The role of temporal lobe and orbitofrontal cortices in olfactory memory function

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Abstract

Differences in verbal and nonverbal olfactory identification and recognition were examined among three groups with brain impairment. A left cerebrovascular accident (LCVA) group, a right CVA (RCVA) group, and a traumatic brain injury (TBI) group were compared with two nonimpaired age-matched comparison groups on olfaction identification and recognition abilities. Odors were presented to the left and right nostrils, which maximized hemispheric differences in olfactory processing. Results showed that persons with LCVA demonstrated the greatest impairment on the verbal identification of odors, while persons with RCVA showed the most impairment on the nonverbal identification of odors. Persons with TBI showed an inconsistent impairment across both verbal and nonverbal odor identification tasks. Odor recognition was impaired in both CVA groups as well. In contrast, persons with TBI performed better on the delayed odor recognition tasks. Results are discussed in relation to hemispheric differences in processing olfactory information. © 2002 National Academy of Neuropsychology. Published by Elsevier Science Ltd.

Keywords: Olfaction; Olfactory identification; Cerebrovascular accident (CVA); Traumatic brain injury (TBI)
Introduction

Damage to the orbitofrontal and temporal lobe brain structures can result in olfactory memory deficits. Previous research studies have shown that olfactory memory problems can result from damage to thalamic, temporal lobe, and orbital frontal brain areas. However, only a few studies have examined the individual roles that specific cortical areas play in various aspects of olfactory memory functioning, such as odor identification, odor recognition, and differences in verbal versus nonverbal olfactory memory functioning.

Mishkin and Appenzeller (1987) have previously described the role of the amygdala, hippocampus, diencephalon, and frontal lobe structures in memory processes. Evidence for their roles in memory has been described in numerous studies and reviews of the memory system (Anderson, 1978; Cermack, 1982; Iverson, 1976; Kolb & Wishaw, 1985; Milner, 1982; Squire, 1982). The olfactory system is linked to the hippocampus and frontal lobes, and damage to these areas can produce olfactory impairment (Eichenbaum, 1998; Varney, 1988).

Clinical support for this link comes from studies of two broad groups of neurological disorders in which olfactory impairments have been found. The first is a group of disorders producing diffuse or generalized neurological damage (at both the cortical and subcortical levels). Problems in olfactory recognition and identification have been reported in persons with Korsakoff’s syndrome (Jones, Moskowitz, & Butters, 1975; Potter & Butters, 1980), dementia of the Alzheimer’s type (Nordin & Murphy, 1998; Rezek, 1987), Huntington’s disease (Moaberg et al., 1987), and Parkinson’s disease (Doty, Deems, & Stellar, 1988).

The second group are persons with localized brain impairment such as epilepsy, temporal lobectomy, cerebrovascular conditions, and closed head injuries. In a study on epilepsy, the lateralization of olfactory function was examined in five right-handed epileptic patients who had undergone a commissurotomy of the cerebral hemispheres to alleviate intractable seizures (Gordon & Sperry, 1969). When odors were presented to the right nostril, participants were unable to verbally identify them, but were able to point to or pick out associated objects by tactile palpitation with the contralateral hand. Odors presented to the left nostril were perceived by the ipsilateral hemisphere and identified verbally.

Olfactory memory has also been evaluated in patients with anterior temporal lobectomy, involving removal of diseased, or damaged cortical tissue (Rausch, Serafetinides, & Crandall, 1977). Participants were required to smell one of four diluted odorants, and following a 10-s distraction period, identify the test odor from four bottles each containing one of the four odor solutions. A study by Rausch et al. (1977) showed that when control right temporal lobe and left temporal lobe participants were asked to identify an odor, the control participants answered 96% of the odors correctly, while right and left temporal lobe subjects identified only 53% and 80% correctly. These results indicated that the right temporal lobe may be more dominant in nonverbal memory processing and that odor information may be coded nonverbally to a greater extent than it is coded verbally.

