Increased olfactory bulb volume and olfactory function in early blind subjects

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It has been shown that the volume of the olfactory bulb (OB) changes with function. The aim of this study was to investigate whether the OB volume and the olfactory function in early blind (EB) subjects increase compared with controls. Psychophysical testing of olfactory performances and OB volumetric measurements assessed by an MRI scan were studied. Quantitative olfactory function expressed in the odor discrimination and odor-free identification scores was higher in EB subjects compared with controls. The mean of right, left and total OB volume was 65.40, 75.48, and 140.89 mm^3, respectively for the EB subjects and 54.47, 52.11, and 106.60 mm^3, respectively for the controls, with these differences being significant. EB subjects have superior olfactory abilities and presented with significantly higher OB volume than the sighted controls. OB plasticity may explain this compensatory mechanism between visual deprivation and enhanced olfactory perception. ***NeuroReport*** **21:1069–1073 © 2010 Wolters Kluwer Health | Lippincott Williams & Wilkins.**

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Introduction

The olfactory bulb (OB) is the first relay in which olfactory information is processed, playing a key role in the human olfactory function [1]. Recently, it has been shown that the volume of the OB changes as a function of olfactory performances and training; therefore, MRI scan-based volumetric measurements of the OB have received much interest [2–6]. In a clinical setting, OB volume may also 'physiologically' increase as shown in subjects with chronic rhinosinusitis recovering from their olfactory loss after a surgical procedure [7].

Early blind (EB) subjects develop enhanced abilities in the use of their remaining senses to compensate for their lack of vision, hypothetically because of a cross-modal reorganization of deafferented visual brain circuitry to process nonvisual information such as sounds or tactile stimuli [8–10]. These higher abilities are speculated to result more from improved perceptual function than from enhanced sensory function. Better performance of EB subjects has also been shown when exploring higher cognitive functions such as auditory memory and attentional tasks [11]. Besides the usual observation of cross-modal reorganization of the occipital cortex, an increasing number of studies report intramodal brain changes in the auditory and somatosensory cortices [12–14]. Compared with other senses, current knowledge about the sense of smell in EB subjects has received scarce attention. Few behavioral studies yielded contradictory results showing that subjects with congenital blindness would not perform differently from sighted controls in odor detection threshold and main basal chemosensory tasks, [15–17] but would generally perform better when olfactory identification tasks require higher-level cognitive ability, for example, in the free-identification or in a semantic task [18–20]. Thus far, as earlier investigational studies yielded contradictory results and non-unequivocal conclusions, we investigated the volume of the OB to determine whether structural changes were consistently present in EB subjects and related to better olfactory performances.

Materials and methods

Subjects

This study was carried out in 10 EB subjects and 10 sighted healthy controls matched for age, sex, and handedness. EB subjects were all affected by total blindness (absence of light perception) as a result of bilateral ocular or optic nerve lesions from birth or within 2 years after birth. They had no history of normal vision and had no memory of visual experience. Except for blindness, all subjects were healthy without olfactory disorder and without medical history of neurological or psychiatric problems. They provided written informed consent before entering the study.

Psychophysical testing with odor discrimination and free identification tasks

Sighted controls were blindfolded during the evaluation. The olfactory capabilities were assessed using a set of 30

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commercially available vials containing microencapsulated granules of odorants selected by a perfumer (*http://www.sentosphere.fr*). When opened, each bottle diffused a fragrance of flower, fruit, plant, or domestic element. Birhinal stimulations were presented to the controls with the vial placed approximately at 2 cm in front of both nostrils at a supra threshold level. An odor discrimination task and an odor-free identification task were used to assess the olfactory abilities [20]. Each trial in the discrimination task consisted of a presentation of a pair of odors, which were constituted pseudorandomly. The controls were asked to smell each stimulus of the pairs and to determine whether the second odor was the same or different with respect to the first one. Thirty pairs of odors were presented and the total number of correct responses provided the odor discrimination score. The odor-free identification task consisted of a set of 30 odorant vials, one by one in a sequential presentation. For each trial, the controls were asked to smell the odorant and to name it if recognized (free identification). The total number of correct responses provided the odor-free identification score.

Olfactory bulb volume

The controls were examined on a 3-Tesla MRI system (Achieva, Philips Healthcare, Best, The Netherlands) with an eight-channel phased array head coil. A T2-weighted fast spin-echo sequence specifically dedicated to the analysis of the OB was performed with the following parameters: time of repetition = 2066 ms, time of echo = 80 ms, echo train length = 13, slice thickness = 1.5 mm with no gap, field of view = 160×130, acquisition matrix = 340×273 (in plane resolution = $0.47 \times 0.48\,mm^2$) and reconstruction matrix = 512×512 (in plane resolution = $0.31 \times 0.31\,mm^2$), number of signal average = 4, and acquisition time = 5 min 51s. The 23 slices were placed in a coronal plane perpendicular to the cribriform plane and covered the middle segment of the basifrontal area. OB volume was calculated by planimetric manual contouring on each slice on which it was present in the coronal plane and the surfaces were multiplied by the 1.5-mm thickness of slices to obtain a volume in mm^3. Measurements were taken twice by two observers. When the volumes showed a difference of more than 10%, a third observer took the third measurement. The mean of these measurements was calculated and included into the database as the definitive volume to be used for statistical analyses.

