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Dichotic listening with forced attention in patients with temporal lobe epilepsy: Significance of left hemisphere cognitive dysfunction

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Fifty right-handed patients with focal temporal lobe epilepsy were administered a dichotic listening test with consonant-vowel syllables under non-forced, forced right and forced left attention conditions, and a neuropsychological test battery. Dichotic listening performance was compared in subgroups with and without left hemisphere cognitive dysfunction, measured by the test battery, and in subgroups with left and right temporal epileptic focus. Left hemisphere cognitive dysfunction led to more correct responses to left ear stimuli in all three attention conditions, and fewer correct responses to right ear stimuli in the non-forced attention condition. This was probably caused by basic left hemisphere perceptual dysfunction. Dichotic listening was less affected by a left-sided epileptic focus than by left hemisphere cognitive dysfunction. General cognitive functioning influenced dichotic listening performance stronger in forced than in non-forced attention conditions. Larger cerebral networks were probably involved in the forced attention conditions due to the emphasis on conscious effort.

Key words: Temporal lobe epilepsy, neuropsychology, dichotic listening, lateralization.

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INTRODUCTION

Patients with temporal lobe epilepsy (TLE) display a number of cognitive difficulties (Hermann, Seidenberg, Schoenfeld & Davies, 1997; Jokeit & Ebner, 1999; Helmstaedter, Kurthen, Lux, Reuber & Elger, 2003), including memory dysfunction (Helmstadter & Kurthen, 2001). The temporal lobes are of central importance to auditory perception (Brodal, 1981). Thus, conditions affecting temporal lobe function, such as TLE, may impair auditory perception. The dichotic listening (DL) method consists of simultaneous bilateral presentation of auditory stimuli. It represents a central experimental method for the study of brain asymmetry (Bryden, 1988; Hugdahl, 1995). It also represents a paradigm suitable to investigate auditory perception in patients with TLE, because of its sensitivity to temporal lobe functioning (Hugdahl, 1995, 2002).

In the non-forced (NF) condition of DL, healthy right-handers report verbal speech stimuli presented to the right ear more often than stimuli presented simultaneously to the left ear, a phenomenon known as the right ear advantage (REA; Hugdahl, 1995). Left hemisphere cognitive dysfunction, assessed by independent neuropsychological measures, leads to a lack of REA in patients with TLE and left hemisphere speech dominance (Gramstad, Engelsen & Hugdahl, 2003). Such an effect, in contrast, has not been reliably shown in patients with a left-sided temporal epileptic focus (Mazzucchi & Parma, 1978; Mazzucchi, Visintini, Magnani, Cattelani & Parma, 1985; Lee, Loring, Varney *et al.*, 1994; Gramstad *et al.*, 2003).

A similar effect of left hemisphere cognitive dysfunction may be present also when subjects are instructed to attend only to right or left ear stimuli, that is, in forced right (FR) and forced left (FL) attention conditions of DL. Furthermore, general impairment of cognitive function may be expected to have a larger effect on the ability to direct attention in DL than more isolated left hemisphere dysfunction. Forced attention must be regarded as cognitively more demanding than non-forced attention. In the forced attention conditions, conscious effort ("top-down") is of particular importance, whereas basic perceptual mechanisms ("bottom-up") are more important in the NF attention condition.

The REA phenomenon in DL is often explained by a structural model (Kimura, 1967; Sparks & Geschwind, 1968), where contralateral auditory projections dominate and ipsilateral auditory projections are suppressed or inhibited. Thus, REA reflects a left-hemisphere dominance for processing of speech sounds. Right ear items have direct access to the left hemisphere, whereas left ear items are projected to the right hemisphere and transferred to the left hemisphere via corpus callosum for processing. Following this model, lesions involving or affecting a left hemisphere speech sound processor would be expected to influence DL performance by reducing or eliminating the REA. Depending upon its location, a lesion involving auditory pathways may influence DL performance in various ways (Niccum & Speaks, 1991).

The main invasive method for determining side of language dominance in patients with epilepsy is the Intracarotid Amytal

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Test (IAT; Wada & Rasmussen, 1960). Based on this test, patients with left hemisphere speech dominance show REA, and patients with right hemisphere speech dominance show a left ear advantage (LEA). With bilateral language representation, no ear preference, or a less pronounced REA than normal is typically observed (Kimura, 1967; Studdert-Kennedy & Shankweiler, 1970; Strauss, Gaddes & Wada, 1987; Strauss, 1988; Zatorre, 1989; Hugdahl, Carlsson, Uvebrant & Lundervold, 1997). A unilateral epileptogenic lesion may impair perception of stimuli to the ear contralateral to the lesion in the DL test (Oxbury & Oxbury, 1969; Berlin, Lowe-Bell, Jannetta & Kline, 1972; McIntyre, Pritchard & Lombroso, 1976; Mazzucchi & Parma, 1978; Efron & Crandall, 1983; Mazzucchi *et al.*, 1985; Lee *et al.*, 1994; Grote, Pierre-Louis, Smith, Roberts & Varney, 1995). Studies on how an epileptic focus without a structural lesion affects DL performance, have been inconclusive (Mazzucchi & Parma, 1978; Mazzucchi *et al.*, 1985; Lee *et al.*, 1994). In a recent study, left hemisphere cognitive function predicted DL performance better than having a left-sided epileptic focus in patients with TLE (Gramstad *et al.*, 2003).

