"Do People Who Became Blind Early in Life Develop a Better Sense of Smell? A Psychophysical Study"

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Do People Who Became Blind Early in Life Develop a Better Sense of Smell? A Psychophysical Study

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Abstract: Using a set of psychophysical tests, we compared the olfactory abilities of 8 persons who became blind early in life and 16 sighted persons in a control group who were matched for age, sex, and handedness. The results indicated that those who became blind early in life developed compensatory perceptual mechanisms in the olfactory domain that involve basic sensory processes, such as the detection of odors.

The study of persons who became blind early in life (hereafter those with early-onset blindness) has found evidence of the functional reorganization of the deafferented visual cortical areas (for a review, see Bavelier & Neville, 2002; Pascual-Leone, Amedi, Fregni, & Merabet, 2005). This cross-modal reorganization is usually associated with the emergence of behavioral compensations that lead these persons to develop superior abilities in the use of their remaining senses (Gougoux, Zatorre, Lassonde, Voss, & Lepore, 2005). Numerous behavioral studies in the auditory and tactile domains have provided evidence of the enhanced performance of persons with early-onset blindness compared with sighted persons in control groups. For instance, those with early-onset blindness showed greater abilities in the localization of sound (Lessard, Pare, Lepore, & Lassonde, 1998; Röder et al., 1999; Voss et al., 2004), the discrimination of pitch (Gougoux et al., 2004), memory and selective attention involving words (Amedi, Raz, Pianka, Malach, & Zohary, 2003; Röder, Rösler, & Neville, 2000), nonverbal stimuli (Röder & Rösler, 2003; Stevens & Weaver, 2005), haptic perception (Heller, 1991), the discrimination of texture (Van Boven, Hamilton, Kauffman, Keenan, & Pascual-Leone, 2000), the recognition of raised-line letters (Bliss, Kujala, & Hämäläinen, 2004), and the detection of grating orientation (Goldreich & Kanics, 2003, 2006). These behavioral compensations generally reflect practice-related changes in perceptual functions and attention strategies that are relevant for people who are blind in everyday activities. However, some behavioral studies have yielded conflicting results in terms of the performance levels of nonvisual tasks (see, for example, Grant, Thiagarajah, & Sathian, 2000; Lewald, 2002; Zwiers, Van Opstal, & Cruysberg, 2001).

Although hearing and touch have been investigated thoroughly in individuals who are blind, knowledge of the sense of smell in this population is clearly minor. However, one may hypothesize that individuals with early-onset blindness rely more extensively on their olfactory sense than do those who are sighted. For example, in the absence of vision, the sense of smell has an increased ecological value for the evaluation of the quality of food and the detection of odors that yield information about the environment (Ferdenzi, Holley, & Schaal, 2004). Furthermore, the ability to focus on relevant olfactory stimuli may be useful for mobility and for the identification of persons and places. However, the results of behavioral studies have diverged with respect to the performance of persons with early-onset blindness on various olfactory tests. Although some studies have shown that individuals with early-onset blindness do not perform differently from those who are sighted in odor-threshold and simple chemosensory tasks, such as the discrimination of odors (Diekmann, Walger, & Von Wedel, 1994; Schwenn, Hundorf, Moll, Pitz, & Mann, 2002; Smith, Doty, Burlingame, & McKeown, 1993), other studies have provided evidence that persons with early-onset blindness outperform age-matched sighted persons in more complex tasks of olfactory identification, such as free identification (Cuevas, Plaza, Rombaux, De Volder, & Renier, 2009; Murphy & Cain, 1986; Rosenbluth, Grossman, & Kaitz, 2000), particularly when semantic aspects are involved (Wakefield, Homewood, & Taylor, 2004).

The contradictory results in previous psychophysical studies could be due to methodological differences, such as the profiles of the participants (for example, the causes and ages of the onset of blindness and for how long the participants were blind), the nature of the stimuli, and the tasks that were used. Some studies have included indiscriminately both participants with late-onset and those with early-onset blindness (Schwenn et al., 2002; Smith et al., 1993), although the performance of participants with late-onset blindness is similar, in most instances, to that of blindfolded sighted participants because compensatory mechanisms are less pronounced than in those with early-onset blindness (Burton & Mc Laren, 2008). The purpose of the study presented here was to investigate the potential effect of early blindness on olfactory abilities. Using standardized psychophysical tests, we tested whether persons with early-onset blindness develop enhanced olfactory abilities to compensate for their lack of vision.

