

Research report

Depth of olfactory sulcus and olfactory function

Thomas Hummel^{a,*}, Michael Damm^b, Julia Vent^b, Matthias Schmidt^c, Peter Theissen^c,
Maria Larsson^d, Jens-Peter Klussmann^b

^aSmell and Taste Clinic, Department of Otorhinolaryngology, University of Dresden Medical School, Fetscherstr. 74, 01307 Dresden, Germany

^bDepartment of Otorhinolaryngology, University of Cologne, Cologne, Germany

^cDepartment of Nuclear Medicine, University of Cologne, Cologne, Germany

^dDepartment of Psychology, Stockholm University, Stockholm, Sweden

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Abstract

The aim of this study was to identify whether the depth of the olfactory sulcus relates to olfactory function in healthy subjects. Forty-four healthy, male volunteers (age range 22–45 years, mean age 28.3 years) were included in this study. Olfactory function was measured for phenyl ethyl alcohol odor thresholds, odor discrimination, and odor identification. Magnetic resonance imaging of the olfactory sulcus was performed immediately following olfactometry. Based on previous investigations the depth of the olfactory sulcus was measured in the plane of the posterior tangent through the eyeballs. Olfactory function correlated significantly with left-sided depth of the olfactory sulcus ($r_{44}=0.33$, $P=0.03$); no such correlation was seen for the right side. In addition, olfactory sulcus depth was found to be significantly deeper on the right compared to the left side ($t=5.61$, $P<0.001$). The present results suggest that there is small, but significant relation between morphological brain structures and measures of olfactory function. Further, lateralization of olfactory sulcus depth may correlate to functional lateralization in the olfactory system. Thus, it may be carefully speculated that sensory input in the olfactory system results in cortical growth in the area of the olfactory sulcus, at least at some developmental stage.

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1. Introduction

Previous work has indicated a correlation between olfactory function and the depth of the olfactory sulcus (OS) in patients with isolated anosmia since birth or early childhood when the olfactory bulb was measured in the plane of the posterior tangent through the eyeballs (PPTE) [1]. Specifically, results from sixteen subjects with isolated congenital anosmia in comparison to eight controls indi-

cated that OS depth in the PPTE was (1) significantly smaller in isolated congenital anosmia compared to controls and (2) significantly larger on the right side compared to the left-sided OS and (3) there was no overlap in OS depth in PPTE in patients with olfactory bulbs/tracts and those without olfactory bulbs/tracts. Based on these data it was hypothesized that the presence of olfactory bulbs/tracts promotes cortical growth in the area of the OS. In other words, the data implied a relation between cortical morphology and olfactory input. Thus, the present study was aimed at the correlation of OS depth in the PPTE estimated by means of magnetic resonance imaging (MRI) and olfactory function characterized by means of phenyl ethyl alcohol odor thresholds, odor discrimination and odor

*Corresponding author. Tel.: +49-351-458-4189; fax +49-351-458-4326.

E-mail address: thummel@rcs.urz.tu-dresden.de (T. Hummel).

identification in a relatively large number of healthy male volunteers.

2. Materials and methods

The study was performed according to the Ethical Principles for Medical Research Involving Human Subjects (World Medical Association, Helsinki). Following oral and written explanation of aims and potential risks of the study informed written consent was obtained. Participants in this study were 44 healthy volunteers with a mean age of 28.3 years (range 22–45 years). To exclude ‘gender’ as a possible source of variation in olfactory function [19], only male patients were included. A detailed history ascertained the absence of diseases with potential impact on olfaction including major head trauma, nasal or sinusoidal disease, neural or endocrinological disorders, or previous nasal surgery. All subjects were in excellent health; none of them reported significant olfactory dysfunction and all subjects scored within the normal range of the olfactory test used [17].

2.1. Study protocol

Olfactory testing, and MRI scans of the entire cranium were performed in all subjects. Prior to these tests, 0.15 mg oxymetazoline (Nasivinetten[®], Merck Darmstadt, Germany) [12] were administered into each nostril to minimize potential effects of fluctuations in nasal airway congestion on olfactory function [9,14]. Olfactory testing, and MRI scans were performed sequentially, with a break of less than 5 min between tests. This was thought to be necessary as olfactory function appears to exhibit a certain day-to-day variability and even fluctuations during 1 day [15,18,21].

