Different Profiles of Verbal and Nonverbal Auditory Impairment in Cortical and Subcortical Lesions

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A B S T R A C T

Introduction: We investigated differential role of cortical and subcortical regions in verbal and non-verbal sound processing in ten patients who were native speakers of Persian with unilateral cortical and/or unilateral and bilateral subcortical lesions and 40 normal speakers as control subjects.

Methods: The verbal tasks included monosyllabic, disyllabic dichotic and diotic tasks, and nonverbal tasks were semantic, asemantic recognition and sound localization.

Results: Different profiles of ear extinction and hemispatial neglect was observed in our Left Hemisphere-Damaged (LHD) patients. Right Hemisphere-Damaged (RHD) patients with basal ganglia lesions showed mild hemi-spatial inattention of the ipsilesional and contralesional hemispace. LHD patients showed deficient performance in sound localization, but no evidence of significant impairment in sound localization was found in RHD patients except one. The patients with basal ganglia lesions irrespective of lesion side had impaired performance in semantic recognition. The results are suggestive of a network consisting of left and right basal ganglia and left cortical regions for non-verbal sound recognition.

Discussion: The results also indicate a different role for left basal ganglia in sound object segregation versus sound localization.

1. Introduction

Functional neuro-imaging and electrophysiological investigations have confirmed the dichotomy of what and where processing streams in human brain (Alain et al., 2001; Maeder et al., 2001). Several case studies have reported independent disruption of sound identification and localization following focal brain lesions centered on one or the other network (Spreen et al., 1965; Fujii et al., 1990, Clarke et al., 2000, 2002; Adriani et al., 2003a, b; Nilipour et al., 2004). Activation studies have demonstrated that sound localization involves largely distributed cortical networks with prominent contribution of the temporal, parietal and prefrontal cortices (Alain et al., 2001; Griffiths et al., 1998, 2000; Bushara et al., 1999; Maeder et al., 2001). It has also been shown that the basal ganglia are involved in spatial attention in non-human primates (Boussaoud and Kermadi, 1997) and human (Mesulam, 1990; Filoteo et al., 1997; Gitelman et al., 1999; Koski et al., 1999); however, the differential role of basal ganglia in environmental sound recognition and localization has not been fully addressed. Since different subsystems are proposed to underlie the what and where of auditory sound recognition two different sets of auditory tests were implemented to differentiate between what and where properties of auditory sound recognition deficits in our patients.

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Neuroimaging studies (Engelien et al., 1995) have also demonstrated that categorization of environmental sounds involves more specifically left prefrontal, temporal, parietal and cingulate regions. In a recent study (Engelien et al., 2005), the contrast in listening to meaningful sounds versus meaningless sounds resulted in predominantly left hemisphere activations in frontal and temporal lobe regions. The significantly activated regions were located in left ventral stream along the superior temporal gyrus and dorsal inferior frontal gyrus as well as parahippocampal gyrus. Consistent with their previous study, Engelien et al. (2006) demonstrated that left hemispheric areas were more engaged during listening to meaningful sound material even in passive listening conditions. The ability to recognize environmental sounds was found to be deficient following right hemispheric lesions (Spreen et al., 1965; Fujii et al., 1990; Schnider et al., 1994; Clarke et al., 1996), bilateral lesions (Albert et al., 1972; Buchtel and Stewart, 1989; L'Hermitte et al., 1971; Mendez and Geehan, 1988; Motomura et al., 1986), and unilateral left lesions (Clarke et al., 2000; Schnider et al., 1994; Nilipour et al., 2004). Several lesion studies have demonstrated that patients with right hemispheric lesions had difficulty discriminating between acoustically related sounds (acoustic error), while those with left hemispheric lesions tended to confuse the true source of the target sound with a semantically related one (semantic error) (Spinnler and Vignolo, 1966; Schnider et al., 1994; Faglioni et al., 1969; Vignolo, 1969, 1982).

Different aspects of neglect phenomena in auditory modality have received attention in the literature (Bellmann et al., 2001; Clarke and Bellmann, 2004). Unilateral omissions or namely extinction of auditory targets when two auditory stimuli are presented simultaneously from the right and from the left, for example by finger clicking, have been interpreted as a manifestation of hemispatial auditory neglect (Hugdahl et al., 1991). An opposing view in current literature considers extinction as a consequence of defective transmission or processing of the sensory stimuli (Clarke and Bellmann, 2004). Currently, auditory neglect has been assessed using two types of tasks; auditory double stimulation, either clinically with finger clicking or with the dichotic listening task, and sound localization. Based on the tasks used, contralesional ear omissions in dichotic listening (De Renzi et al., 1984; Hugdahl et al., 1991) or systemic directional errors towards the ipsilesional side and alloacusis have been considered as auditory neglect phenomena (Pinek et al., 1989; Pinek and Brouchon, 1992; Sterzi et al., 1996; Soroker et al., 1997). However, it has been argued that deficits in sound localization may not reflect attentional deficits as in hemineglect. To address the controversy over structural-perceptive or spatial-attentional mechanisms for ear asymmetry in dichotic listening, and to assess the presence of similar functional disturbances between directional biases and ear extinction, Bellmann et al. (2001) recently designed a new ITD diotic task in which two lateralized acoustic stimuli are received at the same intensity level by both ears. Omissions to report items presented in either side cannot be accounted for ear extinction and reflect a spatial-attentional deficit (Bellmann et al., 2001). They described two types of auditory neglect based on ITD diotic task and auditory localization, one corresponding to a primarily attentional deficit associated with basal ganglia lesions and the other to distortions of auditory space representations associated with parieto-prefrontal lesions (Bellmann et al., 2001). In their recent review of auditory neglect, Clarke and Bellmann (2004) have argued that auditory neglect phenomena could be attributed to selective disruptions in what and where auditory streams: a neglect within the dorsal network leads to spatial bias in auditory localization, whereas an auditory neglect in the ventral stream manifests itself by inter-object omissions.

