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Dissociation between taste and tactile extinction on the tongue after right brain damage

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Abstract

In patients with right brain damage (RBD) or left brain damage (LBD) and healthy subjects, tactile and three basic gustatory stimuli (sour, salty, bitter) were applied to the left or right hemitongues or to both hemitongues simultaneously. Tactile stimuli were detected and localized by verbal report, whereas gustatory stimuli were identified by pointing to the corresponding name on cards bearing the names of the three tastes. In the tactile test, 9 of 18 RBD patients showed extinction of left hemitongue stimuli, whereas the remaining RBD patients, 9 LBD patients and 14 healthy subjects detected virtually all stimuli in all conditions. In the gustatory test, healthy subjects outperformed the two brain damaged groups which nevertheless responded well above chance and did not differ from one another. Unexpectedly, the nine RBD patients with left hemitongue tactile extinction showed no gustatory extinction, since performance did not differ significantly between the two hemitongues on both unilateral and bilateral stimulations. To account for these findings, some evidence suggests that the tongue representation is bilateral in both modalities, but predominantly ipsilateral in the gustatory modality and predominantly contralateral in the tactile modality. The RBD patients with left hemitongue tactile extinction were those with more marked symptoms of left-sided extinction in the visual and auditory modalities, making it likely that their brain damage was also responsible for left lingual tactile extinction. The absence of left gustatory extinction in those patients can be attributed to the predominant channelling of left hemitongue taste inputs into the intact left hemisphere.

Keywords: Lingual sensitivity; Touch-taste asymmetry; Cerebral tongue representation

1. Introduction

Unilateral lesions of various subcortical or cortical brain structures can cause a failure to sense contralesional stimuli in the absence of obvious sensory losses. This failure is defined unilateral extinction if it occurs solely in the case of simultaneous bilateral sensory stimulations, whereas it is defined spatial hemineglect if contralesional sensory inputs are omitted even when presented alone. Unilateral extinction can occur with bilateral visual, auditory and tactile stimuli, as well as with bilateral cross-modal stimulations of these sensory systems, and is more frequent following right brain damage (RBD) than left brain damage (LBD) (e.g. Driver & Vuilleumier, 2001; Karnath, Himmelbach, & Kucher, 2003; Kerkhoff, 2001; Vallar, Rusconi, Bignamini, Geminiani, & Perani, 1994; Vallar, 1998). The anatomical organization of the visual, auditory, and tactile modalities involved in extinction is predominantly crossed, such that the related inputs from the extinguished side are primarily directed to the contralateral damaged hemisphere. Little is known on the side of occurrence of unilateral extinction or neglect for sensory modalities which are traditionally thought to project to the brain in a predominantly uncrossed fashion, such as olfaction and taste (Norgren, 1990; Price, 1990).

With regard to olfaction, RBD patients with left tactile and visual neglect were reported to exhibit neglect and extinction of olfactory stimuli to the left nostril, in spite of the anatomically constrained projection of the olfactory input from that nostril to the intact left hemisphere. This finding was taken to suggest an impaired processing of all inputs from the contralesional side of space, regardless of whether such inputs were primarily directed to the damaged right hemisphere or the intact left hemisphere (Bellas, Novelly, Eskenazi, & Wasserstein, 1988a; Bellas, Novelly, Eskenazi, & Wasserstein, 1988b; Bellas, Novelly, & Eskenazi, 1989;

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Mesulam, 1981). Yet this interpretation is questionable because normal subjects appear unable to localize to a nostril a lateralized olfactory stimulus without the aid of an associated stimulation of the crossed trigeminal input from that same nostril (Doty & Cometto-Muñiz, 2003). Further, and in keeping with the above notion, on a number of unilateral and bilateral olfactory stimulations those patients identified the left nostril input correctly, but misplaced it to the right nostril (Bellas et al., 1988b), possibly because of a rightward response bias related to left-sided neglect.

With regard to taste, there exist in the neurological literature only two reports of intraoral tactile and gustatory extinction in patients with unilateral brain damage. A patient with a right parieto-occipital glioblastoma, tested with local applications of the four basic tastants (bitter, salty, sour, sweet), or with touch and pin prick stimuli to the two sides of the tongue, missed most of the left hemitongue stimuli on bilateral stimulation, or less frequently wrongly attributed to them the quality of the concurrent right stimulus. Combinations of taste and mechanical stimuli showed an interference of left side stimuli on the perception of right stimuli, suggesting a complex alteration of the central tactile and gustatory representations of both sides of the tongue (Bender & Feldman, 1952).

More recent is the description of a buccal hemineglect affecting 12 RBD patients with impaired swallowing and chewing of the contents of the left side of the mouth. As a briefly mentioned additional finding, 6 of the 12 patients extinguished left-sided mechanical and gustatory intraoral stimuli during bilateral simultaneous stimulations. The defective handling of the left mouth content was attributed to these intraoral touch and taste extinction phenomena, which were generally associated with typical hemineglect symptoms in vision and corporeal awareness (André, Beis, Morin, & Paysant, 2000). Given that taste perception is usually co-mingled with tactile sensations (Todrank & Bartoshuk, 1991), it is possible that left-sided gustatory extinction in severe left buccal hemineglect was secondary to left-sided lingual tactile extinction.

The present study was aimed at reinvestigating the issue of whether left-sided sensory inputs primarily directed to the intact left hemisphere of RBD patients can undergo extinction effects parallel to those affecting other sensory inputs directed to the damaged right hemisphere. On the evidence that lingual tactile inputs appear to be predominantly crossed (e.g. Pardo, Wood, Costello, Pardo, & Lee, 1997; Picard & Olivier, 1983), while gustatory inputs appear to be predominantly uncrossed (Aglioti, Tassinari, Corballis, & Berlucchi, 2000; Aglioti et al., 2001; Pritchard, Macaluso, & Eslinger, 1999), we have looked for tactile and gustatory extinction phenomena following unilateral brain damage, and for possible side-to-side associations or dissociations between such phenomena. To this aim, we have first systematically investigated the possible occurrence of tactile extinction on the left side of the tongue in a series of RBD patients with other more typical signs of left sensory extinction, but no clinical phenomena of hemibuccal neglect. Second, we have tested whether left lingual extinction for touch, when present, is obligatorily associated with left-sided taste extinction. The results in RBD patients have been compared with the results of similar tests in LBD patients and in normal controls.