Materials and methods

Participants

The study was conducted with 8 men with early-onset blindness (aged 20–55, mean $\pm$ *SD*: 37.4 $\pm$ 13.1) and 16 sighted men in a control group (aged 20–58, mean $\pm$ *SD:* 36.9 $\pm$ 11.9, $p > .05$). Each participant who was blind was matched for age, sex, handedness, and educational level to two sighted participants in the control group. We decided to test the early-onset blind group against a larger group of control participants to benefit from a better "normative database" for the group comparison. Only men were involved in the study, to limit the variability that is due to uncontrolled confounding factors that are specific to women. Women usually outperform men in olfactory tests (Brämerson, Johansson, Ek,

Table 1
Profile of the participants with early-onset blindness.

Participant	Age (years)	Sex	Handedness	Educational level	Onset of blindness	Cause of blindness
1	21	Male	Ambidextrous	Some college	Birth	Genetic[a]
2	20	Male	Right	Some college	Birth	Lesions of the optic nerves[a]
3	29	Male	Right	College degree	Birth	Genetic[a]
4	40	Male	Right	High school	Birth	Premature birth
5	55	Male	Right	College degree	Birth to 18 months	Bilateral retinoblastoma
6	45	Male	Right	High school	Birth to 24 months	Bilateral retinoblastoma
7	39	Male	Right	College degree	Birth	Premature birth
8	51	Male	Right	College degree	Birth	Genetic[a]

[a] No additional details are available. Participants 5 and 6 had very poor vision from birth and underwent a bilateral eye enucleation by age 18 to 24 months. They did not remember any visual experience. The sighted participants in the control group were matched for age, sex, handedness, and educational level.

Nordin, & Bende, 2004; Hummel, Kobal, Gudziol, & Mackay-Sim, 2007; Landis, Konnerth, & Hummel, 2004), and there are several potential biases in women that are difficult to control, such as the period of the menstrual cycle (Purdon, Klein, & Flor-Henry, 2001; Watanabe, Umezu, & Kurahashi, 2002) and the consumption of oral contraceptives. These factors influence olfactory performance (Landis et al., 2004).

Table 1 provides details regarding the characteristics of the participants with early-onset blindness. All these participants were totally blind (without residual light perception) as a result of bilateral ocular or optic nerve lesions at birth or within the first two years of life, well before the completion of visual development (Wiesel, 1982). Two participants with early-onset blindness had histories of vision during the two first years of life, but they had poor visual acuities and did not have any memories of their visual experience. No participant had an olfactory deficit or a history of neurological or psychiatric problems. They were all independent and well integrated socially, and there was no difference in the educational levels of the two groups (see Table 1). All the participants provided written informed consent before the study. The protocol was approved by the Biomedical Ethics Committee of the School of Medicine of the Université catholique de Louvain.

Experimental procedure

The participants' olfactory abilities were assessed via the nostrils (orthonasal odor perception) or the mouth (retronasal odor perception) using a set of psychophysical tests that were administered during a single testing session. The sighted participants were blindfolded during the testing.

Orthonasal olfactory testing

This first test conformed to the standardized protocol of the Sniffin' Sticks test (by Burghart Medical Technology; see Hummel et al., 2007; Hummel, Sekinger, Wolf, Pauli, & Kobal 1997; Kobal et al., 2000) that includes three components of olfactory acuity: odor detection threshold (T), odor discrimination (D), and odor identification (I). For birhinal stimulation, odors were presented to the participants on felt-tip pens, with the tips of the pens placed approximately 2 centimeters (about 0.8 inch) in front of both nostrils.

Odor detection threshold (T)

The N-butanol detection threshold was assessed using a double-staircase paradigm, with stepwise increases and reductions of concentrations. (A double-staircase paradigm occurs when stimuli is presented in increasing intensity and alternated with stimuli of decreasing intensity—here, concentration of odorant—until the subject detects the stimulation—here, odor target.) A set of 16 felt-tip pens that were ranked in order of successive dilutions was used. For each trial, the participants were presented with triplets of pens in a randomized order; one contained the fragrance, while the other two contained an odorless solvent. Each pen in a triplet was presented at a five-second interval. Then, the participants were asked to identify which of the pens contained the fragrance. The triplets were presented at intervals of approximately 20 seconds. Reversal of the staircase of dilution was triggered when the odor was correctly detected in two successive trials. (*Staircase dilution* refers to the different stepwises of odorant concentration rates used in the stimuli. When one odor was correctly detected twice in a row at the same concentration, we presented odors of decreasing concentration until the subject missed one concentration.) The *threshold* was defined as the mean of the last four of seven staircase reversals. The T score ranged from 1 to 16, the closer to 16 corresponded to the higher sensibility to odors (corresponding to a low threshold), and conversely.