Persons with focal cerebral lesions show olfactory identification deficits associated with the site, but not to the extent of cortical lesions (Jones-Gotman & Zatorre, 1988). Jones-Gotman and Zatorre (1988) found a significant impairment in olfactory identification after right or left temporal lobectomy, right or left frontal lobectomy, and right frontotemporal...
excision, but not when the excision was confined to the left central, parietal, or posterior areas. The above results are consistent with our current knowledge about neurocognitive abilities following a cerebrovascular accident (CVA). Persons who have experienced a CVA oftentimes have lateralized impairments in many areas of functioning, including olfaction. Olfaction may be differentially affected depending on which hemisphere is afflicted. However, there are no empirical studies that have examined the olfactory abilities of persons with lateralized CVA.

Finally, closed head injury can also result in anosmia (the inability to smell) that is typically associated with damage to the orbital frontal cortex (Varney, 1988) resulting from the moving of the olfactory nerve against the stationary cribriform plate in the base of the skull. Also, since one of the olfactory processing areas is located on the inferior aspect of the frontal lobes, anosmia can result from isolated contusions to the orbital frontal cortex.

In summary, numerous studies have shown that olfactory deficits and olfactory memory problems may result from damage to limbic, temporal lobe, and orbital frontal brain areas. Most studies have focused on the ability of participants to recognize odors or retain odor information. A few studies have examined odor identification abilities. In determining odor identification abilities, clinical measures typically require either a verbal or reading response. This may be a limiting factor in populations with verbal processing and verbal memory impairments. Gordon and Sperry (1969) found that odor information presented to a person’s right hemisphere, via the right nostril in commissurotomized persons, could be identified only nonverbally, while the left hemisphere was more effective at verbal identification of odor information. A right nostril, right hemisphere advantage (better identification) in olfactory processing was also reported in a temporal lobectomy group (Jones-Gotman & Zatorre, 1988) and in normal subjects (Zatorre & Jones-Gotman, 1990). The examination of left versus right processing of olfaction separately is important since each hemisphere may process information differently.

The purpose of the present study was to assess for left/right differences in olfactory identification and delayed recognition among three groups of persons with brain impairment. Two groups of participants with a recent CVA in either the left or right hemisphere, and a third group with a recent history of traumatic brain injury (TBI) were assessed and compared with two groups of age-matched controls on olfactory identification and recognition abilities with both verbal and nonverbal testing methods. Evaluating olfactory functioning using both verbal or nonverbal cues allowed a more detailed examination of the role of the left and right hemispheres, respectively. Impairments in visual–spatial processing are common following right hemisphere CVA, and impairments in verbal functioning are often seen following left hemisphere CVA for many patients. Because there is no current assessment tool specifically developed to measure right hemisphere olfactory functioning, this study reports the construction and validation of an additional measure designed for that specific purpose.

It was predicted that left CVA (LCVA) participants would perform most poorly on tests of verbal olfactory identification and persons with RCVA should perform most poorly on nonverbal measures of olfactory identification. It was uncertain what olfactory deficits would be found in the TBI group, but it was possible that this group may show olfactory deficits reflective of impairment in the left, right, or both hemispheres. For all groups, we predicted that olfactory recognition should be better than olfactory identification. All three neurolo-
gically impaired groups were also predicted to perform normally on the odor threshold test, which would indicate that the olfactory system was grossly functional and intact.

2. Method

2.1. Participants

Three groups of participants with neurological impairment (n = 39) were recruited from two medical rehabilitation facilities and an outpatient neuropsychology clinic (LCVA: n = 13, RCVA: n = 13, TBI: n = 13). All CVA participants had cortical damage involving temporal lobe areas as documented from medical records and radiology findings. All TBI participants had a documented history of TBI described as moderate in severity, with a period of unconsciousness ranging from \( \frac{1}{2} \) to 6 h, posttraumatic amnesia for the accident, and an involvement of the orbital frontal lobe areas (as described by medical records).

Within the LCVA group, seven were female and six were male. Mean age was 63.76 years (S.D. = 7.98). Most reported at least 12 years of education (mean = 12.61, S.D. = 1.70). Only one person, a 62-year-old male, was a current cigarette smoker. Time since CVA ranged from just under 1 to 6 months (mean = 2.76 months, S.D. = 1.92).

Within the RCVA group, eight were female and five were male. Mean age was 60.67 years (S.D. = 6.31 years). Most had a high school education (mean = 11.53, S.D. = 2.36). One participant reported occasional cigar smoking, and two participants reported recent cigarette smoking. Time since CVA ranged from 2 weeks to 6 months (mean = 1.56 months, S.D. = 1.84).

