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Research report

Top-down modulation of visual and auditory cortical processing in aging

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HIGHLIGHTS

- No attentional modulation of auditory cortical processing in younger and older adults.
- Attentional modulation of visual cortical processing does not differ between younger and older adults.
- Suppression of visual distraction during auditory attention is intact in older adults.

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ABSTRACT

Age-related cognitive decline has been accounted for by an age-related deficit in top-down attentional modulation of sensory cortical processing. In light of recent behavioral findings showing that age-related differences in selective attention are modality dependent, our goal was to investigate the role of sensory modality in age-related differences in top-down modulation of sensory cortical processing. This question was addressed by testing younger and older individuals in several memory tasks while undergoing fMRI. Throughout these tasks, perceptual features were kept constant while attentional instructions were varied, allowing us to devise all combinations of relevant and irrelevant, visual and auditory information. We found no top-down modulation of auditory sensory cortical processing in either age group. In contrast, we found top-down modulation of visual cortical processing in both age groups, and this effect did not differ between age groups. That is, older adults enhanced cortical processing of relevant visual information and suppressed cortical processing of visual distractors during auditory attention to the same extent as younger adults. The present results indicate that older adults are capable of suppressing irrelevant visual information in the context of cross-modal auditory attention, and thereby challenge the view that age-related attentional and cognitive decline is due to a general deficits in the ability to suppress irrelevant information.

1. Introduction

Selective attention is a core mechanism for perceptual and cognitive functioning [8], which has evolved out of necessity to restrict limited processing capacity to information that is most relevant to ongoing goals and behaviors [31]. Selective attention requires both the ability to attend to relevant information and the ability to ignore irrelevant information. Top-down modulation subserves selective attention by enhancing cortical responses to relevant information and by suppressing cortical responses to irrelevant information in sensory cortical regions [17,27].

Within the field of cognitive aging, a deficit in the ability to ignore irrelevant information has long been proposed to be the main source of age-related cognitive decline [25,29]. In support of this inhibitory deficit hypothesis of aging, older adults have been shown to be disproportionately affected in tasks that require attending to relevant information while ignoring irrelevant information (e.g., Stroop task, [40]; Simon task, [39]; reading-with-distraction tasks, [9]), an effect that is typically observed as an increase in reaction time or a decrease in accuracy in distraction

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conditions relative to no-distraction conditions, or as enhanced memory for irrelevant information.

In recent years, support for this hypothesis has also been obtained at the level of top-down modulation of sensory cortical processing. In a series of seminal studies, using functional magnetic resonance imaging (fMRI) and electroencephalography (EEG), Gazzaley and collaborators [16,17] demonstrated that older adults enhance visual cortical activity for relevant information to the same extent as younger adults, whereas–unlike younger adults–they are unable to suppress visual cortical activity for irrelevant information at the early stages of visual cortical processing.

Taken together, the aforementioned behavioral and neuroimaging results converge on the notion that selective attention is compromised in older age, such that older adults have a specific deficit in the ability to suppress (the cortical processing of) irrelevant information. Importantly, support for this conclusion has been based almost exclusively on the use of unimodal paradigms, in which relevant and irrelevant information are concurrently or sequentially presented within the same (e.g., visual) modality. To the extent that sensory modality has been neglected in prior research, the view that age-related attentional decline is a general, modality-independent phenomenon has dominated the literature.

Evidence gathered in cross-modal paradigms – in which relevant and irrelevant stimuli are presented in different sensory modalities – has started to unveil distinct patterns of age-related changes in selective attention as a function of sensory modality [22]. On the one hand, some studies suggest that cross-modal selective attention is intact in aging [21,26,30]. On the other hand, an asymmetry in vulnerability to cross-modal distraction with age has been proposed, characterized by age-equivalent performance in visual tasks with auditory distraction but age-related deficits in auditory tasks with visual distraction [23,24].