Odor discrimination (D)

Each trial consisted of a randomized presentation of a triplet of pens: two were distracters and contained the same odorant, whereas one was the target and contained a different odorant. The participants had to determine which one of the three pens smelled differently. The presentations of the triplets of pens were each separated by about 20 seconds. The interval between the presentation of each individual pen was approximately 3 seconds. Sixteen different triplets were tested, and the quotation was made on a 0/1 basis, with the total number of correct responses providing the D score.

Odor identification (I)

In this subtest, the participants were asked to identify a set of 16 common odors that were presented sequentially using single felt-tip pens. For each trial, the participants had to select the individual odor from a list of four descriptors (multiple forced-choice). The interval between presentations of the odors was about 20 to 25 seconds (the maximal time allowed was 30 seconds). The I score ranged from 1 to 16 and corresponded to the sum of the correct responses.

TDI score

The results of the three subtests for each participant were compiled into a composite threshold, discrimination, identification (TDI) score, which corresponded to the sum of individual results obtained for the T, D, and I measures. Disregarding sex-related differences, the minimal (TDI) score (at the 10th percentile) for normosmia is 24.9/48 for people aged 15 or younger, 30.3/48 for people aged 16–35, 27.3/48 for people aged 36–55, and 19.6/48 for people aged 55 or older (Hummel et al., 2007).

Retronasal olfactory testing

This second test was based on the protocol of Heilmann, Strehle, Rosenheim, Damm, and Hummel (2002) and includes the identification of odorized powders or granules presented via the mouth. Twenty stimuli were presented in a randomized order: coffee, vanilla, cinnamon, cacao, raspberry, orange, garlic, strawberry, cloves, nutmeg, onion, cheese, curry, milk, banana, mushroom, coconut, lemon, paprika, and celery. Each sample was applied to the midline of the tongue, and the participants were asked to identify the odor from a list of four items. After each single-substance test, the participants rinsed their mouths abundantly with water. The score corresponded to the total number of correct responses and ranged from 1 to 20. In sighted participants, retronasal testing yielded a median score of 18 for people aged 36–55 and 16 for those aged 55 or older (Heilmann et al., 2002).

Statistical analyses

Psychophysical data were analyzed for group differences using the Wilcoxon signed rank test (for small and matched samples) in Statistica software for Windows. The significance level was set at $p < .05$. Wilcoxon signed rank tests were used for the group comparisons because they are more suitable and stricter than are equivalent parametric tests when comparing two groups of a relatively small size and with a different number of participants.

Results

Psychophysical testing of olfactory function

The mean scores on the psychophysical tests are presented as a function of the group in Figure 1. In the orthonasal olfactory test, the group comparison of the composite TDI score revealed a significant difference ($p = .0032$; see Figure 1b). The results at each subtest revealed that the participants with early-onset blindness outperformed the sighted control participants in the odor detection threshold (a lower detection threshold; $p = .007$), odor discrimination ($p = .03$), but not in odor identification ($p = .85$; see Figure 1a). No group difference was observed for the retronasal olfactory test ($p = .75$; see Figure 1c). When compared to published normative data, the odor detection and the composite TDI scores of the sighted control group were at the limit of the normal range (the 10th and 25th percentiles, respectively, for men aged 36–55, according to Hummel et al., 2007). It is worth noting that every participant who was blind outperformed his matched sighted control participants in the detection subtest.

To rule out the potential influence of odor familiarity, difficulty, or linguistic aspects in the identification task, the odorants used in the I component of the Sniffin' Sticks test and in the retronasal test were further classified into natural (plants and fruit), artificial odors (such as leather and turpentine), and odors of alimentary products (like chocolate and cheese). In the two groups, the proportion of errors according to the category of items was compared using Spearman ranking tests. This analysis did not show any correlation between individual scores and categories of items (that is, each group had a roughly similar number of errors in each category; all p-values $>.05$). In addition, the two groups did not differ from each other when odorants were classified according to error frequency. In both groups,

