

Age-related deficits in inhibition in figure-ground assignment

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We assessed age differences in the ability to resolve competition for figural status in stationary displays using small, enclosed, symmetrical silhouettes that participants classified as depicting “novel” or “familiar” shapes. The silhouettes were biased such that the inside was perceived as the shaped figure, and the outside was perceived as a shapeless ground. The critical manipulation was whether a portion of a meaningful object was suggested on the outside of the border of some of the novel silhouettes but not others (M^+ Ground and M^- Ground novel silhouettes, respectively). This manipulation was intended to induce greater inhibitory competition for figural status from the groundside in M^+ Ground silhouettes than M^- Ground silhouettes. In previous studies, young adults classified M^+ Ground silhouettes as “novel” faster than M^- Ground silhouettes (Trujillo, Allen, Schnyer, & Peterson, 2010), suggesting that young adults may recruit more inhibition to resolve figure-ground when there is more competition. We replicated this effect with young adults in the present study, but older adults showed the opposite pattern and were less accurate in classifying M^+ Ground than M^- Ground silhouettes. These results extend the evidence for inhibitory deficits in older adults to figure assignment in stationary displays. The (M^+ Ground – M^- Ground) RT differences were evident in observers’ longest responses, consistent with the hypothesis that inhibitory deficits are evident when the need for inhibition is substantial.

task-irrelevant information. Hasher and Zacks (1988) proposed that inhibitory processes are involved in rejecting task- and goal-irrelevant information. Age-related declines in the efficiency of inhibitory processes have been demonstrated for cognitive tasks by Hasher and colleagues (Healey, Campbell, Hasher, & Ossher, 2010; Healey, Ngo & Hasher, 2014; May, Zacks, Hasher, & Multhaup, 1999; Ryan, Leung, Turk-Browne, & Hasher, 2007) and by others (e.g., Gazzaley, Cooney, Rissman, & D’Esposito, 2005; Jonides, Smith, Marshuetz, Koeppel, & Reuter-Lorenz, 1998). Age-related declines in the efficiency of inhibitory processes have also been demonstrated for a variety of perceptual tasks including contour integration (Andersen & Ni, 2008; Roudaia, Bennett, & Sekuler, 2008; Roudaia, Farber, Bennett, & Sekuler, 2011), bilateral symmetry detection (Herbert, Overbury, Singh, & Faubert, 2002), shape discrimination (Bower & Andersen, 2012; Weymouth & McKendrick, 2012), and the perception of 2D and 3D shape from motion (Norman et al., 2013; Schrauf, Wist, & Ehrenstein, 2000). The perceptual deficits have been attributed to reduced intracortical inhibition (cf., Leventhal, Wang, Pu, Zhou, & Ma, 2003; Pinto, Hornby, Jones, & Murphy, 2010). Reduced intracortical inhibition was also demonstrated in older adults by better performance on a motion discrimination task that in young adults is impaired by surround suppression (Betts, Taylor, Sekuler, & Bennett, 2005). In addition, older adults do not suppress strong task irrelevant information whereas young adults do (Chang, Shibata, Andersen, Sasaki, & Watanabe, 2014).

Introduction

One of the key challenges of perception and cognition is to separate task-relevant information from

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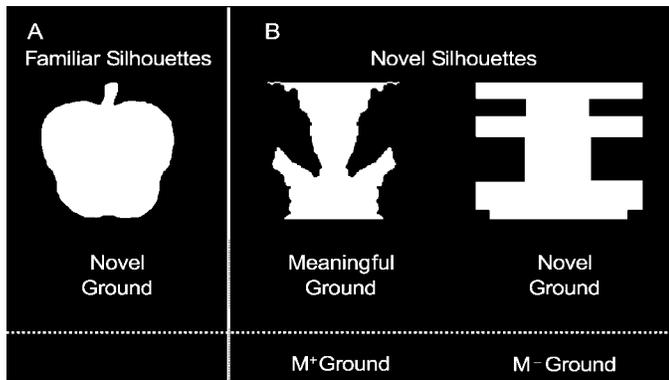


Figure 1. Sample silhouette stimuli in each of three conditions: (A) Silhouette of a familiar (meaningful) real-world object (an apple). (B) Novel silhouettes with meaningful (left) or novel (right) objects suggested outside their borders; these were M^+ Ground and M^- Ground silhouettes, respectively. For the novel silhouette on the left in (B), the meaningful object suggested in part on the outside of the left and right borders is a seahorse.

Our interest is in figure-ground perception, which occurs when two regions in the visual field share a border. When the border is assigned to only one of the regions, that region (the figure) is perceived as having a definite shape, whereas the other region (the ground) appears shapeless near the border, where it seems to simply continue behind the figure. The current understanding is that figure-ground assignment entails inhibitory competition. In current models, inhibitory competition occurs between object properties on opposite sides of borders; the side that wins the competition is perceived as the figure whereas the losing side is inhibited and perceived as the ground (e.g., Craft, Schütze, Niebur, & von der Heydt, 2007; Grossberg, 1994; Kogo & Wagemans, 2013; Peterson, de Gelder, Rapcsak, Gerhardstein, & Bachoud-Lévi, 2000; Sejnowski & Hinton, 1987). Consistent with these models, a recent study using an online measure of neural activity showed evidence of more neural inhibition when observers viewed displays designed to require more inhibitory competition for figure assignment across a border (Sanguinetti, Trujillo, Schnyer, Allen, & Peterson, 2015). In addition, ground inhibition has been demonstrated for both static and moving displays in behavioral and fMRI experiments (e.g., Cacciamani, Scalf, & Peterson, 2015; Lamme, 1995; Likova & Tyler, 2008; Peterson & Skow, 2008; Salvagio, Cacciamani, & Peterson, 2012; Strother, Lavell, & Vilis, 2012).