Among the TBI participants, six were female and seven were male. Mean age was 37.15 years (S.D. = 10.59). Mean education was nearly 12 years (mean = 11.46, S.D. = 1.62). Three subjects were current cigarette smokers, although they reported infrequent smoking, averaging about 5–10 cigarettes per day. Five participants reported that they had recently stopped smoking, and five reported never having smoked cigarettes. Time since TBI ranged from 3 weeks to 6 months (mean = 2.9 months, S.D. = 1.80).

As part of the screening process, disoriented and/or amnestic subjects were excluded from the study based on scores of 74 or lower on the Galveston Orientation and Amnesia Test (GOAT; Levin, O’Donell, & Grossman, 1979), which was recommend as the cutoff score for delimiting the degree of posttraumatic amnesia of brain injured patients. Medical records and participant files were utilized in scoring the GOAT to verify the accuracy of questions about source of transportation to the hospital, and for additional independent information about the period of amnesia. The TBI participants had GOAT scores that were somewhat lower (mean = 78.76, S.D. = 3.96–10.64), but did not differ statistically from those of either the LCVA (mean = 91.30, S.D. = 7.66) or the RCVA (mean = 93.26, S.D. = 4.82) participants. Participants who could not read the words on the odor-word list and identify each of the pictures on the odor-picture display prior to completing the respective tasks were also excluded from the study.
Control participants (n = 26) were selected to form two age groups. The younger control participants (n = 13) were age-matched with the TBI subjects (mean age = 36.76 years (S.D. = 9.57). The older control participants (n = 13) were age-matched with the two CVA groups (mean age = 60.30 years, S.D. = 7.94).

2.2. Procedure

All groups (i.e., LCVA, RCVA, TBI, and controls) were administered the following measures of olfactory function: (1) an olfactory threshold test; (2) an odor identification test including a left nostril verbal odor identification component and a right nostril nonverbal or picture-list odor identification component; and (3) a delayed odor recognition memory test. For each participant, the right and left nostrils were tested separately, which resulted in three scores for the left nostril and three scores for the right nostril (i.e., threshold, odor-picture, or odor-word identification, and delayed recognition for each). Before the actual testing procedures are described, the development of the odor-picture and delayed odor recognition components, along with the procedures used to adjust the intensity of each odor, will be reported.

2.3. Pilot testing and intensity adjustment of olfactory measures

The purpose of this portion of the study was to standardize the quantity of odorants used in the olfactory tasks while maintaining high levels of odor identifiability. The equating of odor intensities is important because differences in odor intensity may play a role in odor identifiability (Doty, 1992). Weak smelling odors may be more difficult to identify, and stronger smelling odors are more easily identified (e.g., see the Connecticut Clinical Chemosensory Research Center — CCCRC; Cain, Goodspeed, Gent, & Leonard, 1988). The 8 CCCRC odorants (which were used in the odor-word test) and 22 additional odorants (which were used in the odor-picture and delayed odor recognition parts of the study) were examined for use in the main experiment. The goal of these initial studies was to adjust the amount of the odorants until normosmic participants judged them to be of nearly equal intensity, while maintaining nearly error-free identifiability (80%+ accuracy rate). A total of 162 persons who were recruited from both university and community samples participated in this portion of the study.

First, the experimenter adjusted the concentrations of each odorant until they were relatively equivalent in intensity. Second, a group of 21 participants were presented with each odor and asked to either identify it by name using the left nostril or by its corresponding picture by using the right nostril. Each person then ranked each odor on a continuum from weak smelling to strong smelling in relation to the other odors. Following this ranking, each odorant was adjusted (by weight) until it was perceived to be of equal intensity to the average odorant (median-ranked odor was used as a comparison). All of the adjusted odors were identified at an 80% or greater accuracy rate. A second participant group (n = 20) completed the second odor adjustment phase of the study. Each person was presented with four odor choices with each one containing a different amount of the previously adjusted odorant (50%, 100%, 150%, or 200% of the adjusted amount). The participants rank ordered each odor and chose the one that
was of equal intensity to the median-ranked odorant. This served to fine tune each odorant amount and to serve as an independent confirmation of the adjustment process.

