When Age Is Irrelevant: Distractor Inhibition and Target Activation in Priming of Pop-Out

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Objectives. Recent research suggests that inhibition at early stages of visual processing may be age invariant. We test this proposal using a priming of pop-out (PoP) measure developed by Lamy, Antebi, Aviani, and Carmel (2008). Priming of pop-out provides reliable measures of target activation and distractor inhibition in selective attention. Vision Research, 48, 30–41. doi:10.1016/j.visres.2007.10.009). In PoP, a unique item, which visually “pops-out” in a field of distractors, grabs our attention faster when its defining feature (e.g., color red) repeats across trials and slower when distractor- and target-defining features switch between trials. Here, we explore whether the processes underlying PoP, which prevent access to distractors and facilitate access to the singleton, remain intact with age.

Method. Participants faced a display of circles and judged the direction of a letter T inscribed within a uniquely colored circle.

Results. All underlying components of PoP were present in older and younger adults. Participants revealed distractor inhibition by responding faster to a color singleton when the color of surrounding distractors repeated and slower when the singleton assumed the color of distractors from the previous trial.

Discussion. Our findings suggest that the inhibitory processes underlying PoP remain intact with age.

Key Words: Aging—Attention—Distractor inhibition—PoP—Target activation.

In the visual world, our attention is drawn to perceptually distinct features, such as a single red rose among yellow ones, or in the laboratory, a red target circle in a display of green distractor circles. The capture of attention, in which attention is automatically oriented to a unique item (singleton) in a field of homogeneous distractors, is referred to as the pop-out effect (e.g., Maljkovic & Nakayama, 1994). A great deal is known about the pop-out effect (Meinecke & Donk, 2002; Sagï & Julesz, 1987; Wolfe, 1992), including that the pop-out effect is age invariant (McCarley, Kramer, Colcombe, & Scialfa, 2004; Yoshida, Wake, & Osaka, 2003) and that it can be enhanced by priming, an effect termed priming of pop-out (PoP; Becker, 2008; Maljkovic & Nakayama, 1994).

Recently, Lamy, Antebi, Aviani, and Carmel (2008) developed a PoP measure that separates PoP into its individual components: target activation and distractor inhibition. Given that older adults have been shown to have deficits in inhibiting irrelevant distractors (e.g., Hasher, Stoltzfus, Zacks, & Rympa, 1991), it is possible that there are age-related differences in PoP. Alternatively, largely preserved implicit processing in older age (Jelicic, Craik, & Moscovitch, 1996) and preexisting attentional biases in PoP (Andres, Guerrini, Phillips, & Perfect, 2008) predict intact inhibitory control and, consequently, intact target activation and distractor inhibition effects in older and younger adults.

Examining these two hypotheses, especially with respect to distractor inhibition, is the focus of the present study. Like target activation, distractor inhibition operates at all stages of information processing (Fox, 1995). Target activation shifts attention toward target features, whereas distractor inhibition is the means by which irrelevant information is ignored. Target activation is typically conceived as the amplification of attentional sensitivity to the target-defining feature (e.g., color red), associated with the increase in the magnitude of the target signal (or target representation) itself (Becker, 2008; Maljkovic & Nakayama, 1994; Tipper, 1991). Distractor inhibition, then, is the reduced processing of irrelevant information associated with the suppression of the distractor signal (Fox, 1995).

One index of target activation and distractor inhibition is the change in reaction times (RT) relative to baseline. In PoP, one may identify the direction of the red singleton among green distractors more quickly when both colors repeat across two successive trials than when the singleton turns green and distractors turn red on a subsequent trial (Lamy et al., 2008). Target activation is associated with a faster response to the singleton when a target-defining feature repeats between trials and a slower reaction when a target-defining feature on trial n − 1 becomes the distractor-defining feature on trial n. Similarly, distractor inhibition is associated with a faster response to the singleton when...
distractor-defining feature repeats between trials and a slower response when the distractor-defining feature on trial \( n - 1 \) becomes the target-defining feature on trial \( n \). A lack of inhibitory control would presumably result in no difference between performance on baseline trials and trials where the distractor-defining feature repeats or swaps with the target-defining feature between trials.