The results showing that figure-ground perception entails inhibition together with the evidence for a decline in the efficiency of inhibitory processes with age leads to the prediction that figure-ground perception should be impaired in older compared to younger adults. Indeed, Blake, Rizzo, and McEvoy (2008)

showed that figure-ground perception based on temporal structure differences between two regions in a display was impaired in older compared to younger adults when the task was difficult (i.e., when the temporal structure difference between the two regions was small). Blake et al. hypothesized that their results could be explained by reductions in the strength of the inhibitory component of a biphasic (excitatory and inhibitory) temporal filter necessary to perceive figure-ground from temporal structure. Blake et al. found no age-related deficits in figure-ground perception based on luminance contrast in stationary displays, even when the task was difficult (i.e., when the contrast between the relevant regions was small). It is possible therefore that age does not affect figure-ground assignment in stationary displays. Alternatively, perhaps the stationary luminance contrast displays used by Blake et al. (2008) did not require sufficient inhibition to reveal an effect of age. In the present experiment, we investigated whether age impairs figure assignment using stationary displays designed to require different amounts of inhibitory competition for figure assignment (e.g., Trujillo, Allen, Schnyer, & Peterson, 2010).

The stimuli were bounded silhouettes designed so that the insides were symmetric, enclosed, smaller in area than the outsides, and were fixated and attended (cf., Peterson & Kimchi, 2013 for a discussion of factors that affect figure assignment). This ensured that the insides of the silhouettes would be perceived as figures, and the outsides would lose the competition and be perceived as shapeless grounds.¹ Indeed, in previous experiments using these stimuli, perceivers predominantly saw the insides as figures (Cacciamani, Mojica, Sanguinetti, & Peterson, 2014; Cacciamani et al., 2015; Peterson, Cacciamani, Mojica, & Sanguinetti, 2012; Peterson & Kim, 2001; Peterson & Skow, 2008; Sanguinetti, Allen, & Peterson, 2014; Sanguinetti et al., 2015; Trujillo et al., 2010; Wager, Peterson, Folstein, & Scalf, 2015). For half of the silhouettes, the insides (the figures) portrayed familiar, meaningful, objects that exist in the real world (Figure 1A). We did not expect that extensive inhibitory competition would precede figure assignment for these familiar silhouettes because very few properties favored perceiving the outside as a figure.

For the other half of the silhouettes, the insides (the figures) portrayed novel meaningless shapes created in the laboratory; these were the critical silhouettes. Unbeknownst to participants, for half of these novel silhouettes, a portion of a familiar, meaningful (M^+) real-world object was suggested on the outside of the novel figure's left and right borders (M^+ Ground novel silhouettes; see Figure 1B). For the other half of the novel silhouettes, a novel and meaningless (M^-) object was suggested on the outside of their borders (M^- Ground novel silhouettes; see Figure 1B).

M⁺Ground and M⁻Ground novel silhouettes were equated for stimulus features (see Methods). For all silhouettes, we expected that the outside of the border would ultimately lose the competition for figural status (because more object properties favored the inside as figure). We further expected that the meaningful objects suggested on the groundside of the M⁺Ground novel silhouettes would compete strongly with the object properties on the inside although ultimately the insides would be perceived as figures. We expected that the novel objects suggested on the groundside of the M⁻Ground novel silhouettes would offer less competition. Therefore, we expected that greater inhibitory competition would precede figure assignment in M⁺Ground novel silhouettes than in M⁻Ground novel silhouettes. Therefore, comparing performance with M⁺Ground novel silhouettes and M⁻Ground novel silhouettes in younger versus older subjects can provide an index of whether inhibitory processes necessary to resolve figure-ground competition in stationary displays are impaired in older adults.

The participants' task was to classify each silhouette as depicting a meaningful/familiar object or a novel object. In two experiments using this task, Trujillo et al. (2010) found that young adults accurately classified M⁺Ground novel silhouettes as "novel" *faster* than M⁻Ground novel silhouettes. This RT effect was surprising because one might expect that it would take longer to determine figure assignment when there is more competition (cf., Peterson & Enns, 2005; Peterson & Lampignano, 2003). Trujillo et al. suggested that efficient inhibition could speed competition resolution. Following Trujillo et al.'s (2010) suggestion, we reasoned that perhaps younger adults can quickly recruit additional inhibition when necessary to resolve the greater figure-ground competition for figural status in M⁺Ground than M⁻Ground silhouettes. It follows that, if the inhibition used for figure assignment in stationary displays is reduced with age, older adults should not show speeded RTs to accurately classify M⁺Ground compared to M⁻Ground novel silhouettes as "novel." Indeed, if they are unable to recruit additional inhibition when there is more competition, older adults might require *more* time to accurately classify M⁺Ground novel silhouettes as "novel" than M⁻Ground novel silhouettes.

To test this hypothesis we recorded classification RTs and accuracy in older and younger adults viewing the three types of silhouettes (familiar; M⁺Ground novel; and M⁻Ground novel). The familiar silhouettes were included so that participants had to make a decision at test. In addition, comparing older and younger performance with the familiar silhouettes allows an index of age-related differences when little competition is involved.

