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Authors
Wais, Peter E
Gazzaley, Adam

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External distraction impairs categorization performance in older adults

Peter E. Wais and **Adam Gazzaley**
Departments of Neurology, Physiology and Psychiatry, Center for Integrative Neurosciences, University of California, San Francisco

Abstract

The detrimental influence of distraction on memory and attention is well established, yet it is not as clear if irrelevant information impacts categorization abilities and if this impact changes in aging. We examined categorization with morphed prototype stimuli in both younger and older adults, using an adaptive staircase approach to assess participants' performance in conditions with and without visual distractors. Results showed that distraction did not affect younger adults, but produced a negative impact on older adults' categorization such that there was an interaction of age and distraction. These results suggest a relationship between the increased susceptibility to visual distraction in normal aging and impairment in categorization.

Keywords

categorization; distraction; aging

Introduction

The presence of visual distraction negatively impacts memory. A growing body of research shows that irrelevant information, which is a common factor in our real-world environment, diminishes performance in visual working memory (WM) (Zanto and Gazzaley, 2009; Clapp, Rubens and Gazzaley, 2010; Ranier, Asaad and Miller, 1998; Lavie, 2005) and in the retrieval of details from long-term memory (LTM) (Wais, Rubens, Boccanfuso and Gazzaley, 2010; Wais, Kim and Gazzaley, 2012a). The ability to remain focused on relevant stimuli in the presence of visual distractors is thought to depend on selective visual attention (Desimone, 1998; Lavie and de Fockert, 2005). Neuroimaging evidence suggests that functional networks guiding visual attention to achieve memory goals are susceptible to the disruptive influence of perceptual processing associated with distractors. Moreover, the effect of visual distraction on performance increases with normal aging in the domains of WM (Gazzaley, Cooney, Rissman and D'Esposito, 2005; Berry, Zanto, Rutman, Clapp and Gazzaley, 2009) and LTM (Wais, Martin and Gazzaley, 2012b) and attention (e.g., Rabbitt, 1965). The circumstances are not clear, however, when the influence of irrelevant

Corresponding authors: Peter Wais & Adam Gazzaley, UCSF – MC0444, 675 Nelson Rising Lane, San Francisco, CA 94158, Tel: 1-415-502-7322, Fax: 1-415-502-7538, peter.wais@ucsf.edu, adam.gazzaley@ucsf.edu.

information also interferes with discrimination underlying categorization performance and if susceptibility to this type of interference changes in normal aging.

Categorization is a fundamental cognitive ability that binds stimulus representations across networks of cortical regions (Reynolds and Desimone, 1999) and makes it possible to recognize external stimuli as relevant to task goals (Freedman, Riesenhuber, Poggio and Miller, 2001). Categorization depends upon assessment of key stimulus attributes according to abstract task rules (Ashby and Maddox, 2005). This capability involves decision-making processes and top-down control of visual attention to focus discrimination processes on the goal-relevant features in complex object representations (Roy, Riesenhuber, Poggio and Miller, 2010; Freedman, Riesenhuber, Poggio and Miller, 2003). Categorization, for example, underlies the ability to accept lemons, but reject tennis balls, as food.

A large literature examines categorization performance based on comparisons of how well people apply two different approaches, or learning structures. One approach uses rule-based learning structures in which category discrimination is based on some explicit reasoning for one or two rules that can be easily described verbally (Ashby and Maddox, 2005). Another approach uses information-integration learning structures in which category discrimination is difficult or impossible to describe verbally (Ashby and Maddox, 2005). A hallmark of categorization based on information-integration structures is that the whole, unified object is taken into account. Additionally, stimulus dimensions have been shown to be relevant in the assessment of boundaries in rule-based, but not information-integration, category learning (Maddox, Filoteo, Hejl and Ing, 2004).

Studies with older adult participants have manipulated all of these factors. Results from tasks using simple geometric stimuli suggest an aging-related decline when information-integration structures are used (Filoteo and Maddox, 2004), yet results from tasks using more complex geometric stimuli do not show age-related differences (Mayhew, Li, Storrar, Tsvetanov and Kourtzi, 2010).

