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Effect of reading on blood flow changes in the posterior cerebral artery in early blind and sighted people — A transcranial Doppler study☆

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ABSTRACT

Background: Neuroimaging studies proved that Braille reading resulted in visual cortex activation in blind people, however, very few data are available about the measure of flow increase in these subjects. Therefore, we investigated the flow response in the posterior cerebral artery (PCA) of eleven early blind and ten sighted subjects induced by reading Braille and print, respectively.

Methods: Two experimental protocols were used in both groups: PCA flow velocity during reading was compared to the resting phase and "NLC" phase (volunteers "read" non-lexical characters; e.g. .,-.:,-.:...,). The use of these experimental protocols allowed to investigate separately the effect of "light stimulus + print reading" versus "print reading alone" in sighted, and "hand/finger movement + Braille reading" versus "Braille reading alone" in blind subjects.

Results: The flow response in the PCA evoked by "Braille reading alone" in blind (10.5 ± 4.5%) and "print reading alone" in sighted subjects (8.1 ± 3.5%) was similar. The flow increase induced by "hand/finger movement + Braille reading" and by "Braille reading alone" did not differ in blind people, however, "light stimulus + print reading" in sighted subjects caused higher PCA flow increase (25.9 ± 6.9%) than "print reading alone" (8.1 ± 3.5%).

Conclusion: The similar PCA flow response induced by Braille and print reading alone suggested a similar degree of occipital cortex activation in blind and sighted subjects. In sighted people, the 3-times higher flow velocity increase induced by "light stimulus + print reading" compared with "print reading alone" indicated that 2/3 of PCA flow increase during reading was due to the light stimulus and only 1/3 of flow response was caused by reading alone.

1. Introduction

There has been an increasing interest in the function of the occipital cortex in blind people for the last three decades. Functional MRI and PET studies detected activation of the visual cortex in blind subjects during Braille reading [1–5], as well as non-Braille tactile discrimination tasks [6–10]. These experiments proved that blind individuals during somatosensory stimuli such as Braille reading and other tactile discrimination tasks used areas of the cerebral cortex normally served for processing visual input. Moreover, more pronounced activation of the visual cortical areas was found during tactile discrimination tasks in blind people than in sighted controls [2,4,6,7–10].

Although the adequate method of reading is reading Braille in blind and reading print in sighted people, to our best knowledge only one study [5] compared the effects of adequate reading methods on the visual cortex activation in blind and sighted groups. In contrast, most studies investigated only the effect of tactile discrimination tasks on the visual cortex activation in both blind and sighted subjects. Furthermore, a number of articles are available reporting the absolute or relative measure of flow increase in the occipital cortex of sighted people during visual stimulation (reading print, or photic or checkerboards stimulation) [11–24]. However, similar results can hardly be found in blind people during reading Braille [2,4], because instead of reporting the absolute or relative flow response in the activated regions, the activation of the visual cortex induced by tactile stimulus was mostly shown by statistical parametric maps in PET and fMRI studies [1,3,5]. On the one hand this is a correct statistical method, but on the other hand it does not provide information about the measure of flow increase as a result of activation. Moreover, previous PET and fMRI studies investigating the effect of Braille reading on the occipital cortex activation used different tasks such as word discrimination [2,4], letter discrimination [5], verb generation [3] instead of free reading.

Based on the available data, while Sadato et al. demonstrated about 8–10% increase of the visual cortex flow during Braille reading (word –

☆ The study was performed at the Department of Neurology, University of Debrecen.

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non-word discrimination) in blind people [2–4], the flow changes, depending on the visual stimulation methods and the investigation techniques, were between 15 and 68% in sighted subjects [11–24].

Our aim was to investigate the effect of reading on the flow response evoked by occipital cortex activation in blind and sighted people. Since the blood supply of the occipital region is ensured by the posterior cerebral artery, we measured the flow velocity changes in the PCA in blind subjects while reading Braille and in sighted subjects during reading print. Flow velocity data were detected by transcranial Doppler, which is an accepted method to assess the flow increase induced by occipital cortex activation [25]. Although the spatial resolution of the TCD is poor, it has an excellent temporal resolution and allows free reading, and thus a direct comparison of the effects of adequate reading methods in the blind and sighted groups.

In the present study, we aimed i) to examine whether significant flow increase could be detected by TCD in the PCA in blind subjects during reading Braille, ii) to determine separately the effect of light stimulus and effect of reading alone on PCA flow changes induced by reading print in sighted subjects, and iii) to compare the flow response in the PCA evoked by reading print in sighted to reading Braille in blind people. To answer these questions we applied two experimental protocols in both the sighted and blind groups, which allowed to investigate separately the effect of "light stimulus + print reading" and "print reading alone" in sighted, and the effect of "hand/finger movement + Braille reading" and "Braille reading alone" in blind subjects.