The hypothesis that inhibition deteriorates with age, proposed by Hasher and Zacks (1988), is widely supported by research (e.g., Hasher et al., 1991; Pratt & Chasteen, 2007; Radavsky, Zacks, & Hasher, 2005; Tipper, 1991). Some of the support for this idea comes from negative priming (NP), which follows the same principles as PoP, but does not build on the preexisting pop-out effect (i.e., in NP, the target is not a singleton). Consistent with the proposal of age-related decline in inhibition, the performance of older adults does not typically improve when distractor features repeat in NP (e.g., Hasher et al., 1991).

Of importance are the qualitative differences between PoP and NP and their underlying components. According to Andres and colleagues (2008), the more automatic inhibition becomes, the less it deteriorates with age (for his proposal of inhibition taxonomy, see Nigg, 2000). Although priming is inherently implicit, its effects are modulated by the types of stimuli on which it operates. Priming of stimuli that rely less on explicit memories and involve primarily implicit or automatic processing may be more resilient to aging (Lamy et al., 2008; Soldan, Hilton, Coooper, & Stern, 2009). Given that the target is specified by the attention-grabbing singleton in PoP, rather than by a specific top-down instruction in NP (e.g., identify the red item), it follows that PoP may be more stimulus-driven than NP (Fox, 1995). Further, as noted by Lamy and colleagues, the coupling between a target-defining feature and a response-related feature is weaker in PoP than in NP. In NP, a single stimulus, such as a specific letter, may simultaneously define the target and trigger a response. In PoP, a stimulus that defines the target is distinct from a stimulus that triggers a response. It is perhaps due to the weak coupling between target-defining and response-related features that PoP is largely attributed to priming of features unrelated to a response by which target is selected (Becker, 2008). In contrast, NP is thought to operate on priming of response-related features (Fox, 1995). Thus, the qualitative differences between PoP and NP suggest that age-related deficits in inhibition in NP may not readily generalize to PoP.

Few studies have looked at age-related differences in distractor inhibition in PoP. Yoshida and colleagues (2003) used a PoP paradigm outlined by Maljkovic and Nakayama (1994) in which targets varied from distractors on a color dimension. In their study, older adults, like younger adults, were quicker to respond when the distractor-defining color repeated and the target-defining color was constant across consecutive trials. This finding suggested preserved inhibitory control in older adults. However, the distractor inhibition effect found by Maljkovic and Nakayama may have been confounded by top-down factors (Lamy et al., 2008). Because older adults may rely more heavily on top-down processing than younger adults (Whiting, Madden, Pierce, & Allen, 2005), it is imperative to use a PoP measure with less predictable sequences of target- and distractor-defining features than in the study of Yoshida and colleagues. Thus, we chose the measure developed by Lamy and colleagues.

In the study by Lamy and colleagues (2008) and our study, the singleton was a uniquely colored circle surrounded by homogeneous distractor circles (Figure 1). Participants responded to the direction (left/right) of the letter “T” inside the uniquely colored circle. The target (thick stroke) and the distractors (thin stroke) appeared at random locations within an invisible 3 x 3 matrix, around the central fixation cross. The colors of circles were randomly drawn from four possible colors. The orientation of “T” randomly varied from left to right across circles and trials. Stimuli are not drawn to scale.

Figure 1. Example of the stimulus display. The task was to identify the direction of the head or the tail of the “T” inside the uniquely colored circle. The target (thick stroke) and the distractors (thin stroke) appeared at random locations within an invisible 3 x 3 matrix, around the central fixation cross. The colors of circles were randomly drawn from four possible colors. The orientation of “T” randomly varied from left to right across circles and trials. Stimuli are not drawn to scale.
condition as the baseline. Our second objective was to examine whether or not target activation and distractor inhibition underlying PoP remain intact with age. If inhibition underlying PoP deteriorates with age, then older adults may not show distractor inhibition effects, leaving target activation as the primary contributor to PoP. If the inhibition underlying PoP is resilient to aging, then participants in both age groups should react faster relative to baseline when the distractor-defining color repeats between trials and slower relative to baseline when the distractor color from the preceding trial becomes the target-defining color.