As will be seen, we analyzed the RTs for both mean and distributional differences, using a vincentile analysis. The latter was done because it has been shown that older adults experience disproportionate slowing relative to younger adults in their slowest responses (e.g., Balota et al., 2010; McAuley, Yap, Christ, & White, 2006; Spieler, Balota, & Faust, 1996; Tse, Balota, Yap, Duchek, & McCabe, 2010; West, Murphy, Armilio, Craik, & Stuss, 2002). This pattern has been tied to weak or sluggish inhibitory mechanisms, making this analysis relevant for our experiment where the slowest responses are expected to occur when competition is highest, and the need to recruit inhibition is concomitantly greatest. Therefore, we expect that the hypothesized differences between younger and older participants' responses to M⁺Ground and M⁻Ground novel silhouettes should be most robust in their slowest responses.

Methods

Participants

The participants were 27 older adults and 23 young adults. All data were collected in accordance with the Declaration of Helsinki. Older adults received monetary compensation, and young adults received partial course credit. The data from three older adults and one young adult were excluded because they reported either depression or severe head injuries with subsequent memory loss. All participants had self-reported normal or corrected-to-normal vision. Of the remaining subjects, five older adults and two younger adults reported being aware of the familiar shapes in the grounds of the M⁺Ground Novel silhouettes in a postexperiment questionnaire (see Methods, below). Data from these subjects were eliminated prior to analysis because we are interested in the speed and accuracy of categorization responses made by young and older participants for whom the outcome of the competition for figural status was held constant; that is, the insides of the silhouettes were perceived as the figures, and the outsides of the silhouettes were perceived as shapeless grounds. Although older adults were more than twice as likely to report awareness as younger adults (odds ratio), this relationship was not statistically significant, $\chi^2 = 1.89$, $p = 0.168$. The final sample was 19 older (six male, 13 female) adults and 20 younger (seven male, 13 female) adults.

Table 1 shows descriptive statistics. The MMSE (Mini-Mental Status Examination; Folstein, Folstein, & McHugh, 1975) scores for older adults were above the commonly used cutoff of 24 for cognitive impairment (Folstein et al., 1975; Lopez, Charter, Mostafavi,

	Young ($N = 20$)		Older ($N = 19$)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Age (years)	19.71	2.63	66.89	4.89***
Education (years)	14.62	2.45	17.56	8.47
Shipley	29.91	3.69	33.49	4.34**
MMSE	NA		28.66	1.46

Table 1. Descriptive statistics. Notes: *** = $p < 0.001$, ** = $p < 0.01$.

Nibut, & Smith, 2005). The older adults' vocabulary scores on the Shipley Institute of Living Questionnaire (Shipley, 1946) were included as a measure of verbal crystallized intelligence/semantic knowledge. Their scores were higher than those of younger adults, consistent with evidence that knowledge increases with age (Bowles & Salthouse, 2008; Park, 2000).

Materials and procedure

The stimuli were 80 white silhouettes: 40 silhouettes of common familiar objects (none with meaningful objects suggested on the groundside; see Figure 1A) and 40 silhouettes of novel (meaningless) objects, of which 20 were M⁺Ground silhouettes and 20 were M⁻Ground silhouettes (see Figure 1B). The two types of novel silhouettes were equated for low-level features (size, luminance, spatial frequency, and contour length) and for properties known to affect figure-ground perception (enclosure, symmetry, convexity, and area: see Trujillo et al., 2010). Materials were identical to those used in Trujillo et al.'s 2010 experiment (i.e., white silhouettes shown on a black background) and can be obtained from http://www.u.arizona.edu/~mapeters/Stimuli/Trujillo_et_al_Stimuli.zip. The stimuli averaged 20.3 cm by 20.3 cm.

We used the same design as Trujillo et al. (2010). In each of four blocks of trials participants viewed 80 white silhouettes with silhouette type randomly intermixed.² Silhouettes were presented individually for 175 ms centered on a black background on a 38.1 cm Micro-touch 3M touch-screen (60 Hz). One of five randomly selected pattern masks followed each silhouette for 250 ms. Participants sat \approx 54 cm from the screen.

For each silhouette, participants indicated their “novel” versus “familiar/real world” response by pressing one of two buttons. Once the stimulus appeared, participants could respond at any time until the arrival of the next stimulus. If they failed to respond within this period, the experiment advanced automatically, and the trial was counted as a time-out. Between trials, a fixation cross was shown centered on a blank screen; all silhouettes and masks were also centered (see Figure 2). Intertrial intervals varied from 2625 ms to 4675 ms to reduce predictability.

Postexperiment questionnaire

After the experiment, participants were asked twice whether they ever saw a familiar object on the outside of the silhouettes, first without a demonstration silhouette and again while the experimenter showed them one such familiar object suggested on the outside of a demonstration silhouette. We eliminated those participants who said they saw a familiar object on the outside of any of the experimental silhouettes at any point during the question period (i.e., reported being aware of even one object suggested on the groundside of the M⁺Ground novel silhouettes); they were not required to remember the identity of the object. We eliminated these participants because we were interested in examining the time required to correctly classify the silhouettes as “novel” when the competition was successfully resolved in favor of the inside as figure.

Results

We assessed both accuracy and RTs (for correct responses only). To eliminate responses that were premature, we trimmed RTs at 200 ms. In addition, for the calculation of means, RTs were winsorized within participants and condition at 10% (Erceg-Hurn & Mirosevich, 2008). To provide a sensitive test of age-related differences, we divided unwinsorized RTs for the two novel silhouette types into four vincentiles for each age group. For this analysis, each participant's RTs were ordered from fastest to slowest for each type of novel silhouette and then were divided into four

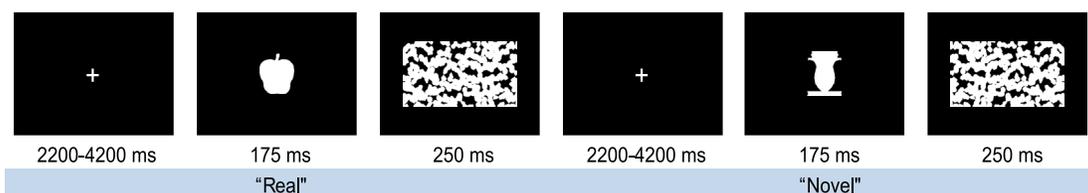


Figure 2. Illustration of sample trials displaying a familiar silhouette (an apple) followed by a mask and then an M⁺Ground novel silhouette with portions of a familiar object suggested on the left and right groundsides (in this case, portions of a bell).

