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Research report

Electrophysiological correlates of mental navigation in blind and sighted people

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HIGHLIGHTS

- Oscillatory EEG signature of naturalistic navigation in blind and sighted participants differ.
- Functional reorganization leads to stronger activity in the visual cortex in blind than in sighted participants.
- Differences between blind and sighted participants were task-specific and cannot be explained by resting-state EEG or motor imagery performance.

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ABSTRACT

The aim of the present study was to investigate functional reorganization of the occipital cortex for a mental navigation task in blind people. Eight completely blind adults and eight sighted matched controls performed a mental navigation task, in which they mentally imagined to walk along familiar routes of their hometown during a multi-channel EEG measurement. A motor imagery task was used as control condition. Furthermore, electrophysiological activation patterns during a resting measurement with open and closed eyes were compared between blind and sighted participants. During the resting measurement with open eyes, no differences in EEG power were observed between groups, whereas sighted participants showed higher alpha (8–12 Hz) activity at occipital sites compared to blind participants during an eyes-closed resting condition. During the mental navigation task, blind participants showed a stronger event-related desynchronization in the alpha band over the visual cortex compared to sighted controls indicating a stronger activation in this brain region in the blind. Furthermore, groups showed differences in functional brain connectivity between fronto-central and parietal–occipital brain networks during mental navigation indicating stronger visuo-spatial processing in sighted than in blind people during mental navigation. Differences in electrophysiological parameters between groups were specific for mental navigation since no group differences were observed during motor imagery. These results indicate that in the absence of vision the visual cortex takes over other functions such as spatial navigation.

1. Introduction

In sighted people, the visual cortex of the brain located in the occipital lobe is primarily responsible for processing incoming information coming from the visual path of the brain [1]. However, there is evidence that in the absence of visual input this part of the brain takes over other functions [2,3]. For instance, in blind people the primary visual cortex is activated by Braille reading and other tactile discrimination tasks [4–10], somatosensory processing [11], verbal tasks [8,12], and auditory tasks [13,14]. This functional reorganization of the occipital cortex in blind people was interpreted as a form of cross-modal plasticity and may be involved in functional compensation [4,9,15]. The role of the visual cortex in spatial navigation, where blind individuals have to compensate missing visual information for successful navigation through space, is not fully clarified yet. In the present study, we investigated the

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task-dependent functional reorganization of the occipital cortex observed in the blind during mental spatial navigation.

Generally, vision is highly relevant for successful navigation. For instance, salient visual cues or landmarks in the environment serve as reference points to help recognizing paths and spatial locations and enable us to keep track of our movements [16,17]. Nevertheless, blind people are able to move independently in space and have no major problems when localizing and reaching specific targets. There is behavioural evidence that the abilities to recognize travelled routes and to represent spatial information are comparable in blind and sighted individuals [18–24]. Apparently, blind people can compensate the missing visual information by using tactile, auditory, and olfactory cues, as well as motion-related cues arising from the vestibular and proprioceptive systems [21]. For instance, blind people display higher auditory spatial abilities than sighted people in an auditory spatial localization task, which indicates auditory spatial compensation in the blind [14,25–28]. Hence, the absence of visual information is compensated by spatial information obtained via other senses than vision, which might contribute positively to the mental mapping of spaces and consequently, to successful spatial performance [29,30].

Based on the assumption that blind people rely more on idiothetic cues and echolocation as well as on other senses than vision to move about independently in space [20], spatial navigation in completely blind people is thought to involve different brain areas than those engaged in sighted people [21]. In sighted people, functional imaging studies determined key regions for navigation and spatial processing in the hippocampus, the medial and right inferior parietal cortex, parts of the basal ganglia, the parahippocampus and the left prefrontal cortex [17,31–33]. Electroencephalography (EEG) studies showed an increased theta (4–8 Hz) power over fronto-central brain regions during spatial processing [34–36]. In contrast, the neuronal correlates of spatial navigation in completely blind people remain largely elusive.