In light of previous findings we further investigated the spatial and non-spatial auditory processing in ten native speakers of Persian with cortical and subcortical lesions using ITD diotic task, three non-verbal auditory and three verbal auditory dichotic tasks.

2. Methods

2.1. Patients

Ten right-handed educated patients (mean education =12 years) with a primary unilateral left or right hemispheric lesion participated in this study (Table 1). All patients were recruited from incoming outpatients in two major rehabilitation centers, in Tehran. Six patients suffered from a left hemispheric lesion, two of them had left basal ganglia (BG) lesion. Four patients had a right-hemispheric lesion, two of them suffered from a right BG lesion. The participated subjects fulfilled the following criteria: (i) unilateral hemispheric lesion; (ii) no previous history of brain damage; (iii) normal hearing; (iv) monolingual native speaker of Persian; (V) absence of any major behavioral disturbances (see Table 1 for details).

Table 1. Demographic characteristics of LHD & RHD patients with and without basal ganglia lesions in this study. BG= Basal Ganglia; LHD= Left Hemispheric damage; RHD= Right Hemispheric damage; H. CVA= Hemorrhagic CVA; E. CVA= Embolic CVA; L= Left Hemisphere; R= Right Hemisphere; FTP= Fronto-Temporo-Parietal; T= Temporal; P= Parietal; TP= Temporo-Parietal; IC-BG: Internal Capsule- Basal Ganglia.

Patient	Age/sex	Education (years)	Lesion Side	Lesion Site	Etiology	Post-Onset (months)	Aphasia
HS	54/ M	14	L	IC-BG	H. CVA	20	Non-Fluent Anomia
SR	37/ F	14	L	F-T- P-BG	E. CVA	36	Non-Fluent
SE	19/ F	8	L	F-T-P	Aneurism	36	Non-Fluent
MM	37/ M	12	L	T-P	H. CVA	23	Non-Fluent Anomia
ZM	44/ M	19	L	P	Head Trauma	26	Fluent with slow rate
PA	45/ M	12	L	T-P	Aneurism	5	Fluent with dysarthria
NP	48/ F	9	R	IC-BG	E. CVA	60	no aphasia
KT	61/ M	12	R	IC -BG	H. CVA	11	no aphasia
RMH	39/ F	7	R	P	Head Trauma	51	no aphasia
LM	32/ F	12	R	F	E. CVA	38	no aphasia

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All patients were assessed for visual hemispatial neglect, using line cancellation task, line bisection task, drawing, coping pictures, and writing. Based on these assessments, none of the patients showed any evidence of visual neglect. A sample of descriptive speech was recorded from all subjects and analyzed as a criterion for the presence of language deficits in each patient. All left hemisphere-damaged (LHD) patients were evaluated for aphasic deficits using the standard Persian Aphasia Test (Nilipour, 1993). Based on our aphasiological assessment, four LHD patients (HS, SE, MM and SR) were classified as non-fluent with good comprehension and two (ZM and PA) as fluent with fair comprehension (Table 1). All patients participated in three auditory verbal and three non-verbal tasks. Informed consent of the patients and control subjects was obtained according to the Declaration of Helsinki.

2.2. Auditory Tasks

Two sets of auditory tasks were used in this experiment: three verbal and three non-verbal auditory tasks. The performance of each patient in each task was compared with the control population. All tasks were adaptations of the tests used in previous studies (Bellmann et al., 2001; and Clarke et al., 1996, 2000, 2002) with cultural and linguistic modifications for the speakers of Persian (Nilipour et al., 2004). The verbal and non-verbal auditory tasks were run on Pentium IV PC using Presentation software (version 0.55, www.neurobs.com). The tests were performed in a quiet room in front of the examiner. The stimuli were played through earphones directly linked to the computer, and the volume was adjusted to the comfortable level for each subject.

2.2.1. Verbal Auditory Tasks

Three different verbal auditory tasks were designed: disyllabic dichotic listening task, monosyllabic dichotic listening task, and ITD diotic task. The verbal auditory tasks were adapted and developed for the Persian language based on the framework of verbal auditory tasks developed by Bellman et al., (2001, 2003). The disyllabic words used in the verbal tasks were chosen from a pool of most frequent disyllabic Persian words. Two professional male and female opera singers repeated the words and their voices were recorded in a professional music studio. The recorded words were then adjusted for amplitude, appropriate volume and minimum noise level. The same procedures were followed for the monosyllabic words used in the Persian version of the monosyllabic dichotic listening task.

The verbal auditory tasks were performed on 68 control native speakers of Persian and a mean lateralization index was obtained for the normal population in each task. The control population consisted of three healthy educated age groups, aged between 20-75 years (mean age= 40 years, mean education= 13 years, seventeen males) with normal hearing. Twenty eight subjects were aged 20-34 years, twenty 35-49 years, and twenty were over 50 years old.

