Neuropsychologia 51 (2013) 938–949

Contents lists available at SciVerse ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Shape-specific activation of occipital cortex in an early blind echolocation expert

Stephen R. Arnott [a,*], Lore Thaler [b], Jennifer L. Milne [c], Daniel Kish [d], Melvyn A. Goodale [c]

[a] The Rotman Research Institute, Baycrest, 3560 Bathurst Street, Toronto, Ontario, Canada, M6A 2E1
[b] Department of Psychology, Durham University, Durham, UK
[c] Department of Psychology, Western University, London, Ontario, Canada, N6A 5C2
[d] World Access for the Blind is now located in Plancentia, California 92870

ARTICLE INFO

Article history:
Received 22 June 2012
Received in revised form
21 January 2013
Accepted 27 January 2013
Available online 4 February 2013

Keywords:
Auditory
Blind
Echolocation
fMRI
Occipital cortex
Retinotopy

ABSTRACT

We have previously reported that an early-blind echolocating individual (EB) showed robust occipital activation when he identified distant, silent objects based on echoes from his tongue clicks (Thaler, Arnott, & Goodale, 2011). In the present study we investigated the extent to which echolocation activation in EB's occipital cortex reflected general echolocation processing per se versus feature-specific processing. In the first experiment, echolocation audio sessions were captured with in-ear microphones in an anechoic chamber or hallway alcove as EB produced tongue clicks in front of a concave or flat object covered in aluminum foil or a cotton towel. All eight echolocation sessions (2 shapes $\times$ 2 surface materials $\times$ 2 environments) were then randomly presented to him during a sparse-temporal scanning fMRI session. While fMRI contrasts of chamber versus alcove-recorded echolocation stimuli underscored the importance of auditory cortex for extracting echo information, main task comparisons demonstrated a prominent role of occipital cortex in shape-specific echo processing in a manner consistent with latent, multisensory cortical specialization. Specifically, relative to surface composition judgments, shape judgments elicited greater BOLD activity in ventrolateral occipital areas and bilateral occipital pole. A second echolocation experiment involving shape judgments of objects located 20° to the left or right of straight ahead activated more rostral areas of EB's calcarine cortex relative to location judgments of those same objects and, as we previously reported, such calcarine activity was largest when the object was located in contralateral hemispace. Interestingly, other echolocating experts (i.e., a congenitally blind individual in Experiment 1, and a late blind individual in Experiment 2) did not show the same pattern of feature-specific echo-processing calcarine activity as EB, suggesting the possible significance of early visual experience and early echolocation training. Together, our findings indicate that the echolocation activation in EB's occipital cortex is feature-specific, and that these object representations appear to be organized in a topographic manner.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

It is now well recognized that humans, like dolphins and bats, can actively produce sounds in order to acquire echo information that enables them to localize and identify silent objects in their surrounding environment (Schenkman & Nilsson, 2010; Stoffregen & Pittenger, 1995; Teng, Puri, & Whitney, 2012; Teng & Whitney, 2011; Thaler et al., 2011). We have recently reported the first functional brain imaging investigation of active echolocation in humans, showing that the calcarine cortices of an early blind (EB) and a late blind (LB) echolocation expert were activated when they identified otherwise silent objects from echolocation audio recordings (Thaler et al., 2011). Specifically, when lying in a magnetic resonance imaging (MRI) machine and listening to binaural in-ear audio recordings of their pre-recorded echolocation mouth clicks sessions that included echo information, both participants were not only able to identify the silent objects present in the recordings, but their corresponding blood oxygen-level dependent (BOLD) activity was found to increase in auditory and occipital cortices. Most impressively, when this brain activity was contrasted with that related to listening to the same sounds but with the very faint echoes removed, activity in occipital but not auditory cortex remained. The results indicated that the processing of the echo information was being carried out in occipital cortex.