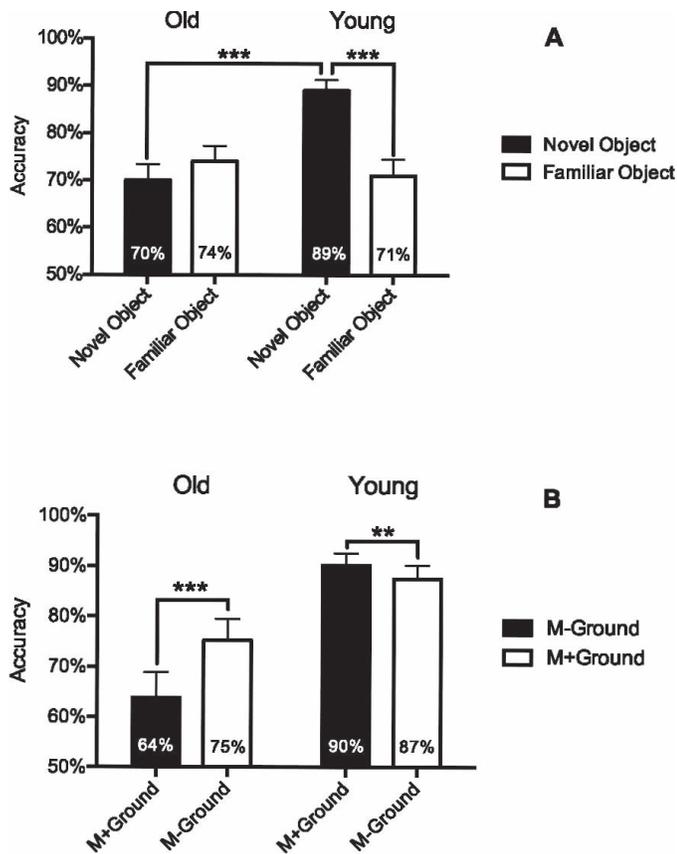


Figure 3. Accuracy (on the y axis) by age group and silhouette type. (A) Accuracy for novel silhouettes (averaged over M^+ Ground and M^- Ground silhouettes) and for familiar silhouettes. (B) Accuracy for the two types of novel silhouettes (M^+ Ground and M^- Ground) shown separately. Error bars are averaged within subject ± 1 SEM, ** = $p < 0.05$, *** = $p < 0.01$.

equally spaced vincentiles. This resulted in individual vincentile estimates, which were then averaged for each group. In what follows, we present accuracy results, the mean RT results, and the analysis of RTs by vincentiles, in that order. The results support the hypothesis that the inhibitory mechanism involved in figure assignment is impaired in older adults.

Accuracy

Discriminating familiar versus novel silhouettes

Initially, to compare accuracy for “familiar” and “novel” responses, the two novel silhouette conditions were collapsed and compared to the familiar silhouette condition. This analysis was a 2 (age-group) \times 2 (familiar vs. novel silhouette) repeated-measures ANOVA, with the silhouette type as a repeated measure. The results are shown in Figure 3A. There was a significant interaction between age and silhouette type, $F(1, 37) = 11.99$, $p < 0.002$, $\eta_p^2 = 0.24$. Young and older

adults were equally accurate in labeling silhouettes of familiar objects as “familiar,” indicating that age did not necessarily affect accuracy. An age-related difference was evident in responses to novel silhouettes, however; on these, younger adults were more accurate than older adults, Welch’s $t(27.97) = 3.74$, $p < 0.001$. Moreover, young adults classified novel silhouettes more accurately than familiar silhouettes, $t(19) = 4.36$, $p < 0.001$, whereas older adults classified both types of silhouettes equally accurately, $t(18) = 0.93$, $p = 0.36$.

Differences in accuracy for M^+ Ground versus M^- Ground novel silhouettes

We next investigated whether there was an age-related difference in accuracy for the M^+ Ground versus M^- Ground novel silhouettes using a repeated-measures ANOVA (see Figure 3B). We found an age by silhouette type interaction, $F(1, 37) = 16.35$, $p < 0.001$, $\eta_p^2 = 0.31$. Paired t tests revealed that young adults classified M^+ Ground novel silhouettes as “novel” more accurately than M^- Ground novel silhouettes, $t(19) = 2.44$, $p = 0.025$. In contrast, older adults classified M^+ Ground novel silhouettes as “novel” less accurately than M^- Ground novel silhouettes, $t(18) = 3.365$, $p = 0.003$. A main effect of novel silhouette type, $F(1, 37) = 6.15$, $p = 0.018$, $\eta_p^2 = 0.14$, was also observed but was subsumed by the interaction between age and silhouette type.

