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Note

The effect of age on involuntary capture of attention by irrelevant sounds: A test of the frontal hypothesis of aging

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Abstract

The aim of this study was to examine the effects of aging on the involuntary capture of attention by irrelevant sounds (distraction) and the use of these sounds as warning cues (alertness) in an oddball paradigm. We compared the performance of older and younger participants on a well-characterized auditory–visual distraction task. Based on the dissociations observed in aging between attentional processes sustained by the anterior and posterior attentional networks, our prediction was that distraction by irrelevant novel sounds would be stronger in older adults than in young adults while both groups would be equally able to use sound as an alert to prepare for upcoming stimuli. The results confirmed both predictions: there was a larger distraction effect in the older participants, but the alert effect was equivalent in both groups. These results give support to the frontal hypothesis of aging [Raz, N. (2000). Aging of the brain and its impact on cognitive performance: integration of structural and functional finding. In F.I.M. Craik & T.A. Salthouse (Eds.) *Handbook of aging and cognition* (pp. 1–90). Mahwah, NJ: Erlbaum; West, R. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin*, *120*, 272–292].

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Human attention is a limited commodity. Being able to suppress irrelevant information to concentrate on the task at hand constitutes therefore a pivotal cognitive mechanism against distraction. Research has shown that the prefrontal cortex is strongly involved in this important 'filtering' function. Evidence from delayed-response tasks suggests that distraction due to a failure in inhibitory control underpins deficits observed in monkeys (Malmo, 1942) and humans with prefrontal lesions (Chao & Knight, 1995).

The frontal cortex presents an early deterioration with aging, particularly the dorsolateral prefrontal cortex (Raz, 2000; West, 1996). This fits well with evidence demonstrating that older adults show less efficient inhibitory functioning than younger adults in a variety of paradigms (see Hasher, Zacks, & May, 1999 for a review). However, existing studies often use multi-determined paradigms and difficult task instructions, such that young and older adults often show differential baseline performance levels.

In the present study, we tested the prefrontal neuronal loss hypothesis of aging using a well characterized auditory–visual distraction task based on the oddball paradigm (Escera, Alho, Winkler, & Näätänen's, 1998; Escera, Alho, Schröger, & Winkler, 2000; Escera, Yago, & Alho, 2001; Escera, Corral, & Yago, 2002; Escera, Yago, Corral, Corbera, & Nuñez, 2003) to measure the ability of young and older adults to filter irrelevant auditory information. In this cross-modal task, participants are presented with a sequence of visual stimuli (e.g. digits) that they must categorize (e.g. as odd or even) as quickly as possible. Shortly before each visual stimulus, a task-irrelevant sound is presented that participants are instructed to ignore. In the majority of trials, the same sound is repeated (hereafter referred to as standard sound). However, in a small proportion of randomly selected trials, novel sounds are used. The typical finding in this paradigm is a delay in the response to the visual stimulus when preceded by a novel sound compared to the response when preceded

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by the standard sound. This effect results from the temporary and involuntary capture of attention by the distracting sound. Concomitant recordings of event-related brain potentials have revealed the implications of the frontal cortex in the physiological response (MMN and P3a) to the distracting novel sound, as well as in the reorientation of attention towards the primary task after distraction (Escera et al., 1998; Knight, 1984; Schröger, Giard, & Wolff, 2000; Yago, Escera, Alho, & Giard, 2001; Yago, Escera, Alho, Giard, & Serra-Grabulosa, 2003).

In addition to the detrimental effect of aging on frontal attentional networks, research has shown a relative sparing of posterior attentional networks (Greenwood, Parasuraman, & Haxby, 1993; Hartley, 1993; McDowd & Shaw, 2000). Such networks underlie basic attentional functions such as alertness (Posner & Petersen, 1990). Although not routinely measured in previous oddball studies, alertness can be measured in the oddball paradigm by including a silent condition. Alertness is then defined as the speeding of responses in the digit task when each digit is preceded by the standard sound relative to silence. In studies including a silent condition (e.g. Escera et al., 2003; see also Escera et al., 1998), the significant speeding of responses in the presence of the standard sound is interpreted as the use of this sound as a warning to prepare oneself for the upcoming visual stimulus.

There is surprisingly little research on gating mechanisms and aging using the oddball paradigm. The few studies investigating this issue did not report systematic analyses of behavioral data (Fabiani & Friedman, 1995; Fabiani, Friedman, & Chen, 1998; Gaeta et al., 1998), and others presented relevant and irrelevant stimuli within the same sensorial modality (e.g. Gaeta, Friedman, Ritter, & Cheng, 2001). As a result, it is unclear whether aging results in observable behavioral deficits of high-order (i.e. cross-modal) attention mechanisms.