2.2.1.1. Disyllabic Dichotic Listening Task

This task consisted of 30 pairs of disyllabic Persian words, one transmitted exclusively to the left ear, the other to the right ear through earphones. The onset of the stimuli was synchronized. The subjects were instructed that they would hear two simultaneous words. They were asked to concentrate equally on both words and to repeat both of them if possible. Subjects were not required to indicate the corresponding ear of each word. The performance was assessed based on the number of correctly repeated words presented to the right or left ear and by a lateralization index. The lateralization index was calculated from the number of correctly reported words from the right ear minus the left, divided by right plus left ear, the whole multiplied by 100. A monaural right and left presentation of 10 items each were included in the task. In the control population, the right ear average score was 29.6 (SD= 0.67) and the left ear average score was 29.55 (SD= 1.15). Paired t-tests between right and left ear scores revealed no statistically significant right ear advantage (p= 0.65). The average lateralization index for the normal population was 0.13 (SD= 1.97).

2.2.1.2. Monosyllabic Dichotic Listening Task

This task was made up of 72 pairs of nine meaningful monosyllabic Persian words, one transmitted exclusively to the left ear, the other to the right ear through earphones. In each pair, one word was presented in a male voice and the other was presented in female voice. The same number of words in male and female voice was presented to right and left ears. The onset of the stimuli was synchronized. The subjects were instructed that two simultaneous words would be presented only once to their ears through the earphones. They were asked to concentrate equally on both words and to repeat both of them if possible. The subjects were not required to indicate the corresponding ear of each word. Their performance was assessed as the number of correctly repeated words presented to the right or left ear and by a lateralization index. The lateralization index was calculated in the same manner mentioned in the previous task. In the control population, the right ear average score was 59.3 (SD= 9.05), and the left ear average score was 54.6 (SD= 10.53). Paired t-tests between right and left ear scores revealed statistically significant right ear advantage (p< 0.001). The average lateralization index for the normal population was 4.5 (SD= 7.99).

2.2.1.3. ITD Diotic Task

This task consisted of 30 pairs of disyllabic Persian words used in the dichotic listening task. Both ears received items of each pair at the same intensity level, but one of them was lateralized in the left hemispace and the other in the right hemispace. The spatial lateralization was stimulated by interaural time difference (ITD) of 1ms. The ITD diotic task was perceived subjectively by the normal control population as identical to the dichotic task. They reported hearing word pairs presented to the left and the right ears. As in the dichotic task, the subjects were instructed to report both items. Performance was assessed as the number of correctly reported words on the right or left side, and by the lateralization index. In the control population, the right side average score was 27.3 (SD=3.32), and the left side average score was 27.6 (SD=2.97). Paired t-tests between right and left side scores revealed no statistically significant advantage of any side (p=0.175). The average lateralization index was -0.6 (SD= 3.35).

2.2.2. Non-Verbal Auditory Tasks

Two types of non-verbal auditory tasks were used: spatial localization task (explicit localization task) and sound recognition tasks (semantic and asemantic). The non-verbal auditory tasks were normalized using twenty seven normal subjects of three age groups aged between 20-75 years (mean age= 40, mean education=15 years, ten males). Ten subjects aged 20-34 years, ten 35-49 years, and seven were over 50 years.

2.2.2.1. Sound Localization

This test has already been described and used in previous studies (Nilipour et al., 2004; Clarke et al., 2000). It consisted of sixty 2s broadband “bumblebee” sounds, shaped with 100 ms rising and falling times, and presented through earphones at the intensity level judged comfortable by the subject. Five different azimuthal positions were simulated by varying interaural time difference. One central (ITD=0) and four lateral positions, two in each hemi-space (ITD= 1ms or 0.3ms, respectively) were created. The subjects were asked to choose one of the five positions marked on a head drawing presented on the screen by pushing the proper labeled key on the keyboard to indicate the position of the target sound. Mean performance of the control population (n=27) was 43 out of 60 trials (SD=5.7). The directional bias was measured by the spatial asymmetry index for the 48 lateralized stimuli, i.e. the number of right responses minus the number of left responses, irrespective of correctness of replies, divided by number of right responses plus left responses multiplied by 100. The mean response asymmetry index in control population was 3.0 (SD=9). The number of alloacuses was also recorded independently.

2.2.2.2. Sound Recognition Tasks

2.2.2.2.1. Semantic Recognition of Environmental Sounds

The test consisted of 44 environmental sounds. Each sample lasted 7s and was accompanied by a multiple-choice display of five drawings: the target; an object acoustically and semantically related to the target sound; semantically related; acoustically related; and an object neither acoustically nor semantically related. The subjects were required to indicate the correct sound source by pressing the proper key on the keyboard. The performance was assessed as the number of correct replies and error types. The average number of correct replies among the control population was 39 (SD= 2.38). Normal subjects never selected acoustically and semantically unrelated choices.

2.2.2.2.2. Asemantic Sound Recognition

The test consisted of 30 pairs of two consecutive environmental sounds used in the semantic recognition task. The stimuli were presented directly via earphones connected to the computer. The subjects were asked to indicate whether the two consecutive sounds belonged to the same or different sound objects by pressing the proper key on the keyboard. In the inter-stimulus intervals, subjects were required to count the number of target letters among distracters. The performance was assessed by the number of correct replies. The average number of correct replies was 27 (SD= 1.7) for control population (n=27).

3. Results

The performance of LHD and RHD patients in verbal tasks is represented by the number of right and left ear/side correct replies in Table 2. The lateralization indexes for each patient and normal population are presented in Figure 1. The performance of the patients and normal population in non-verbal tasks is summarized in Table 3.

3.1. Left Hemisphere-Damaged (LHD) Patients

Based on the data presented in Tables 2 and 3, LHD patients with basal ganglia and without basal ganglia lesions did not have the same profile in verbal and non-verbal auditory tasks.