**Method**

**Participants**

Twenty younger adults (4 men, 16 women; 17–28 years old, \( M = 19.8, SD = 2.4 \); 11–23 years of education, \( M = 17.1, SD = 3.5 \)) and 20 older adults (3 men, 17 women; 61–75 years old, \( M = 69.4, SD = 4.8 \); 12–16 years of education, \( M = 13.4, SD = 1.3 \)) participated. Younger adults were University of Toronto students who received a course credit for participation. Older adults received monetary compensation. One older and two younger adults were left handed; the remaining participants were right handed. Mean self-reported health on a 1–10 scale with 10 the best was high in both age groups (\( M \) [older] = 8.1, \( SD = 1.5 \); \( M \) [younger] = 7.7, \( SD = 1.3 \)).

**Stimuli**

The stimulus display is shown in Figure 1. It consisted of an invisible \( 3 \times 3 \) matrix, the fixation sign (+) in the central cell, and five colored circles (subtending 7.2°) in the remaining cells of the matrix. The colored circles appeared at random locations around the fixation sign.

Inscribed within each circle was a letter “T,” rotated by 90° or −90° (with the tail of a “T” subtending 2.9° in length and 0.5° in width and the head of a “T” subtending 2.8° in length and 0.3° in width). The T’s assumed left or right direction with an equal probability. On each trial, the color of the target circle was different from that of distractors. Four colors were used (red [RGB = 255, 0, 0], blue [RGB = 0, 0, 255], green [RGB = 0, 255, 0], and yellow [RGB = 255, 255, 0]). All target-distractor color combinations were equally probable.

**Procedure**

The experiment was programmed under E-Prime (Psychology Software Tools, 2001). Participants were instructed to indicate the direction of the tail or the head of a letter T inside the uniquely colored circle and pressed the “z” key on a keyboard with their left hand to indicate left direction and the far “3” key with their right hand to indicate right direction. On each trial, a 500-ms fixation display was followed respectively by a 2,000-ms stimulus display and a 500-ms blank screen. Errors or missed responses were cued with a 500-ms feedback sound.

Trials were divided into one practice block and three experimental blocks. The practice block consisted of 42 trials, and each experimental block consisted of 112 trials, for a total of 336 experimental trials. Optional 5-min breaks followed blocks of trials.

**Results**

The PoP effect, distractor inhibition, and target activation were separately examined in older and younger adults. Error trials, constituting 2.8% of all trials in older adults and 2.0% of all trials in younger adults, were eliminated from the data together with RTs that were 2.5 standard deviations away from the mean. RT outliers constituted 2.5% of responses in older adults and 1.2% of responses in younger adults. Intertrial effects of PoP and its components are shown in Table 2 as differences in RT between conditions.

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**Table 1. Description of Intertrial Effects Underlying Distractor Inhibition and Target Activation in Priming of Pop-Out**

<table>
<thead>
<tr>
<th>PoP component</th>
<th>Description of intertrial changes in color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distractor inhibition</td>
<td>Distractor color on trial ( n ) = distractor color on trial ( n + 1 )</td>
</tr>
<tr>
<td>Target switch</td>
<td>Distractor color on trial ( n ) = singleton color on trial ( n + 1 )</td>
</tr>
<tr>
<td>Target activation</td>
<td>Singleton color on trial ( n ) = singleton color on trial ( n + 1 )</td>
</tr>
</tbody>
</table>

