younger observers’ data have been transformed to match for mean slowing in older observers’ RTs. Here, the relationship between older and younger observers’ mean RTs was well described by a multilayered slowing model (Cerella, 1990):

$$RT_{\text{Older}} = -380.30 + 1.97 \times RT_{\text{Younger}}$$

The $R^2$ for this equation was .796. Older observers’ raw RTs and younger observers’ transformed RTs were submitted to statistical analysis identical to that described above. Neither the interaction of age by target color, $F < 1$, nor the interaction of age by target position, $F(1, 38) = 3.420, p = .072, MSE = 9315.986$, remained significant, though the latter effect approached the .05 level. Main effects of target color and position were again both highly significant, $F(1, 38) = 136.430, p < .001, MSE = 10785.000$, and $F(1, 38) = 21.260, p < .001, MSE = 9315.986$, respectively.

Figure 2 bottom presents mean error rates. Omnibus statistical analysis was identical to that for RTs. The main effects of RSI, target position, and target color were similar to those in RT data; performance was again better with an RSI of 3000 ms than 1000 ms, $F(1, 38) = 22.582, p < .001, MSE = 7.340$, and was primed by repetition of target color, $F(1, 38) = 28.491, p < .001, MSE = 4.296$, or target position, $F(1, 38) = 26.461, p < .001, MSE = 10.608$. The effects of priming, furthermore, again appeared to decay across the temporal interval separating trials, as evidenced by a reliable interactions RSI by target color, $F(1, 38) = 8.815, p = .005, MSE = 5.130$, and RSI by target position, $F(1, 38) = 11.426, p = .002, MSE = 3.998$. Two-way interactions of age by target color and age by target position fell well short of reliability, $Fs < 1$, confirming that the age-related differences in priming seen in RTs were not the result of speed-accuracy tradeoffs. Within-subject analyses conducted separately for young and elderly observers confirmed that the effects of priming by target color were significant for both age groups, $F(1, 19) = 10.674, p = .004, MSE = 4.913$ for young adults and $F(1, 19) = 19.199, p < .001, MSE = 3.678$, for older adults, as were the effects of priming by target position, $F(1, 19) = 6.962, p = .016, MSE = 13.758$ for young adults, and $F(1, 19) = 25.933, p < .001, MSE = 7.457$ for older adults. Only one effect was reliable in the error rate data that was not also reliable in the RT data. The interaction of target color by target position, $F(1, 38) = 4.057, p = .051, MSE = 4.414$, indicated that the increases in error rates produced by changes in target color and position were super-additive. This effect was not reliably modulated by age, $F(1, 38) = 2.557, p = .118$.

**DISCUSSION**

This experiment assessed the effects of aging on trial-to-trial priming by target color and target position in a visual search task (Maljkovic & Nakayama, 1994, 1996, 2000; McPeek et al., 1999). Observers were asked to make an orientation discrimination of a color singleton target, where target and distractors reversed colors and switched locations randomly between trials. Past studies have found that RTs for younger observers are reliably reduced by between-trials repetition of either target color or target position, suggesting that shifts of focal attention to the target are speeded. The current results indicate that effects of priming by both target color and by target position exist and are exacerbated in older observers’ data, with age-related increases in the strength of priming appearing to result primarily from generalized slowing of older observers’ performance.