To our knowledge, forced attention conditions have not been used in other studies of patients with TLE. Functional neuroimaging studies have suggested that the frontal lobes may be of particular importance in forced attention conditions in DL (Thomsen, Rimol, Ersland & Hugdahl, 2004), whereas the temporal lobes may be of particular importance in the non-forced attention condition (Hugdahl, 1995; Binder, Frost, Hammeke, Rao & Cox, 1996; Jäncke, Wüstenberg, Scheih & Heinze, 2002). There are close anatomical interconnections between the temporal and frontal lobes (Brodal, 1981; Goldman-Rakic, Selemon & Schwartz, 1984). In patients with TLE, dysfunctional performance on tests thought to be sensitive to frontal lobe dysfunction, such as sorting tests, have been demonstrated (Hermann, Wyler & Richey, 1988; Corcoran & Upton, 1993; Hermann & Seidenberg, 1995; Horner, Flashman, Freides, Epstein & Bakay, 1996; Martin *et al.*, 2000; Giovagnoli, 2001). Based on these findings, some impairment in ability to direct attention might be expected also in patients with TLE. However, because the patients had a primary temporal lobe neurophysiological dysfunction, we did not expect any frontal lobe affection to be strong enough to override the influence of basic auditory perception mediated by the temporal lobes.

To evaluate the level of left hemisphere functional integrity, the Left Neuropsychological Deficit Scale (LNDS; Reitan & Wolfson, 1993) was used. This is a composite measure based on tests from the Halstead-Reitan Battery (HRB), incorporating motor and sensory-perceptual dysfunction and language-related deficits. In the original validation study of this scale (Reitan & Wolfson, 1993), 169 patients with left, right and generalized brain damage of various etiology were tested. Patients with focal left hemisphere damage showed elevated LNDS and normal scores on a similar measure of right hemisphere integrity (Right Neuropsychological Deficit Scale; RNDS), while patients with focal right hemisphere damage showed elevated RNDS and normal LNDS. Patients with generalized damage showed elevations on both scales. All three patient groups showed elevations on a scale measuring generalized brain dysfunction (General Neuropsychological Deficit Scale; GNDS). A control group of 41 subjects without brain damage showed normal results on all three scales.

Thus, we hypothesized that patients with left hemisphere cognitive dysfunction would have fewer correct responses to right ear stimuli and more correct responses to left ear stimuli than patients with normal left hemisphere function in the NF attention condition of DL. Furthermore, we hypothesized that this pattern would remain stable also under forced-attention conditions. Having a left-sided temporal epileptic focus was not expected to influence DL results to the same degree as having left hemisphere cognitive dysfunction. Impact of general cognitive functioning, as measured by the GNDS, full scale IQ and general memory index, was expected to be stronger in the forced-attention conditions than in the NF attention condition.

METHODS

Study sample

We examined 50 patients with an ascertained diagnosis of TLE. All patients were thoroughly examined with repeated EEGs. Both routine EEGs, sleep EEGs and in most instances video-EEG recordings in hospital were performed, with up to 100 hours of recording. Moreover, cerebral CT and at least one cerebral MR scan was performed in all patients. One had a PET scan and two had intracranial EEGs performed. Twenty-three were males, with a mean age of 33.8 (*SD* = 7.4) years and 27 were females, with a mean age of 33.1 (*SD* = 9.8) years. The age of seizure onset varied between 6 months and 38 years, 11 patients were 4 years or younger at seizure onset. The mean duration of epilepsy at time of testing was 17.8 years, with a median of 17 years (minimum 0.5 year and maximum 44 years). The diagnosis of TLE was based on interictal or ictal EEG, distinct seizure semiology in part based on ictal videometry, and/or radiological signs of temporal lobe pathology like hippocampal sclerosis (*n* = 30), cavernomas (*n* = 5), arteriovenous malformations and aneurysmal hemorrhage (*n* = 3), benign tumors (*n* = 2), possible posttraumatic focal epilepsy (*n* = 1) and postencephalitic focal epilepsy (*n* = 1). In eight patients the epilepsy was considered focal cryptogenic of temporal origin. In all cases, a temporal seizure focus was established. In two patients the lateralization was discussed based on some discrepancies between repeated EEGs, MR and PET findings and the clinical semiology (*n* = 1), and alternating EEG lateralization (*n* = 1), but both were classified according to a sum of indicators with focus on the clinical semiology. In no case did the neuropsychological test results contribute to the final focal epilepsy diagnosis. Twenty-two patients had right-sided and 28 left-sided epileptic focus.