2.2. Olfactory testing

Olfactory function was evaluated using the ‘Sniffin’ sticks’ test battery [13,17]. Odor identification was measured bilaterally. This was done because subjects might have remembered the odor labels when the left and right sides would have been tested sequentially which, in turn, would have impacted on the test results. Odor discrimination and phenyl ethyl alcohol odor thresholds were measured separately for the left and right nostril. The sequence of the lateralized measurements was randomized across all participants. Odor identification was assessed by means of sixteen common odors (forced choice task from a list of four descriptors each). Phenyl ethyl alcohol odor thresholds were assessed using a single-staircase, triple-forced choice procedure [6,13]. In the odor discrimination task, sixteen triplets of pens were presented in a randomized order. Two of them contained the same odorant, while the third contained a different odorant. Subjects had to find out

which of the three odor-containing pens smelled differently. When measuring odor thresholds and odor discrimination, subjects were blindfolded to prevent visual identification of some of the odorant-containing pens. Results of individual olfactory tests were summed up to a TDI score which is clinically used to estimate subjective olfactory function ([13,17,22]; compare [4]); specifically, results from odor identification were added to the results of phenyl ethyl alcohol odor thresholds and odor discrimination that had been obtained for the better performing nostril. This is done because overall olfactory function largely depends on the side with higher olfactory sensitivity at the time of testing [3,7].

2.3. MRI

A 1.0 Tesla scanner (Gyrosan ACS- NT, Philips, Hamburg, Germany) was used. Immediately following olfactometry T2-weighted turbo spin echo sequences were obtained in the head coil with a repetition time of 3000 ms and an echo time of 100 ms in transverse and coronal planes. Slice thickness was 4 mm with 0.4 mm intersectional gap. The acquisition matrix was 256×256 pixel, and the field of view was 230 mm. Scan percentage was set to 90% of the phase encoding profiles resulting in a spatial resolution of 0.9×1.0 mm. No contrast agent was administered. Measurements of olfactory sulcus depth were performed in all subjects in a selected slice of the acquired coronal images [1]. To confirm identical slice positions for that measurement the most posterior coronal slice through the eyeballs was used; at least on one side a partial volume cut of the eyeballs had to be visible. According to previous research this slice was named the ‘plane of the posterior tangent through the eyeballs’ (PPTE). Coronal slices were positioned perpendicular to a virtual midline through the nasal septum and the cerebral falx. MRI scans were transferred to an IBM-compatible workstation and converted to tagged image file format for further processing. Depth of the olfactory sulcus was measured using IMAGE PRO PLUS[®] 1.3 (Media Cybernetics, Silver Spring, MD, USA) (Fig. 1). At the time of measurement the observer was blinded to the subject’s results in olfactory function tests. Measurements were done with reference to a caliper.

2.4. Statistical methods

For statistical analyses SPSS[®] for Windows[™] was used (Statistical Package for the Social Sciences, Version 10.0, SPSS, Chicago, IL, USA). Comparisons between left- and right-sided measures were performed using a *t*-test for paired samples. The relation between olfactory function and OS depth in the PPTE was evaluated using correlation analyses according to Pearson. In addition, two separate stepwise regression analyses with left and right OS depth as criterion measures and olfactory threshold, discrimina-

Example of measurements of the olfactory sulcus in the PPTE (using Image Pro Plus® 1.3)