**Table 2. Intertrial Effects Underlying PoP in Younger and Older Adults**

<table>
<thead>
<tr>
<th>Effect</th>
<th>Younger</th>
<th>Older</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M ) (SE)</td>
<td>( M ) (SE)</td>
<td></td>
</tr>
<tr>
<td>PoP</td>
<td>75.50 (6.10)</td>
<td>130.92 (13.33)</td>
</tr>
<tr>
<td>Distractor repetition</td>
<td>18.90 (5.84)</td>
<td>23.48 (9.85)</td>
</tr>
<tr>
<td>Target switch</td>
<td>−16.62 (5.99)</td>
<td>−38.84 (11.02)</td>
</tr>
<tr>
<td>Target repetition</td>
<td>14.45 (5.51)</td>
<td>16.84 (12.42)</td>
</tr>
<tr>
<td>Distractor switch</td>
<td>−20.93 (5.63)</td>
<td>−32.95 (11.30)</td>
</tr>
</tbody>
</table>

Notes: PoP = priming of pop-out; RT = reaction time; SE = standard error; SS = switched target color, switched distractor color; RR = repeated target color, repeated distractor color; NN = new target color, new distractor color; RN = new target color, repeated distractor color; SN = switched target color, new distractor color; NS = new target color, switched distractor color.

\( ^a \)PoP is measured as the difference in RT between SS and RR trials. The remaining effects are differences in RT between the baseline (NN) and given conditions.
revealed a significant effect of target switch, the within factor and age group as the between factor revealed a significant condition by age group interaction, $F(1,38) = 101.68$, $p < .001$, $\eta^2 = 0.75$, and a near-significant interaction between condition and age group, $F(1,38) = 3.14$, $p = .085$, $\eta^2 = 0.08$. After controlling for general slowing, the effects of target switch, $F(1,38) = 23.88$, $\eta^2 = 0.39$, and age group, $F(1,38) = 117.55$, $\eta^2 = 0.76$, persisted (both $p < .001$), with no significant interaction between condition and age group, $F(1,38) = 0.89$, $p = .35$, $\eta^2 = 0.02$.

### Target Activation

Two target activation effects included target repetition (NN vs. RN) and distractor switch (NN vs. NS).

A mixed ANOVA with condition (NN vs. RN) as the within factor and age group as the between factor revealed a significant effect of target repetition, $F(1,38) = 5.31$, $p = .03$, $\eta^2 = 0.12$, with older adults responding faster on RN trials ($M = 900$, $SD = 104$) than on NN trials ($M = 917$, $SD = 98$) and younger adults responding faster on RN trials ($M = 629$, $SD = 64$) than on NN trials ($M = 643$, $SD = 73$). The analysis further revealed a significant effect of age group, $F(1,38) = 106.09$, $p < .001$, $\eta^2 = 0.74$, and no interaction between condition and age group, $F(1,38) = 0.03$, $p > .80$, $\eta^2 = 0.001$.

Another mixed ANOVA with condition (NN vs. NS) as the within factor and age group as the between factor revealed a significant effect of distractor switch, $F(1,38) = 18.24$, $p < .001$, $\eta^2 = 0.32$, with older adults responding faster on NN trials ($M = 917$, $SD = 98$) than on NS trials ($M = 950$, $SD = 109$) and younger adults responding faster on NN trials ($M = 643$, $SD = 73$) than on NS trials ($M = 664$, $SD = 76$). The analysis further revealed a significant effect of age group, $F(1,38) = 100.88$, $p < .001$, $\eta^2 = 0.73$. There was no significant interaction between condition and age group, $F < 1$.

### Accuracy

Table 3 suggests that older adults committed more errors than younger adults in each condition, but their accuracy was relatively the same when compared with the baseline. Indeed, older and younger adults did not differ significantly in accuracy on distractor inhibition measures of NN versus NR, $F(1,38) = 1.0$, $p > .30$ and NN versus SN, $F < 1$, or on target activation measures of NN versus NS, $F = 2.59$, $p > .10$ and NN versus RN, $F = 1.58$, $p > .20$. Further, there were no significant differences in accuracy between NN and NR trials, $F(1,38) = 1.36$, $p = .25$, or NN and SN trials, $F(1,38) = 1.52$, $p > .20$, and no significant interactions between distractor inhibition effects and age, all $F < 1$. Similarly, there were no significant differences in accuracy
between NN and RN trials, $F(1,38) = 0.19, p > .60$, or between NN and NS trials, $F(1,38) = 0.20, p > .60$, and no significant interactions between age and target activation measures of NN versus RN, $F < 1$, and NN versus NS, $F(1,38) = 1.23, p > .20$.

