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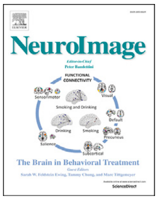

Neurophysiological evidence for enhanced tactile acuity in early blindness in some but not all haptic tasks

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ABSTRACT

Previous research assessing the presence of enhanced tactile skills in early-blind (EB) population obtained conflicting results. Most of the studies relied on behavioral measures with which different mechanisms leading to the same outcome go unnoticed. Moreover, the scarce electrophysiological research that has been conducted focused exclusively on the processing of microgeometric properties. To clarify the extent of superior tactile abilities in EBs using high-density multichannel electrophysiological recordings, the present study compared the electrophysiological correlates of EBs and sighted controls (CON) in two tactile discrimination tasks that targeted microgeometric (texture) and macrogeometric (shape) properties. After a restricted exploration (haptic glance), participants judged whether a touched stimulus corresponded to an expected stimulus whose name had been previously presented aurally. In the texture discrimination task, differences between groups emerged at ~75 ms (early perceptual processing stages) whereas we found no between-group differences during shape discrimination. Furthermore, for the first time, we were able to determine the latency at which EBs started to discriminate micro- (EB: 170 ms; CON: 230 ms) and macrogeometric (EB: 250 ms; CON: 270 ms) properties. Altogether, the results suggest different electrophysiological signatures during texture (but not shape) discrimination in EBs, possibly due to cortical reorganization in occipital areas and their increased connectivity with S1.

1. Introduction

Neural and behavioral consequences of blindness are still under debate. On one hand, visual deprivation is related to the atrophy of elements of the visual system (Pan et al., 2007; Noppeney et al., 2005) which may lead to perceptual maladjustments in the remaining modalities, in particular those with spatial components (e.g., audition and touch). Since localization tasks in these senses benefit from visual calibration, it has been observed that blind Braille readers tend to mislocate tactile stimuli (Sterr et al., 2003) and perform worse in sound localization tasks (Lewald, 2002). Moreover, unsighted children underperform in haptic orientation discrimination (Gori et al., 2010) and auditory spatial tasks (Gori et al., 2013; Vercillo et al., 2016; Cappagli et al., 2017). On the other hand, it is assumed that a sensory deficit will lead to enhanced abilities when using the spared senses as a consequence of cortical reorganization in regions associated with the spared modalities as well as in areas initially responsible for the absent sense. In this line, superior performance of EBs compared to sighted individuals has been described in grating orientation tasks (Van Boven, Hamilton, Kauffman, Keenan and Pascual-Leone, 2000; Goldreich and Kanics, 2003), vibrotactile perception (Wan et al., 2010), 2D-angle differentiation tasks with a predefined exploration (Alary et al., 2008) and discrimination of surfaces with raised dots (Alary et al., 2009). However, other studies assessing the presence of enhanced tactile skills in EB population obtained alternative results. EBs were not found to outperform in orientation discrimination of gratings, vibrotactile perception, discrimination of braille-like dot patterns (Alary et al., 2009; Grant et al., 2000) or smoothness judgments with active or passive exploration (Heller, 1989).

Several authors point to individual differences in the use of exploratory strategies and to task-specific effects as an explanation for the discrepant results obtained by the previous studies. Even considering that the natural strategies for acquiring somatosensory information about texture and shape are *lateral motion* and *contour following* (Lederman and Klatzky, 1987), a brief haptic exposure without active exploration

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(termed 'haptic glance'), (Klatzky and Lederman, 1995) is enough to identify previously presented stimuli eliminating individual differences in the exploration. Likewise, a superior performance of EBs in certain tactile tasks is not mandatorily associated with possessing enhanced skills in all the tasks pertaining to the haptic modality. Taking into account that tactile object recognition seems to depend on parallel information processing of micro- (e.g. texture) and macrogeometric attributes (such as shape) (Bohlhalter et al., 2002), it is plausible that EBs show different abilities in the processing of micro- and macrogeometric properties. Differences between blind and sighted population in the preferred sensory modality to encode each type of property support this idea, since vision is the dominant sense to encode shape-relevant information in sighted population while both sighted and EBs use haptics to encode texture-related information (Lederman and Klatzky, 1987; Lederman et al., 1996).

Importantly, former studies investigating the presence of superior somatosensory abilities in EBs relied almost exclusively on behavioral measures and up to present, very few researches have analyzed the neurophysiological correlates of tactile processing in EBs. Brain electrical activity (assessed by event-related brain potentials, ERPs) may contribute in the clarification of the results for various reasons. First, plasticity mechanisms may be present at multiple levels (e.g. molecular, neural or behavioral). Thus, superior tactile abilities (such as a higher speed of somatosensory processing in EBs compared to sighted) may be identified at the neurophysiological level despite not leading to different performance between groups. Second, neurophysiological data can provide temporal and topographical information of events assessing differences in the mechanisms underlying haptic discrimination in each group as well as identifying the processing stage at which EBs process tactile information distinct to sighted.