Statistical analysis

All statistical analyses were carried out using the Medcalc Software Release 9.1 [Medcalc Software Mariakerke (Belgium)] [21]. The significance level threshold was at a P value of less than or equal to 0.05. The Kolmogorov–Smirnov test was used to assess the normal distribution of ages in both the groups to be compared. Psychophysical scores and OB volumetric measurement values were submitted to an independent samples t-test. One-way analysis of variance was used to test age as a co-factor in EB subjects and controls. Pearson correlation coefficients between volumetric measurements of OB and free-identification scores were calculated.

Table 1 **Descriptive statistics of the results of olfactory testing and measurements of OB volume, between controls and EB subjects**

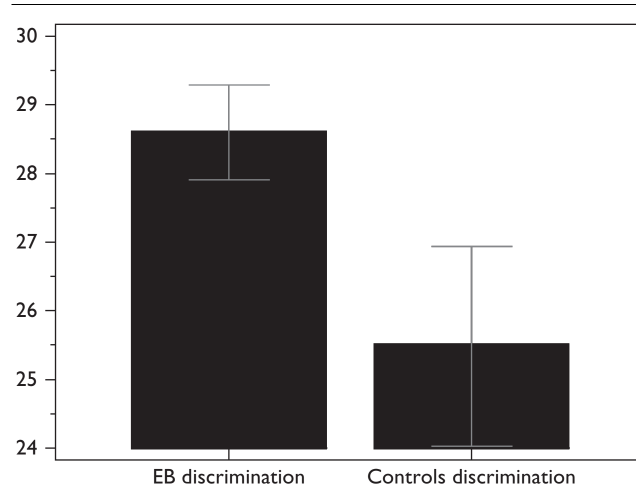
	Minimum	Maximum	Mean	SD
OB volume right (cmm) Controls	42.16	66.60	54.47	6.84
OB volume right (cmm) EB subjects	49.14	80.85	65.40	10.59
OB volume left (cmm) Controls	44.99	60.70	52.11	5.75
OB volume left (cmm) EB subjects	58.03	88.92	75.48	10.21
OB volume total (cmm) Controls	92.16	127.07	106.60	10.04
OB volume total (cmm) EB subjects	107.17	169.87	140.89	18.47
Free identification score Controls	4.0	8.0	6.4	1.51
Free identification score EB subjects	10.0	16.0	13.0	1.94
Discrimination score Controls	21.0	28.0	25.5	2.01
Discrimination score EB subjects	27.0	30.0	28.6	0.96

EB subjects, early blind subjects; OB volume, olfactory bulb volume.

Results

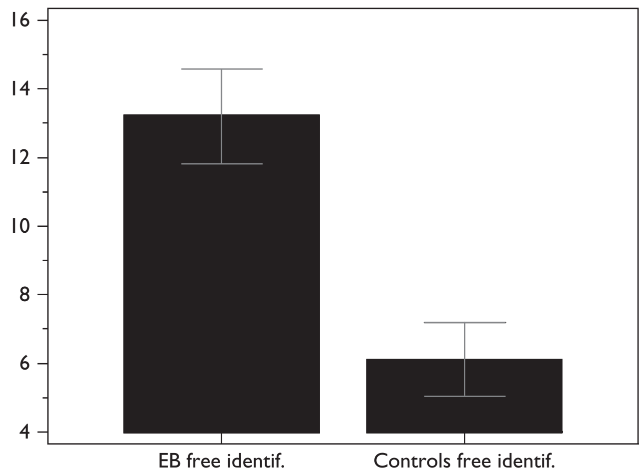
A total of 10 EB subjects and 10 controls were included in the analysis. Age distribution was mean age of 39.5 years (range: 23–57 years) in the EB group and 38.9 years (range: 22–55 years) in the control group. The Kolmogorov–Smirnov test rejected the hypothesis that the two groups were significantly different in terms of age and confirmed