3.1.1. LHD Patients with Basal Ganglia Lesions

Patients HS and SR showed a marked right ear disadvantage in disyllabic dichotic listening (Table 2 and Fig. 1). In monosyllabic dichotic task, they presented marked right ear extinction similar to their performance in disyllabic dichotic task. Both patients showed a significant hemispatial asymmetry in disfavor of right hemi-space in ITD diotic task. Based on the results, both patients suffered right ear extinction as well as right hemispatial inattention (Table 2 and Fig. 1).

3.1.2. LHD Patients without Basal Ganglia Lesion

The four patients without basal ganglia lesion presented different profiles in verbal and non-verbal tasks as compared with HS and SR. Patients SE and MM showed a marked right ear disadvantage in disyllabic dichotic listening task, while ZM and PA performed differently. They showed left ear extinction in disyllabic dichotic listening task (Table 2 and Fig. 1). Patients SE and MM presented marked right ear extinction in monosyllabic dichotic task similar to their performance in disyllabic dichotic task. On the other hand, patients ZM and PA had marked left ear extinction in monosyllabic dichotic task consistent with their performance in disyllabic dichotic task (Table 2 and Fig. 1). With respect to their performance in ITD diotic task, SE and MM presented a significant hemi-spatial asymmetry in disfavor of right hemi-space. Despite their left ear extinction, ZM and PA presented no hemi-spatial asymmetry in ITD diotic task (Table 2 and Fig. 1).

	Patients	Disyllabic Dichotic Task	Monosyllabic Dichotic Task	Diotic Task
LHD with BG lesions	HS	3/26 (-79)	6/43 (-76)	6/17 (-48)
	SR	13/17 (-13)	10/25 (-43)	6/11 (-29)
LHD without BG lesions	SE	0/29 (-100)	1/56 (-97)	10/14 (-17)
	MM	8/16 (-86)	8/37 (-68)	8/16 (-33)
	ZM	30/24 (11)	63/9 (75)	26/25 (2)
	PA	29/24 (9)	61/34 (28)	26/24 (4)
RHD with BG lesions	NP	30/29 (2)	49/44 (5.4)	29/25 (7)
	KT	30/30 (0)	56/43 (13)	23/27(-8)
RHD without BG lesions	RMH	29/30 (-2)	58/39 (20)	25/25 (0)
	LM	30/30 (0)	69/71 (-1)	26/27 (-2)
Normal		29.6/29.55 (.13)	59.3/54.6 (4.5)	27.3/27.6 (-.6)

* Number of correct responses in each case (3 out of 26)

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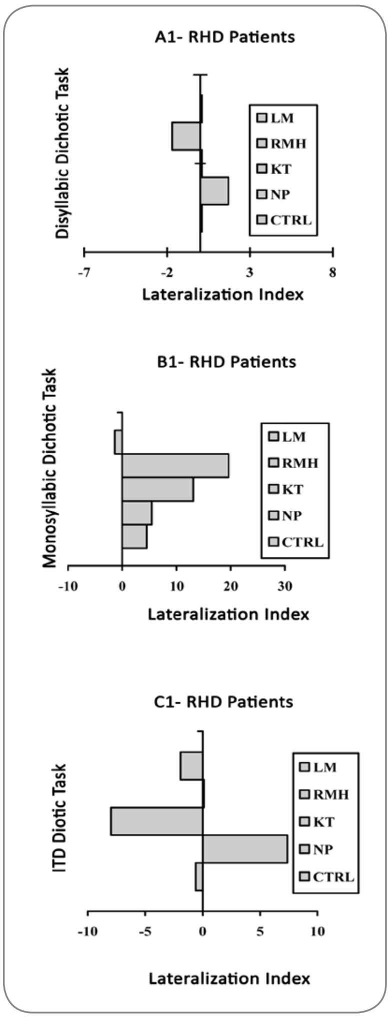
Table 2. Performance of LHD and RHD patients with and without basal ganglia lesions in three auditory verbal tasks compared with the performance of normal subjects in each task. The performance is represented as the number of correct responses to right ear or side of space and the number of correct responses to left ear or side of space. The lateralization index is shown in parentheses. The scores significantly different from normal are presented in bold.



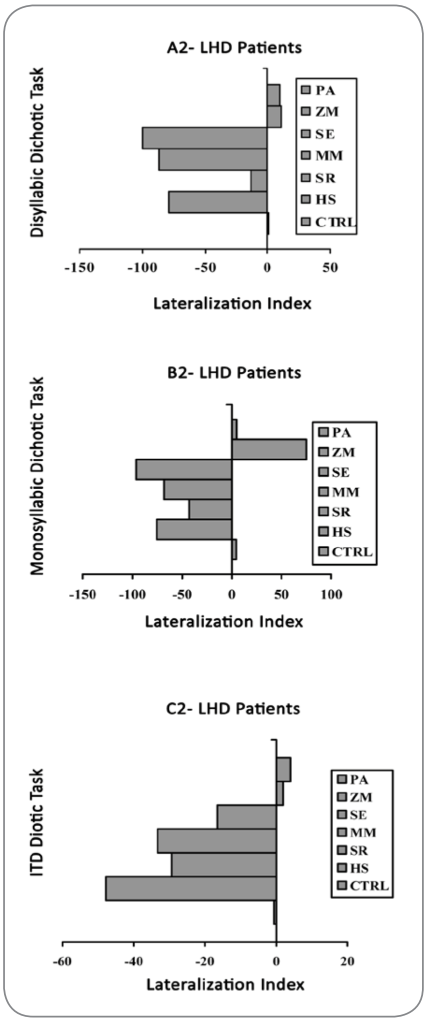


Figure 1. Lateralization indexes for disyllabic and monosyllabic dichotic listening tasks and ITD diotic task. The lateralization index corresponds to 100 × (Rcorrect − Lcorrect)/ (Rcorrect + Lcorrect); 'R/Lcorrect'= total number of correct responses to either the right/ left ear or the right/left side of space. The maximum asymmetry is equal to 100. The mean value for control population (CTRL) and the individual index for each patient are presented.