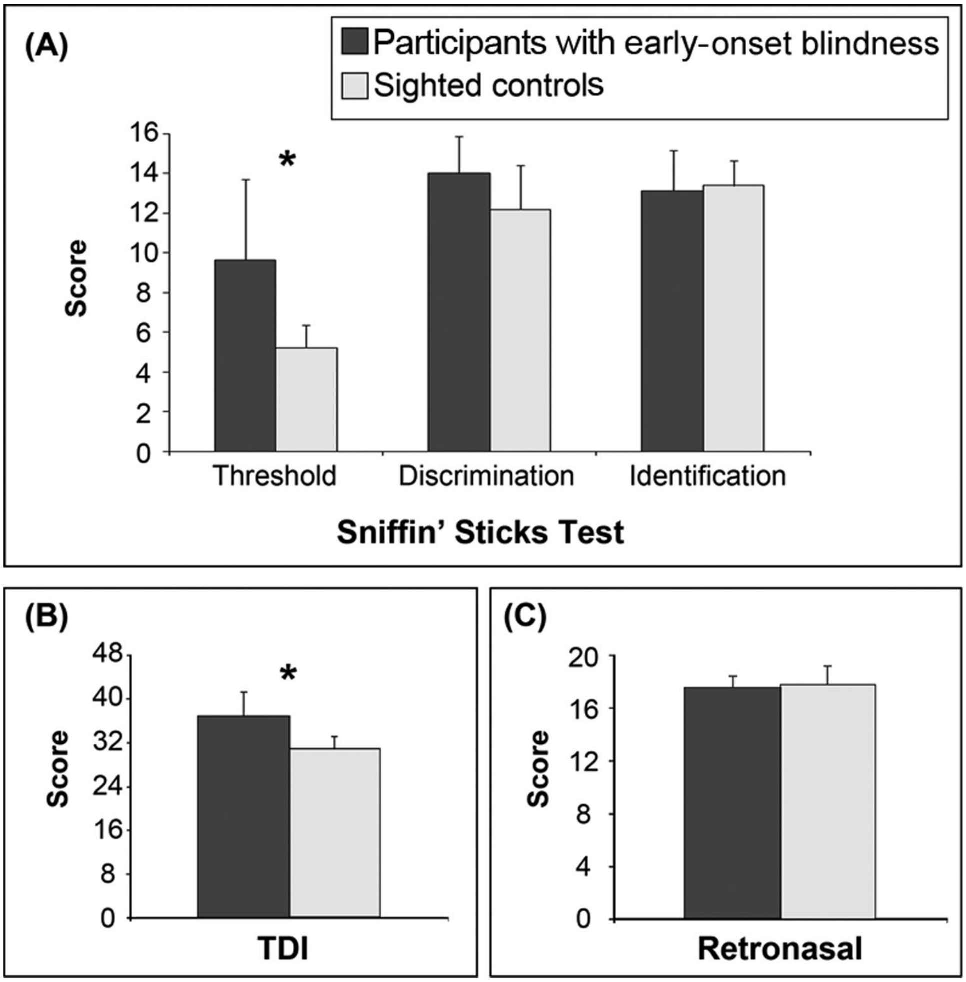

Figure 1. Scores on the psychophysical tests as a function of the group. (A): results from orthonasal olfactory testing: odor detection threshold (higher score corresponds to a lower threshold, see methods), odor discrimination and odor identification; (B): results from the composite (threshold + discrimination + identification) score; (C): results from retronasal olfactory testing. Histograms represent the mean values and standard deviations of these scores. (*): significantly different ($p < .05$, Wilcoxon test).

"apple" and "cinnamon" in the orthonasal test and "paprika" in the retronasal test were the items that were less frequently correctly identified. It is interesting that in the group of participants with early-onset blindness, the best TDI composite scores were found in the oldest participants, whereas the reverse pattern was observed in the sighted control group: Age was positively correlated with the TDI score in the group with early-onset blindness ($r = 0.8$, $p = .01$), whereas this correlation was negative in the sighted control group ($r = -0.81$, $p = .01$).

Discussion

In contrast to earlier reports, in our study the participants with early-onset blindness outperformed their matched sighted control participants in detecting and discriminating odors. However, no significant difference was observed in the identification of odors in either orthonasal or retronasal olfactory stimulation.

Because we used the Sniffin' Sticks test to evaluate olfactory abilities in participants with normal to supranormal performance, this clinical test may have lacked sensitivity at some point because of a potential ceiling effect in some participants, especially in the identification subtest; one participant with early-onset blindness and one sighted control participant had a maximal score in the identification task. It should be noted, however, that when we excluded these participants from the analyses, no group difference was observed in the identification task ($p > .05$). Notwithstanding this potential limitation, the study is one of the rare attempts to investigate the influence of early visual deprivation on olfactory abilities.