The final portion of this study involved the administration of the complete study protocol (odor threshold, word, picture, and delayed recognition tests) using the adjusted odor weights to 25 persons from the community (ages 19–73 years) who served as a normative group for the expanded odor tests. The results showed that this group was able to identify the odors at a 90.51% accuracy rate. There were no gender or left–right nostril differences found for this group \( (n=25) \) or for the total sample \( (N=162) \).

Reliability of the expanded olfactory test was found to be satisfactory in an examination of test performance for the nonimpaired participants who took the complete test. The 30 odorants had adequate internal consistency using the Kuder–Richardson procedure \( (r=.80) \) with regard identifiability and recognition \( (r=.87) \). As a means of assessing test–retest reliability, 20 of the 25 community participants took the test a second time 4 to 6 weeks following the first test. Scores were moderately stable over time for these participants with regard to threshold \( (r=.51, P>.05) \) identification \( (r=.79, P>.05) \), and recognition \( (r=.77, P>.05) \). These rather moderate correlations are likely due to a restricted range of variability in test scores, in that nearly all of the participants had close to complete accuracy on both the first and second administrations of the test. Thus, the odor measures developed for and used in this study demonstrate acceptable levels of reliability and stability.

### 2.4. Measures

#### 2.4.1. Olfactory threshold test

Based on testing methods found in the CCCRC (Cain et al., 1988). The threshold test was used to determine if the olfactory system was grossly functional and intact. Serial aqueous dilutions of \( n \)-butyl alcohol were used constructed using 10 dilution steps with concentrations ranging from 4% to 0.0000002% butanol. Each nostril was tested separately while the other was held shut by the participant’s finger.

The order of nostril stimulation for the threshold test was counterbalanced for all participants to control for the effects of learning (Cain et al., 1988). For each sniff, participants were instructed to inhale slowly and deeply for 3 s, as timed by the experimenter. The experimenter then removed the first stimulus and presented the second, quasi-randomizing the order of the blank and the trial stimulus across presentations following a Gellerman (1933) series. The procedure was then repeated for the other nostril. The interstimulus interval was 3 s between the butanol and the blank, and the intertrial interval was 10 s between dilution steps (Potter & Butters, 1980). Four correct identifications of a given dilution step determined the threshold. Threshold scores were recorded for each nostril.

#### 2.4.2. Odor-word identification test

The procedure was also adapted from Cain et al. (1988) and employed the CCCRC testing method. Participants were presented the odorants individually to the left nostril using the same counterbalanced procedure and instructed to occlude the right nostril. Eight 175-ml
opaque plastic jars that contained the intensity-adjusted odorants concealed from visual identification by loosely folded surgical gauze were presented to participants. The examiner held the odorant jars while participants sniffed the odorant to insure uniform placement near the nostril and sniff duration (3 s). Participants were then told to select the name of the stimulus from a 20-item word list. The list contained the names of the 8 test items and 12 distractors. The interstimulus interval was at least 3 s between odorants, however, subjects were permitted to inspect the odor-word list for a maximum of 30 s per odorant. Participants could name or point to the word label they associated with the odor smelled. The experimenter gave participants feedback, informing them whether or not they were correct in each trial. Participants who indicated that they had smelled something but could not identify the odorant in the first trial were presented the same odorant a second time during the presentation of the remaining stimuli. Responses such as “I don’t know” or “no sensation” were permitted and recorded as such. Stimuli identified on the second presentation (Trial 2) were scored as correctly identified following the CCCRC procedure (Cain et al., 1988).

2.4.3. Odor-picture identification test

The second odor identification task was also similar to the CCCRC test with regard to administration procedures. The odor-picture odorants were smelled exclusively with the right nostril for all participants. The odor-picture identification display presented 3 × 5-in. pictures of the odorant stimuli and/or associated objects, rather than odor names. The test odorants were represented by 8 of the pictures and 12 were distractor pictures. The interstimulus intervals were the same as in the odor-word task (3–30 s) and sniff duration was also 3 s. For the Odor-Picture Identification Test, participants were instructed to point to the picture associated with the odor stimuli and to avoid speaking the name of the odor or picture, although verbal responses were accepted. Corrective feedback was given and odors that were perceived but not identified during the first trial were smelled again and credit was given for those odors correctly identified on the second exposure.