2. Methods

2.1. Subjects

Eighteen RBD patients (9 women), 9 LBD patients (3 women) and 14 healthy control subjects (C, 8 women) participated in the study. The three groups were matched for age (RBD $= 66.7 \pm 7.5$ years; LBD $= 63.7 \pm 12.2$ years; C $= 70.5 \pm 6.4$ years) and education (RBD $= 7.5 \pm 5.3$ years; LBD $= 7.2 \pm 4.6$ years; C $= 8.5 \pm 4.8$ years of school). All patients were submitted to a standard neurological examination for the assessment of sensorimotor deficits, extrapersonal and personal neglect, and anosognosia (Aglioti, Smania, & Peru, 1999).

2.2. Procedure

Each patient and healthy subject was submitted to two experimental tests of lingual sensitivity, which were carried out while the patients were blindfolded to avoid visual cues about the side of the stimulus. Tactile and gustatory stimulation was delivered to the same locations on the two hemitongues, at a distance from the midline that warranted a complete lateralization of the stimulus. In the *tactile lingual test* two fixed-volume micropipettes were positioned above the right and left dorsal margins of the maximally protruded tongue just in front of the papillae foliatae. The stimulus consisted in the ejection of a 50 μl drop of deionized distilled water on either side of the tongue or on both sides simultaneously. The water temperature (about 20 °C) was such that it did not produce any thermic sensation. Although water can be a gustatory stimulus (Zald & Pardo, 2000), all subjects without exception reported that the stimuli were felt as purely tactile in nature. There were two experimental blocks, each of which consisted of 24 trials including 6 left, 6 right and 12 bilateral stimuli presented in a random order. On each trial, subjects had to report whether they had perceived a single or double stimulus, and to indicate the stimulus side in the former case. They were instructed not to retract the tongue until making their report verbally or by appropriate manual gestures.

The *gustatory test* was similar to the tactile test except that each stimulus delivered through the micropipettes consisted of one 50 μl drop of one of three sapid solutions. These were a sour tasting 0.1 M citric acid solution, a salty tasting 1 M NaCl solution, and a bitter tasting 0.001 M quinine hydrochlorate solutions. At these concentrations, each stimulus to each side of the tongue normally generates a definite taste sensation, in accord with the notion that all qualities of taste can be elicited from all tongue locations that contain taste buds (Smith & Margolskee, 2001). The gustatory sensation is unavoidably accompanied by a tactile sensation that may aid in the detection and localization of the gustatory stimulus. According to control tests using a methylene blue solution, the ejected volume of sapid solutions remains fully lateralized to the application side (Aglioti et al., 2000).

All subjects performed in at least two experimental blocks, each of which consisted of 24 trials including 12 trials with single stimuli, 6 to the left hemitongue and 6 to the right hemitongue, and 12 trials with simultaneous bilateral stimuli. The different types of stimuli in each block were randomly intermixed. The task involved reporting the number and side of the stimuli, and pointing with the right index to the name(s) of the perceived tastant(s) on each trial. The Italian nouns 'acido' (sour), 'salato' (salty), and 'amaro' (bitter) were presented in block letters on a card in front of the subject. The vertical arrangement of the three nouns was changed every five to six trials in order to enforce responses guided by reading rather than by positional cues. On each trial, responses were evoked by a vocal prompter from the examiner following lingual stimulation. Subjects were informed that all stimuli belonged to three categories of tastants, but were allowed to report the occurrence of unidentified taste stimuli detected solely as touch stimuli. Thus, the information conveyed by each report indexed the subject's detection of one or two stimuli, his/her identification of the tastant(s), and his/her localization of any given stimulus to the right or left hemitongue. Accuracy rather than speed of response was encouraged. All subjects were non-smokers, and rinsed their mouth with pure water following each response. The comprehension of the task by brain damaged patients was ascertained by giving them two practice trials for each taste stimulus. The order of the gustatory and tactile tests was counterbalanced across subjects. The subjects' consent was obtained according to the Declaration of Helsinki and the experimental procedures were approved by the Departmental Internal Review Board.

2.3. Statistical analysis

Since the number of trials was different in the single and double stimulation conditions, percentages of correct responses rather than raw scores were used for purposes of statistical analyses. These were carried out by means of series of mixed design analyses of variance (ANOVAs) and post hoc comparisons with the Scheffé test.

3. Results

3.1. Tactile detection test

The results of the tactile detection test allowed a neat division of the RBD group into two subgroups, each composed of nine subjects. One subgroup showed a perfect or near-ceiling detection performance in all conditions of tactile stimulation of the tongue. In this group, the mean percentage of correct detections of single stimuli was 100% for the right hemitongue and 98.6% (range 87.5–100%) for the left hemitongue, whereas the mean percentage of correct detections on bilateral stimulations was 98.6% (range 93.7–100%) for the right hemitongue and 95.8% (range 81.2–100%) for the left hemitongue. Hereafter, this group will be referred to as RBD E− (RBD group without lingual tactile extinction).

In contrast, the other nine patients of the RBD group showed a clear impairment in their detection of left hemitongue stimuli which was restricted to the bilateral stimulation condition. In this group, the mean percentage of correct detections of single stimuli was 100% for both hemitongues, whereas the mean percentage of correct detections on bilateral stimulations was 97.2% (range 87.5–100%) for the right hemitongue and only 32.5% (range 0–68.5%) for the left hemitongue. The large mean difference of 67.45% (range 31.25–100%) between the percentages of correct detections on the left hemitongue in the single and double stimulation conditions, along with the absence of any overlap between the related individual scores in the two conditions, justifies the diagnosis of left (contralesional) unilateral extinction for tactile lingual stimuli in this group, which therefore will be referred to as RBD E+ (right brain damaged group with lingual tactile extinction).

In the other two groups, the detection performance was perfect or near ceiling in all conditions of tactile stimulation of the tongue. C subjects performed perfectly in all conditions of stimulation. In the LBD group, the mean percentage of correct detections was 100% for both hemitongues on unilateral stimulations, whereas on bilateral stimulations it was 98.6% (range 87.5–100%) for the right hemitongue and 94.4% (range 75–100%) for the left hemitongue. The results of the tactile test in all four groups are summarized in graphic form in the left part of Fig. 1.