In the current study, we used a morphed prototype task to study age differences in category learning. Morphed prototypes, which involve intricate stimuli such as images of automobiles or animals (Jiang, Bradley, Rini, Zeffiro, VanMeter, Riesenhuber, 2007; Freedman, Riesenhuber, Poggio and Miller, 2002) encourage the use of categorization assessment based on information-integration structures over rule-based structures because of the large number and complexity of distortions in relevant stimulus dimensions resulting from morphing transformations.

Psychology and neuroscience research suggest compatible models for mechanisms that underlie categorization via integration of top-down processes to support sharpening of featural details and bottom-up processes to support perceptual discrimination. For example, both models for a visuo-spatial sketchpad (Baddeley, 2010) and for neuronal ensembles as coherence fields (Serences and Yantis, 2006) propose that a junction in cognitive processing integrates goal-directed control of visual attention onto bottom-up representations of relevant perceptual information. This interface, which is thought to enable sharpening in perceptual discrimination, may be a locus where the influence of visual distractors could interfere with top-down processes supporting categorization. Interference with assessment of goal-relevant details (i.e., sharpening stimulus representations) might be the result of additional task demands on top-down modulation networks to suppress visual distraction. Filtering the influence of distractors, therefore, may overlap and interfere with the integration of top-down and bottom-up signals at the locus of sharpening of goal-relevant perceptual information.

WM decline in older adults is attributed to a combination of underlying factors, such as changes in basic capabilities for visual search (Hommel, Li and Li, 2004) and deficits in the ability to suppress irrelevant information (Gazzaley et al., 2008; Gazzaley et al., 2005; Hasher, Zacks and May, 1999). Rabbitt (1965) showed that response times in a visual discrimination task slowed to a greater degree for older than younger adults, when the amount of irrelevant information in a stimulus increased incrementally. These findings implicate an age-related slowing in perceptual discrimination and suggest such delays may underlie the failure of older adults to learn or employ optimal strategies to ignore distractors (Rabbitt, 1965). An additional important question is whether age-related slowing in visual discrimination is accompanied by a decline in categorization performance. Measuring categorization performance with a task requiring a complex strategy (i.e., an information-integration learning structure), with and without distraction, could provide an important qualitative measure of performance.

Results from studies that examined age-related changes in categorization performance are divergent whether learning based on an information-integration strategy declines in older adults (Glass, Chotibut, Pacheco, Schnyer and Maddox, 2012; Filoteo and Maddox, 2004), or remains intact at a level similar to younger adults (Mayhew et al., 2010). Previous studies have not considered the impact of distractibility on categorization of morphed prototypes, or whether age-related susceptibility to distraction changes categorization performance based on information-integration strategies.

In order to bring further insight to these divergent findings, we developed complex morphed stimuli that, based on environmentally common prototypes of automobiles and snowboards, tested participants' assessment of category boundaries after integration of 75 to 100 corresponding stimulus dimensions. Critically, the morphed prototype images we used in the distractor condition were identical to the plain condition, with the difference between conditions being the irrelevant grayscale surround information on the distractors. If performance is similar for both older and younger adults with presentation of uncluttered exemplars paradigms, but older adults' categorization is disrupted by the presence of distractors that do not affect relevant stimulus dimensions, then age-related changes in categorization could be attributed in part to increased susceptibility to distraction.

Materials and Methods

Participants

Twenty healthy younger adults between the ages of 20 and 29 years (mean education 15.6 ± 1.2 years, 9 males) who were native speakers of English, and screened to be free from any psychotropic or thyroid medications, gave their informed consent to perform the experimental tasks in return for a small fee. All participants had normal or corrected-to-normal vision. One younger participant's data were excluded from analysis because she fell asleep during one of the test blocks. The final analysis included 19 younger adults. Twenty-three healthy older adults (mean age = 68.5 ± 7.2 years, mean education 14.2 ± 2.1 years, 10 males), who met the same criteria as the younger adults, also participated. One older participant's data were excluded from analysis because her performance on one set of exemplars was at the level of chance. The final analysis included 22 older adults (10 males, mean age = 68.2 ± 7.2 years).