The present study tested a simple hypothesis. If (1) the prefrontal cortex is instrumental in filtering out task-irrelevant information and maintaining the focus of attention on task-relevant stimuli, and (2) aging is accompanied by an early frontal neuronal loss, then older adults should show a deficit in a simple binary categorization task known to involve the prefrontal cortex. However, they should show a relatively preserved alertness, since this aspect of attention is underpinned by posterior regions relatively unaffected by aging.

1. Method

1.1. Participants

Forty-four healthy volunteers with normal hearing and normal or corrected-to-normal visual acuity participated in the study. Half the participants were young adults ($M = 22.227$, S.D. = 3.741, range: 16–29, 15 females, 7 males) and half were older adults ($M = 67.954$, S.D. = 8.875, range: 50–83, 16 females, 6 males). The older adults completed the Mini Mental State Examination (MMSE, Folstein, Folstein, & McHugh, 1975). All older adults scored above the cut-off score for a risk of dementia ($M = 29.391$, S.D. = 1.242). The Mill-Hill vocabulary test (Raven, Raven, & Court, 1988) showed a significant effect of age [$t(42) = 6.293$, $p < 0.001$], reflecting the better performance in the older ($M = 25.609$, S.D. = 3.473) than in the young ($M = 19.491$, S.D. = 2.623) adults.

1.2. Stimuli and procedure

Participants were presented with four blocks of 424 trials each. In each trial, participants had to categorize a random digit (1–8) as odd or even. A fixation cross was visible at the centre of the screen at all times except during the presentation of a digit. The digits were presented in random order but equal probability at the centre of the computer screen for 200 ms in black on a white background, with a viewing angle of approximately 2.6° (participants were seated at approximately 50 cm of the screen).

In three sound blocks, a 200 ms sound was presented 300 ms before the onset of the visual stimulus. In the silent block, the digit was preceded by 300 ms of silence. Participants were told that the sound was a distracter and that they should ignore it. From the onset of a digit, participants had 1200 ms to respond, after which the next trial was automatically initiated after a further 100 ms. In each block, the first 24 trials were treated as warm-up trials and not included in the data analysis.

Two sound conditions were implemented. In the standard condition, the sound was a 600 Hz sinewave tone of 200 ms duration (10 ms of rise/fall times). Trials in this condition represented 90% of the sound trials. In the novel condition (10% of sound trials), we used different environmental sounds, such as those produced by a drill, hammer, rain, door, telephone ringing, etc. (adapted from Escera et al., 1998, 2003). Each sound had a 200 ms duration (including 10 ms rise/fall times), was digitally recorded and low-pass filtered at 10,000 Hz. All sounds were normalized and presented binaurally through headphones at approximately 75 dB SPL. Each novel sound was used only three times across the experiment. Novel sounds were always preceded by at least one trial with a standard sound. Across the 1200 test trials involving sound, 12 novel sounds were used within every successive group of 120 trials to ensure an even distribution of novel sounds across trials.

Participants were tested individually in a quiet room. They were instructed to focus on a fixation cross in the centre of the computer screen and to press one of two keys for odd and even numbers, respectively (the keys to response mapping was counterbalanced across participants), using two fingers from their dominant hand. Instructions emphasized the need for both speed and accuracy. Half the participants completed a silent block followed by three sound blocks (in which novel and standard sound trials were randomized). The remaining participants completed three sound blocks before completing the silent block.

2. Results

The critical dependent measure was response latency, for, unsurprisingly, accuracy levels in the digit categorization task approached ceiling in both age groups (see Fig. 1, bottom panel)[1]. The data was analyzed with regards to the two key constructs high lightened above: distraction and alertness.

A 2 (young versus older) × 3 (silence, standard, novel) ANOVA revealed a general slowing of responses with age, $F(1, 42) = 20.141$, MSE = 10873.18, $p < 0.001$, a main effect of condition, $F(2, 84) = 22.173$, MSE = 632, $p < 0.001$, as well as an age × condition interaction, $F(2, 84) = 5.447$, MSE = 632, $p < 0.01$. Contrast analyses, reported below, were carried out to analyze this interaction with regards to distraction and alertness.