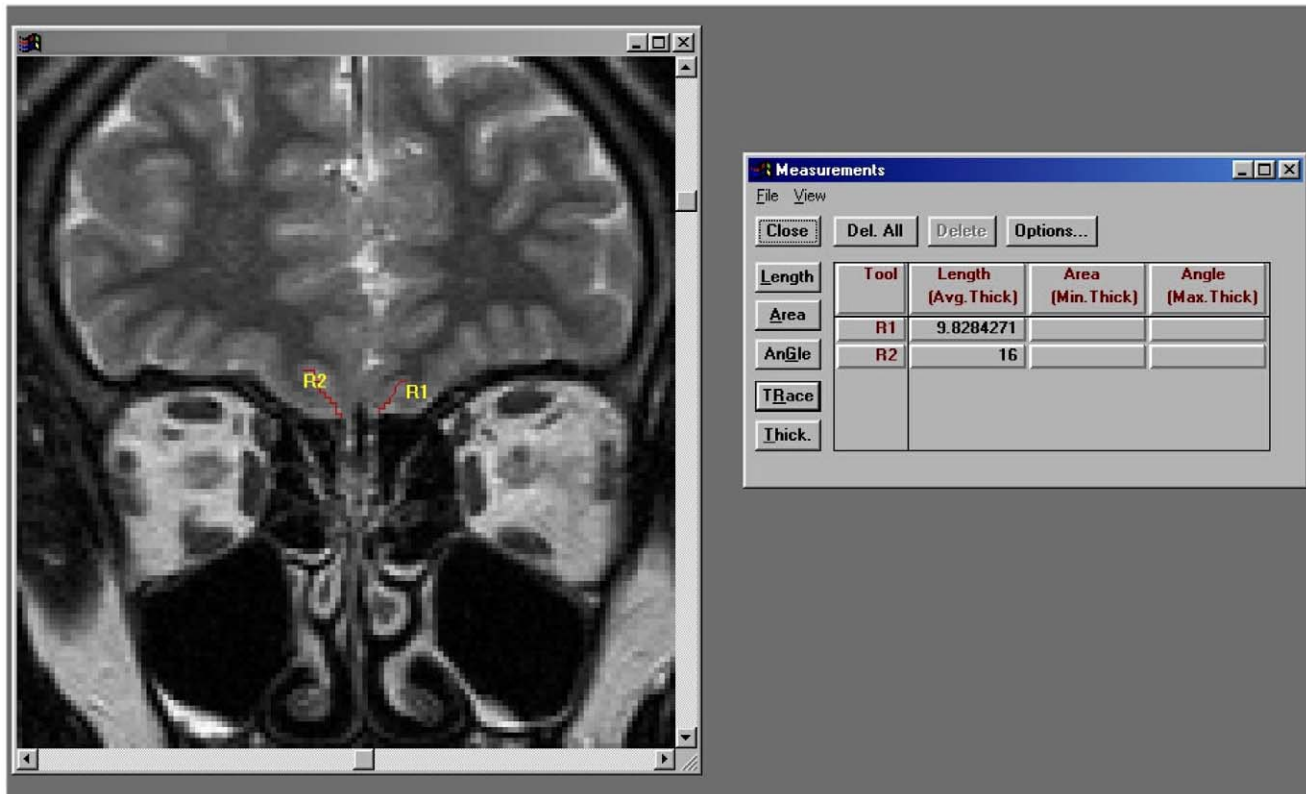


Fig. 1. Example of measurements of the olfactory sulcus in the PPTE using IMAGE PRO PLUS® 1.3 (Media Cybernetics, Silver Spring, MD, USA).

tion, and identification as predictor variables were performed. For all analyses, the α level was set at 0.05.

3. Results

Descriptive statistics of the acquired parameters are presented in Table 1. Measures of OS depth in the PPTE were found to be significantly deeper on the right compared to the left side ($t=5.61$, $P<0.001$).

In addition, olfactory function measured for the dominant nostril exhibited a significant correlation with left-sided OS depth ($r_{44}=0.33$, $P=0.03$), but not with the right-sided OS (Fig. 2). The assumption that a deeper left-sided OS would indicate higher olfactory sensitivity

was further supported by a significant difference ($t=2.18$, $P=0.043$) between subjects with higher (≥ 75 th percentile of this sample) or lower sensitivity (≤ 25 th percentile of this sample), respectively. This difference was not observed for the right-sided OS ($t=0.007$, $P=0.995$).

When correlations were performed between lateralised measures of olfactory function and the depth of the OS no significant correlations emerged. Further, the stepwise regression performed separately for left- and right-sided OS depth did not reveal a significant contribution from the respective independent factors entered in the regression model (odor thresholds, odor discrimination, odor identification). The individual behavioral measures accounted for a total of 1.5% of the variance in the left OS and explained 3.4% of the variance in the right OS.

Table 1

Descriptive statistics of measured parameters [minimum, maximum, means, standard errors of means (S.E.M.), $n=44$]

	Minimum	Maximum	Mean	S.E.M.
Olfactory sulcus depth right (mm)	15.0	28.8	19.1	0.5
Olfactory sulcus depth left (mm)	9.4	24.4	16.7	0.5
Olfactory function expressed as TDI score of the better nostril (units)	31.3	44.8	37.4	0.6

