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Reduced EEG alpha activity over parieto-occipital brain areas in congenitally blind adults

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Abstract

Objective: Goal of the present study was to compare the amplitude and topography of EEG alpha activity between congenitally blind and sighted adults both in a primarily sensory and a primarily cognitive task.

Methods: Congenitally blind and blindfolded sighted adults performed a somatosensory perception task (experiment 1), which required to discriminate tactile stimuli at different fingers, and a mental imagery task (experiment 2), in which a previously haptically encoded map had to be mentally scanned. The EEG was recorded with 61 electrodes and was analyzed with the Fast Fourier Transformation (FFT).

Results: Results showed a significant reduction of alpha power in the blind compared to the sighted controls over parieto-occipital recording sites in both tasks.

Conclusions: It is speculated that brain structures, which have been associated with the generation of posterior alpha rhythms in sighted adults, including the geniculo-cortical pathway, depend on visual input and might either be reorganized or atrophied following blindness from birth.

Significance: The present study demonstrates that oscillatory activity of the brain might serve as a marker of cortical reorganization.

Keywords: Alpha activity; Blindness; EEG; Neuroplasticity; Spatial imagery; Tactile discrimination

1. Introduction

There is increasing evidence that the loss of sight elicits neuroplastic changes not only in brain areas primarily associated with the intact sensory systems and in multimodal brain areas but also brain structures primarily associated with the deprived visual system (for a review see Bavelier and Neville, 2002; Röder and Rösler, 2004). Studies using electrophysiological methods and brain imaging techniques as functional magnetic resonance imaging (fMRI) or positron emission tomography (PET) have reported a higher activation of ‘visual’ brain areas in blind humans compared to sighted controls in non-visual tasks including auditory and tactile stimulus discrimination (Burton et al., 2004; Röder et al., 1996; Sadato et al., 2004), Braille reading (Büchel et al., 1998; Burton et al., 2002; Sadato et al., 1996), auditory localization (Gougoux et al., 2005; Röder et al., 1999; Weeks et al., 2000), language processing (Burton et al., 2003; Röder et al., 2002), memory (Amedi et al., 2003; Raz et al., 2005) and mental imagery (De Volder et al., 2001; Röder et al., 1997). It has been suggested that this additional activity reflects crossmodal reorganization supporting enhanced performance in the blind (e.g. Sadato et al., 2002). This notion is supported by studies employing transcranial magnet stimulation (TMS), i.e. a method that makes it possible to transiently change the functionality of a circumscribed cortical area (e.g. Cohen et al., 1997; Hamilton and Pascual-Leone, 1998; Wittenberg et al., 2004; Zangaladze et al., 1999). For example, Cohen et al. (1997) demonstrated that repetitive transcranial magnet stimulation (rTMS) of the occipital

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cortex of early blind individuals disrupted Braille reading abilities as well as reading of embossed Roman letters while not having any effects on tactile performance in sighted controls. However, occipital TMS did not only interrupt Braille letter perception in the blind but also verb generation (Amedi et al., 2004). Therefore, it was suggested that the occipital cortex of the blind is generally involved in higher-order cognitive functions (Pascual-Leone et al., 2005).

Earlier EEG studies examined the frequency content of blind people's spontaneous EEG. While Berger (1929) did not report any differences between sighted and blind adults, others claimed quite consistently, that alpha waves were reduced or even missing in the blind, predominantly over posterior recording sites (Adrian and Matthews, 1934; Birbaumer, 1971; Enge et al., 1973; Noebels et al., 1978; Novikova, 1974). Novikova (1974) analyzed individuals of varying degrees of blindness and demonstrated a correlation between the alpha reduction and the remaining visual acuity. Moreover, the onset and duration of blindness predicted the decline of alpha activity in the blind. Rockstroh et al. (1989) suggested that the alpha activity and the amplitude of slow negative potentials are negatively correlated. Therefore, the reports on reduced posterior alpha activity in the blind fit very well with EEG studies that had found enhanced negative slow waves over the occipital brain of blind people (e.g. Röder et al., 1997; Rösler et al., 1993). Moreover, a reduction of the alpha band activity at a right central electrode for blind compared to sighted adults has more recently been reported during sleep by Bértolo et al. (2003).

However, to our knowledge, the alpha reduction in blind-born humans has never been investigated with high density EEG recordings, which allow a more precise localization of group differences in the alpha activity between sighted and blind adults. Thus, one goal of the present study was to gain more detailed knowledge about the topography of group differences in the alpha activity in the EEG by using multichannel EEG.

A second goal of the present study was to separately examine the upper and lower alpha frequency range, because there is evidence that they are linked to different functions (Klimesch et al., 1993, 1994; Rösler, 1975). Moreover, Fast Fourier Transformation (FFT) was applied to the EEG data, an analysis tool not used at the time when most of the cited studies were conducted.

In most of the published studies on alpha activity in the blind, the EEG was recorded during a rest condition. This setting has a major disadvantage: the mental state of the participants is not controlled resulting in between participant variance that might cover group differences. We used data of two experiments that had previously been conducted in our laboratory: the first experiment employed a tactile discrimination paradigm, the second experiment investigated mental spatial imagery. Both experiments differed markedly in the processes activated: while experiment 1 involved sensory processing (triggered by external stimulation transmitted via thalamic activity to primary somatosensory areas), experiment 2 comprised a complex cognitive task of endogenously driven spatial imagery (associated with the parietal cortex). Analyzing EEG from both tasks allowed testing whether or not group differences in the alpha band are task specific (third goal). A task specificity would imply a functional significance of cross-modal plasticity.

2. Methods

2.1. Experiment 1

2.1.1. Participants

Nine congenitally blind adults took part in experiment 1 (5 female, 8 right-handed, 1 ambidextrous, mean age: 22.1 years, range 20–29 years). They were either totally blind ($n=7$) or had only rudimentary brightness sensations without pattern vision ($n=2$). In all cases, blindness was due to peripheral defects (retinopathy of prematurity ($n=5$), inherited eye disease ($n=1$), nervus opticus atrophy ($n=1$), nervus opticus hypotrophy ($n=1$), detached retina ($n=1$)). The control group consisted of 11 volunteers with normal or corrected to normal vision (5 female, 11 right-handed, mean age: 22.8 years, range 19–26 years). All participants had no history of neurological illness. Informed consent was obtained and all participants received monetary compensation or course credits. The experiment was performed in accordance with the ethical standards laid down in the Declaration of Helsinki (2004).

2.1.2. Materials

Tactile stimuli consisted of low electrical pulses (duration: 1 ms), which were applied to all 10 fingers with brass electrodes. The anode and the cathode were fixed at the proximal and distal phalanx at each finger, respectively, with a distance of 3 cm. Fingers were separated by cotton pads. Metallic bracelets were attached to both wrists for electrical grounding. Hands rested with a distance of 50 cm on a pillow that was placed on a table in front of the participants. The stimulus intensity was individually adjusted by the participants, so that they perceived them as just not painful. Electric stimuli were generated by a specially constructed multiple inductive stimulus generator, which was controlled by a computer. Two classes of stimuli were delivered: frequent standard stimuli (80%), which were perceived as a single pulse, and rare deviants (20%) that were double stimuli with a short ISI of 150 ms.

2.1.3. Procedure

Participants were instructed to attend to a certain finger (either the right or the left index finger or the little finger of the right hand) and to respond to deviants at the attended finger (targets, $P=2\%$) by pressing a foot pedal. The attention condition (which finger was task relevant) was