The results of the tactile test were submitted to an ANOVA with group (four levels: RDB E+, RDB E−, LBD, C), hemitongue (two levels: ipsilesional and contralesional in the patient groups, right and left in the normal group), and number of stimuli (two levels: one and two) as main factors. The main purpose of this ANOVA, in which differences between the RBD E+ and the RBD E− groups were of course predetermined by the prior subdivision of the RBD patients into two groups on the basis of the tactile test, was to compare these two groups separately with normal subjects and LBD patients. The group factor was significant ($F(3, 37) = 67.06$, $P < 0.00001$) because the overall mean accuracy of the RBD E+ group (82.4%) was lower than that of the other three groups (RBD E− 98.2%; LBD 98.3%, normals 100%). Post hoc Scheffé test revealed significant differences in accuracy ($P < 0.00001$ in all cases) between the RDB E+ group and each of the other three groups, which in turn did not differ significantly from one another ($P > 0.05$ in all cases). The significant hemitongue factor ($F(1, 37) = 66.99$, $P < 0.00001$) reflected the difference

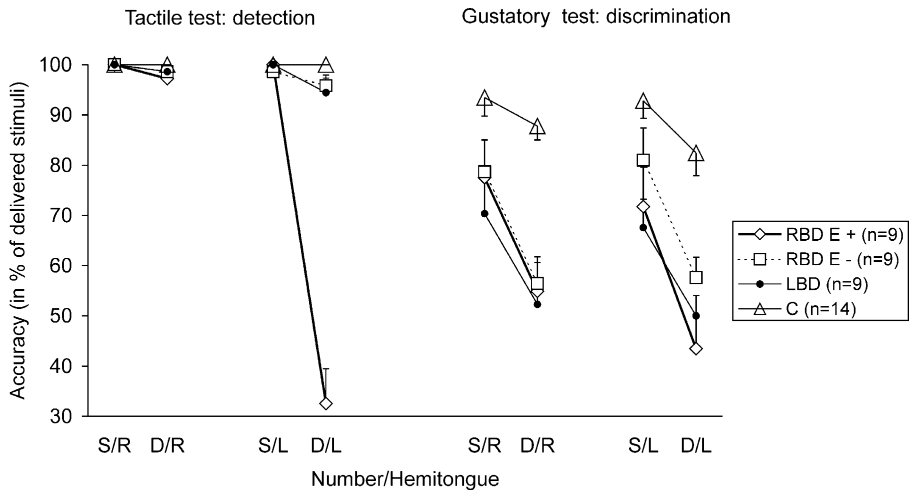

Fig. 1. Mean percent correct detections (standard errors in parentheses) of tactile and gustatory stimuli in the four groups (RBD E+, RBD E−, LBD and C). Legend: S, single; D, double; L, left; R, right.

between the 99.8% mean accuracy for the ipsilesional hemitongue and the 90.7% mean accuracy for the contralesional hemitongue in the three brain damaged groups. (This difference also included the difference between the right and left hemitongues in the C group.) However, the significance of the hemitongue factor depends on an interaction with group ($F(3, 37) = 64.13$, $P < 0.00001$) because only in the RBD E+ group was the performance with the contralesional hemitongue significantly inferior to that with the ipsilesional hemitongue. The percent difference in accuracy between the ipsilesional and contralesional hemitongues was 32.3% in the RBD E+ group ($P < 0.00001$), as compared with a statistically insignificant difference in each of the other two brain damaged groups (2.1% in RBD E− and −2.1% in LBD) and no difference between the right and left hemitongues in the C group. The number factor was significant ($F(1, 37) = 126.48$, $P < 0.00001$) because accuracy was higher for single than for double stimuli (99.8% versus 89.6%), but, as indicated by the significant group × number interaction ($F(3, 37) = 82.33$, $P < 0.00001$), the advantage for single over double stimulations was entirely restricted to the RBD E+ group where such advantage amounted to a difference of 35.1% ($P < 0.00001$), as contrasted with statistically insignificant differences of 2.1% in the RBD E− group, 3.5% in the LBD group, and 0% in the C group. The hemitongue × number interaction ($F(1, 37) = 67.07$ $P < 0.00001$) was significant because the advantage for single over double stimulations applied to the contralesional hemitongue (a difference of 17.9%, $P < 0.00001$) but not to the ipsilesional hemitongue (a difference of 2.4%, ns). Finally the significant triple group × hemitongue × number interaction ($F(3, 37) = 71.41$, $P < 0.00001$) was accounted for by the demonstration by post hoc Scheffé tests that only for the left hemitongue of the RBD E+ group did the difference between single and double stimuli (67.5%) reach significance ($P < 0.00001$).

3.2. Gustatory discrimination test

The results from the same four groups as in the tactile test are presented in the right part of Fig. 1. Since unilateral stimuli were never referred to the wrong side, and considering that each individual stimulus could elicit four types of identification reports (bitter, salty, sour and no-taste), a correct tastant identification on each hemitongue had a 25% probability of occurring by chance alone. In the RBD E+ group, the mean percentage of correct identifications of unilateral taste stimuli was 77.5% (range 41.7–100%) for the right hemitongue and 71.7% (range 33.3–100%) for the left hemitongue, whereas the mean percentage of correct identifications on bilateral stimulations was 54.9% (range 16.6–75%) for the right hemitongue and 43.5% (range 8.3–75%) for the left hemitongue. Therefore, the gustatory test did not bear out the marked selective drop in left hemitongue performance on bilateral stimulations that distinguished this group from the other groups in the tactile test. In the RBD E− group the mean percentage of correct identifications of unilateral taste stimuli was 78.7% (range 50–100%) for the right hemitongue and 81% (range 50–100%) for the left hemitongue, whereas the mean percentage of correct identifications on bilateral stimulations was 56.5% (range 25.0–91.7%) for the right hemitongue and 57.6% (range 41.0–83.3%) for the left hemitongue.

In the LBD group, the mean percentage of correct identifications of unilateral taste stimuli was 70.4% (range 50.0–100%) for the right hemitongue and 67.6% (range 41.6–91.7%) for the left hemitongue. Corresponding values on bilateral stimulations were 52.3% (range 41.7–62.5%) for the right hemitongue and 50.0% (range 29.2–66.7%) for the left hemitongue.

In the C group, the identification performance amounted to 93.4% (range 66.7–100%) for the right hemitongue and 92.8% (range 66.7–100%) for the left hemitongue on unilateral stimulation, whereas the corresponding values on bilateral stimulation were 87.8% (range 75.0–100%) and 82.4% (range 50.0–100%).

The results of the gustatory test were submitted to an ANOVA corresponding to that run on the results of the tactile test. The group factor was significant ($F(3, 37) = 15.89$, $P < 0.00001$) because the performance of the normal group (89.1%) was superior to that of the other three groups ($P < 0.002$ in all cases). The performances of the RBD E+ group (61.9%), RBD E− group (68.4%), and LBD group (60.1%) did not differ significantly from each other. The number factor was significant ($F(1, 37) = 54.01$, $P < 0.00001$) due to a higher accuracy for single (79.2%) than for double stimuli (60.6%). Among the interactions, only the group/number interaction approached significance ($F(3, 37) = 2.74$, $P = 0.056$) because the difference of accuracy between single and double stimulation conditions was significant in the RBD E+ (25.4%; $P = 0.007$) and RBD E− groups (22.8%; $P = 0.02$), but not in LBD (17.8%, $P = 0.15$) and in controls (8.04%; $P = 0.81$). No other factors or interactions were significant.