Patients SE and MM performed significantly poorer than the control population in semantic recognition task (Chi-square, P= .007 and P= .03, respectively); while the performance of ZM and PA was not significantly different from control population (Chi-square, P> .05) (Table 3). There was no significant difference between the error types of these patients and control population in semantic task (Chi-square, P> .05). None of these patients had deficient performance in asemantic recognition (Chi-square, P> .05) (Table 3).

The performance of SE and MM in sound localization was significantly poorer than control population (Chi-square, P= .02 and P< .001, respectively). Patient SE showed a significant shift to the right hemi-space as revealed by her spatial asymmetry index (one sample t-test, P< .001) and her alloacuses, but patient MM did not present any directional bias as his spatial asymmetry index was not significantly different from control population (one sample t-test, P> .05) with no incidence of alloacusis (Table 3).

Patients ZM and PA performed significantly poorer than control population in sound localization (Chi-square, P< .001). ZM presented a significant shift to the right hemi-space (one sample t-test, P= .007). Responses of patient PA were significantly deviated towards left hemi-space (one sample t-test, P< .001) with no incidence of alloacusis (Table 3).

3.2. Right Hemisphere-Damaged (RHD) Patients

Based on the results presented in Tables 2 and 3, RHD patients with basal ganglia and without basal ganglia lesions did not have the same profile in the verbal and non-verbal auditory tasks.

3.2.1. RHD Patients with Basal Ganglia lesions

Based on the data presented in Table 2, patients NP and KT had no ear asymmetry in disyllabic dichotic listening. In monosyllabic dichotic task, they showed no significant ear asymmetry consistent with their performance in disyllabic dichotic task. NP presented a mild hemi-spatial asymmetry in disfavor of left hemi-space, while KT showed a mild hemi-spatial asymmetry in disfavor of right hemi-space in ITD diotic task (Table 2 and Fig.1).

Table 3. The performance of LHD and RHD patients with and without basal ganglia lesions in semantic, asemantic sound recognition and localization compared with normal subjects in their number of correct responses. The directional bias in sound localization task is represented as spatial asymmetry index, which corresponds to 100 × (Responseright – Responseleft) / (Responseright + Responseleft). The scores significantly different from normal are presented in bold.

Lesion Site	Patients	Semantic Recognition Task	Asemantic Recognition Task	Sound Localization Task		
				Performance	Spatial Asymmetry Index	No. of Alloacuses
LHD with BG lesions	HS	33/44*	28/30	31/60	18.2	2 R
	SR	33/44	27/30	22/60	25.0	2 R
LHD without BG lesions	SE	33/44	28/30	35/60	25.7	2 R, 1 L
	MM	34/44	27/30	22/60	0	0
	ZM	39/44	29/30	28/60	8.1	1 L
	PA	39/44	25/30	27/60	-15.0	0
RHD with BG lesions	NP	31/44	25/30	37/60	12.0	1 R
	KT	35/44	23/30	40/60	-2.1	0
RHD without BG lesions	RMH	36/44	22/30	36/60	13.6	1 R
	LM	38/44	27/30	31/60	-6.9	1 L
Normal		39 (± 2.4)/44	27 (± 2) /30	43 (± 5.7)/60	3.0(± 9.0)	0

* Number of correct responses in each case (33 out of 44)

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The performance of patient KT was similar to control population, while NP was significantly deficient in semantic recognition. There was no significant difference between the error types of these patients and control population in semantic task (Chi-square, P> .05). In asemantic recognition task, KT was significantly poorer than control population, while patient NP performed similar to normal subjects (Table 3).

Patients NP and KT performed similar to normal subjects in sound localization (Chi-square, P> .05). NP showed a significant shift to the right hemi-space as indicated by her spatial asymmetry index (one sample t-test, P< .001) and one alloacusis to right hemifield; however, KT's responses were significantly deviated towards left hemi-space (one sample t-test, P< .006) with no incidence of alloacusis (Table 3).

3.2.2. RHD Patients without Basal Ganglia lesions

Patients RMH and LM presented no ear asymmetry in disyllabic and monosyllabic dichotic listening. There was no sign of hemi-spatial asymmetry in ITD diotic task (Table 2 and Fig.1). In semantic recognition task, RMH and LM performed similar to normal population (Chi-square, P> .05) with no significant difference between their error types and control population (Chi-square, P>.05). RMH performed significantly poorer than control population in asemantic recognition while the performance of LM was not significantly different from normal subjects (Chi-square, P=.007 and P> .05, respectively) (Table 3).

Patients RMH and LM were deficient in sound localization (Chi-square, P=.04 and P= .001, respectively). RMH showed a significant shift to the right hemi-space as manifested by her spatial asymmetry index (one sample t-test, P< .001) as well as one alloacusis to the right hemifield. The responses of LM were significantly deviated towards left hemi-space (one sample t-test, P< .001) with one alloacusis to the left hemifield (Table 3).

4. Discussion

Several double dissociations between semantic and asemantic recognition were observed in our patients. Deficient semantic sound identification accompanied by normal asemantic sound recognition was found in HS, SR, MM, SE and NP; while opposite dissociation was observed in KT and RMH. These dissociations are consistent with the parallel processing model for non-verbal auditory recognition proposed by Clarke et al. (1996). In their model, Clarke et al. (1996) proposed that three aptitudes regarding non-verbal sound recognition, namely sound object segregation, asemantic recognition, and semantic identification are processed largely in parallel networks and rely on cortical circuits that are different from those involved in verbal comprehension.