Neuropsychological Testing—All olderAll All older participants were administered 15 standardized neuropsychological tests of executive, memory function and depression, and they were found to be cognitively intact (within two standard deviations) relative to normative values for age-matched controls (Table 1). The neuropsychological evaluation included the following tests: MMSE, geriatric depression (GDS), working memory and verbal learning (CVLT-II), incidental recall (WAIS-R), visual-motor sequencing (DKEFS Trail-Making A and B), executive function (DKEFS Stroop interference test), semantic fluency and phonemic fluency.

Stimuli—Color images of one prototype pair of cars and one prototype pair of snowboards were used in the main experiment (snowboards example in Figure 1). A pre-test orientation session used a pair of beer mugs. The prototype pairs were used to create three category sets of stimuli using FantaMorph© 5 and (Abrasoft Corporation) and Adobe Photoshop© 4.0 software programs. For each of the two experiment categories, 760 exemplar images were morphed at 75 to 100 corresponding and significant features of the category prototypes. The 75 to 100 points selected as morph points fell along the edges of each prototype and at the defining features (i.e., the side-view mirrors and headlights on the cars, or the binding clips and design decals on the snowboards). The morph ratio between prototype pairs ranged from 75:25% to 25:75% in 15 levels, with the smallest ratio at 51%:49%. The smaller the morph ratio, the more ambiguous the exemplar was between prototypes and, therefore, more challenging to categorize correctly. The orientation of the exemplars was equated (e.g., one half of the car exemplars faced to the left and the other half faced to the right). Stimuli were displayed at 768 × 1024 pixel resolution on an LCD computer monitor positioned approximately 60 cm away from the participant. One half of the morphed exemplars in each level were centered on a 10% gray background (i.e., plain condition), and the other half were centered on a grayscale collage composed from fragmented views of the category prototypes (i.e., distractor condition).

Procedure—The main experiment consisted of eight blocks with 36 trials in each block. Blocks were divided evenly between the car and snowboard categories and between plain and distractor conditions. The presentation order of the categories, and the order of two plain and two distractor blocks within each category, were counterbalanced across each group of participants.

Each trial began with a fixation cross, followed by a grayscale mask (500 ms), a side-by-side image of the prototype pair (1000 ms), another grayscale mask (500 ms), a plain or distractor morphed exemplar (1500 ms), another grayscale mask (500 ms), and a response screen (2000 ms). The response screen prompted the participant to make a left button press to indicate categorization of the exemplar with the left prototype, and a right button press to indicate categorization of the exemplar with the right prototype. The participant received on-screen feedback (500ms) reporting “correct,” incorrect,” or “no response detected.” The inter-trial interval, at fixation, was 2500 ms.

An adaptive staircase algorithm adjusted the level of exemplar morph ratio on each trial such that a correct response reduced the ratio presented on the next trial by one level and an incorrect response increased the ratio presented by two levels. Trials without a response detected were calculated as incorrect. The adaptive staircase algorithm with feedback held accuracy constant at approximately 70%. Each block began at the level with the widest range in morph ratio (i.e., 25%/75%), which represented the least categorization difficulty. The succeeding three levels narrowed the morph ratio in 3% increments, and the remaining 10 levels narrowed the morph ratio in approximately 1.5% increments. During creation of the morphed exemplar stimuli, two raters made side-by-side comparisons of exemplars between successive levels to ensure that differences between levels were noticeable. The experiment blocks and practice were presented using E-prime© 2.0.