A further analysis was made by comparing the two RBD groups by breaking down correct scores with bilateral gustatory stimuli into responses to same or different tastants on the two sides. Upon bilateral stimulation, two patients of the RBD E+ group and two patients of the RBD E− group were tested exclusively with different tastants to the two sides. All the other patients in these two groups received six stimuli with the same tastant to both sides and six stimuli with different tastants to the two sides. In the RBD E− group, the mean percentage of correct identifications on bilateral stimulation with the same tastants was 51.8% for the right hemitongue and 50.9% for the left hemitongue, whereas with different tastants on the two sides it was 48.2% for the right hemitongue and 49.1% for the left hemitongue. Corresponding values for the RBD E+ group were 50.9% for the right hemitongue and 52.6% for the left hemitongue with the same tastants on the two sides, and 49.1% for the right hemitongue and 47.4% for the left hemitongue with different tastants on the two sides. Chi-square tests showed the absence of significant differences between the two groups, between the two hemitongues in each group, and between the same- and different-tastant conditions in each group.

A final analysis involved the computation of the percentage of correct tastant identifications for the two hemitongues of the RBD E+ group on correctly detected bilateral stimulations. The purpose of this analysis was to see whether gustatory performance with the left hemitongue on bilateral trials might have been underestimated because extinction of the tactile component of the stimulation had caused the loss of some left-sided gustatory stimuli. This possibility was confirmed by the finding that when both stimuli were perceived, the mean percentage of the tastant recognition with the left hemitongue (65.2%) was greater than that with the right hemitongue (54.9%). Although this difference did not reach statistical significance, it was present in six subjects out of nine. Further, the percentage of left hemitongue tastant recognition on bilaterally perceived trials (65.2%) was significantly greater than the corresponding percentage on all bilateral trials (43.5%: $t(8)$ −2.68, $P = 0.027$, by a paired *t*-test). In the RBD E− group the percentages of correct right hemitongue tastant recognition on bilaterally perceived trials and all bilateral trials were exactly the same (54.9%), and performance with either hemitongue was about the same when percentages were calculated on all bilateral trials ((left hemitongue 61.2%; right hemitongue 57.4%) or on bilaterally perceived trials (left hemitongue 57.6%; right hemitongue 56.5%).

3.3. A comparison between the results of the tactile test and the gustatory test

Some differences between the results of the two tests were fully expected and do not deserve a detailed comment. The healthy subjects were expected to perform better than all brain damaged groups on both tests, and they did. As expected, the overall performance of all groups was better on the tactile test, which required simple stimulus detections and localizations, than on the taste test, which additionally required stimulus identifications. Again according to the expectations, all brain damaged groups performed better with single than with bilateral stimuli in both tests, as did the normal subjects on the taste test but not on the tactile test, which they performed at ceiling level in all conditions.

There was a clear contrast between the evidence for a left hemitongue extinction in the tactile test in the RBD E+ group, and the absence of such evidence in the gustatory test in the same group. The contrast is statistically supported by the significance of the three-way group/hemitongue/number interaction in the ANOVA for the tactile test but not in the ANOVA for the gustatory test. The mean performance with the left hemitongue of the RBD E+ group under double stimulation conditions was numerically (but not significantly) greater in the gustatory (43.5% of correct discriminations) than in the tactile test (32.5% of correct detections), contrary to the other groups which in all stimulation conditions performed better in the tactile than in the gustatory test.

Additional evidence for a better performance of the RBD E+ group's left hemitongue on double stimulation in the taste test than in the tactile test was provided by a comparison between the percentage of detected bilateral tactile stimuli and percentage of bilaterally detected gustatory stimuli, regardless of the correctness of the identification of the latter stimuli (see Table 1).

The corresponding percentages for the RBD E+ group were entered into a repeated measures ANOVA with test (tactile versus gustatory), hemitongue (ipsilesional versus contralesional) and number (single versus double) as main factors. The most important result of this analysis is a significant three-way interaction ($F(1, 8) = 10.9$; $P = 0.01$), due, as shown by Scheffé post hoc comparisons, to the fact

Table 1
Mean percentages (and standard errors) of detections of single and double tactile and gustatory stimuli to the left and right sides of the tongue in the RBD E+ group

	Left tongue		Right tongue	
	Single	Double	Single	Double
Tactile test	100.0 (0)	32.5 (6.9)	100 (0)	97.2 (1.8)
Gustatory test	98.1 (1.7)	65.2 (9.9)	100 (0)	90.8 (5.1)

that only for stimuli delivered to the left hemitongue, was detection in the bilateral stimulation condition significantly worse in the tactile test (32.5%) than in the taste test (65.2%) ($P = 0.035$).

3.4. Further differences between the RBD E+, the RBD E− and the LBD groups

Site and extent of lesions in RBD patients were documented by means of CT or MRI scans, and a reconstruction of the lesions for each of the two RBD subgroups is provided in Fig. 2.

Subjects in the RBD group were considered to have visual, auditory or tactile extinction when they omitted the contralesional stimulus in at least 30% of bilateral stimulations, but detected this stimulus in at least 70% of the single trials. Percentages of correct detections of contralesional stimuli under single and double stimulation conditions for RBD patients are reported in Table 2 along with additional clinical information. The table shows that in the test for tactile extinction, two patients in the RBD E+ subgroup detected no stimulus to the left hand on both unilateral and bilateral presentations, indicating the existence of a left-sided somatosensory deficit that was absent in all RBD E− patients, who detected all or most left hand stimuli on unilateral presentations. At least five of the RBD E− patients showed left-sided tactile extinction insofar as the mean detection rate of left-sided stimuli on bilateral presentations (18%, range 0–45%) was definitely inferior to the mean detection performance on unilateral presentations (96%, range 90–100%). In the RBD E+ subgroup, all seven subjects who detected some or all left hand stimuli on unilateral presentations (mean 71.4%, range 20–100%)