In the present study we wished to further explore EB's echo-related brain activity by examining the functional MRI (fMRI) responses associated with extracting different object features from the same echolocation recordings. For example, to what

* Correspondence to: Rotman Research Institute, Baycrest Centre, Toronto, Ontario, Canada, M6A 2E1. Tel.: +1 416 785 2500x2335.
E-mail address: sarnott@research.baycrest.org (S.R. Arnott).

0028-3932/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.neuropsychologia.2013.01.024

extent does the brain activity differ between different types of object feature processing, e.g. shape, location or material? Moreover, if such feature-specific activations are found, do they occur in cortical regions normally associated with similar types of feature processing within the auditory and/or visual modality?

In sighted individuals, visual form perception is typically associated with increased haemodynamic activity in the inferotemporal and occipito-temporal brain regions (e.g., the lateral occipital complex (LOC), Cant, Arnott, & Goodale, 2009; Grill-Spector, Kourtzi, & Kanwisher, 2001; Haxby et al., 2001; Malach et al., 1995), as is tactile form perception in sighted (Amedi, Malach, Hendler, Peled, & Zohary, 2001; James et al., 2002) and non-sighted individuals (Burton, Snyder, Diamond, & Raichle, 2002; Ptito et al., 2012). Owing to the fact that shape perception tends not to be as conspicuous from sound alone, evidence in favor of auditory-induced form activation of these areas is more equivocal. For example, while some studies investigating LOC activation in response to auditory stimuli have not supported an association (Amedi, Jacobson, Hendler, Malach, & Zohary, 2002), more recent studies in both blind and sighted individuals have, albeit often not without involving extensive auditory-shape training prior to functional imaging (Amedi et al., 2007; James, Stevenson, Kim, Vanderklok, & James, 2011; Kim & Zatorre, 2011; Lewis, Brefczynski, Phinney, Janik, & DeYoe, 2005; Ptito et al., 2012).

Brain regions involved in object localization on the other hand are more clear cut, with visual localization tasks activating regions of the occipital cortex, precuneus and posterior parietal lobe (Ungerleider, Courtney, & Haxby, 1998), and auditory localization tasks predominately activating the inferior parietal lobule as well as the posterior superior temporal sulcus, and superior frontal sulcus (frontal eye fields, Arnott, Binns, Grady, & Alain, 2004). In the blind, sound localization has additionally been found to activate dorsal regions of the occipital cortex (Collignon, Voss, Lassonde, & Lepore, 2009; Weeks et al., 2000). With respect to the processing of an object's surface composition (e.g., whether an object is soft or hard, wood or rock), several visual studies have noted the importance of medial ventral brain areas including the collateral sulcus, inferior occipital gyrus, and posterior parahippocampal area (Cant et al., 2009; Cant & Goodale, 2011; Cavina-Pratesi, Kentridge, Heywood, & Milner, 2010). A proximal region in the posterior parahippocampus has also been found to respond to aurally-conveyed object surface composition (Arnott, Cant, Dutton, & Goodale, 2008).

A secondary question that the topic of feature-specific activation in the blind raises relates to the broader issue in sensory substitution literature concerning how the occipital lobe is colonized by non-visual sensory input, once it is deprived of visual input as occurs in the blind (Collignon et al., 2011). Converging evidence indicates that the age of onset of visual deprivation affects the degree of functional as well as structural brain reorganization that occurs within occipital cortex, with the largest amount of reorganization occurring when sight loss coincides with sensitive periods of neurodevelopment (for a review, see Noppeney, 2007). EB's visual loss at age one year old as well as his active use of echolocation shortly thereafter, certainly coincides with such a sensitive period as the synaptic density in his striate cortex, having reached its apex only months before, would have just started its decade-long process of synaptic pruning (Huttenlocher & de Courten, 1987). It is therefore possible that the functional patterns of echolocation activity within striate cortex may differ depending on when an echolocator lost his or her sight and began to actively echolocate.