Reaction times

Discriminating familiar versus novel silhouettes

Mean RTs for correct classification responses were analyzed in the same manner as accuracy scores. RTs were initially collapsed across the two types of novel silhouettes (M^+ Ground and M^- Ground) so that RTs for “novel” and “familiar” responses could be compared. Older adults were slower overall than younger adults, $F(1, 37) = 8.94$, $p = 0.005$, $\eta_p^2 = 0.19$ (Figure 4A). There was also a significant age by silhouette type interaction, $F(1, 37) = 18.11$, $p < 0.001$, $\eta_p^2 = 0.33$. Young adults showed no detectable difference in their RTs to accurately categorize familiar versus novel silhouettes, $t(19) = 0.27$, $p = 0.78$, whereas older adults were slower to accurately categorize novel silhouettes as “novel” than familiar silhouettes as “familiar,” $t(18) = 4.375$, $p < 0.001$. These results show that the age-related accuracy differences cannot be attributed to speed-accuracy trade-offs.

Differences in classification RTs for M^+ Ground versus M^- Ground novel silhouettes

Next we compared participants’ mean RTs to correctly report “novel” for the two types of novel

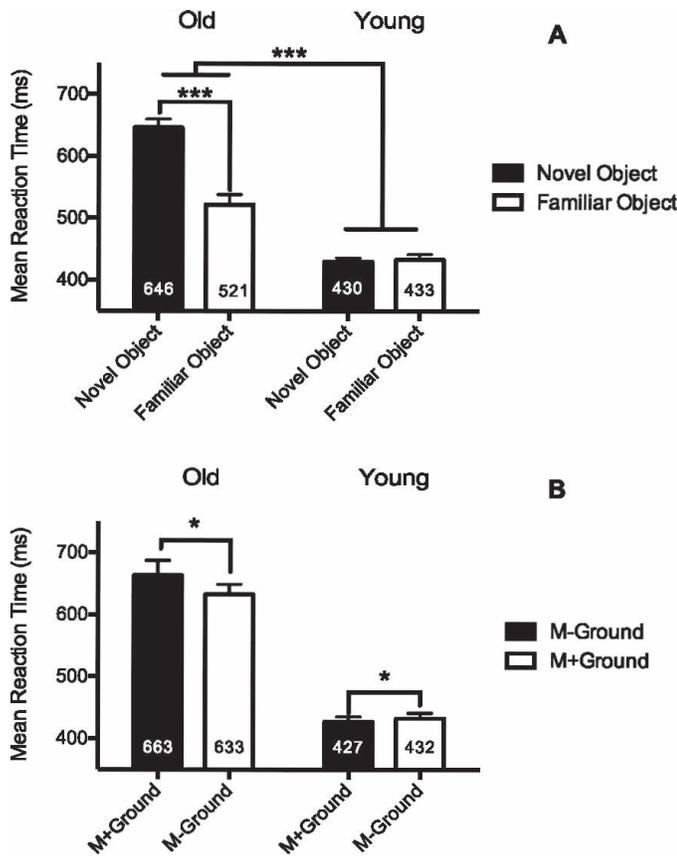


Figure 4. Mean RTs in ms (on the y axis) by age group and condition. (A) Reaction times for novel silhouettes (averaged over both types of novel silhouettes) and for familiar/real-world silhouettes. (B) Reaction times for the two types of novel silhouettes (M⁺Ground and M⁻Ground) shown separately. Error bars are averaged within subject ± 1 SEM, * = $p < 0.05$ (one-tailed), ** = $p < 0.05$ (two-tailed), *** = $p < 0.01$.

silhouettes (M⁺Ground vs. M⁻Ground), using a repeated-measures ANOVA. Reduced inhibition in figure assignment in older adults should be evident in slower RTs for M⁺Ground silhouettes that require more

inhibitory competition to assign figural status than for M⁻Ground silhouettes. Consistent with this prediction, the age X silhouette type interaction was significant, $F(1, 37) = 5.19, p = 0.029, \eta_p^2 = 0.12$ (see Figure 4B). Follow-up one-tailed t tests revealed that older adults took longer to accurately classify the M⁺Ground than the M⁻Ground novel silhouettes as “novel,” $t(18) = 1.916, p = 0.035$, as predicted if the inhibition necessary to resolve competition is reduced, whereas younger adults took less time to accurately classify the M⁺Ground than the M⁻Ground novel silhouettes as “novel,” $t(19) = 2.06, p = 0.026$, replicating the effect reported by Trujillo et al. (2010).³ There was no main effect of silhouette type, $F(1, 37) = 2.55, p = 0.119, \eta_p^2 = 0.06$.

Vincentile analysis comparing RTs for M⁺Ground versus M⁻Ground novel silhouettes

Because it has been shown that older adults are disproportionately slower than younger adults when their response times are longest, we expected that the differences between younger and older participants’ responses to M⁺Ground and M⁻Ground novel silhouettes would be most robust at their longest RTs. The means for each silhouette type in each vincentile are shown in Table 2 separately for the older and younger adults along with the difference in their RTs for M⁺Ground versus M⁻Ground silhouettes (M⁺Ground – M⁻Ground) difference scores. We are interested in the (M⁺Ground – M⁻Ground) difference score as an assay of whether more inhibition can be recruited when competition is greater (i.e., when RTs are longest as in the longest vincentiles). If more inhibition can be recruited when competition is high, then the (M⁺Ground – M⁻Ground) difference score should be negative in the longest vincentiles, and this was the pattern observed in young adults (see Table 2 and Figure 5). By contrast if inhibition is diminished, we

Age	Vincentile	Mean M ⁺ Ground	Mean M ⁻ Ground	Difference	SE
Older	0.2	523	519	4	12
	0.4	593	578	14	13
	0.6	686	642	44**	20
	0.8	808	740	68**	28
Young	0.2	362	363	-1	3
	0.4	402	405	-3	3
	0.6	440	446	-6**	3
	0.8	491	502	-12***	4

Table 2. Means, difference, and standard error of the difference (in ms) by age group and vincentile for M⁺Ground and M⁻Ground novel silhouettes. Notes: Group mean difference scores per vincentile. Difference scores were calculated as (mean M⁺Ground RT – mean M⁻Ground RT) for each individual per vincentile. The 0.8 vincentile corresponds to the 80th percentile. Positive difference scores indicate that observers took more time to accurately categorize M⁺Ground than M⁻Ground silhouettes as “novel.” Negative difference scores indicate that observers took less time to accurately categorize M⁺Ground than M⁻Ground silhouettes as “novel.” Asterisks indicate significant differences from zero (two-tailed tests). ** = $p < 0.05$; *** = $p < 0.01$.