These results are consistent with the common finding that implicit memory is maintained with age (e.g., Hay & Jacoby, 1999; Jelicic et al., 1996;
Jennings & Jacoby, 1997). They also add to a body of evidence that the control of attention is preserved in older adults, at least among the young-old (i.e., those under 75). As noted in the introduction, previous studies have demonstrated age-equivalence in many aspects of adults’ ability to exploit spatial and temporal grouping processes to facilitate visual search (Humphrey & Kramer, 1997; Kramer & Atchley, 2000; Madden et al., 1999; Plude & Doussard-Rossevelt, 1989). Data have also indicated similarities in older and younger adults responses to various forms of attentional cues (see Kramer, Scialfa, Peterson, & Irwin, 2001 for review). A number of experiments, for example, have found that young and old subjects benefit to a similar extent from peripheral/exogenous attentional cues (e.g., Atchley & Kramer, 1998; Gottlob & Madden, 1998; Greenwood & Parasuraman, 1999; Greenwood, Parasuraman, & Haxby, 1993; Hartley, Kieley, & Slabach, 1990; though see Lincourt, Folk, & Hoyer, 1997). Other studies have likewise found that the ability to utilize central/endogenous spatial cues remains largely intact with age (e.g., Greenwood et al., 1993; Hartley et al., 1990; Lincourt et al., 1997). The current results expand on these findings by demonstrating age-equivalence in a form stimulus-triggered top-down cuing, neither purely endogenous or exogenous. Some data, it should be noted, have suggested an age-related decrease in the ability to suppress task-irrelevant stimulus onset (Juola, Koshino, Warner, Mickell, & Peterson, 2000; Pratt & Bellomo, 1999). In other respects, however, the mechanisms of attentional control are apparently robust in normal aging to at least 75 years (though see Greenwood, Parasuraman, & Alexander, 1997; Parasuraman, Greenwood, & Alexander, 2000 for evidence of impaired attentional control in the old-old and in Alzheimer patients).

The present data also provide insight as to the temporal characteristics of PoP. Previous results (Maljkovic & Nakayama, 2000) have suggested that trial-to-trial priming is largely immune to passive decay, and that “forgetting” is produced by interference from attentive visual encoding of stimuli irrelevant to the search task. In contrast, the present study found that the strength of priming is significantly weaker after an RSI of 3 s than after an RSI of 1 s, both for younger and older adults, even when observers are not asked to perform any secondary visual task – that is were not asked to encode any search-irrelevant visual stimuli - within the RSI. A number of differences in the stimuli and experimental procedure of the current study and that conducted by Maljkovic and Nakayama might explain this apparent discrepancy in results; of perhaps particular relevance is that the present experiment was a large n study employing relatively inexperienced observers, while Maljkovic and Nakayama's study of decay over short intervals (Maljkovic & Nakayama, 2000, Experiment 4) was a small n study employing experienced psychophysical observers. In any case, the present results demonstrate clearly that decay of priming is possible even over short intervals of time. The rate of this decay is similar, however, in younger and older adults, providing further evidence of the preserved function of priming with age.

An interesting question is whether PoP is functionally similar to performance costs in task switching (W.D. Rogers & Monsell, 1995). Task switching costs occur when subjects must switch from one to another task set (e.g., classifying a number as odd or even vs. deciding whether a number is greater than or lesser than 5) while PoP is defined in terms of performance benefits for repeated versus switched singleton defining attributes. Another potential similarity between these phenomenon is that age differences in switch costs have been small and inconsistent when switch trials are compared to non-switch trials (called local switch costs) within a block of trials (Mayr, 2001; Mayr & Kliegl, 2000). Indeed, in the present experiment age differences in switch costs were small and unreliable after correcting for general slowing.

Despite the similarities between the task switching and PoP phenomenon there are several reasons to believe that they reflect different underlying mechanisms, and therefore different age-related effects. First, pre-knowledge of the subsequent task set results in a large reduction in switch costs (Kramer, Hahn, & Gopher, 1999; W.D. Rogers & Monsell, 1995) while the PoP effect appears to be largely immune to
pre-knowledge of a singleton defining feature (Hillstrom, 2000; Maljkovic & Nakayama, 1994). Second, switch costs are often reported to be transitory in nature, diminishing after a single trial. On the other hand, PoP effects gradually diminish over the course of several trials (Maljkovic & Nakayama, 1994, 1996). Finally, task switching clearly requires an explicit knowledge of and memory for the task rules while PoP appears to be largely implicit (Maljkovic & Nakayama, 2000). Therefore, it seems reasonable to conclude that task switching and PoP reflect different underlying mechanisms and likely explicit and implicit memory processes, respectively.

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