2.4.4. Delayed odor recognition test

Following the threshold and identification tasks, participants were interviewed regarding their medical history and demographic information. This interview required 15 min to complete and included the GOAT for the CVA and TBI participants. Delayed odor recognition testing was also counterbalanced. Participants who began the initial tasks with the left nostril, began the odor recognition test with the right nostril and vice-versa. Each of the seven odorants was paired with one of seven distractor odorants. Participants were instructed to sniff each odor pair for 3 s and were asked to indicate verbally which odorant they had smelled previously. Participants used the left nostril only. Presentation of the odor pairs were, however, quasi-randomized, with participants sniffing either the test odorant first in approximately 50% of the trials, or the distractor first in the remaining 50% of trials.

This procedure was repeated for the right nostril using the odor-picture odorants and seven distractors. Participants were again required to determine which of the two odorants they had
smelled previously. Again, the correct odor was paired with a distractor. During testing, the pairs were randomly presented with the odorant first for 50% of the trials and the distractor first for the other 50% of trials.

2.5. Data analytic plan

Planned pair-wise comparison tests were used for all between groups analyses to determine if there were any significant differences in odor identification and recognition scores. Comparisons were made between the younger control group and the TBI group. The older control group was compared with the CVA groups. Finally, comparisons were made among all three brain impaired groups. A Bonferroni correction procedure (of the alpha significance level) was employed to control for alpha error inflation (Kirk, 1982). This correction yielded a conservative comparison-wise significance level of .0014 for each paired comparison (.05/34 comparisons). The experiment-wise error rate was set at .05.

3. Results

Mean scores for the left and right nostril threshold, identification, and delayed recognition scores and ages are presented in Table 1. Threshold scores range from 0 to 10 with higher scores indicating a more sensitive olfactory threshold. Identification scores range from 0 to 8 and recognition scores range from 0 to 7 with higher scores indicating a better performance.

An analysis of variance conducted on olfactory threshold scores for the left and right nostril were not significantly different (all $P$s > .05) among the two CVA groups and the older control group or between the young control group and the TBI group. In general, the younger control group had the most sensitive threshold scores, but these differed only from those of the two CVA groups and were thus not considered practically relevant comparisons.

<table>
<thead>
<tr>
<th>Group</th>
<th>Age</th>
<th>Left TH</th>
<th>Right TH</th>
<th>Left ID</th>
<th>Right ID</th>
<th>Left RE</th>
<th>Right RE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Older controls</td>
<td>60.30</td>
<td>5.84</td>
<td>5.59</td>
<td>6.30</td>
<td>6.23</td>
<td>6.46</td>
<td>6.46</td>
</tr>
<tr>
<td>Younger controls</td>
<td>36.76</td>
<td>6.46</td>
<td>6.84</td>
<td>6.30</td>
<td>6.30</td>
<td>6.38</td>
<td>6.38</td>
</tr>
<tr>
<td>TBI</td>
<td>37.15</td>
<td>5.84</td>
<td>5.84</td>
<td>3.46</td>
<td>3.00</td>
<td>4.76</td>
<td>4.84</td>
</tr>
<tr>
<td>LCVA</td>
<td>63.76</td>
<td>5.23</td>
<td>4.84</td>
<td>2.15</td>
<td>4.53</td>
<td>3.00</td>
<td>5.92</td>
</tr>
<tr>
<td>RCVA</td>
<td>60.76</td>
<td>4.23</td>
<td>4.69</td>
<td>4.61</td>
<td>1.15</td>
<td>5.53</td>
<td>3.30</td>
</tr>
</tbody>
</table>

For threshold scores, higher scores (range 0–10) indicate a more sensitive threshold. For identification (range 0–8) and recognition scores (range 0–7), higher scores indicate a better performance on the task.
Therefore, it can be concluded that there were no preexisting differences in olfactory thresholds between the neurologically impaired groups in this study.