Distraction by irrelevant sounds. The distraction effect was defined as the difference in response times (for cor-

[1] The two age groups produced similar levels of performance, $F(1, 42) < 1$. A significant effect of condition was observed, $F(2, 84) = 3.673$, MSE = 0.0011, $p < 0.05$, reflecting a slightly better performance in the standard condition relative to the silent, $F(1, 41) = 5.744$, $p < 0.05$, and the novel, $F(1, 41) = 5.944$, $p < 0.05$, conditions, while silent and novel trials did not differ from each other, $F(1, 41) < 1$. No age × condition interaction was observed, $F(2, 84) = 1.057$, MSE = 0.0011, $p > 0.35$.

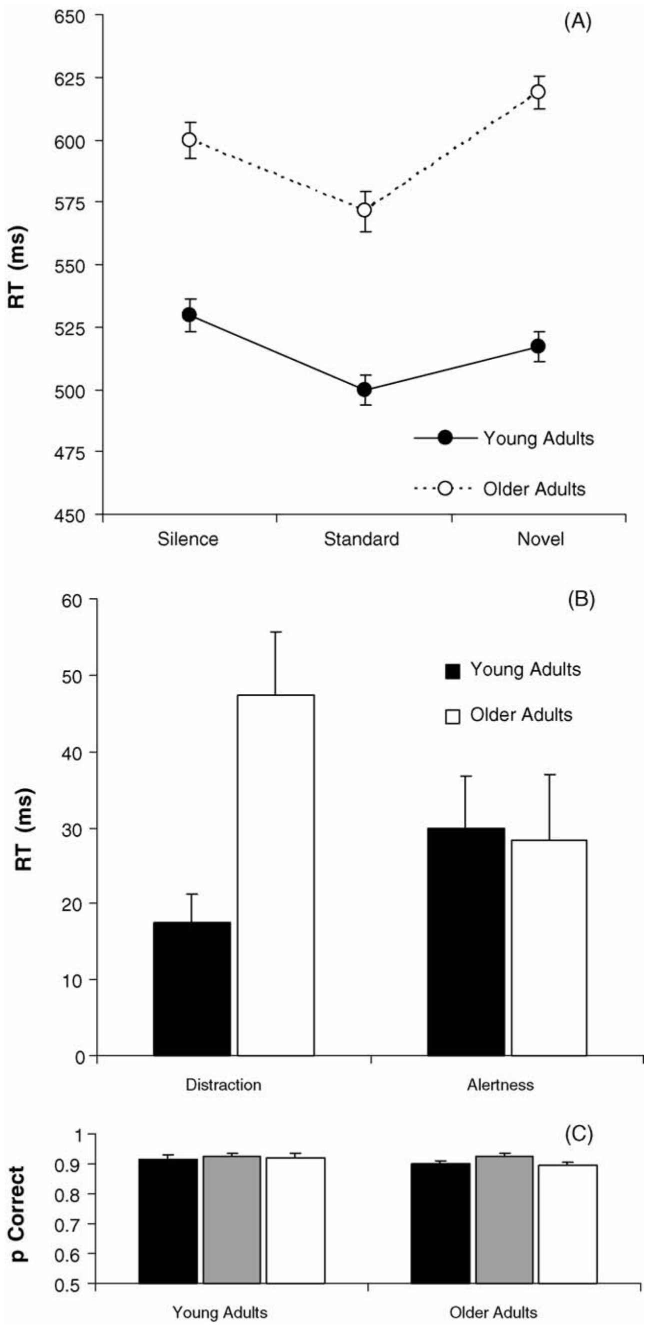

Fig. 1. Performance of young and older participants. Panel A: mean response times for each age group in the three experimental conditions (silence, standard and novel). Panel B: mean alertness and distraction effects for young and older participants. Panel C: mean proportion of correct responses for each age group in the three experimental conditions (silence, standard and novel). Bars represent standard error of the mean.

rect responses) between the novel and standard conditions. Significant effects of distraction were observed for both the younger, $F(1, 42) = 7.527$, MSE = 445.864, $p < 0.01$, and the older, $F(2, 84) = 55.482$, MSE = 445.864, $p < 0.001$. Most importantly, older participants showed a significantly greater sensitivity to distraction than the younger participants (see Fig. 1, panel B), $F(1, 42) = 11.069$, MSE = 445.864, $p < 0.005$. The size of the effect of aging on distraction, as measured by Cohen's d (Cohen, 1988), was 1.03 (large effect).

Alertness. Alertness was measured as the difference in RTs between silent and standard conditions. Both age groups exhibited alertness effects; $F(1, 42) = 15.246$, MSE = 648.346, $p < 0.001$ for the younger participants, and $F(1, 42) = 13.708$, MSE = 648.346, $p < 0.001$ for the older. Importantly though, this effect was equivalent in older and younger adults [$F(1, 42) < 1$, MSE = 648.346, $p = 0.887$].