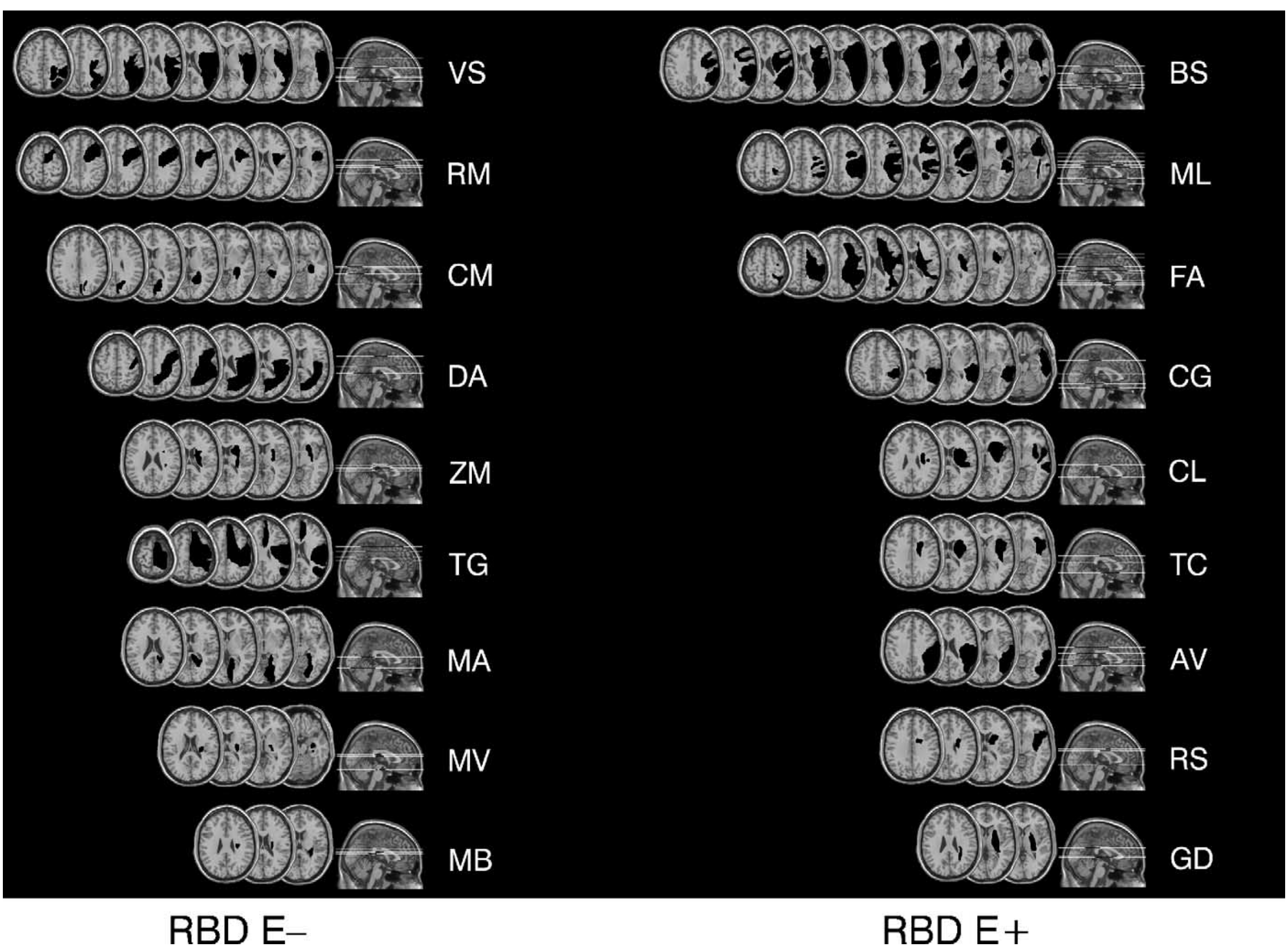

Fig. 2. Lesion reconstruction for RBD patients using MRIcro software (http://www.mricro.com). The figure shows the site and the size of the lesion (in black) for each RBD patient. The reconstruction of the lesions has been made by an investigator who was blind as to the symptoms of the patients.

Table 2
Demographic and clinical information on RBD patients

Pts.		Age	School	Sex	Left hand touch		Left Vis.		Left Aud.		Mot.	Anos.	Extr. Negl.	Pers. Negl.	Interval L–T (months)
					Sin.	Dou.	Sin.	Dou.	Sin.	Dou.					
RBD E+	BS	66	19	M	0	0	10	0	100	50	3	0	3	0	5
	ML	61	5	W	60	0	0	0	60	0	3	0	2	0	1
	FA	63	13	W	100	70	0	0	40	0	3	1	3	0	5
	CG		5	W	20	0	80	20	100	70	0	0	2	0	3
	CL	72	8	W	40	0	100	30	np	np	3	1	0	0	1
	TC	75	5	M	100	10	40	0	np	np	1	1	1	0	3
	VA	68	0	W	80	25	100	10	100	10	2	0	2	0	2
	RS	57	13	M	100	20	100	0	100	30	0	0	2	0	32
	DG	69	5	M	0	0	80	0	100	80	3	0	3	0	1
RBD E−	VS	63	5	M	90	45	np	np	np	np	0	0	1	0	3
	RM	47	18	M	100	90	100	100	100	100	3	0	1	0	1
	CM	76	5	W	100	100	0	0	100	80	3	0	1	0	I
	DA	49	13	W	100	0	0	0	100	100	2	0	1	0	1
	ZM	89	5	W	100	20	100	100	100	60	3	0	0	0	1
	TG	64	5	M	90	25	100	80	100	100	3	0	3	0	2
	MA	59	5	M	100	100	0	0	100	100	1	0	2	0	2
	MV	82	5	W	100	90	100	100	0	0	3	1	1	3	1
	BM	68	2	M	100	0	100	10	np	np	3	3	2	0	6

The RBD E+ and RBD E− groups were matched for age (67.2 ± 6.1 years vs. 66.3 ± 14.1 years) and education (8.1 ± 5.8 years vs. 7 ± 5.1 years of schooling). Results of tests for left-sided extinction are reported as percentages of detections of left-sided stimuli when applied singly (Sin.) or bilaterally (Dou.) in the touch, visual (Vis.) and auditory (Aud.) modalities. Regarding motor deficits (Mot.), anosognosia (Anos.) extrapersonal (Extr.) and personal (Pers.) neglect (Negl.), a score of 0 indicates absence of deficits and a score of 3 indicates a maximal deficit. Interval L–T indicates the months elapsed between lesion onset and testing.

exhibited a much reduced detection performance on bilateral presentations (mean 17.8%, range 0–70%). In the test for visual extinction, three patients in each of RBD subgroups did not respond or responded very rarely to stimuli in the left hemifield on both unilateral and bilateral stimulations, suggesting the presence of left hemianopsia. The remaining patients in the RBD E− subgroup responded at a high level to left hemifield stimuli on both unilateral and bilateral presentations, indicating that they did not suffer from left-sided visual extinction. In contrast, all the six patients in the RBD E+ subgroup with fair-to-perfect detection of left hemifield stimuli on single presentations (mean 83.3%, range 40–100%) missed all or most of left-sided stimuli on bilateral presentations (mean difference between unilateral and bilateral presentations 73.3%, range 40–100%), clearly indicating the presence of a left-sided visual extinction in each of them. Left-sided auditory extinction was tested in seven patients in each of the RBD subgroups. One patient in the RBD E− subgroup did not respond to left-sided auditory stimuli on both unilateral and bilateral presentations, but the other six patients in that subgroup detected all or most left-sided auditory stimuli regardless of the unilateral or bilateral type of presentation (mean difference between unilateral and bilateral presentations 6%, range 40–100%).