To investigate these questions, we present results from two fMRI echolocation experiments in which our echolocating expert, EB performed object feature judgments. In Experiment 1, mouth click 'echolocation' recordings made in front of silent objects of different shapes (flat disc or concave) and covered in different materials (aluminum foil or cotton towel) were presented to EB while he made shape or material judgments of the 'silent' objects based on the echo information in those recordings. In Experiment 2, echolocation recordings made in front of a flat or concave object located 20° to the left or right of straight ahead were presented to EB while he made shape or location judgments. We were particularly interested in determining whether extracting different object features from the exactly the same auditory (i.e., echo) input would activate similar areas of cortex, especially in the occipital lobe, and how this would replicate across different experiments. Finally, in order to get a sense of the uniqueness of EB's functional results with respect to his case history, we present results from two additional blind echolocating experts (CB in Experiment 1 and LB in Experiment 2) who differed from EB in terms of age-of-onset of blindness (i.e., congenital blindness and late blindness) and echolocation history.

Based on our previous work with EB (Thaler et al., 2011), as well as other work on auditory processing in the blind (Amedi et al., 2007), it was expected that echo-specific shape recognition in EB would invoke activity in the ventrolateral occipital areas such as the fusiform gyrus and area LOC. Importantly, this type of activity was expected to be enhanced relative to when EB listened to exactly the same sounds, but was required to extract another object feature such as material properties (Experiment 1) or location properties (Experiment 2), that could only be acquired through the echo processing of the mouth clicks. Moreover, given that EB lost his sight at critical period in his visual development, we were interested to see how activation in his striate cortex would compare to those of a congenitally blind and late blind echolocator.

2. Material and methods

All testing procedures were approved by the ethics board at Western University, and the participants gave informed consent prior to testing.

2.1. Participants

Participant EB was a 45 year-old right-handed male who had his first eye removed at age 7-months followed by his second eye at age 13-months due to retinoblastoma. EB reported normal hearing, and this was confirmed by audiological testing results (Thaler et al., 2011). EB has been using echolocation since "as long as (he) can remember", and continues to use it on a daily basis to navigate as well as to perceive and interact with objects in the world. He produces his echolocation sounds using tongue clicks generated by a quick withdrawal of the tongue tip from the front palate (i.e., oral click, Rojas, Hermosilla, Montero, & Espi, 2009). Prior amplitude measurements (Larson-Davis System 824) of EB's clicks registered intensities between 71 and 74 dB SPL at the ear, dropping to approximately 53.6 and 49.0 dB SPL at distances of 1 m and 2 m respectively.

Control participants CB (Experiment 1) and LB (Experiment 2) were blind individuals who also echolocate on a daily basis, but who did not start (actively or consciously) doing so until later in life. CB was a 44 year-old right-handed male who lost his vision at birth due to retinopathy of prematurity. He did not begin to actively echolocate until approximately age 40 years-old. LB was a 27 year-old right-handed male who lost his vision at age 14 years and who began echolocating approximately three years after that. At the time of testing, all participants were acting as orientation and mobility coaches, teaching the technique of active echolocation to others.

2.2. Echolocation objects

Experiment 1: Four objects were used for generating echolocation stimuli. Each was constructed of wire mesh (wire gauge 0.8 mm; spacing of 4.0 mm^2). Two of the objects were disc-shaped (30 cm diameter), while the remaining two were bowl-shaped (30 cm in diameter, 12 cm depth). One of each unique-shaped object was covered with non-smooth (i.e., crinkled) 'heavy-duty' household aluminum foil material (~0.024 mm thickness), while the remaining two objects were covered with a thin cotton, towel material.

Experiment 2: Two echolocation objects were used. The first was a rigid concave-shaped plastic object approximately 30 cm diameter and 15 cm in depth oriented with the concavity facing the listener. The second was a 12 cm painted

Download English Version:

https://daneshyari.com/en/article/10464874

Download Persian Version:

https://daneshyari.com/article/10464874

Daneshyari.com