We have recently started to investigate age-related differences in top-down modulation during cross-modal selective attention by means of EEG [21]. In this study, we adapted the procedure originally developed by [17], so that participants attended to visual stimuli (i.e., faces) and ignored auditory stimuli (i.e., voices), attended to auditory stimuli (i.e., voices) and ignored visual stimuli (i.e., faces), or passively perceived both stimuli. The existence of stimulus-specific event-related potentials (ERPs) for both faces (i.e., N170; [3]) and voices (i.e., "fronto-temporal positivity to voices" occurring in the latency of the P2; [7]) enabled us to probe attentional modulation of visual and auditory cortical processing, as well as age-related differences thereby. This study revealed age-equivalent top-down modulation of sensory cortical processing during cross-modal selective attention, such that both younger and older adults displayed a tendency towards visual enhancement when attending to the visual modality (but no significant cross-modal visual suppression when attending to the auditory modality) and cross-modal auditory suppression when attending to the visual modality (but no significant auditory enhancement when attending to the auditory modality). This study therefore led us to conclude that the age-related top-down suppression deficit that is typically observed during unimodal visual selective attention [18,16] does not seem to extend into the realm of cross-modal selective attention.

The goal of the present study was to further investigate age-related differences in top-down modulation of sensory cortical processing, by presenting a group of younger and older adults with all combinations of visual and auditory, relevant and irrelevant information, while undergoing fMRI. fMRI yields a higher spatial resolution than EEG, enabling us to extract activation levels from different visual and auditory stimulus-selective regions of interest, thereby making it possible to investigate top-down modulation in all combinations of relevant and irrelevant, visual and auditory information. We therefore adapted and extended the paradigm originally developed by [17], by incorporating two auditory stimulus categories that have been proposed to elicit stimulus-selective activations in the auditory cortex, namely voice and music sounds (e.g., [1,41]). Throughout this experiment, younger and older participants performed five tasks with perceptually equivalent stimulus displays, in which the attentional instructions were varied in order to create instances of unimodal and cross-modal, visual and auditory selective attention to specific stimulus categories (Fig. 1). In addition to assessing attentional modulation effects at the cortical level, unexpected post-experiment recognition testing enabled us to assess these effects also at the behavioral level.

Based on the hypothesis that age-related attentional and cognitive decline is due to top-down suppression deficits (e.g., [18,16]), we expected age-equivalent enhancement of sensory cortical processing of relevant information but an age-related deficit in suppression of sensory cortical processing of irrelevant information. Importantly, based on the hypothesis that age-related differences in selective attention are modality dependent [22], we predicted age-related deficits in the ability to suppress sensory cortical processing of visual distraction, but not of auditory distraction. If, however, top-down modulation is age-equivalent during cross-modal selective attention (e.g., [21]; Hugenscmidt et al., 2009; [30]), then older adults should enhance cortical processing of relevant information and suppress cortical processing of cross-modal (visual and auditory) distraction to the same extent as younger adults.

2. Materials and methods

2.1. Participants

Seventeen younger adults (aged 20–29 years, $M = 23.41$, $SD = 2.94$, 7 males) and 21 older adults (aged 60–71 years, $M = 64.81$, $SD = 3.57$, 9 males) participated in this experiment. One younger adult and five older adults were excluded from all data analyses due to excessive head motion (i.e., >3 mm). The final sample comprised 16 younger adults (aged 20–29 years, $M = 23.25$, $SD = 2.96$, 7 males) and 16 older adults (aged 60–71 years, $M = 65.25$, $SD = 3.94$, 5 males). The study was approved by the local ethics committee and, in accordance with the Declaration of Helsinki, written informed consent was obtained from each participant. All participants had normal hearing and normal or corrected-to-normal vision, and were right-handed. Demographic characteristics are presented in Table 1.

2.2. Stimuli

The visual stimuli were those used by Gazzaley and collaborators (e.g., Guerreiro, Cooney, McEvoy, 2005; [18]) and they consisted of grayscale images of faces and natural scenes, which were 225 pixels wide and 300 pixels tall. Both male and female faces were used, although the sex of the face stimuli used within a trial was kept constant in half – rather than in all – of the trials in order to keep task difficulty at an intermediate level.

The voice stimuli consisted of trisyllabic, low-frequency Portuguese words, selected from the Porlex database [20], and spoken by two female and two male native speakers. In addition to selecting lower-frequency words, each word was checked for similarity with the same word in other Romanic languages using Google Translate (Google Inc., Santa Clara, CA), in order to select only words that were considerably different from other Romanic languages. Furthermore, only participants who had no knowledge of Portuguese participated in this study. These procedures were followed to ensure that participants did not semantically process the voice stimuli, but instead relied solely on their phonological