Distraction versus alertness. In order to contrast the effect of age on alertness and distraction, a 2 (young versus older) × 2 (distraction versus alertness) ANOVA was carried out. Older adults were marginally slower than the young, $F(1, 42) = 3.243$, MSE = 1391.915, $p = 0.079$. No main effect of measure type was observed, $F(1, 42) < 1$. Most critically, a significant interaction was revealed, $F(1, 42) = 6.726$, MSE = 799.099, $p < 0.05$, confirming that older adults are more sensitive to distraction than the young while the two groups show equivalent levels of alertness. The effect size of this interaction, as measured by Cohen's d, was 1.14, which is referred to as a large effect.

3. Discussion

The aim of this study was to test the age-related increase in cross-modal involuntary distraction predicted by the frontal neuronal loss hypothesis of cognitive aging, and to contrast the filtering of irrelevant distracters to another attentional function, namely, alertness. This was achieved using a task known to be sensitive to the capture of attention by sound distracters that young and older adults were able to perform at similar levels of accuracy and involving a gating mechanism controlled by frontal regions. Older adults were more distracted by novel irrelevant sounds than young adults, indicating a relatively larger temporary capture of their attentional resources. Importantly however, both young and older adults were able to use the presentation of sound as a warning cue, indicating similar levels of alertness (see e.g. Greenwood & Parasuraman, 1994; Hartley, 1993, for other reports of age-preserved cueing effects). Given the neuropsychological evidence showing frontal involvement when filtering irrelevant information (distraction; Chao & Knight, 1995; Knight, Scabini, & Woods, 1989) and posterior involvement in response to the standard sounds (alert) preceding the visual stimulus (Posner & Petersen, 1990), these results support the hypothesis that there is an early and selective deterioration of frontal or anterior attentional networks of the brain (Hartley, 1993; Raz, 2000; West, 1996).

There are to our knowledge only two studies reporting both ERP and behavioral data and comparing young and older participants in a unimodal oddball task (Gaeta et al., 2001; Woods, 1992). In these studies, participants engaged in a listening task where targets presented were preceded by irrelevant sounds (repeated or deviant). In addition to overall longer response latencies, older participants exhibited a greater slowing of responses in the presence of deviant distracters relative to standard ones in both studies. The electrophysiological data displayed a reduction in amplitude and a longer latency of MMN and P3 responses, which may reflect the defective control of the focus of attention by the prefrontal cortex. Our data suggest that the greater capture of attention by deviant sounds in these studies can be generalized outside the situation in which participants must perform an attentional segregation within the same modality. One may argue that when distracters and targets are presented in the same modality, participants face a selection problem. In that sense, our task gave participants a better opportunity to shut down a perceptual modality. Another difference with these studies is our use of a silent control condition in order to demonstrate that gating is selectively affected by aging, while alertness is preserved.

The question of interest here is why older participants show a greater attention capture effect. According to Näätänen's (1992) model of attention, the brain is equipped with transient and change detection systems scanning the acoustic environment for unexpected events. Thus, when an unexpected change occurs in a sequence of stimuli and the activation of the change detection system passes a threshold (based on an assessment of the mismatch between the current stimulus and a neural model of previous stimuli), an interrupt message is sent to a frontal centre which in turn triggers the automatic and involuntary orienting of attention towards the deviating stimulus. Within this theoretical framework, our results suggest that older participants exhibit a spared ability to build a neural model of the standard sound; since a failure to do so would lead to a reduction of the attention capture, not an enhancement. In that sense, the memory of the neural model may be preserved in the older participants and this memory may be of a different nature to that required in effortful rehearsal-based memory to which frontal damage or aging are detrimental.

The slowing of response in our older participants is consistent with a large body of literature showing a general slowing in aging (Salthouse, 1996). General slowing does not account for the selective slowing of responses in the novel condition, however. This slowing may rather be explained, by an age-related delay of the frontally-controlled attention interrupt from the comparator mechanism and/or orienting response (c.f. delayed MMN and P3 responses in older participants reported by Gaeta et al., 2001). Another contributor may be a difficulty to redirect attention towards the visual modality. Some possible causes may be a partial failure of the frontal cortex to inhibit the orienting response; or a slower acoustic and/or semantic analysis of the sound which would delay the reorientation of attention toward the visual modality (see Escera et al., 2001, for evidence of a frontal involvement in the orientation and reorientation of attention in the cross-modal oddball paradigm). New electrophysiological research using the cross-modal oddball paradigm is needed to explore these avenues.

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