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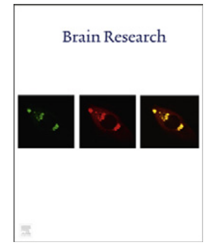

Research Report

Brain activity during auditory and visual phonological, spatial and simple discrimination tasks

Emma Salo[a,b,*], *Teemu Rinne*[a], *Oili Salonen*[c], *Kimmo Alho*[a,d]

[a]*Division of Cognitive Psychology and Neuropsychology, Institute of Behavioural Sciences, University of Helsinki, Finland*
[b]*Advanced Magnetic Imaging Centre, Aalto University School of Science and Technology, Finland*
[c]*Helsinki Medical Imaging Center, Helsinki University Central Hospital, Finland*
[d]*Helsinki Collegium for Advanced Studies, University of Helsinki, Finland*

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ABSTRACT

We used functional magnetic resonance imaging to measure human brain activity during tasks demanding selective attention to auditory or visual stimuli delivered in concurrent streams. Auditory stimuli were syllables spoken by different voices and occurring in central or peripheral space. Visual stimuli were centrally or more peripherally presented letters in darker or lighter fonts. The participants performed a phonological, spatial or "simple" (speaker-gender or font-shade) discrimination task in either modality. Within each modality, we expected a clear distinction between brain activations related to nonspatial and spatial processing, as reported in previous studies. However, within each modality, different tasks activated largely overlapping areas in modality-specific (auditory and visual) cortices, as well as in the parietal and frontal brain regions. These overlaps may be due to effects of attention common for all three tasks within each modality or interaction of processing task-relevant features and varying task-irrelevant features in the attended-modality stimuli. Nevertheless, brain activations caused by auditory and visual phonological tasks overlapped in the left mid-lateral prefrontal cortex, while those caused by the auditory and visual spatial tasks overlapped in the inferior parietal cortex. These overlapping activations reveal areas of multimodal phonological and spatial processing. There was also some evidence for intermodal attention-related interaction. Most importantly, activity in the superior temporal sulcus elicited by unattended speech sounds was attenuated during the visual phonological task in comparison with the other visual tasks. This effect might be related to suppression of processing irrelevant speech presumably distracting the phonological task involving the letters.

1. Introduction

Previous studies on auditory and visual information processing in the human brain suggest that different stimulus features (e.g., pitch, location, color, form) are processed in separate areas of the cerebral cortex. These areas are also assumed to be organized in parallel processing pathways. In the visual modality, two separate systems beginning from the primary visual cortex have been identified: a ventral pathway projecting to the inferior temporal cortex (ITC) and a dorsal pathway projecting to the posterior parietal cortex. These pathways are assumed to use object and spatial information

*Corresponding author at: Division of Cognitive and Neuropsychology, Institute of Behavioural Sciences, PO Box 9, FI-00014 University of Helsinki, Finland. Fax: +3589 191 29481.
E-mail address: emma.salo@helsinki.fi (E. Salo).

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differently (Cardoso-Leite and Gorea, 2010; Farivar, 2009; Goodale and Milner, 1992; Marois et al., 2000; Milner and Goodale, 2008; Mishkin and Ungerleider, 1982). Two parallel processing streams have been identified also in the auditory modality (Arnott and Alain, 2011; Arnott et al., 2004; Kaas and Hackett, 2000; Lomber and Malhotra, 2008; Rauschecker and Tian, 2000; Rauschecker and Scott, 2009; Recanzone and Cohen, 2010; Romanski et al., 1999). The ventral pathway projects from auditory cortex to the inferior frontal cortex and the dorsal pathway to the inferior parietal cortex. Analogously to the visual dual-pathway model, it is widely accepted that these two auditory pathways process object-related (e.g., pitch) and spatial information differently.