**Discussion**

The PoP effect and all of its components were present in older and younger adults, indicating that the inhibition of distracting information in PoP remains intact with age. More specifically, the effects of distractor repetition and target switch were the same for older and younger adults. Consistent with previous research (McCarley et al., 2004; Yoshida et al., 2003), we also found preserved target activation effects of target repetition and distractor switch. Overall, older adults responded slower than younger adults, and this effect persisted after the log transformation of data. The PoP effect and its components were of similar magnitudes in older and younger adults after controlling for general slowing.

The presence of distractor inhibition effects of comparable magnitudes in both age groups indicates that inhibitory processes of older adults seem to operate as efficiently as the inhibitory processes of younger adults. The results are consistent with the argument that age-related deficits do not necessarily extend to basic perceptual attributes of objects such as color. The results of our study contrast with NP findings that suggest age-related deficits in inhibition. The contrasting results could be due to the different levels of processing underlying PoP and NP. According to Becker (2008), priming can occur at the stage of visual selection, before the response is selected, or at the stage of response selection. Although both types of processing are implicated in PoP and NP, PoP seems to operate primarily at the early stage of visual selection (Eimer, Kiss, & Cheung, 2010; Lamy, Yasher, & Ruderman, 2010). Priming of response-related features, in turn, is characteristic of NP (Lamy et al., 2008). It is possible that inhibition at the stage of response selection is more prone to age-related decline than inhibition at the stage of target selection.

Further, evidence for age-related reduction in inhibitory efficiency on priming tasks, such as NP, is mostly derived from studies that use target-distractor letter arrays (Connelly & Hasher, 1993; Hasher et al., 1991, Experiment 1) and semantic stimuli, such as word fragments (e.g., Ikier & Hasher, 2006). In the study by Hasher and colleagues, younger adults, but not older adults, were slower to react (e.g., name a letter) when colors of distractor and target letters switched when they were repeated. Unlike the singleton displays in PoP tasks, the target-distractor letter arrays often consist of a single distractor per target item. Although distractors are distinguished from targets based on color, it is the repetition of a letter itself that primes attention to the target. This contrasts with our PoP study, where attentional biases were facilitated or inhibited through the repetition of color alone.

Noteworthy are the less common instances of intact NP in older adults. According to Kane, May, Hasher, Rahhal & Stoltzfus (1997), such instances, may be specific to degraded visual conditions, requiring the support of episodic memory. In this context, episodic memories may be less relevant to PoP, because the singleton, by its nature, is salient. Although episodic retrieval has also been implicated in PoP (Hillstrom, 2000), the recent evidence from eye movement (Becker, 2008) and event-related brain potential experiments (Eimer et al., 2010) favors selective inhibition as the principal mechanism.

In non-PoP priming paradigms, attentional biases are created through priming. In PoP, attentional biases exist prior to priming due to the pop-out phenomenon. Attention is automatically directed to the unique item among a number of homogenous distractors. This characteristic renders the distinction between target and distractors more implicit than by a top-down instruction. By contrast, items in two-item arrays do not pop-out. Participants must receive explicit instructions to direct their attention toward one item or another. This suggests that performance on two array tasks fundamentally relies more on higher cognitive processes than PoP. The proposal that lower level inhibitory control is more resilient to aging is further supported by the performance of older and younger adults on singleton visual search tasks (Lawson, Guo, & Jiang, 2008; Madden, Spaniol, Bucur, & Whiting, 2005). Regardless of age, participants detect a singleton item faster when its features and/or features of distractors repeat from one trial to the next. This is in line with our finding that older adults respond faster to the singleton when the target-defining color or the distractor-defining color persists to the next trial.

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