Analysis—Categorization threshold was the measure of interest for each participant's performance on each experiment block. Categorization threshold was estimated as the morph ratio indicated by the mean of the levels of the final correct and the final incorrect trials in a time-window of interest. Performing at a lower morph ratio, therefore, indicated successfully discriminating more ambiguous stimuli. An initial analysis showed that the lengthy time on task (6 minutes 20 seconds) resulted in deterioration of within-block performance over the final third of trials for the majority of older and many of the younger participants. For older adults, on average, six of the ten final trials resulted in reversals of the stair-cased morph level. For younger adults, on average, four of the ten final trials resulted in reversals. All participants mentioned sensing some degree of eye fatigue in their post-experiment debriefing. The final analysis was limited, therefore, to data from the first 26 trials in each block (i.e., the initial 69% of each block).

Results

Participants' categorization threshold was assessed in terms of the thresholded morph ratio, and performance was compared between groups of younger and older adults using mixed-effects ANOVA that contrasted repeated measures of condition (plain|distractor), block (first|second), and stimulus type (cars|snowboards). A summary of the groups' descriptive statistics is apparent in Figure 2b. A lower morph ratio indicates better categorization ability. The results showed the following main effects: Block, such that categorization improved from the first to the second block collapsed across conditions (F 1,38 = 17.67, $p < 0.001$; mean morph level block 1 = 60.82 ±0.49, and block 2 = 58.94 ±0.50); Age, such that younger adults categorized at a lower morph ratio than older adults (F 1,38 = 4.20, $p < 0.05$; mean morph level younger = 58.97 ±0.6, and mean morph level older = 60.79 ±0.61); and Stimulus type, such that snowboard exemplars were categorized with a lower morph ratio than car exemplars (F 1,38 = 6.24, $p < 0.01$; mean morph level snowboard exemplars = 59.57 ±0.74, and mean morph level car exemplars = 61.79 ±0.98).

An interaction of age × condition (F 1,38 = 4.17, $p < 0.05$) revealed that older adults were more susceptible to visual distraction during categorization than younger adults (Figure 2b). Comparisons between age groups showed no difference in performance in the plain condition ($p = 0.42$; mean morph level younger = 59.33 ±0.73, and mean morph level older = 60.17 ±0.70), but older adults categorized with a higher morph ratio in the distractor condition than did younger adults ($p < 0.01$; mean morph level younger = 58.63 ±0.73, and mean morph level older = 61.41 ±0.70). We further analyzed the basis for this pattern in the results by comparing the mean distractibility index between age groups. An index for each participant was calculated as morph ratio in the distractor condition minus morph ratio in the plain condition, such that a positive value showed a disruptive effect of distractibility (Figure 2c). An independent samples t-test (assuming unequal variances) showed that distractibility during categorization was greater for older than younger adults ($p < 0.05$).

Based on the main effect of block, we followed up with comparisons of group and condition by each block separately. For block 1, the follow-up test showed an interaction of age × condition (F 1,38 = 8.53, $p < 0.01$) such that younger adults performed equally between conditions, yet older adults' categorization was disrupted by distraction (mean morph levels: younger plain = = 60.47 ±0.83, younger distractor = 59.55 ±0.85, older plain = 60.25 ±0.79, older distractor = 63.01 ±0.81). For block 2, the follow-up test showed no interaction, and both groups performed equally between conditions.

Results within the group of younger adults showed a main effect of block (F 1,18 = 11.40, $p < 0.005$), and no main effect of condition (pair-wise t-test, $p = 0.37$). Results within the group of older adults showed a main effect of block (F 1,20 = 6.86, $p < 0.02$) and a strong trend for an effect of condition, such that distractor exemplars were categorized with a higher morph ratio than plain exemplars (F 1,20 = 3.99, $p = 0.06$). Notably, both the younger and the older adults improved performance from block 1 to block 2, showing that categorization learning occurred for both groups of participants. For the older adults, an interaction of condition × block (F 1,20 = 5.69, $p < 0.03$) indicated that categorization improved to a greater degree with successive blocks of distractor exemplars (morph level first block > second block, $p < 0.005$) than with successive blocks of plain exemplars (morph level first block = second block). Overall, 15 of 22 older participants showed disruption from distraction, whereas only 6 of 19 younger participants were distractible.