Seminal work investigating haptic processing in blind population using electrophysiological measures revealed that blind individuals presented shorter latencies in the somatosensory N1 event-related potential (ERP) component during a tactile oddball task with Braille-like dotted patterns (Roder et al., 1996). This result suggests a more efficient processing of information in the blind group in this modality. However, this research pooled together early- and late-blind participants, whose neural development has been seen to vary moderately between them since the extent of cortical reorganization depends on the timing of the onset of blindness (Voss et al., 2010; Merabet and Pascual-Leone, 2010). In addition, results obtained in a tactile spatial attention task determined that EBs differed between attended and non-attended vibrotactile stimuli 6 ms earlier than sighted population as indexed by the peak amplitude of the P100 component (Forster et al., 2007). To note, the stimuli used in the former electrophysiological studies focused on microgeometric properties and no research has yet focused on the tactile processing of macrogeometric properties in EBs, in order to compare the processing of both types of attributes.

The purpose of the present study was to investigate for the first time whether a group of EBs and sighted participants showed similar electrophysiological correlates in two haptic discrimination tasks targeting microgeometric (texture) and macrogeometric (shape) properties. Importantly, the use of high-density multichannel EEG recordings (64 locations) permitted a more precise delineation of cortical activity compared to previous work. Furthermore, restricted exploratory procedures have enable to control for individual differences in the exploratory procedures. In line with previously reported results, we expected the EB group to show a reduction in the time required for texture discrimination, whereas we hypothesized that such temporal advantage could be reduced in the shape discrimination task (possibly due to the use of supplementary visual mechanisms in sighted controls).

2. Materials and methods

2.1. Participants

14 early blind (EB) (7 women, mean ± SD, age $= 35.7 \pm 10.9$ years) and 15 sighted controls (CON) (9 women, mean age $= 29.3 \pm 9.0$ years) took part in the experiment. The two groups were matched by age ($p = 0.1$) and years of education ($p = 0.8$). With the exception of one blind subject with well managed epilepsy, no subjects had neurological disorders. The inclusion criteria for the EB group included right handedness, less than 10% of visual residual abilities (as determined by ONCE standards for visual acuity and visual field), blindness onset before 5 years of age (the age at which synaptic density in the visual cortex reaches adult levels) (Johnson, 1997) and the ability to avoid blinks and to control eye movements for 3 s. The latter requirement was the most exclusive criterion and 8 EB subjects could not participate in the study due to it. The EB group was heterogeneous with respect to the degree of Braille reading and light perception level. Blindness of cerebral origin was an exclusion criterion (see Table 1 for further demographic information). Three congenitally blind participants were excluded from the ERP analysis and two of them were also excluded from the behavioral analysis. EB4 was only removed from the ERP analysis due to excessive muscular artifacts. She performed the tasks correctly so she was included in the behavioral analysis. EB10 was rejected from both the ERP and the behavioral analyses due to residual abilities to read with a very high contrast and magnifiers, despite reporting 3% of residual visual abilities. EB14 was also removed from both the ERP and the behavioral analyses because he did not perform the shape discrimination task for time reasons and consequently, we could not test differences between tasks. The experiment was undertaken with the understanding and written consent of each participant and was approved by the local ethics committee in accordance with the declaration of Helsinki.

Table 1

Demographic characteristics of early blind participants and control samples. The 'LP' column indicates whether the subjects have light perception. The 'onset' and 'duration' columns refer to the age of blindness onset and the duration of blindness until present (years). 'Education' represents the years of education. 'Braille duration' refers to the years spent reading Braille. 'Hrs/week Braille' details how many hours a week the subjects dedicate to Braille reading (at present). EB = Early blind, Con = sighted controls. M = Male, F = Female.

	Age & Gender	Cause of blindness	LP	Onset	Duration	Education	Braille duration	Hrs/week Braille
EB 1	24 M	Congenital glaucoma & retinal detachment	No	0	24	14	19	0
EB 2	30 F	Microphthalmia & Congenital cataracts	Yes	0	30	15	25	1
EB 3	28 F	Premature retinopathy	Yes	0	28	22	24	1
EB 4	30 F	Congenital glaucoma	Yes	0	30	12	26	0
EB 5	31 F	Leber's congenital amaurosis	Yes	0	31	19	25	3
EB 6	46 F	Atrophy of the optic nerve	No	1.5	44.5	23	41	6
EB 7	29 M	Bilateral retinoblastoma	No	4	25	24	24	10
EB 8	53 M	Atrophy of the optic nerve	No	0	53	7	37	1
EB 9	35 F	Bilateral retinoblastoma	No	4	31	20	30	1
EB 10	35 F	Bilateral retinoblastoma	Yes	1	34	19	–	–
EB 11	23 M	Premature retinopathy	No	0	23	20	19	0
EB 12	52 F	Bilateral retinoblastoma	No	0	50	36	47	14
EB 13	43 M	Premature retinopathy	Yes	0	43	19	38	40
EB 14	19 M	Bilateral retinoblastoma	No	0	19	16	15	1
Con	29 (±9) 9F	–	–	–	–	20 (±4)	–	–