Also in our study, several LHD and RHD patients presented selective deficits in either sound identification or sound localization (Table 3). Patients ZM, PA and LM had impaired performance in sound localization but not in sound recognition; on the other hand, NP, KT and RMH were deficient in sound recognition with normal performance in sound localization. The present double dissociations are consistent with previous findings in other studies and are suggestive of what and where parallel auditory processing streams model proposed by Clarke (Clarke et al., 2000, 2001, 2002, 2003a, 2003b; Nilipour et al., 2004; Alain et al., 2001).

4.1. Role of Cortical and Subcortical Regions in Sound Recognition

Despite several studies assessing sound recognition deficits following right and left cortical lesions, only a few studies have investigated the role of basal ganglia lesions in environmental sound recognition (Schnider et al., 1994; Tanaka et al., 2002). Clarke et al. (2002) reported deficits of environmental sound recognition in several RHD patients who suffered both subcortical and cortical lesions. In a recent study, Tanaka et al. (2002) demonstrated that mild impairment of environmental sound recognition resulted from right and left subcortical lesions disrupting the geniculo-auditory association cortex projection fibers. Unlike cortical lesions, Tanaka et al. (2002) did not find any different pattern of errors related to the side of subcortical lesion. Our data is consistent with Tanaka et al. (2002). Two patients with left basal ganglia lesions (HS and SR) and two with right basal ganglia lesions (NP and KT) showed evidence of marked environmental sound recognition deficits. NP was deficient in semantic recognition task; however, KT performed deficiently in asemantic sound recognition. None of our patients showed evidence of significant error pattern biased towards acoustic or semantic errors. Regarding recent (Engelien et al., 2005; Engelien et al. 1995) and previous studies (Vignolo 1982; Schnider et al. 1994) indicating the prominent role of left hemisphere in recognition of meaningful environmental sounds; our results suggest that a network consisting of left and right basal ganglia and left cortical regions might be necessary for environmental sound recognition.

4.2. Auditory Extinction and Hemispatial Inattention

In their evaluation of auditory neglect, Bellmann and Clarke (2001) characterized two behaviorally and anatomically distinct types of auditory neglect: (i) deficits in allocation of auditory spatial attention following lesions of basal ganglia; and (ii) distortion of auditory spatial representation following fronto-temporo-parietal lesions. Bellmann and Clarke (2001) evaluated four patients with right brain damage and left ear extinction: two with right subcortical lesions and two with right cortical lesions in frontal and temporo-parietal cortices. Our patients with right subcortical lesion (NP and KT) did not show the same profile (Tables 2 and 3). There was no sign of ear extinction, as revealed by their normal performance in two versions of dichotic listening task. Patient NP presented mild left hemispatial inattention in ITD diotic task, while KT surprisingly showed mild ipsilesional hemispatial inattention. Both patients performed similar to normal population in sound localization; however, despite their normal performance and unlike patients in Bellmann and Clarke (2001), NP presented a significant directional bias towards ipsilesional hemispace, as revealed by her spatial asymmetry index and one alloacusis to right hemifield (Table 3). KT showed a significant spatial bias towards contralesional hemispace, as indicated by his negative spatial asymmetry index (Table 3). Our RHD patients with cortical damage (RMH with parietal and LM with frontal lesions) did not show any evidence of ear extinction or hemispatial inattention in dichotic and diotic tasks. Despite her normal performance in sound localization, RMH showed a directional bias towards ipsilesional hemifield which is consistent with patients with fronto-temporo-parietal lesions in Bellmann and Clarke (2001). LM presented a spatial bias towards contralesional hemispace as an indication of ipsilesional auditory neglect reported by Bellmann and Clarke (2001).

The auditory data obtained from six LHD patients are suggestive of two different profiles of ear extinction and hemispatial inattention. Two patients with left temporo-parietal lesions (ZM and PA) showed ipsilesional ear extinction in dichotic listening along with normal performance in diotic task; however, they presented deficient performance as well as directional bias towards ipsilesional (PA) and contralesional (ZM) hemifield in sound localization. On the other hand, our patient with subcortical lesion (HS) as well as three other LHD patients (SR with cortical and subcortical lesions, SE and MM with temporo-parietal lesions) showed contralesional ear extinction and hemispatial inattention. Evidence of impaired contralesional dichotic and diotic performance in HS with confined subcortical lesion clearly indicates that left basal ganglia lesions could lead to contralesional auditory extinction and neglect. Although the role of basal ganglia in neglect has been supported by anatomo-clinical correlations (Hier et al. 1977; Healton et al., 1982), further investigation is needed to underline specific involvement of right and left basal ganglia in attentional type of neglect.