Discussion

Older and younger adults performed equally well with plain morphed exemplars, but the influence of irrelevant visual information diminished categorization performance for older adults, relative to younger adults. Notably, the morphed prototype images were identical in both the plain and distractor conditions, with the difference between conditions being the irrelevant grayscale surround information on the distractors. Our results revealed the susceptibility of older adults to the negative impact of distraction on categorization of morphed prototype images. The findings suggest, therefore, that older adults' impairment was a reflection of the disruptive influence of distraction on their limited attentional resources, rather than an aging-related decline in categorization performance. These are the first results, to the best of our knowledge, showing the impact of distraction on categorization of morphed prototypes in aging. Our findings, which are based on complex object stimuli, offer broader understanding of age-related changes in categorization performance than previous studies that showed age-related decline in categorization of simple line stimuli without distractors (Filoteo & Maddox, 2004).

Visual categorization is a fundamental capability in higher cognition that involves sharpening the representations of relevant stimulus features in order to accept or reject the value of a stimulus for task goals (Ashby and Maddox, 2005). In the context of categorization performance, sharpening can be thought of as the process that instantiates a sharp boundary between representations of similar stimuli (Freedman et al., 2001). Sharpening the representation of relevant stimulus features depends on reciprocal processes that integrate bottom-up stimulus-driven information, mediated by primary visual regions, with top-down task-specific information, mediated by prefrontal decision-making regions (Freedman et al., 2003; Jiang et al., 2007). As integration of information associated with task goals and visual perception proceeds with practice, learning improves the fidelity of relevant stimulus attributes so that finer and finer discriminations are successful. In this manner, selective visual attention guides improvement of the coherence of goal-relevant representations via-a-vis competing perceptual information (Serences and Yantis, 2006). Visual categorization with images morphed from two prototypes is thought to be particularly demanding on the integration of top-down and bottom-up signals that successively tunes relevant stimulus features (Zeithamova, Maddox and Schnyer, 2008).

We found that distractors did not affect categorization of morphed prototypes for younger adults. This finding revealed that top-down processes engaged to enhance representations of relevant stimulus features during categorization were undisturbed when additional control resources were required to suppress processing of irrelevant bottom-up information during the distractor condition (Lavie & De Fockert, 2005). Interestingly, older adults were just as able as younger adults to categorize morphed exemplars in the plain condition, a finding that is consistent with some other rule-based categorization learning results (Glass et al., 2012; Mayhew et al., 2010; Filoteo and Maddox, 2004). The interaction of age and distraction in the present study, however, showed that concurrent demands to integrate information for categorization processing and to suppress bottom-up influences from irrelevant visual information disrupted performance for older adults.

Our categorization task drove participants to increase sharpening of attributes in the morphed exemplars (Ashby and Maddox, 2011), and this process has been associated with the voluntary focus of visual attention on selective areas within complete object representations maintained in visual WM (Freedman et al., 2002). The ensemble of activity that builds an object representation via the hierarchy of visual perceptual processing has been characterized as a coherence field in interpretations of fMRI results (Serences and Yantis, 2006; Serences et al., 2005). Because categorization in the setting of visual distraction occurs in the presence of additional bottom-up visual information, there may be increased demands on processes that mediate coherence fields and thus diminish the precision of relevant object representations. Our results showing reduced performance for older adults in the distractor condition and no deficit in the plain condition suggest that age-related distractibility during categorization has to do with the cost of interference on sharpening processes, such that discrimination of morphed prototypes suffers. This interference has a disruptive cost for older, but not younger, adults because of the relative limitation in the former group's resources to support concurrent demands on top-down control of visual attention. In the distractor condition, our task engaged top-down control resources to sharpen feature boundaries between category representations and to resolve bottom-up interference from irrelevant information.