Table 3
Demographic, clinical, and radiological information on the lesion site in LBD patients

Pts.	RH touch		R visual		R Auditory		Mot.	Anos.	Extr. Negl.	Pers. Negl.	Token	Interval L–T (months)	Lesion site
LBD	Sin.	Dou.	Sin.	Dou.	Sin.	Dou.					Err/sever		
CA	100	100	100	100	100	90	0	0	0	0	24/light	2	F–T
TF	100	100	0	0	100	90	1	0	0	0	26/light	8	P–O
ZR	100	100	100	100	100	100	1	0	0	0	28/moderate	3	F–T–P
ML	70	70	100	100	100	80	3	0	0	0	13/light	23	F–T
BD	100	100	100	100	100	100	2	0	0	0	14/tight	5	BG
SG	50	40	0	0	100	100	3	0	0	0	4/absent	3	BC–T–O
CE	100	100	100	100	100	90	1	0	0	0	12/light	2	F
ML	60	50	100	100	100	100	3	0	0	0	15/light	24	F–T–P
RL	40	30	100	100	np	np	3	0	0	0	21/light	1	T–BC

Non-contextual comprehension abilities of each patient were inferred from the number of errors on the token test (Luzzatti, Willmes, & De Bleser, 1991). Fewer errors (Err) than seven indicate absence of deficits or an impairment of minimal severity (Sever); errors ranging from 8 to 21 indicate deficits of light severity; errors between 22 and 39 indicate deficits of moderate severity; errors above 40 indicate severe deficits. Other abbreviations and conventions as in Table 2.

A left-sided auditory extinction was instead clearly apparent in at least five of the seven RBD E+ patients, two of whom detected no left-sided stimulus on bilateral presentations, as opposed to 60 and 40% on unilateral presentations. The other patients tested for left auditory extinction exhibited a perfect detection performance with left-sided stimuli on unilateral presentations, as against a 48% mean detection performance (range 10–80%) on bilateral presentations. Among these patients with a performance demonstrating or suggestive of left-sided auditory extinction, three also suffered from left hemianopsia and four from left-sided visual extinction. In conclusion there was evidence for left-sided tactile extinction, as tested with stimuli applied to the hands, in both RBD subgroups, but evidence for left-sided visual and auditory extinction was no doubt more frequent and more severe in the RBD E+ subgroup than in the RBD E− subgroup.

Table 3 reports demographical, clinical and radiological information on LBD patients, who, in addition to the same tests as administered to RBD patients, also underwent standard tests for ascertaining the possible presence of aphasia. A detailed neuroradiological description of lesions was available for all LBD patients, as reported in Table 3, but CT or MRI scans for reconstruction of the lesions were not available for many of them.

4. Discussion

The main thrust of this study was aimed at the question of whether left-sided sensory inputs primarily directed to the left intact hemisphere of RBD patients can be as prone to extinction as other left-sided inputs primarily directed to the damaged hemisphere. To this aim we have compared and contrasted two aspects of lingual sensitivity on the assumption that they are at least partly distinguished by the laterality of their afferent pathways: touch, whose primary afferent path is mainly crossed, and taste, whose primary afferent path is mainly uncrossed. Contrary to a largely crossed cortical representation of the limbs and other exteroceptive body sites, the tongue has been traditionally thought to enjoy a bilateral representation in the cortex for both somatic and gustatory modalities (Penfield & Rasmussen, 1950). However, several combined pieces of evidence from more recent electrophysiological recording and stimulation studies, lesion studies, brain imaging studies and split brain studies in humans appear to indicate that processing of touch inputs from each hemitongue occurs predominantly in the contralateral hemisphere (Pardo et al., 1997; Picard & Olivier, 1983; Van Buren, 1983), whereas the processing of taste inputs from each hemitongue occurs predominantly in the ipsilateral hemisphere (Aglioti et al., 2000, 2001; Lenz et al., 1997; Pritchard et al., 1999; Sánchez-Juan & Combarros, 2001; Small, Zatorre, & Jones-Gotman, 2001). Both touch and taste pathways from the tongue are conjointly stimulated during feeding, and taste inputs are normally referred to the whole tongue or to the sites of contact with solid or liquid food, suggesting that touch normally plays an important part in the localization of taste sensations (Todrank & Bartoshuk, 1991). By using single small liquid drops as stimuli, we have aimed at a selective stimulation of the two modalities while at the same time matching tactile stimulation and gustatory stimulation for intensity as best as possible. Given the small volumes employed, taste receptor stimulation by water (Zald & Pardo, 2000) in the tactile test was extremely unlikely and was never reported, but gustatory stimulation was not devoid of a tactile component that may have had some influence on the performance (see Section 2 and below). However, tactile involvement in the gustatory test was no doubt minor compared to the earlier study on gustatory extinction by Bender and Feldman (1952), where gustatory stimuli were delivered by means of an imbibed cotton applicator.

We found that some RBD patients with signs of left-sided extinction in vision, bodily touch, or audition were also affected by a similar left-sided extinction of lingual tactile sensitivity. All members of a group of 18 RBD patients performed like normal controls in detecting unilateral tactile stimuli to the right and left hemitongues, but on bilateral stimulation nine of them differed from the other RBD patients by failing to detect a sizeable proportion of left hemitongue stimuli, thus justifying the diagnosis of left-sided tactile lingual extinction. There were no clear-cut associated clinical or pathological features that could differentiate the patients with this lingual extinction from those without it, except that in the former patients the symptoms of extinction in other modalities tended to be decidedly more severe than in the latter patients. The 50% rate of occurrence of a left hemitongue tactile extinction suggests that this deficit is probably far from rare in RBD patients, although it is likely to be overlooked in routine neurological examinations, which usually do not include thorough tests of lingual sensitivity. In keeping with the notion that unilateral extinction and neglect are strikingly more common after right than left brain damage (e.g. Kerkhoff, 2001; Vallar et al., 1994), we found no signs of lingual tactile extinction in nine LBD patients whose lesions were comparable for extent and intrahemispheric locations with those of the RBD group.