Fig. 1



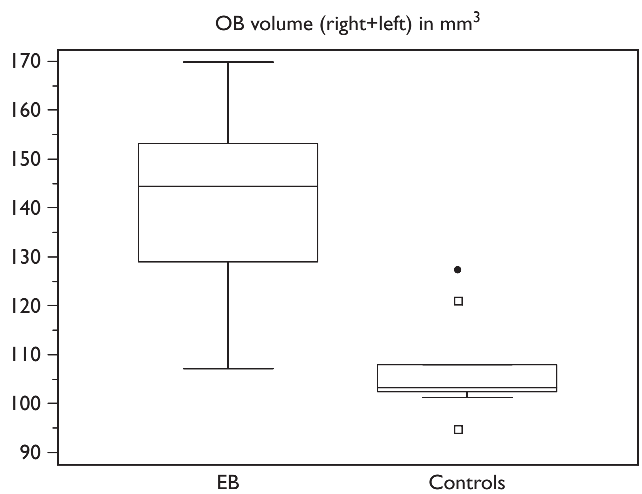
Data from discrimination task from early blind (EB) subjects and controls.

Fig. 2



Data from free-identification task from EB subjects and controls.

Fig. 3



Box and whisker plots of total (right + left) olfactory bulb (OB) volume between EB subjects and controls.

that the samples were equivalent ($D = 0.32$, $P = 0.11$). Independent samples *t*-test showed that the EB subjects had superior abilities in the discrimination task: 18 degrees of freedom, *t*-test statistic -4.389, two-tailed probability and a P value equal to 0.004; and the in free-identification task: 18 degrees of freedom, *t*-test statistic -8.489, two-tailed probability, and a P value less than or equal to 0.0001 (Table 1; Figs 1 and 2). The mean of right, left, and total OB volumes was 65.4, 75.5, and 140.9 mm^3, respectively, for EB subjects and 54.5, 52.1, and 106.6 mm^3 for controls (Table 1). The difference between the sample mean OB volume (right + left) in EB subjects and the controls was 34.3 mm^3, with a 95% confidence interval from 20.3 to 48.3 mm^3; the *t*-test statistic was -5.16 with 18 degrees of freedom and an associated P value equal to 0.0001 (Fig. 3).

The ANOVA with both groups (EB and C) and age as factors showed no significant effect of the age [$F(19) = 0.983$; $P = 0.544$] on the OB volumes. The correlation between total OB volume and free-identification score did not reach statistical significance.

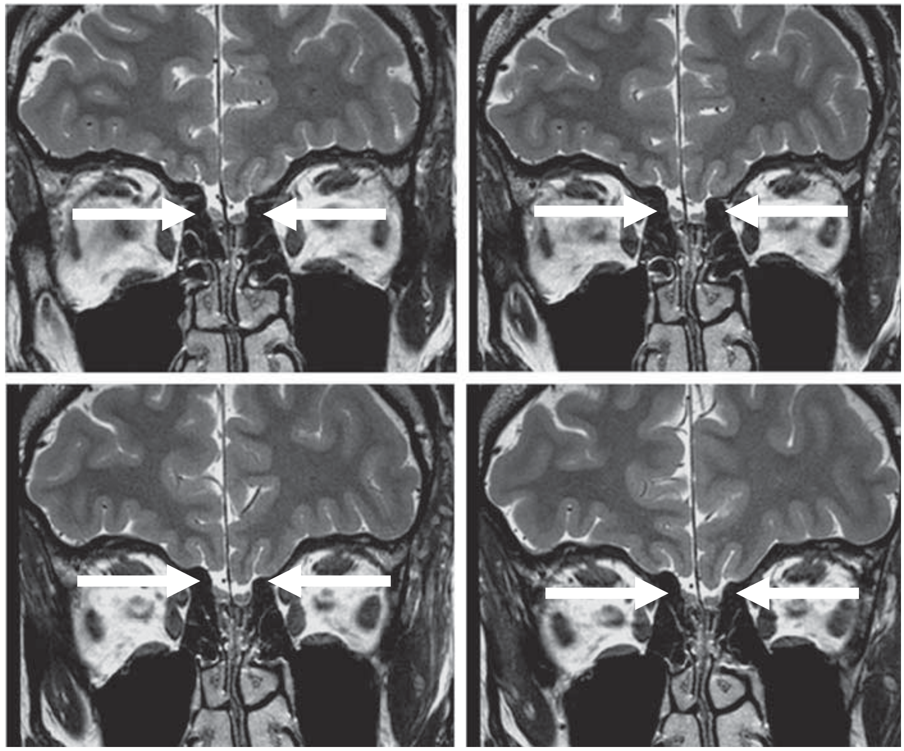
Discussion

This study suggests that EB subjects have larger OB volume as measured by an MRI scan compared with paired sex and age in sighted controls (Figs 4 and 5) and that the free-identification and odor discrimination tasks yielded higher scores in EB subjects compared with the controls. Although based on a relatively small, but carefully selected study population, as in most behavioral and morphological studies in EB subjects, this study highlighted the increase in the OB volume in male EB subjects. This result is consistent with the earlier morphometric studies reporting that although regions along the visual pathways are atrophied in EB subjects, some regions outside the occipital cortex may be hypertrophied, suggesting widespread compensatory adaptations [22,23].