In the study, most compensatory mechanisms took place at a basic sensory level; the best scores were obtained by the participants with early-onset blindness in the odor detection threshold and odor discrimination, which did not involve higher-order perceptual processing, such as semantic access. However, behavioral compensations are generally thought to reflect practice-related perceptual enhancements and attention strategies (Collignon, Renier, Bruyer, Tranduy, & Veraart, 2006) that are relevant to individuals who are blind in everyday activities, rather than to changes in sensory acuity. Compared to vision and hearing, the sense of smell seems to play a less prominent role in humans (Hummel & Nordin, 2005). Similarly, persons who are blind use mainly hearing and touch to gather information about their environment (Hatwell, 2003). Nevertheless, in the absence of vision, olfaction may be particularly important in everyday life because it allows people who are blind to access environmental information that may not be conveyed by touch or hearing (such as in the detection of hazards like the smoke of a fire, poisonous fumes, or spoiled food). Some people who are blind have also reported using olfaction, in addition to touch and hearing, to recognize objects and persons (Hatwell, 2003). Doing so may promote some practice-related enhancements of the sense of smell at a basic level.

The results stand in contrast with those obtained by Schwenn et al. (2002) using the same test in which the T, D, and I scores were comparable in the two groups. Other investigations that have used nonstandardized olfactory tests have also suggested that participants who are blind do not differ from those who are sighted for odor-threshold and other basic chemosensory tasks, such as the discrimination of odors (Diekmann et al., 1994; Smith et al., 1993). However, differences in sample size, participants' profiles, and methodology could account for these differences. For instance, Schwenn et al. (2002) included mainly women and participants with late-onset blindness in their sample, which introduced uncontrolled confounding factors. The behavioral performance of persons with early-onset blindness usually differs from that of persons with late-onset blindness (Burton & Mc Laren, 2008; Goldreich & Kanics, 2003; Gougoux et al., 2004; Grant et al., 2000; Voss et al., 2004). In our study, we did not find any difference between the participants with early-onset blindness and the sighted participants in a multiple-choice identification task. This finding is in accordance with those of previous studies that showed that participants with early-onset blindness outperform their age-matched sighted controls only when the olfactory identification task is more complex, that is, in free identification (Cuevas et al., 2009; Murphy & Cain, 1986; Rosenbluth et al., 2000) or in a task that involves semantic aspects (Wakefield et al., 2004).

Although no study has investigated the neural correlates of olfactory processing in people who are blind using neuroimaging techniques (such as functional magnetic resonance imaging or positron emission tomography, one may expect that the occipital cortex of individuals with early-onset blindness supports these individuals' superior olfactory abilities as it does in the case of hearing and touch. In the auditory and tactile domains, several neuro-imaging studies have shown that the occipital cortex of persons with early-onset blindness was recruited during the processing of nonvisual information, such as sounds (Gougoux et al., 2005; Weeks et al., 2000) or tactile stimuli (Büchel, Price, Frackowiak, & Friston, 1998; Burton et al., 2002). Learning and brain plasticity are difficult to dissociate in individuals with early-onset blindness, since they are inextricably linked. Because of their deprivation, individuals who are blind rely more on their remaining senses, which has an effect on the brain (plasticity). In return, the reorganized occipital cortex of those with early-onset blindness would be the neural basis of the improved behavioral abilities that are usually observed in this population. The relationship between brain activity in the occipital cortex and the performance in sound-localization tasks (Gougoux et al., 2005) and verbal memory (Amedi at al., 2003), as well as the functional role of this cortex in other tasks, such as braille reading (Amedi, Floel, Knecht, Zohary, & Cohen, 2004; Cohen et al., 1997), has been demonstrated. It is worth noting that although participants with late-onset blindness (Büchel et al., 1998; Burton et al., 2002; Sadato, Okada, Honda, & Yonekura, 2002) and sighted participants who were blindfolded for a couple of days (Merabet et al., 2008; Pascual-Leone & Hamilton, 2001) experienced some functional changes in their occipital cortex, although the degree of these changes is far less important than those observed in participants with early-onset blindness (see Burton, 2003).

In conclusion, the study provides evidence of better odor-detection and odor-discrimination abilities in the participants with early-onset blindness than in the sighted participants. The better scores of the participants with early-onset blindness in these tasks may reflect a generally higher sensitivity to odorant stimuli and alertness. Further examination with more differentiating psychophysical tests should allow us to investigate the semantic aspects of olfaction (identification) and related learning characteristics (including episodic memory). A better understanding of the compensatory mechanisms in individuals who are blind should allow us to develop more adapted rehabilitation programs and strategies to improve their mobility and autonomy. Neuroimaging studies should allow us to test whether cross-modal recruitment of the occipital cortex can be observed during olfactory tasks in persons with early-onset blindness. Despite its limitations, our study is one of the rare attempts to evaluate the olfactory function in individuals with early-onset blindness. Although additional studies are clearly needed, the results of our study indicate that persons with early-onset blindness could make greater use of odorous stimuli than sighted individuals to compensate for the lack of vision.

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