2. Subjects and methods

2.1. Subjects

Eleven healthy congenitally or early blind adults (8 males, 3 females, mean age: 23 ± 5 years) and 10 age- and sex-matched healthy sighted subjects (7 males, 3 females, mean age: 22 ± 4 years) were included in the study. The study was approved by the Regional and Institutional Ethics Committee, Clinical Center, University of Debrecen, Hungary, as well as by the National Scientific and Ethical Committee, Hungary. Each volunteer gave a written, informed consent. Cerebrovascular risk factors such as smoking habit, arterial hypertension, obesity (body mass index), diabetes mellitus (fasting glucose levels), and hyperlipidemia (levels of total cholesterol, LDL, HDL), as well as history of migraine, coronary or peripheral artery diseases were screened, and subjects with risk factors were excluded. The included subjects did not take any medicine regularly. The study protocol included a complete neurological examination, carotid artery and vertebral artery duplex, transcranial color-coded duplex, and routine clinical laboratory tests (serum ions, blood urea nitrogen, creatinine, fasting glucose, hepatic enzymes, creatine-kinase, haemostasis screening test, serum lipids and inflammatory markers, capillary blood gases and pH). Blood was drawn after overnight fasting between 8 and 10 a.m.

Blind subjects were early blind having no sight at birth or by 5 years of age. They were blind as the result of peripheral lesions, but otherwise they were neurologically normal. Blindness was caused by retinopathy of prematurity (8/11), congenital glaucoma (2/11), and primary retinal degeneration (1/11). All but one of the blind subjects were right-handed, although 8 of 11 blind volunteers included in our study used both hands to read Braille (they followed the line with the right index finger and recognized the Braille signs with the left one). All blind subjects denied light perception, and visual-evoked-potential examination did not reveal any detectable signal. All blind volunteers started Braille reading between the ages of 6–8 years and read Braille at least 1 h a day. In sighted subjects normal vision was confirmed by neurological and ophthalmological examinations, moreover, they had normal visual-evoked-potential parameters. All sighted people were right-handed.

Besides neurological, ophthalmological, carotid and vertebral artery duplex examinations, and transcranial color-coded duplex imaging, all volunteers underwent functional TCD (fTCD) and visual-evoked-potential (VEP) investigations.

2.2. Functional TCD and VEP investigations

The fTCD tests were performed in the morning in a quiet room at about 22 °C while the subjects were sitting comfortably. All volunteers had abstained from caffeine overnight before the study. TCD examinations were always performed by the same examiners (L.O., S.V.).

Two 2-MHz probes were mounted by an individually fitted headband. In all cases, the P2 segment of the PCA was insonated through the temporal cranial window on both sides at a depth of 58–60 mm. The procedure of finding and identifying the vessels followed the description of Fujioka and Donville for the transtemporal approach [26]. In order to be sure that the PCA was insonated the position and depth of the PCA were checked by transcranial color coded duplex ultrasound before the fTCD study. Peak systolic, mean, and end-diastolic blood flow velocities were recorded with a Multidop T2 Doppler device (DWL, Überlingen, Germany). The reason for the separated evaluation of systolic, mean, and end-diastolic blood flow velocities was that the indices showed different time courses in dynamic blood flow regulation. Being less influenced by Doppler artefacts [27], the peak systolic velocity index was used for the following analysis. The other reason for the use of the peak systolic flow velocities in the present study was that this flow parameter reflected most appropriately the dynamic flow regulation [28].

As a stimulation paradigm, we used an emotionally neutral text that the volunteers could read freely. This "reading" test had been previously validated in sighted subjects against a checkerboard stimulation paradigm [25]. The stimulation protocol consisted of 10 cycles with a control phase of 20 s and a stimulation phase of 40 s for each cycle. Certainly, sighted subjects read print, while blind people read Braille text during the stimulation phase. The print and Braille texts were identical.

Beat-to-beat intervals of cerebral blood flow velocity data were interpolated linearly with a "virtual" time resolution of 10 ms for averaging procedures. Within one person, flow velocity data of 10 cycles were averaged. To ensure independence from the insonation angle and to allow comparisons between volunteers, absolute data were transformed into relative changes of cerebral blood flow velocity in relation to baseline. Baseline was calculated from the blood flow velocity averaged for a time span of 5 s at the end of the control phase, before the beginning of the stimulation phase. To analyze the maximum increase of relative flow velocity changes, the highest of the relative values obtained during the stimulation phase was taken from each subject. Relative flow velocities were expressed in percent of baseline.

After recording the PCA flow velocity changes, the position of the TCD probes was changed to detect the flow parameters in the middle cerebral artery (MCA) [26], and the same experimental protocols were repeated as for the PCA flow velocity measurement. Recording of MCA flow velocity changes was necessary to determine nonspecific effects during the experiment.

Half an hour after the fTCD examination, visual-evoked-potentials (VEP) were also investigated over the occipital cortex (Neuropack, Nihon Kohden Corporation, Tokyo, Japan) and amplitudes and latencies of P100 waves were calculated.

2.3. Experimental design

Two experimental protocols were used in both the sighted and blind groups (Fig. 1). In one of the two experimental protocols (Sighted/Rest-Reading protocol), sighted subjects were instructed to close their eyes for 20 s without doing or thinking about anything during the control period (Rest). After this 20-second period they opened their eyes and read an emotionally neutral text silently for 40 s during the stimulation phase (Reading print text). In the other experimental protocol (Sighted/NLC-Reading protocol), sighted volunteers were asked to "read"