Behavioral compensations are generally thought to reflect practice-related perceptual adjustments and attention strategies that are usually performed by EB subjects to contribute to an accurate representation of their environment. One may hypothesize that EB subjects would pay more attention to nonvisual cues, including olfactory ones, and might process olfactory information more efficiently than sighted individuals. When explored with complex olfactory identification tasks or tasks including higher-level cognitive process, such as semantic memory for odors [20], the EB subjects outperformed their age-matched controls. This study has shown that larger OB volumes correlate to higher olfactory performances and that morphological and behavioral conditions play a synergistic role in this adaptative mechanism.

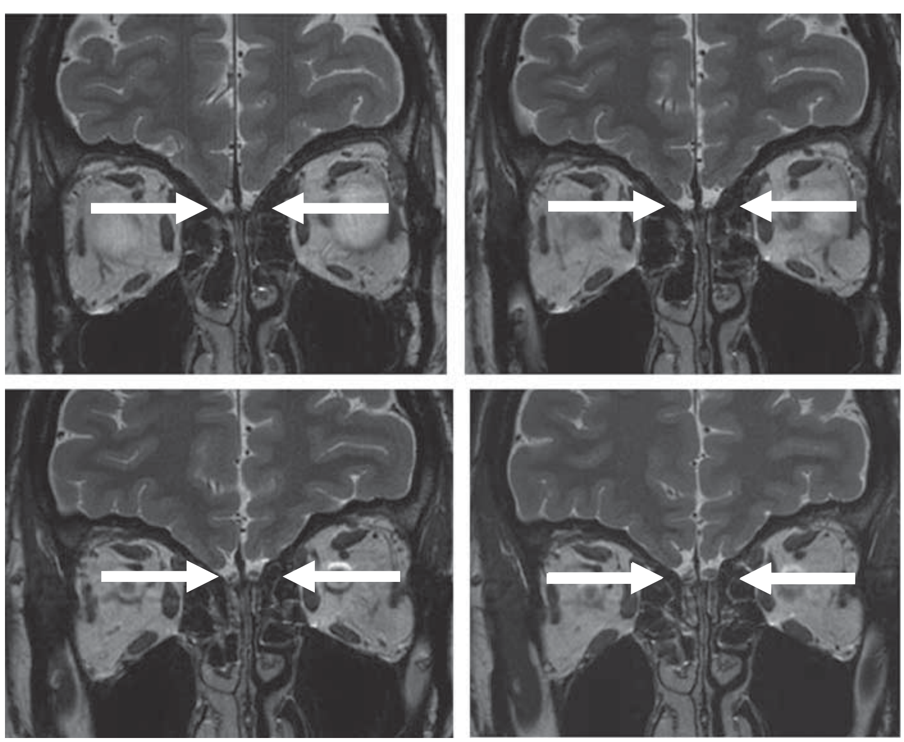
OB volume was shown to be decreased in many clinical conditions and this volume loss correlated with the reduced olfactory performances of the subjects when explored by both psychophysical and electrophysiological testing [4–6]. Posttraumatic olfactory disorder, postinfectious olfactory loss, and sinonasal-related olfactory dysfunction were studied in various subject cohorts showing that loss of function was related to a decrease of volume at the level of the OB [3,6]. This is likely because of a disruption of sensory inputs from the peripheral chemoreceptors to the OB, leading to a decreased number of olfactory neurons. In contrast, dynamic changes in the OB volumes have also been shown after a better transmission of olfactory stimuli in the olfactory cleft (after an endoscopic sinus surgery for

Fig. 4



Coronal T2 sequence magnetic resonance imaging scans (MRI) showing OB (arrows) with increased size in EB subject (from anterior to posterior).

Fig. 5



Coronal T2 sequence MRI scans showing normal OB volume (arrow) in a healthy individual (sighted) (from anterior to posterior).

subjects with chronic rhinosinusitis) or simply after a period of several months after the initial injury, showing that the OB may exhibit a certain degree of plasticity [7,24]. In a reverse way, one may hypothesize that positive reinforcement of olfactory cues processing during daily life is present in EB subjects as a compensatory mechanism of which indirect proof is given by the present OB volume measurements.

In conclusion, neuroimaging techniques allowed us to show that the EB subjects have an increased volume of the OB compared with the controls. This might explain better performance in odor-free identification and discrimination tasks, which are considered as high-level tasks for olfactory perception. Reorganization of deafferented visual brain areas, which has already been observed for auditory and tactile processing, may also be present in EB subjects supporting their better olfactory performances shown here. EB subjects may be regarded as a unique cohort of subjects with 'functional' increased OB volume inversely mirroring many subject cohorts with olfactory deprivation in which the OB volume is decreased.

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