In the gustatory test, the healthy subjects performed well in all conditions of lingual stimulation and did not show any difference between the right and left hemitongues, in agreement with previous psychophysical evidence that the two sides of the human tongue are functionally equivalent for taste sensitivity (McMahon, Shikata, & Breslin, 2001). Whereas normal controls showed a statistically insignificant drop in gustatory performance in the bilateral compared to the unilateral trials, all the patients with hemispheric lesions, either right or left, found it significantly more difficult to identify bilateral compared to unilateral gustatory stimuli, but all performed well above chance.

The main result is that bilateral stimulation did not bring about any significant difference in tastant identification between the two tongue sides even in the patients with left hemitongue tactile extinction. The present gustatory test was no doubt more exacting than the simple tactile detection task employed with the same patients, yet the RBD patients with left tactile lingual extinction did not suffer from a comparable left-sided gustatory lingual extinction, and indeed upon bilateral gustatory stimulation they were significantly more successful in the identification and localization of left stimuli than they were in the detection of left stimuli upon bilateral tactile stimulation. Although the RBD with tactile lingual extinction showed a trend toward poorer performance with the left than the right hemitongue on the total number of bilateral gustatory trials, this trend fell far from statistical significance. An opposite trend actually emerged if one considered only correct detections of bilateral stimuli, thus excluding those bilateral gustatory trials on which left stimuli may have been omitted because stimulus detection was interfered with by tactile extinction. The mean percentage of correct tastant identifications by the left hemitongue on bilaterally detected stimuli was indeed higher than the corresponding percentage for the right hemitongue, and this was true in six patients out of nine, even though the difference did not reach statistical significance. It is thus reasonable to propose that evidence for gustatory extinction on the left hemitongue, if any, was predicated on the negative interference of tactile extinction on the mere detection of left stimuli on bilateral gustatory trials. Conversely, even when misidentifying tastants, patients with left hemitongue tactile extinction were significantly better in the detection of bilateral gustatory stimuli than in the detection of bilateral tactile stimuli, as if detection of left-sided tactile stimuli were aided in some way by concurrent gustatory stimuli. The absence of gustatory extinction on a left hemitongue affected by tactile extinction in RBD patients can thus be accounted most parsimoniously for by a substantial participation of the intact left hemisphere in the processing of taste inputs from that hemitongue. Crossed gustatory inputs from the right hemitongue to the left hemisphere may have allowed the relatively good performance with that hemitongue, if one considers that the left hemisphere is probably superior to the right in verbal gustatory tests such as the present one (Aglioti et al., 2000, 2001; Henkin, Comiter, Fedio, & O'Doherty, 1977; Pritchard et al., 1999).

Unilateral sensory extinction is thought by most to be explained by competition models of selective attention in which each stimulus competes for gaining access to limited pools of attentional resources (e.g. Duncan, Humphreys, & Ward, 1997). Because of a special role of the right hemisphere in attention, lesions of that hemisphere would disadvantage sensory inputs from the contralateral left hemispace relative from those from the right space (Smania et al., 1998). Experiments with visual stimuli have suggested that extinction can be modulated by perceptual and attentional factors, insofar as extinction can be reduced if the contralesional visual stimulus can be combined with the ipsilesional visual stimulus in a unitary perceptual configuration (e.g. Ward, Goodrich, & Driver, 1994), whereas it can be enhanced if ipsilesional and contralesional visual stimuli are identical but not parts of a whole (e.g. Vuilleumier & Rafal, 2000). Neither of these side-to-side effects can be suspected to have occurred in the gustatory testing of the present patients with left-sided tactile lingual extinction, because identification of left-sided gustatory stimuli on bilateral stimulation was equally successful with identical or different stimuli to the two sides.

The present claim for a dissociation between touch and taste extinction on the tongue of RBD patients can be contrasted with conclusions drawn from the few previous studies which have examined left-sided neglect and extinction with regard to differences in the laterality of different sensory pathways. The absence of gustatory extinction in cases with left-sided tactile lingual extinction disagrees with previous reports of a co-occurrence of the two kinds of lingual extinction as a result of right hemisphere lesions (Bender & Feldman, 1952; André et al., 2000). This discrepancy is best accounted for by a more severe impairment of general intraoral sensitivity in the patients of the two above mentioned previous studies compared to the present ones. Apart from the already mentioned procedural differences, the single patient studied by Bender and Feldman (1952) had a tumoral rather than vascular lesion of the right parieto-occipital cortex and did not detect any stimulus to the left hemitongue upon bilateral tactile stimulation. By contrast, in only one patient of the present study was detection of tactile stimuli to the left hemitongue totally suppressed by simultaneous tactile stimuli of the right hemitongue. The patient described by Bender and Feldman (1952) further exhibited a complex pattern of reciprocal interferences between tactile and taste stimuli simultaneously delivered to the two sides of the tongue, so that deficits of detection could be observed in the right and left hemitongues alike depending on the kind of stimulation. On the contrary, comparisons with normal controls and LBD patients of the present study offered no indications that right hemitongue sensitivity was abnormal in the present RBD patients with left hemitongue tactile extinction. The paper by André et al. (2000), which does not specify the method of gustatory stimulation, describes patients suffering from buccal hemineglect who showed a marked extinction of tactile and gustatory stimuli to left perioral and intraoral regions when bilaterally stimulated. Moreover, those patients suffered from marked alterations of chewing and swallowing on the left side of the mouth in association with subjective left ageusia, a pattern of disturbances clearly more akin to neglect than extinction. Since none of these severe disturbances was manifest in any of the present RBD or LBD patients, it seems reasonable to assume that gustatory extinction surfaces only as an accompaniment and possibly a consequence of a very marked extinction of tactile lingual sensitivity, or even a full blown intraoral tactile hemineglect. The relatively mild degree of lingual tactile extinction in the present RBD patients may have allowed the preservation of gustatory sensitivity on the side of touch extinction simply because gustatory inputs from the left side enjoyed the benefit of being processed by the intact left hemisphere.

Support for the notion that inputs from the contralesional side of space may undergo a faulty processing regardless of whether they are primarily directed to the damaged or intact hemisphere has been provided chiefly by studies on olfactory neglect and extinction by Bellas et al. (1988a, b, 1989). However, as mentioned in the Introduction, their claim of extinction of both olfactory and irritant trigeminal inputs from the left nostril in RBD patients is rendered problematic by evidence that localization to one or the other nostril is only possible via trigeminal and not olfactory activation (Doty & Cometto-Muñiz, 2003), as well as by the finding that their patients displaced to the right nostril correctly identified left nostril olfactory inputs.

In conclusion, we propose that in left-sided extinction from right brain damage the laterality of the sensory inputs does make a difference insofar as left-sided inputs to the intact left hemisphere are not affected by extinction, or affected to a much smaller degree than left-sided inputs directed to the damaged right hemisphere. In more general terms, the present study suggests that the lateral organization of sensory inputs should be reconsidered as a far from negligible factor in the cross-modal pattern of unilateral sensory extinction from unilateral brain damage.