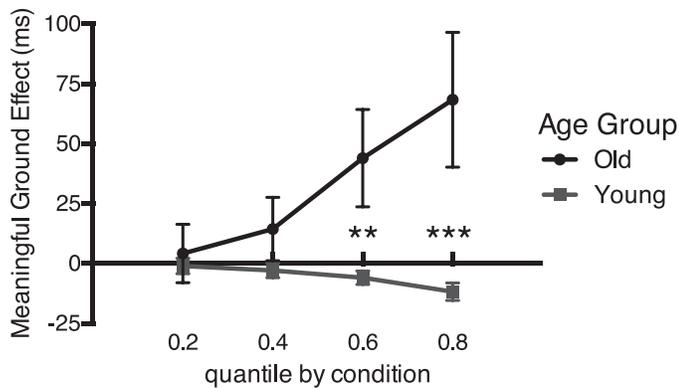


Figure 5. Differences between reaction times for accurate classification by vincentile (M^+ Ground RT – M^- Ground RT). A positive difference indicates slowing of correct RTs for M^+ Ground compared to M^- Ground novel silhouettes (evident for older adults). A negative difference indicates speeding of correct RTs for M^+ Ground compared to M^- Ground novel silhouettes (evident for younger adults). Error bars are ± 1 SEM. Asterisks indicate significant group differences, ** = $p < 0.05$, *** = $p < 0.01$.

would expect longer RTs for the M^+ Ground than the M^- Ground silhouettes in which case the (M^+ Ground – M^- Ground) difference score should be positive; this was the pattern observed in older adults (see Table 2 and Figure 5). Note that comparing (M^+ Ground – M^- Ground) difference scores in younger versus older adults removes any difference between the age groups due simply to variability in their RTs.

Difference scores (M^+ Ground – M^- Ground) were analyzed in a 2 (age-group) by 4 (vincentile) mixed design ANOVA with vincentile treated as a repeated measure. As the tests for sphericity were significant, we used Greenhouse-Geisser corrected p values. The interaction between age and vincentile was significant, $F(3, 111) = 4.81$, $p = 0.021$, $\eta_p^2 = 0.12$. As illustrated in Figure 5, where the (M^+ Ground – M^- Ground) RT differences are plotted as a function of vincentile in the two groups, older and younger adults differed reliably only in the two longest vincentiles (using Welch's two-sample t tests: for the 0.6 vincentile, $t(18.69) = 2.42$, $p = 0.026$; and for the 0.8 vincentile, $t(18.63) = 2.82$, $p = 0.011$). No differences were observed for vincentiles 1 and 2, both $t_s < 1.26$, $p_s > 0.22$. That we observed this effect in RTs only in the two longest vincentiles is consistent with the hypothesis that differential effects of inhibitory efficiency in young versus older adults are most evident when figure-ground resolution is most difficult.

Given the interaction between age and vincentile, we investigated the vincentile effects in each group separately. Specifically, young adults classified M^+ Ground novel silhouettes as “novel” significantly faster than M^- Ground novel silhouettes in the two

longest vincentiles, $t(19) = 2.13$ and 3.17 , $p_s = 0.047$ and 0.005 , for vincentiles 0.6 and 0.8, respectively (see Table 2). In contrast, older adults took significantly longer to classify M^+ Ground novel silhouettes as “novel” than M^- Ground novel silhouettes in the two longest vincentiles, $t(18) = 2.16$ and 2.43 , $p_s = 0.044$ and 0.025 for vincentiles 0.6 and 0.8, respectively (see Table 2).

Thus, for older adults, the suggestion of a meaningful object on the groundside of a novel silhouette slowed the assignment of figural status to the inside of the silhouettes, whereas, for younger adults, the opposite pattern was observed. These results are evident only in the two longest vincentiles in each group and are consistent with the suggestion that figure-ground assignment in stationary displays relies on an inhibitory mechanism that is engaged effectively by younger adults but is impaired in older adults.

Discussion

Aging is associated with worse performance on motion-defined object perception and figure-ground perception tasks, findings that have been attributed to reduced inhibition in the visual cortex (e.g., Blake et al., 2008; Norman et al., 2013; Schrauf et al., 2000; however, see Andersen, Ni, Bower, & Watanabe, 2010 for some evidence that training can mitigate age-related decline in perceptual learning). To date, age-related deficits in the perception of stationary figure-ground displays have not been reported. Yet current models of figure assignment entail inhibitory cross-border competition (e.g., Craft et al., 2007; Grossberg, 1994; Kogo & Wagemans, 2013; Peterson et al., 2000; Sejnowski & Hinton, 1987), and these models are supported by behavioral and neural evidence from young adults (e.g., Cacciamani et al., 2015; Lamme, 1995; Likova & Tyler, 2008; Peterson & Skow, 2008; Salvagio et al., 2012; Sanguinetti et al., 2015; Strother et al., 2012). We tested whether aging reduced the availability of inhibition used to resolve competition for figural status in stationary displays.