3.1. Odor identification

3.1.1. Left nostril

Planned comparisons between the older control group and the two CVA groups revealed that the control participants had significantly higher odor-word identification scores than the RCVA group \( t(24) = 4.84, P = .00016 \) or the LCVA group \( t(24) = 9.10, P < .00001 \). The younger control participants had significantly higher odor-word identification scores than the TBI group \( t(24) = 5.13, P = .0001 \). Comparisons among the three patient groups revealed that the RCVA group had the highest odor identification ability using the left nostril, and the LCVA group obtained the lowest left nostril identification scores that were significantly different from each other \( t(24) = 5.49, P = .00001 \). In sum, the LCVA group obtained the lowest left nostril odor-word identification scores as compared to the RCVA and older control groups.

3.1.2. Right nostril

Planned comparisons between the older controls and the two CVA groups revealed that controls had significantly higher scores than both the LCVA group \( t(24) = 4.55, P = .00006 \) and the RCVA group \( t(24) = 14.94, P < .00001 \). The TBI group scored significantly below the younger control participants using the right nostril odor-picture format \( t(24) = 8.30, P < .00001 \). Comparisons among the three brain impaired participant groups revealed that the LCVA group identified more odors with the right nostril than either the TBI group \( t(24) = 3.33, P = .0001 \) or the RCVA group \( t(24) = 8.14, P < .00001 \). The TBI group also identified more odors than the RCVA group \( t(24) = 4.23, P = .00001 \) using the right nostril. In sum, the RCVA group obtained the lowest right nostril odor-picture identification scores as compared to the LCVA, TBI, and older control group.

An analysis of the left versus right nostril identification scores showed that the LCVA group identified fewer odors with the left nostril than the right nostril \( t(24) = 5.52, P = .00006 \). Likewise, the RCVA group identified fewer odors with the right nostril than the left nostril \( t(24) = 9.66, P < .00001 \). The TBI and both control groups did not exhibit left versus right nostril differences on the odor identification task, although the TBI group’s performance was lower than the controls bilaterally.

3.2. Delayed odor recognition

3.2.1. Left nostril

Planned comparisons revealed that the older controls and RCVA patients had similar left nostril recognition scores. As expected, the LCVA group, which recognized the fewest odors with the left nostril, scored significantly below the older controls \( t(24) = 6.90, P < .00001 \). Younger control participants recognized more odors than the TBI group \( t(24) = 3.60, P = .0007 \). Comparisons among the three brain impaired participant groups found significant
differences only between the RCVA and LCVA groups $[t(24) = 4.93, P = .0002]$, with the TBI group performing at an intermediate level.

### 3.2.2. Right nostril

Right nostril odor recognition scores were lowest for the RCVA subjects. The older control participants recognized almost all seven of the test odors after a 15-min delay (mean = 6.23, S.D. = 0.92), as compared to the LCVA group (mean = 5.93, S.D. = 1.25), and the RCVA group (mean = 3.30, S.D. = 1.93), which scored slightly below chance expectancy (3.50 of 7 odors) using the right nostril. The younger controls also correctly recognized most of the odors with their right nostril (mean = 6.38, S.D. = 0.76), while the TBI group recognized fewer odors (mean = 4.84, S.D. = 1.06), but at a level in excess of chance.

Planned comparisons revealed that the older control and LCVA groups had similar scores. Older control participants recognized significantly more odors than the RCVA group $[t(24) = 4.91, P = .0002]$. Younger controls recognized significantly more odors than TBI subjects $[t(24) = 4.21, P = .0001]$. Comparisons among the three brain damaged groups were significant only for differences between the LCVA and the RCVA groups $[t(24) = 4.09, P = .0002]$, which had the highest and the lowest right nostril delayed odor recognition abilities, respectively.

An analysis of differences between recognition scores for the left and right nostril revealed that the LCVA group recognized fewer odors with the left nostril than the right nostril $[t(24) = 5.57, P = .0006]$. Likewise, the RCVA group recognized fewer odors with the right nostril than the left nostril $[t(24) = 3.71, P = .001]$. In contrast, the TBI and both control groups did not exhibit left versus right nostril differences on the odor recognition task.