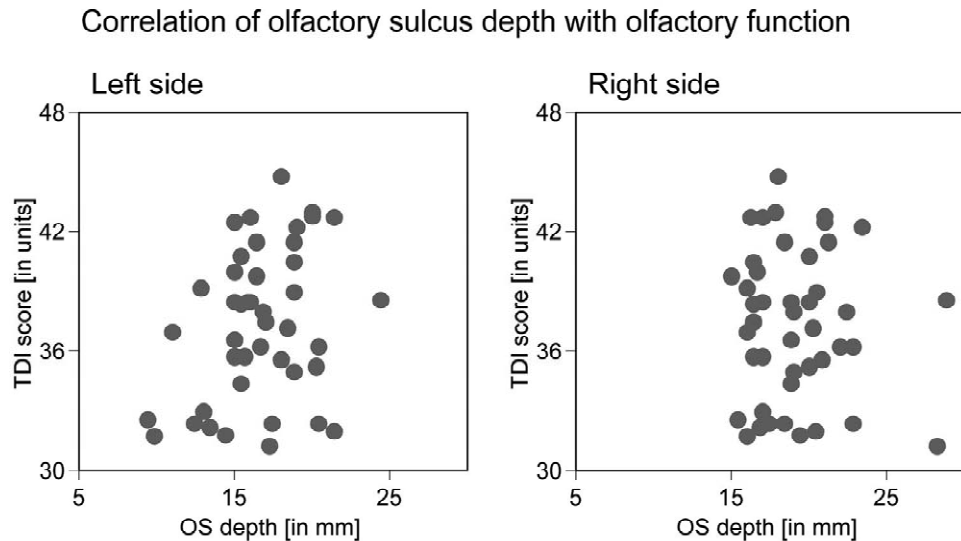


Fig. 2. Correlation between depth of the left and right olfactory sulcus (in mm) and olfactory function, expressed as TDI score of the better nostril (in units).

4. Discussion

To our knowledge, this is the first study demonstrating a correlation between olfactory eloquent brain structures and overall olfactory function in healthy subjects. These findings are supported by previous work in subjects with olfactory dysfunction since birth or early childhood [2]. They indicated that OS depth was significantly smaller than in controls. It was hypothesized that these findings indicated on a developmental level that the formation of the OS is, at least to some degree, dependent on the presence of an olfactory tract (compare [23]). In combination with the present results this may indicate that the morphological development of certain brain structures is dependent on the flow of input to the brain. Along the same line others have reported mild to moderate volume loss in temporal and frontal lobes in patients with Kallmann's syndrome where olfactory bulbs/tracts are found to be aplastic or hypoplastic in combination with hypogonadotropic hypogonadism [24]—although the olfactory sulcus has not been investigated. This indicates indirectly that the presence of a functioning olfactory system affects the volume of secondary or tertiary cortical centers involved in the processing of olfactory information.

Similar to previous work in healthy controls [1] the present study indicated that the OS measured in the PPTE was significantly larger on the right than on the left side. This structural difference between the left and right OS bears similarities to work in experimental animals where laterality has been reported for olfactory bulb volume. This has been shown to be larger on the right compared to the left side [10]. In contrast, in humans there is little support for such lateralized differences in structures involved in the processing of olfactory information. Yousem et al. [25] had no evidence for lateralized differences at the level of the

olfactory bulb or the temporal lobe. The presently reported data may, however, relate to the functional lateralization of the olfactory system. Specifically, there is accumulating evidence on the basis of psychophysical, clinical, electrophysiological, and imaging studies that, in general, the right hemisphere is more important to the sense of smell than the left hemisphere [8,11,20,26,27].

It is interesting to note that the correlation between olfactory function and OS depth was seen only on the left but not on the right side. While the reason for this is unclear it may be sought in the lateralization of OS depth. It could be hypothesized that the right side is maximally developed in healthy subjects while the left side still has room for plasticity—which then might be governed by relatively subtle differences in overall olfactory function. This hypothesis might help to explain why left-sided OS depth correlated to olfactory function whereas there was no such correlation for right-sided OS.

Further, it is difficult to understand why the stepwise regression performed separately for the left- and right-sided measures did not account for a major portion of the variance of OS depth. This is especially interesting as the processing of olfactory information is thought to be predominantly lateralized (e.g. [11]; for review [5]). Reasons for the negative findings may include the idea that the variance of the left-sided or right-sided measures of olfactory function is higher than the variance of the measures obtained for the respective best nostril (compare [16]). This also relates to the fact that overall olfactory function is quite stable over time, and that overall olfactory function depends on the sensitivity of the better nostril [3,7]. In contrast, olfactory sensitivity measured separately for the left and right nostrils may vary tremendously, for example due to the nasal cycle [9,14,20].

In conclusion, the present study indicated that OS depth

in the coronal plane perpendicular to the frontal skull base posterior to the eyeballs is (1) related to overall olfactory function and (2) deeper on the right compared to the left side—which may also be an expression of functional lateralization. Thus, it may be carefully speculated that sensory input in the olfactory system promotes cortical growth in the area of the olfactory sulcus, at least at certain developmental stages.

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