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References

Aglioti, S. M., Smania, N., & Peru, A. (1999). Frames of reference for mapping tactile stimuli in brain-damaged patients. *Journal of Cognitive Neuroscience*, *11*, 67–79.

Aglioti, S., Tassinari, G., Corballis, M. C., & Berlucchi, G. (2000). Incomplete gustatory lateralization as shown by analysis of taste discrimination after callosotomy. *Journal of Cognitive Neuroscience*, *12*, 238–245.

Aglioti, S. M., Tassinari, G., Fabri, M., Del Pesce, M., Quattrini, A., & Manzoni, T. et al., (2001). Taste laterality in the split brain. *European Journal of Neuroscience*, *13*, 195–200.

André, J. M., Beis, J. M., Morin, N., & Paysant, J. (2000). Buccal hemineglect. *Archives of Neurology*, *57*, 1734–1741.

Bellas, D. N., Novelly, R. A., Eskenazi, B., & Wasserstein, J. (1988a). The nature of unilateral neglect in the olfactory sensory system. *Neuropsychologia*, *26*, 45–52.

Bellas, D. N., Novelly, R. A., Eskenazi, B., & Wasserstein, J. (1988b). Unilateral displacement in the olfactory sense: A manifestation of the unilateral neglect syndrome. *Cortex*, *24*, 267–275.

Bellas, D. N., Novelly, R. A., & Eskenazi, B. (1989). Olfactory lateralization and identification in right hemisphere lesion and control patients. *Neuropsychologia*, *27*, 1187–1191.

Bender, M. B., & Feldman, D. S. (1952). Extinction of taste sensations on double simultaneous stimulation. *Neurology*, *2*, 195–202.

Doty, R. L., & Cometto-Muñiz, J. E. (2003). Trigeminal chemosensation. In R. L. Doty (Ed.), *Handbook of olfaction and sensation* (pp. 981–999). New York: Marcel Dekker.

Driver, J., & Vuilleumier, P. (2001). Perceptual awareness and its loss in unilateral neglect and extinction. *Cognition*, *79*, 39–88.

Duncan, J., Humphreys, G., & Ward, R. (1997). Competitive brain activity in visual attention. *Current Opinion in Neurobiology*, *7*, 255–261.

Henkin, R. I., Comiter, H., Fedio, P., & O'Doherty, D. (1977). Defects in taste and smell recognition following temporal lobectomy. *Transactions of the American Neurological Association*, *102*, 146–150.

Karnath, H. O., Himmelbach, M., & Kuker, W. (2003). The cortical substrate of visual extinction. *NeuroReport*, *14*, 437–442.

Kerkhoff, G. (2001). Spatial hemineglect in humans. *Progress in Neurobiology*, *63*, 1–27.

Lenz, F. A., Gracely, R. H., Zirh, T. A., Leopold, D. A., Rowland, L. H., & Dougherty, P. M. (1997). Human thalamic nucleus mediating taste and multiple other sensations related to ingestive behavior. *Journal of Neurophysiology*, *77*, 3406–3409.

Luzzatti, C., Willmes, K., & De Bleser, R. (1991). Aachener aphasie test. *Versione italiana*. Firenze: Organizzazioni Speciali.

McMahon, D. B., Shikata, H., & Breslin, P. A. (2001). Are human taste thresholds similar on the right and left sides of the tongue? *Chemical Senses*, *26*, 875–883.

Mesulam, M. M. (1981). A cortical network for directed attention and unilateral neglect. *Annals of Neurology*, *10*, 309–325.

Norgren, R. (1990). Gustatory system. In G. Paxinos (Ed.), *The human nervous system* (pp. 845–861). San Diego: Academic Press.

Pardo, J. V., Wood, T. D., Costello, P. A., Pardo, P. J., & Lee, J. T. (1997). PET study of the localization and laterality of lingual somatosensory processing in humans. *Neuroscience Letters*, *234*, 23–26.

Penfield, W., & Rasmussen, T. (1950). *The cerebral cortex of man: A clinical study of localization of function*. New York: McMillan Press.

Picard, C., & Olivier, A. (1983). Sensory cortical tongue representation in man. *Journal of Neurosurgery*, *59*, 781–789.

Price, J. L. (1990). Olfactory system. In: G. Paxinos (Ed.), *The human nervous system* (pp. 979–998). San Diego: Academic Press.

Pritchard, T. C., Macaluso, D. A., & Eslinger, P. J. (1999). Taste perception in patients with insular cortex lesions. *Behavioral Neuroscience*, *113*, 663–671.

Sánchez-Juan, P., & Combarros, O. (2001). Síndromes lesionales de las vías nerviosas gustativas. *Neurologia*, *16*, 262–271.

Small, D. M., Zatorre, R. J., & Jones-Gotman, M. (2001). Increased intensity perception of aversive taste following right anteromedial temporal lobe removal in humans. *Brain*, *124*, 1566–1575.

Smania, N., Martini, M. C., Gambina, G., Tomelleri, G., Palamara, A., & Natale, E. et al., (1998). The spatial distribution of visual attention in hemineglect and extinction patients. *Brain*, *121*, 1759–1770.

Smith, D. V., & Margolskee, R. F. (2001). Making sense of taste. *Scientific American*, *284*(3), 26–33.

Todrank, J., & Bartoshuk, L. M. (1991). A taste illusion: Taste sensation localized by touch. *Physiology and Behavior*, *50*, 1027–1031.

Vallar G. (1998). Spatial hemineglect in humans. *Trends in Cognitive Sciences*, *2*, 87–97.

Vallar, G., Rusconi, M. L., Bignamini, L., Geminiani, G., & Perani, D. (1994). Anatomical correlates of visual and tactile extinction in humans: A clinical CT scan study. *Journal of Neurology, Neurosurgery and Psychiatry*, *57*, 464–470.

Van Buren, J. M. (1983). Sensory responses from stimulation of the inferior Rolandic and Sylvian regions in man. *Journal of Neurosurgery*, *59*, 119–130.

Vuilleumier, P. O., & Rafal, R. D. (2000). A systematic study of visual extinction. Between- and within-field deficits of attention in hemispatial neglect. *Brain*, *123*, 1263–1279.

Ward, R., Goodrich, S., & Driver, J. (1994). Grouping reduces visual extinction: Neuropsychological evidence for weight-linkage in visual selection. *Visual Cognition*, *1*, 101–129.

Zald, D. H., & Pardo, J. V. (2000). Cortical activation induced by intraoral stimulation with water in humans. *Chemical Senses*, *25*, 267–275.