### 3.3. Identification versus recognition

#### 3.3.1. TBI group

The TBI group scored slightly below 50% correct on the odor identification task for both nostrils (left nostril mean = 3.46, right nostril mean = 3.00). The TBI group correctly recognized 68% of these same odorants after a 15-min delay (left nostril mean = 4.76; right nostril mean = 4.84). The chance expectancy of guessing which odor was smelled previously out of seven odor–distractor pairs would be an average of 3.50, or 50% of the odors. The probability of correctly recognizing a total of 68% of the odors (averaged for the two nostrils) by chance alone is quite low ($P = .09$). For the TBI group, both the left and right nostril recognition scores were above the hypothetical chance value of 3.5 $[t(24) = 3.21, P = .0037]$ and $[t(24) = 4.54, P = .0003]$, respectively.

#### 3.3.2. CVA groups

In contrast, for the two CVA groups, recognition scores were essentially at chance levels. Using the nostril ipsilateral to the CVA (the nostril connecting with the stroke damaged hemisphere), both CVA groups identified less than 50% of the odors (LCVA — left nostril, mean = 2.15; RCVA — right nostril, mean = 1.15). With the same ipsilateral nostril, their recognition scores were not significantly different from chance as well, or a hypothetical
value of 3.50 out of 7 odors recognized [left nostril — LCV A, mean = 3.00, \( t(24) = 1.14, P = .13 \); right nostril — RCV A, mean = 3.30, \( t(24) = 0.35, P = .36 \)]. The probability of an individual correctly recognizing three of the seven odorants (42% correct) is rather high \( (P = .27) \), when there is a 50% chance of being correct on each trial. In contrast, both the RCV A and LCV A participants were above the chance expectancy range for the nostril contralateral to the damaged hemisphere recognizing 5.5 to 5.9 of the 7 odors \( (P = .05) \). Furthermore, both groups of control participants recognized most of the odors correctly, an event that would occur by chance alone with a very low probability (ranging from \( P = .05 \) to \( P = .007 \)).

4. Discussion

The essential findings of this study are that damage to left or right temporal areas of the brain produces different effects upon olfactory functioning than damage to primarily orbitofrontal brain areas. These results are consistent with anatomical descriptions of the olfactory system that differentiate mesial temporal primary olfactory cortex from frontal olfactory areas (Guyton, 1987; Kopala & Clark, 1990; Montemurro & Bruni, 1988; Smith & Shipley, 1992). More specifically, the findings of this study are similar to those of Jones-Gotman and Zatorre (1988) who reported poor odor identification abilities for patients with temporal lobe excisions, and even more impaired abilities for patients with orbitofrontal excisions. In the present study, these differences are observed in the varied pattern of performance of the three brain damaged groups.

The LCV A group had the lowest left nostril odor identification and left nostril odor recognition scores of the three brain damaged groups. In contrast to the RCV A and TBI groups, they had the highest right nostril identification and recognition scores. While their right nostril identification scores were slightly below those of the older control participants, their recognition scores were similar to their age matched controls. The poor left nostril identification and recognition scores are consistent with the left hemisphere brain damage involving cortical areas important to olfactory functioning in these LCV A participants. That is, left nostril odor identification and odor recognition abilities were impaired concurrently with left temporal lobe damage (the result of a recent left hemisphere CV A), and right nostril odor identification and odor recognition abilities were essentially intact reflecting apparently normal right hemisphere functioning for the LCV A participants.

The RCV A group produced a virtual mirror image pattern of performance when compared to the LCV A group. RCV A participants had the lowest right nostril odor identification and recognition scores of the three patient groups reflecting right temporal lobe damage. They also had the highest left nostril scores for these three groups, consistent with essentially normal left hemisphere functioning. Again, these were the predicted outcomes, and for both the RCV A and LCVA groups, these findings are consistent with other studies that have observed lateralized olfactory deficits following lesions restricted to either hemisphere (Gordon & Sperry, 1969; Jones-Gotman & Zatorre, 1988; Rausch et al., 1977).
This pattern of impaired left and right nostril olfactory functioning suggests that little olfactory information was processed, or stored for later comparison, in the damaged temporal cortex of the CVA subjects. This appears to be the case since both odor identification and delayed odor recognition functioning were impaired in these two CVA groups where cortical damage was primarily in temporal regions. Smith and Shipley (1992) refer to these temporal lobe areas as the primary olfactory cortex and the present results support the description of these areas as the initial processing station of olfactory information within the cortex.