Also of interest, our results suggest that age-related distractibility that diminished categorization performance may be minimized after additional practice. Other findings for this sort of practice-based improvement in older adults has been attributed to their slower focus of attention toward resolving fine-grained visual representations of goal relevant stimuli (McCarley, Yamani, Kramer and Mounts, 2012; Becic, Boot and Kramer, 2008). An active direction in examination of age-related changes in top-down control is to determine under which circumstances attentional guidance in older adults remains fully operative or suffers and yields coarser representations (Madden, 2007). Our results contribute to the understanding of this important topic by revealing distractibility during categorization for older adults, as well as a benefit of practice.

It is important to consider another potential interpretation of the findings in our study. Age-related decline in visual processing includes a documented effect on object recognition (Betts, Sekuler and Bennett, 2007; Fahle and Daum, 1997), and, therefore, it is possible that older adults did not perceive the edges of morphed prototypes as effectively in the distractor condition as in the plain condition. We believe this was not likely an issue, however, as the prototypes were morphed using 75 to 100 mostly centralized featural elements in order to avoid rule-based categorization determined by perimeter shape (Ashby & Maddox, 2005).

Categorization is fundamental for visual learning, which is the primary means by which we adapt to the surrounding environment. The natural environment is rife with visual stimuli, some relevant and some irrelevant to our task goals. The current results reveal that visual distraction does not affect categorization performance in younger adults, but disrupts performance for older adults. Moreover, the comparison of results between younger and older adults suggests that age-related distractibility during categorization arises from interference at the locus of coherent object representations rather than a simple deficit in top-down control of visual attention. Further research that examines the neural correlates of perceptual discrimination and age-related alterations is needed to answer the empirical question of how top-down control processes associated with prefrontal and parietal regions are impacted by the influence of visual distraction.

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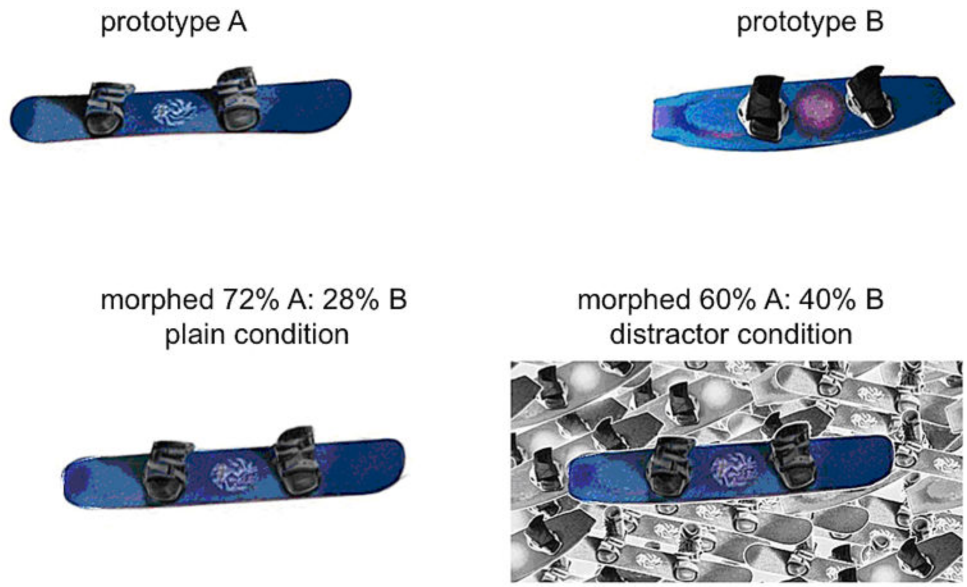

Figure 1. Snowboard prototypes

A and B are shown above examples of two morphs, one presented in the plain condition and the other presented in the distractor condition.