We used small, enclosed, symmetrical silhouettes that participants classified as depicting “novel” or “familiar” shapes. The silhouettes were biased such that the inside would be perceived as the figure, and the outside would be perceived as a shapeless ground. The critical manipulation was whether or not a portion of a meaningful, familiar, real world object was suggested on the outside of the border of some of the novel silhouettes but not others (M^+ Ground and M^- Ground novel silhouettes, respectively). The suggestion of a portion of a meaningful object on the outside of the border of M^+ Ground silhouettes was intended to

induce greater inhibitory competition for figural status in those silhouettes than in M⁻Ground silhouettes.

We predicted that if inhibitory competition is involved in figure-ground perception in stationary displays, then older adults tested with displays that entail sufficient competition should show evidence of inhibitory deficits. This is exactly what we observed: Compared to younger adults, older adults made more errors and had longer mean RTs when they classified the M⁺Ground novel silhouettes as “novel” compared to the M⁻Ground silhouettes. A vincentile analysis revealed that the age-related RT difference was evident only in the slowest responses: In vincentiles 0.6 and 0.8, older adults took longer to correctly classify the M⁺Ground novel silhouettes as “novel” compared to the M⁻Ground silhouettes, whereas younger adults took less time to correctly classify the M⁺Ground novel silhouettes as “novel” compared to the M⁻Ground silhouettes. Because we compared (M⁺Ground – M⁻Ground) difference scores for older and younger adults, the age effect cannot be due to greater variability in the older participants’ responses; such differences are removed by subtracting M⁻Ground RTs from M⁺Ground RTs. Longer vincentiles are assumed to index harder trials (e.g., Balota et al., 2010; Tse et al., 2010). For our stimuli, harder trials are those on which the competition for figural status is strong. On such trials, we propose that young adults can recruit more inhibition, allowing them to resolve the competition more quickly for M⁺Ground than for M⁻Ground silhouettes. In contrast older adults unable to recruit additional inhibition require more time when more competition is present.

It is likely that most of the processes involved in the perception of our stimuli occur in the visual cortex. Greater inhibition of the groundside of M⁺Ground than M⁻Ground silhouettes has been observed in visual areas as early as V1 (Cacciamani et al., 2015; Salvagio et al., 2012). Therefore, we propose that the inhibitory deficits observed in the present experiment are due to deficits in GABA-mediated inhibition in the visual cortex, although future research is necessary to be certain that GABA is involved. It is clear, however, that mid- and high-levels of the visual hierarchy are activated before, and contribute to, figure assignment: Greater competition for figure assignment is present in M⁺Ground than M⁻Ground silhouettes because memory representations of the shape of the familiar objects suggested on the outside of the M⁺Ground silhouettes compete for figural status. Effects of object memories on figure assignment have been shown to require multiple object parts arranged properly in space (e.g., Barense, Ngo, Hung, & Peterson, 2012). Therefore, the object representations that compete for figural status are probably mid- or high-level object representations. Consistent with this claim, Peterson and Skow (2008) observed inhibition of responses to objects with the same basic-level shape of the familiar objects

that lost the competition for figural status. In addition, there is evidence that semantics are accessed for the object suggested on the groundside of the border of M⁺Ground silhouettes, even though that object loses the competition for figural status and is not consciously perceived (Peterson et al., 2012; Cacciamani et al., 2014). These results implicate higher levels than traditionally thought to be involved in figure assignment (cf., Peterson & Cacciamani, 2013), although the relevant areas may still be classified as “visual.” Future experiments must determine the extent to which high and low levels of the visual hierarchy are involved in figure assignment.

The silhouettes were exposed for only 175-ms. Our design assumes that this exposure duration was sufficient for the object memories corresponding to the familiar objects suggested on the groundside of the silhouettes to be accessed and to exert an influence on competition for figure assignment. Substantial evidence supports this assumption. First, with the procedure used in the current experiment, Trujillo et al. (2010; cf Sanguinetti et al., 2014) showed that human ERP responses are modulated by the suggestion of meaningful objects on the groundside of M⁺Ground silhouettes as early as 106–156 ms post stimulus onset. Second, using other tasks, but the same 175-ms exposure duration, Cacciamani et al. (2015) and Salvagio et al. (2012) observed evidence of more inhibition of the grounds of M⁺Ground silhouettes than M⁻Ground silhouettes. Third, Sanguinetti et al. (2015) measured higher activity in the alpha band of the EEG while subjects viewed 175-ms exposures of M⁺Ground silhouettes compared to M⁻Ground silhouettes. Increased activity in the EEG alpha band has been linked to increased neural inhibition.⁴ Because the M⁺Ground and the M⁻Ground silhouettes were equated for stimulus properties, the evidence discussed above has been attributed to access to memories of the object suggested on the groundside of the M⁺Ground silhouettes. Fourth, testing monkeys, Zipser, Lamme, and Schiller (1996) observed differential responses to figures and grounds starting 80–100 ms after stimulus onset; they hypothesized that this time was sufficient for high-level factors including object memories to influence figure assignment. Indeed, Peterson and Skow (2008) found that responses to the shape of the familiar object suggested on the groundside of M⁺Ground silhouettes were inhibited when a test display appeared only 80 ms after the onset of the silhouette. Fifth, the 175-ms exposure duration used here was sufficient for 75%–95% accuracy in classifying the familiar silhouettes as “familiar,” which requires access to object memories. Given these other results, we are confident that the exposure duration used in the present experiment was sufficient to allow us to gauge differential inhibitory competition due the access to object memories for the groundside of the M⁺Ground but not the M⁻Ground novel silhouettes.