Auditory and visual attention-engaging tasks strongly modulate activity observed with functional magnetic resonance imaging (fMRI) in auditory and visual cortices, respectively (Cate et al., 2009; Corbetta et al., 1990; Hall et al., 2000; Kastner and Ungerleider, 2000; Petkov et al., 2004; Reynolds and Chelazzi, 2004; Rinne et al., 2005; Rinne et al., 2009; Schwartz et al., 2005; Smith et al., 2000; Woodruff et al., 1996). Further, different attention-engaging tasks (e.g., discrimination vs. memory) are associated with different modulation patterns (Rinne et al., 2009, Rinne et al., 2012). Thus, in addition to the characteristics of the stimuli (e.g., spatial vs. nonspatial), activations strongly depend on attention (attended vs. ignored) and task requirements (e.g., discrimination vs. memory). However, such effects are often ignored in studies focusing on other aspects of human information processing. For example, some previous studies on spatial processing have contrasted a task condition requiring active spatial processing (e.g., a spatial discrimination task) with a passive condition. In such comparison, it is difficult to tell apart activations associated with processing of spatial features from more general attention or task effects. Moreover, a study interested in nonspatial auditory processing might compare activations to tones varying in pitch and activations to tones with a constant pitch during passive listening but ignore the possibility that participants' state of attention or arousal might be different while they perceive varying stimuli than when they perceive fixed stimuli (Jones and Macken, 1993; Näätänen and Picton, 1987).

In the present fMRI study, we investigated activations during nonspatial and spatial discrimination tasks involving the same auditory or visual stimuli. Participants were presented with concurrent asynchronous streams of spoken syllables and written letters. In six different tasks, they attended either to the auditory or visual stream and performed either phonological, spatial, or a "simple" (speaker-gender or font-shade) discrimination task within the attended modality (Fig. 1). During all tasks, participants' attention was monitored by measuring speed and accuracy of task performance. Two distinct comparisons were used to compare different tasks. First, each task was contrasted with the simple discrimination task of the other modality allowing us to study and compare activations related to three different auditory tasks and three different visual tasks. These comparisons reveal the effect of a certain task, from which the stimulus-dependent effects are removed. Second, direct comparisons between phonological and spatial tasks within both modalities were performed to reveal the differences between nonspatial and spatial processing. The present design also allowed us to compare activations associated with auditory and visual phonological tasks, and those associated with auditory and visual spatial tasks, such direct comparisons not done in previous studies.

We expected, based on previous results, that activity would be enhanced in the auditory and visual cortices during the auditory and visual tasks, respectively, and that there would be activation differences between the phonological, spatial and simple tasks within each modality. We also hypothesized that there would be task-specific overlaps between activations associated with the auditory and visual phonological tasks and between those associated with the auditory and visual spatial tasks.

2. Results

2.1. Performance

Participants successfully performed the demanding tasks during the fMRI. For the reaction times (RTs, Fig. 2 left),

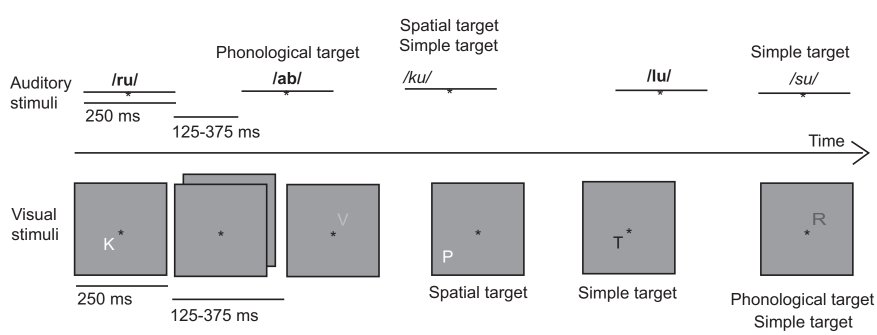

Fig. 1 – Schematic illustration of the auditory and visual stimulus streams. Participants selectively attended to auditory syllables' (consonant–vowel or vowel–consonant) or visually presented letters' phonological, spatial or simple (voice and font) features. In the auditory stream, the targets in phonological, spatial, and voice tasks were syllables starting with a vowel (non-target: syllables ending in a vowel), syllables presented at the lateral left or right loci (central loci), and syllables spoken by female (male) voices. In the figure, female and male voices are indicated in italic and bold font, respectively. In the visual stream, the targets in phonological, spatial, and font tasks were letters with their name beginning with a vowel (non-target: ending in a vowel), letters presented farther off (closer to) the fixation asterisk, and letters with font darker (lighter) than the background. NB: locations of visual stimuli in the figure are not in proportion to the actual stimuli.