Except MM with no directional bias, impaired sound localization was accompanied by contralesional directional bias in other LHD patients (HS, SR and SE), which is in clear contrast with profile of their performance in diotic task. In interpreting the data, the difference between sound localization and ITD diotic task should be born in mind. In their review of auditory neglect, Clarke and Bellmann (2004) have indicated to several differences between these two tasks. In sound localization task, the subject is to process one auditory object at a time, whereas in ITD diotic task, two auditory objects are presented simultaneously. Cusack et al., (2000) investigated dissociation between the processing of one object versus multiple auditory objects, and reported between-objects attention deficits without within-object attention deficit in patients with visual hemineglect. Although sound objects were arranged in temporal order as opposed to ITD diotic task, their study indicates that attentional mechanisms are involved in processing of multiple auditory objects. On the other hand, theories of neglect as a distortion of egocentric space representation (Bisiach et al. 1996, 1998a, 1998b; Karnath, 1997) convincingly explain the directional spatial bias in tasks where only one object is processed at a time. There is also a difference in task demand between sound localization and ITD diotic tasks. In the former, subject is required to explicitly attribute a spatial location to the sound target, while in the latter, subject is asked to acknowledge and report the content of auditory target. Clarke and Bellmann (2004) have argued that directional bias in auditory localization could clearly be attributed to distortion error within dorsal-spatial or where system. However, they have indicated that dichotic or diotic tasks do not require overt spatial processing, and have actually more links with auditory ventral-object or what system. Clarke and Bellmann (2004) have argued that auditory spatial information can also be used by what system for sound object segregation, and categorized ITD diotic task as a tool for assessment of sound segregation. They have proposed that the two types of distortion found in auditory neglect, i.e., contralesional omissions and directional errors (Bellmann and Clarke, 2001) are linked with disruptions in auditory what and where networks due to brain lesions (Clarke and Bellmann, 2004).

In summary, the observed data from LHD patients with cortical and subcortical lesions support ear extinction as well as auditory hemispatial inattention. The incongruity between hemifield neglect in diotic task and the directional shift in sound localization observed in patients with left BG lesion, as opposed to RHD patients with subcortical lesions suggest a different role for left basal ganglia in processing sound object segregation versus explicit sound localization. Also, the data support the existence of the proposed where and what cortical streams with a subcortical precursor network consisting of right and left basal ganglia for non-verbal sound recognition.

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References

Adriani, M., Bellmann, A., Meuli, R., Fornari, E., Frischknecht , R., Bindschaedler, C., Rivier, F., Thiran, J-Ph., Maeder, P., Clarke, S. (2003a) Unilateral hemispheric lesions disrupt parallel processing within the contralateral intact hemisphere: An auditory fMRI study. Neuroimage 20 (Suppl), S66-74.

Adriani, M., Maeder, P., Meuli, R., Bellmann, Thiran A., Frischknecht, R., Villemure, JG., Mayer, J., Annoni, JM., Bogousslavsky, J., Fornari, E., Thiran, J-Ph., Clarke, S. (2003b) Sound recognition and localization in man: specialized cortical networks and acute effects of circumscribed lesions. Exp Brain Res 153, 591-604.

Albert, ML., Sparks, R., Von Stockert, T., Sax, D. (1972) A case study of auditory agnosia: Linguistic and non-linguistic processing. Cortex, 8, 427-443.

Alain, C., Arnott, SR., Hevenor, S., Graham, S., Grady, CL. (2001) “What” and “Where” in the human auditory system. Proc Natl Acad Sci USA 98, 12301-12306.

Bellmann, A., Meuli, R., Clarke, S. (2001) Two types of auditory neglect. Brain 124, 676-687.

Bellmann, A., Clarke, S. (2003) Preserved use of spatial cues for sound segregation in a case of spatial deafness. Neuropsychologia 41, 1254-1261.

Bisiach, E., Pizzamiglio, L., Nico, D., Antonucci, G. (1996) Beyond unilateral neglect. Brain, 119, 851-857.

Bisiach, E., Ricci, R., Lualsi, M., Colombo, MR. (1998a) Perceptual and response bias in unilateral neglect: Two modified versions of the Milner Landmark Task. Brain and Cognition 37, 369-386.

Bisiach, E., Ricci, R., Neppi, Modona M. (1998b) Visual awareness and anisometry of space representation in unilateral neglect: A panoramic investigation by means of a line extension task. Consciousness and Cognition 7, 327-355.

Boussaoud, D., Kermadi, I. (1997) The primate striatum: neuronal activity in relation to spatial attention versus motor preparation. Eur J Neurosci 9, 2152-68.

Buchtel, HA., Stewart, JD. (1989) Auditory agnosia: apperceptive or associative disorder? Brain Lang 37, 12-25.

Bushara, KO., Weeks, RA., Ishii, K., Catalan, M-J., Tian, B., Rauschecker, JP., Hallett, M. (1999) Modality-specific frontal and parietal areas for auditory and visual spatial localization in humans. Nat Neurosci 2, 759–766.

Clarke, S., Bellmann, A. (2004) Auditory neglect: what and where in auditory space. Cortex 40, 291-300.

Clarke, S., Bellmann, A., De Ribaupierre, F., Assal, Gil. (1996) Non-verbal auditory recognition in normal subjects and brain-damaged patients: evidence for parallel auditory processing. Neuropsychologia 34, 587-603.

Clarke, S., Bellmann, A., Meuli, R., Assal, G., Steck, A. (2000) Auditory agnosia and auditory spatial deficits following left hemispheric lesions: evidence for distinct processing pathways. Neuropsychologia 38, 797-807.

Clarke, S., Bellman, A., Maeder, P., Adriani, M., Vernet, O., Regli, L., Cuisenaire, O., Thiran, JP. (2002) What and where in human audition: selective deficits following focal hemispheric lesions. Exp Brain Res 147, 8-15.

De Renzi, E., Gentilini, M., Pattacini, F. (1984) Auditory extinction following hemisphere damage. Neuropsychologia 22, 733–44.

Engelien, A., Tuscher, O., Hermans, W., Isenberg, N., Eidelberg, D., Frith, C., Stern, E., Silbersweig, D. (2005) Functional neuroanatomy of non-verbal semantic sound processing in humans. J Neural Transmission

Engelien, A., Silbersweig, D., Stern, E., Huber, W., Doring, W., Frith, C., Frackowiak, RS. (1995) The functional anatomy of recovery from auditory agnosia. A PET study of sound categorization in a neurological patient and normal controls. Brain 118, 1395–1409.