The results of the TBI group were not as clear and did not show a consistent pattern of deficits as compared to the CVA groups. As predicted, the TBI group obtained scores at a level intermediate to that of control participants and the CVA participants (when comparisons were made with the scores for the nostrils ipsilateral to the hemisphere with the CVA-related brain damage). This intermediate level of odor identification and recognition functioning was significantly below that of the age-equated controls, and can be associated with brain damage that was primarily orbitofrontal. However, what was not predicted (or expected) was the TBI participant’s ability to correctly recognize more odors than they could identify. Superior odor recognition ability occurred for both nostrils and at levels in excess of chance expectancy (i.e., greater than 3.50 of 7 odors recognized). This general pattern of performance suggests that TBI participants were moderately impaired in terms of olfactory identification ability, and could best be described as hyposmic rather than anosmic. It also suggests that TBI patients are processing and storing more odor-related information than their odor identification ability indicates, given their relatively higher level of odor recognition than odor identification ability. The performance of the TBI participants is consistent with the observation of odor identification deficits in head injury patients (Varney, 1988). However, the finding of odor recognition abilities being greater than odor identification abilities (and chance expectations) has not been previously reported in the olfactory literature.

To summarize the present findings, the temporal and orbitofrontal olfactory cortices appear to have distinct roles in odor memory functioning. Damage to temporal olfactory cortex results in both odor identification and odor recognition deficits, while orbitofrontal damage results in primarily odor identification deficits, suggesting specialization of olfactory cortex. This interpretation of the data is generally consistent with known olfactory pathways within the brain (Kopala & Clark, 1990; Smith & Shipley, 1992). It is believed that olfactory information is first relayed to mesial temporal lobe areas in both hemispheres, which have been referred to as the primary olfactory area. Should these primary olfactory areas be damaged, only limited odor information would be relayed onward to orbitofrontal areas for further processing (odor identification deficit) or relayed to limbic areas for memory processing (odor recognition deficit). This is what may have occurred in the case of unilateral temporal lobe damage (CVA).

In contrast, should temporal olfactory cortex be undamaged or minimally damaged while orbitofrontal cortex is more severely damaged, olfactory processing and odor memory processing within the temporal lobes would be relatively intact and odor memory ability (odor recognition) would be only minimally impaired. Odor information would still be relayed onward to orbitofrontal areas. However, it is suggested that with damage in
orbitofrontal cortex, further processing of that information with regard to naming or labeling a specific odor would be severely limited (odor identification deficit). This is what may have occurred in the case of TBI.

There are two primary limitations in this study. First, it cannot be neglected in this discussion, that the participants in this study had significant brain impairment. While age, gender, educational background, and other participant variables were controlled for in the three neurologically impaired groups there may have been some overlap between the three participant groups in terms of actual brain areas damaged by CVA and TBI incidents. Second, while all participants were screened for moderate and severe language and cognitive deficits, it is doubtful that more than a few of these neurologically injured participants were free of residual deficits in their neurocognitive abilities. Thus, there may differences in the pattern of residual impairments that may account for the results.

The present data suggest that the temporal lobes and the essential olfactory areas within the temporal lobes are the initial point of odor memory processing. Odor information that is effectively processed within these temporal areas is relayed forward to orbitofrontal olfactory areas, which the present data suggest is an area important to identifying specific odors and is involved in the process of attaching a verbal and/or nonverbal label to a given odor.

Damage to the temporal lobe cortex was found to produce deficits in the odor identification and odor recognition functioning of the CVA subjects in this study. This is consistent with the findings of Jones-Gotman and Zatorre (1988) who reported a significant role for temporal lobe cortex in odor identification functioning. In addition, they also reported that orbitofrontal damage had a greater impact upon odor identification abilities than did temporal lobe damage. In the current study, odor recognition abilities were less impaired than odor identification abilities in the TBI participants, who had much less temporal lobe damage than orbitofrontal damage. Similar to Jones-Gotman and Zatorre, the results suggest that temporal olfactory cortical areas are involved in the initial processing of odors and for recognizing an odor as novel or familiar, but that orbitofrontal cortex is critical to the process of identifying specific odors. The present study, therefore, provides additional understanding of the role these brain areas play in olfaction.

References