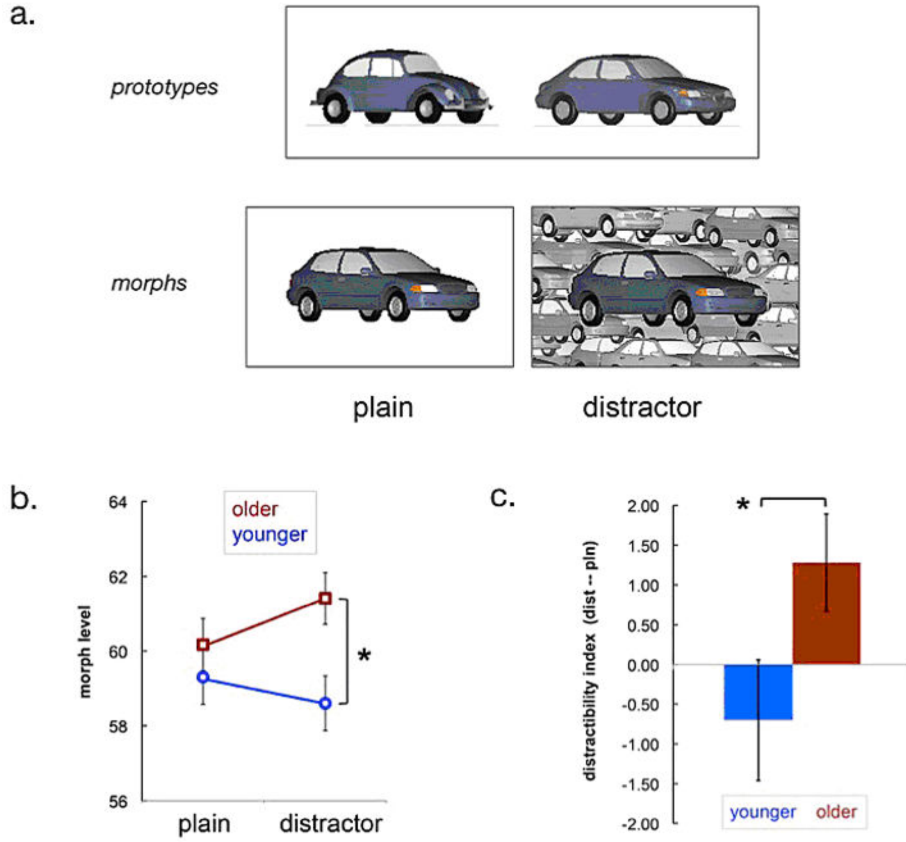

Figure 2.

The procedure (**a.**) presented a side-by-side pair of category prototypes (car stimuli shown), and then an exemplar morphed from the prototypes in blocks of either plain or distractor conditions. Results for the categorization thresholds for groups of older and younger adults (**b.**) showed a main effect of age. Performance by younger adults did not differ between conditions, and the categorization thresholds for older adults showed a strong trended toward decline in distractor, relative to plain. Comparisons between age groups for an index of distractibility (**c.**) revealed that older adults were more susceptible to the negative impact of distraction during categorization than younger adults ($p < 0.05$). Error bars indicate the standard error of the mean; and ***** indicates a difference between means, $p< 0.05$.

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Table 1
Neuropsychological test results for older adults

mean scores for the older adults are shown for the standardized neuropsychological tests (standard deviation) in which each participant scored within two standard deviations of their age-matched normative value. The mean of age-matched normative test values is shown for each test in the right column of the table.

Neuropsychological Test	Mean score	Normative score
Mini-mental state exam	29.2 (1.0)	29
Geriatric depression scale	4.5 (5.2)	<9
CVLT: trial 5 recall	12.6 (2.5)	10
CVLT: short delay free recall	10.9 (2.4)	7
CVLT : short delay cued recall	11.7 (2.2)	9
CVLT : long delay free recall	11.2 (2.2)	7
CVLT : long delay cued recall	11.7 (2.1)	9
WAIS-R: digit symbol (90s)	53.3 (8.7)	47
DKEFS trail making A: numbers	41.3 (15.8)	54 > 59
DKEFS trail making B: numbers & letters	85.8 (37.5)	118 >132
DKEFS Stroop: color naming	31.9 (6.3)	33.5
DKEFS Stroop: reading	23.1 (5.7)	25.5
DKEFS Stroop: interference	56.5 (10.2)	73
Semantic fluency: animals	24.4 (5.3)	21.7
Phonemic fluency (FAS)	50.8 (13.5)	35