A few prior neurophysiological studies investigated structural and functional correlates of spatial cognition in the brain of blind people. These studies reported on contradicting results. Differences in brain structure and function associated with spatial tasks between blind and sighted people were found [5,18,24,37–39]. For instance, differences in hippocampal volume [18], differences in activation patterns in the hippocampus and parahippocampus, as well as the occipital cortex [5,24,39], and differences in functional brain connectivity [39] could be observed between blind and sighted controls during diverse spatial tasks. In contrast, some other studies reported comparable brain activation patterns during spatial tasks in blind and sighted people [21,40]. These prior studies that investigated brain correlates of spatial cognition in the blind used rather specific spatial tasks such as tactile navigation tasks using the tongue [21], tactile navigation tasks using the hand [24,38,39], auditory spatial localization tasks [14,27,28], haptic mental rotation [5], visuo-spatial imagery of grid patterns [40], etc. Brain correlates of more 'conventional' spatial navigation tasks, in which blind participants should for instance navigate from a starting point to an endpoint in a specific environment, have not been investigated so far. Therefore, the first aim of the present study was to examine electrophysiological correlates of spatial navigation on familiar routes in blind and sighted people. Participants were instructed to mentally navigate on different well known routes of their hometown. There is evidence that neuronal activation patterns underlying navigation in real and mental space are similar [40,41].

The second aim of the present study was to investigate EEG activation patterns in sighted and blind participants during resting measurements with open and closed eyes. General and unspecific differences in brain structure [2,42,43] and activation patterns [44] between blind and sighted individuals have often been reported in the literature. EEG studies provide strong evidence for difference in EEG frequencies between blind and sighted people during resting conditions [45,46] as well as during sleep [47]. Especially the alpha rhythm (8–12 Hz) is uncommon in the blind [45,46,48]. One explanation for reduced or even missing alpha rhythm in the blind may be that this rhythm is generally due to the spontaneous beat of neurons in the occipital cortex usually dedicated to activities connected to visual feature processing. In sighted individuals, neurons in the occipital cortex discharge spontaneously at a fixed rate when the visual area is unoccupied. This yields in increased alpha power for instance during an eyes-closed resting condition. In contrast, when vision is lost, the visual area does not remain unoccupied and therefore has to become more accessible to incoming information from the rest of the brain [45,48]. Although there is evidence of abnormalities in the alpha rhythm in the blind, it is assumed that blind people generally show alpha oscillations in the EEG (see [45] for a review). Note that prior studies demonstrating differences in the EEG activity during resting measurements between blind and sighted individuals were performed towards the middle of the 20th century [45,46,48], except for one recent study using magnetoencephalography (MEG) [49]. Recent EEG studies primarily focused on differences in EEG activation patterns between blind and sighted individuals during different tasks [5,39,50] indicating reduced alpha power in the EEG of blind participants [50].

In the present study we investigated possible differences in EEG activation patterns (absolute and relative power) between blind and sighted participants during resting measurements as well as during mental navigation on familiar routes. We hypothesize that blind and sighted participants show different EEG activation patterns during rest, particularly in the alpha rhythm [45,46,48,50]. According to the literature, sighted participants should generally show more pronounced EEG alpha activity than the blind [50]. Regarding the mental navigation task, we expect that in comparison to sighted participants, blind participants should show an increase in activity in occipital brain areas during a spatial task. In line with the evidence that blind people rely more on tactile and auditory cues during navigation [3,20,21] and also based on the findings that the visual cortex of blind people takes over tactile and auditory processing [3], we hypothesize that the visual cortex of blind people is also involved in spatial cognition. Furthermore, we investigated possible differences in functional brain connectivity during mental navigation between blind and sighted individuals. Although there is some evidence for differences in connectivity measures between blind and sighted people [39], this analysis is explorative. To investigate the specificity of brain activation patterns in blind and sighted people during mental navigation, we also performed a motor imagery task as a control condition. When increased activation in the visual cortex is specific to the spatial task in the blind, no differences in brain activation patterns between groups should be observed during the motor imagery task.

2. Material and methods

2.1. Participants

Eight blind adults (4 male, 4 female) recruited through local institutions for the blind took part in this study. The age of the blind participants ranged from 27 to 64 years (M = 45.75 yrs., SE = 5.34 yrs.). All blind participants were completely blind. Detailed description of the blind participants can be found in Table 1. In all cases, blindness was due to an inherited degenerative eye disease (Retinitis Pigmentosa) (N = 4), detached retina (N = 1), Nervus Opticus Atrophy (N = 2), or Glaucoma (N = 1). Preliminary analysis revealed no significant differences in EEG activation patterns between congenitally blind participants and participants who became blind