Our design requires that the familiar object on the outside of M⁺Ground silhouettes lost the competition for figural status; when this occurs, the region outside the silhouettes' borders is perceived as a shapeless ground and participants are unaware of an object that might be perceived there. This raises the question of whether we can be confident that the observers whose data we analyzed were not aware of the familiar objects suggested on the groundside of the silhouettes. The postexperimental question procedure designed to eliminate those who were aware is quite stringent: Participants were asked whether they ever saw a familiar object on the outside of the silhouettes both before and after the experimenter showed them one such familiar object on a demonstration silhouette. We eliminated those participants who said they saw a familiar object on the outside of the silhouettes at any point during the question period; they were not required to remember the identity of the object. Because our rejection criteria are conservative, we are confident that we retained data only from those participants for whom the familiar object on the outside of the M⁺Ground silhouettes lost the competition for figural status. Older adults were not more likely to be aware of the familiar objects suggested on the groundside of the M⁺Ground silhouettes (see *Participants* section); thus both older and younger adults seem to have sufficient inhibition to resolve the competition in favor of the insides as figures; it simply takes longer for older adults than younger adults to resolve the competition.

Recall that older adults who were classified as unaware of the familiar objects suggested on the groundside of the borders of the M⁺Ground silhouettes nevertheless made more errors than younger adults in classifying M⁺Ground silhouettes as “novel.” We propose that errors can occur when classification responses for M⁺Ground novel silhouettes are generated while the representations of the meaningful objects are still active, even though they are ultimately suppressed and observers perceive the grounds as shapeless. Previously, testing young adults, Peterson and Lampignano (2003) showed that evidence for task-relevant responses begins to accumulate while figure-ground assignment is in progress and the two objects that might be perceived on opposite sides of borders are still active (cf., Cacciamani et al., 2014; Peterson et al., 2012). In the present experiment, it is likely that activation of the meaningful objects persisted longer in older than in younger adults because older adults could not muster sufficient inhibition to resolve figure assignment quickly (cf., Gazzaley et al., 2008). In this way, the longer resolution time may therefore have led to more classification errors for M⁺Ground silhouettes in older than in younger adults.

An interesting question raised by our findings is whether the enhanced inhibition recruited by young adults to resolve competition in the M⁺Ground

silhouettes lasts long enough to affect performance on subsequent trials. We did not expect it would because successive trials were separated by at least 2.5 s, much longer than ground suppression has been observed to last after the onset of competition in previous research (e.g., Cacciamani et al., 2014; Peterson and Skow, 2008; Salvagio et al., 2012). Nevertheless, we investigated whether accurate responses to M⁻Ground silhouettes were speeded when they followed M⁺Ground silhouettes, as might be expected if greater inhibition summoned to resolve the competition in M⁺Ground silhouettes lasted long enough to affect performance on the subsequent trial. We did not find any such influences, in either older or younger adults, all $ps > 0.24$. We conducted similar analyses for M⁺Ground trials following either M⁺Ground or M⁻Ground—neither the main effect of preceding trial nor the interaction with age was significant (both $ps > 0.49$).⁵

A limitation of this study is that although all participants reported having normal or corrected to normal vision, we did not obtain measures of vision (such as acuity). Nevertheless, it is unlikely the age-related differences we found in the perception of stationary figure-ground displays are due to differences in acuity for three reasons. First older and younger adults were equally accurate in categorizing the familiar objects as “familiar.” Poor acuity should impair the perception of familiar objects as well as novel objects. Second, no simple explanation based on impaired acuity can account for the age-related *reversal* in the direction of the difference between RTs for M⁺ Ground versus M⁻Ground silhouettes in the two longest vincentiles, whereas differential inhibitory regulation does predict this effect. Finally, although age-related declines in optical and retinal function do contribute to visual decline, in most cases age-related cortical changes have been shown to account for differences in visual acuity (for reviews see: Sekuler & Sekuler, 2000; Spear, 1993). Thus, we do not believe that our results are due to differences in visual acuity. Nevertheless, it will be important to replicate these results in another sample of older adults.

In conclusion, we have extended evidence of deficits in inhibitory processing in older adults to figure-ground perception in stationary displays, consistent with views that this task requires inhibition (Craft et al., 2007; Grossberg, 1994; Kienker, Sejnowski, Hinton, & Schumacher, 1986; Kogo & Wagemans, 2013; Peterson and Skow, 2008; Sanguinetti et al., 2015; Sejnowski & Hinton, 1987; Trujillo et al., 2010). Our results show that unlike younger adults, older adults do not quickly recruit more inhibition when it is needed to resolve greater inhibitory competition for figure assignment. In future research, it will be interesting to assess the differential magnitude and time course of inhibitory competition in figure assignment in older versus younger adults using indices of neural responses.

Keywords: aging, object perception, figure-ground, inhibition

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Footnotes

¹ We used intensive postexperiment questioning to verify that subjects were unaware of familiar objects suggested on the outside of the silhouettes, as expected if the outsides were perceived as shapeless grounds; see Methods.

² Trujillo et al. (2010) found that although RTs became faster with block, the difference between M⁺ and M⁻Ground silhouettes remained stable. We replicate this finding in both groups in the present study.

³ These were one-tailed tests because we predicted the direction of the differences. For additional information on these differences see the vincentile analysis, below.

⁴ A reviewer suggested that inhibitory efficiency might be impaired in older adults even in the fastest trials. To investigate this possibility it would be interesting to compare activity in the alpha band of the EEG in younger versus older adults viewing M⁺Ground versus M⁻Ground silhouettes as a function of RT.

⁵ This interesting possibility was suggested by a reviewer.

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