Faglioni, P., Spinnler, H., Vignolo, LA. (1969) Contrasting behavior of right and left hemisphere-damaged patients on a discriminative and a semantic task of auditory recognition. Cortex 5, 366-389.

Filoteo, JV., Delis, DC., Salmon, DP., Demadura, t., Roman, MJ., Shults, CW. (1997) An examination of the nature of attentional deficits in patients with Parkinson's disease; evidence from a spatial orienting task. J Int Neuropsychol Soc 3, 337-47.

Fujii, T., Fukatsu, R., Watabe, S., Ohnuma, A., Teramura, K., Saso, S., Kogure, K. (1990) Auditory sound agnosia without aphasia following a right temporal lobe lesion. Cortex 26, 263–268.

Gitelman, DR., Nobre, AC., Parrish, TB., LaBar, KS., Kim, YH., Meyer, JR., Mesulam, M. (1999) A large-scale distributed network for covert spatial attention: further anatomical delineation based on stringent behavioural and cognitive controls. Brain 122 (Pt 6),1093-106.

Griffiths, TD., Buchel, C., Frackowiak, RSJ., Patterson, RD. (1998) Analysis of temporal structure in sound by the human brain. Nat Neurosci 1, 422–427.

Griffiths, TD., Green, GGR., Rees, A., Rees, G. (2000) Human brain areas involved in the analysis of auditory movement. Hum Brain Mapp 9, 72–80.

Healton, EB., Navarro, C., Bressman, S., Brust, JC. (1982) Subcortical neglect. Neurology 32, 776-778.

Hier, DB., Davis, KR., Richardson, EP., Mohr, JP. (1977) Hypertensive putaminal hemorrhage. Annals of Neurology 1, 152-159.

Hugdahl, K., Wester, K., Asbjornsen, A. (1991) Auditory neglect after right frontal lobe and right pulvinar thalamic lesions. Brain Lang 41, 465–73.

Karnath, HO. (1997) Neural encoding of space in egocentric coordinates? Evidence for and limits of a hypothesis derived from patients with parietal lesions and neglect. In P Thier and H-O Karnath (Eds), Parietal lobe Contributions to Orientation in 3D space. Springer, Berlin, pp 497-520.

Koski, L., Paus, T., Hofle, N., Petrides, M. (1999) Increased blood flow in the basal ganglia when using cues to direct attention. Exp Brain Res 129, 241-6.

L'Hermitte, F., Chain, F., Escourolle, R., Ducarne, B., Pillon , B., Chedrue, F. (1971) Etude des troubles perceptifs auditifs dans les lesions temporales bilaterales. A propos de trois observations dont deux anatomo-cliniques. Rev Neurol 124, 329-351.

Maeder, P., Meuli, R., Adriani, M., Bellmann, A., Fornari, E., Thiran, JP., Pittet, A,. Clarke, S. (2001) Distinct pathways involved in sound recognition and localization: A human fMRI study. Neuroimage, 14, 802-816.

Mendez, MF., Geehan, GR. (1988) Cortical auditory disorders: clinical and psychoacoustic features. J Neurol Neurosurg Psychiatr 51, 1-9.

Mesulam, MM. (1990) Large-scale neurocognitve networks and distributed processing for attention, language, and memory. Ann Neurol 28, 597-613.

Motomura, N., Yamadori, A., Mori, E., Tamaru, F. (1986) Auditory Agnosia. Analysis of a case with bilateral subcortical lesions. Brain 109, 379-391.

Nilipour, R. (1993) Farsi Aphasia Test. Iran University of Medical Sciences Press. Tehran, Iran.

Nilipour, R., Clarke, S., Noudoost, B., Tarighat, Saber G., Najlerahim, A. (2004) Response time as an index for selective auditory cognitive deficits. Acta Neurobiol Exp 64, 163-170.

Pinek, B., Duhamel, J-R., Cavé, C., Brouchon, M. (1989) Audio-spatial deficits in humans: differential effects associated with left versus right hemisphere parietal damage. Cortex 25, 175–86.

Pinek, B., Brouchon, M. (1992) Head turning versus manual pointing to auditory targets in normal subjects and in subjects with right parietal damage. Brain Cogn 18, 1–11.

Schnider, A., Benson, DF., Alexander, DN., Schnider-Klaus, A. (1994) Non-verbal environmental sound recognition after unilateral hemispheric stroke. Brain 117 (Pt 2), 281-7.

Sterzi, R., Piacentini, S., Polimeni, M., Liverani, F., Bisiach, E. (1996) Perceptual and premotor components of unilateral auditory neglect. J Int Neuropsychol Soc 2, 419–25.

Soroker, N., Calamaro, N., Glicksohn, J., Myslobodsky, MS. (1997) Auditory inattention in right-hemisphere-damaged patients with and without visual neglect. Neuropsychologia 35, 249–56.

Spinnler, H., Vignolo, LA. (1966) Impaired recognition of meaningful sounds in aphasia. Cortex 2, 337-348.

Spreen, O., Benton, AL., Fincham, RW. (1965) Auditory agnosia without aphasia. Arch Neurol 13, 84–92.

Tanaka, Y., Nakano, I., Obayashi, T. (2002) Environmental sound recognition after unilateral subcortical lesions. Cortex 38, 69-76.

Vignolo, LA. (1969) Auditory agnosia: A review and report of recent evidence. In Benton AL (eds), Contributions to Clinical Neuropsychology. Aldine, Chicago, pp 172-208.

Vignolo, LA. (1982) Auditory agnosia. Philo Trans Royal Soc London series B: Biological Sciences 298, 49-57.