Based on all available evidence, but the neuropsychological test results, 9 patients were considered to have likely lateral or neocortical temporal epilepsy, 40 to have mesiotemporal epilepsy and 1 female patient most likely mesial and lateral epileptic zones adjacent to a larger postoperative/radiation lesion after a temporal tumor. One female patient was without antiepileptic drug (AED) treatment, 19 patients were on monotherapy, 20 were on 2 AED and 10 used 3 AED. The most frequently used AED was carbamazepin (*n* = 32) and second most frequent was lamotrigin (n = 18). Of those on monotherapy, 8 patients used carbamazepine, 3 lamotrigin, 2 patients used oxcarbazepin, clobazam and phenobarbital, respectively, and one each used sodium valproat and phenytoin. Six patients were seizure free last year or longer, most had 1–10 CPS a month and 9 had secondarily generalized tonic clonic seizures last year prior to testing. All patients were right-handed, assessed from the lateral dominance examination of the HRB (Reitan & Wolfson, 1993). No subject had any clinically evident hearing disorders, or seizures with auditory hallucinations. Perception of finger rubbing (Auditory Imperception Test; Reitan & Wolfson, 1993) was normal for all patients. Mean full scale IQ (Wechsler Adult Intelligence Scale/WAIS; Wechsler, 1955) was 98.7 (range 75–120, SD = 11.5). Mean General Memory Index (GMI, Wechsler Memory Scale – Revised/WMS-R; Wechsler, 1987) was 90.3 (range 56–128, SD = 17.0). On the HRB, mean Impairment Index (Matthews, Shaw & Kløve, 1966) was 0.48 (range 0.0–1.0, SD = 0.29), and mean score on the General Neuropsychological Deficit Scale (GNDS; Reitan & Wolfson, 1993) was 31.0 (range 11–66, SD = 12.3). Nineteen of the patients were evaluated for surgery because of focal TLE, and had left hemisphere speech dominance established by IAT. In addition, two patients had left speech dominance established by IAT performed at another institution. Sixteen of the patients tested with IAT also participated in another study (Gramstad *et al.*, 2003). No significant differences were found between those patients and the rest of the patients (n = 34) on age, gender distribution, IQ, memory or neuropsychological summary measures. If right hemisphere speech dominance had been demonstrated, patients were excluded from the study. Of the 11 patients with early seizure onset (4 years or younger), five had left hemisphere speech dominance demonstrated by the IAT.

Neuropsychological testing

All patients were administered a standardized test battery by the first author or by trained test personnel under his supervision. It included DL, WAIS, WMS-R, HRB, and various other tests and questionnaires (Gramstad *et al.*, 2003). Only results of WAIS, WMS-R and HRB are analyzed here, in relation to DL performance.

The HRB administered deviated somewhat from standard instructions (Reitan & Wolfson, 1993). A Norwegian translation of a modified Halstead-Wepman Aphasia Screening Test (Halstead & Wepman, 1949; Matthews, Shaw & Kløve, 1966) was used instead of the Reitan-Indiana Aphasia Screening Test (Reitan, 1984; Reitan & Wolfson, 1993). The two tests are reasonably similar in structure and purpose. Scoring rules for the Reitan-Indiana test were closely followed when scoring performance and calculating the Neuropsychological Deficit scales. Because the patients spoke Norwegian, the Speech Perception Test was omitted. GNDS, LNDS and RNDS scores were calculated. GNDS is originally based on 42 different HRB test items. Because the Speech Perception Test was omitted, GNDS was based on 41 items. Each item was rated on a four-point scale or given a designated score indicating degree of deviation from perfectly normal. More deviant performances resulted in higher scores. LNDS (21 items) and RNDS (13 items) evaluate hemisphere-specific deficits. Signs of verbal dysfunction, defined as a relative deficit on verbal compared to non-verbal WAIS IQ or signs of dysphasia on the aphasia screening test, were scored on LNDS. In addition, relative deficit in the right compared to the left body-half on six sensory-perceptual measures (tactile, auditory and visual imperception, tactile finger localization, fingertip number writing and tactile forms test), and three motor measures (tactual performance test, finger tapping and grip strength), were scored on LNDS. Similarly, a result was scored on RNDS if it revealed non-verbal dysfunction or a relative deficit in the left body half. Scoring details and detailed validation data are given in the scoring manual (Reitan & Wolfson, 1993).

This manual gives no standard cut-off score between normal and brain-damaged patients on LNDS and RNDS. In a previous study (Gramstad *et al.*, 2003), we arbitrarily defined a cut-off score between 5 and 6 on LNDS, which was the score that best fitted the data in terms of defining comparable groups and yielding maximum contrasts with regard to DL results. The same approach was used in this study, and the same cut-off score was chosen. A score of 5 or less is within one standard deviation of the mean result in a control group without brain damage (Reitan & Wolfson, 1993). Thus, it could be argued that a subgroup with LNDS < 6 shows normal left hemisphere function, whereas a subgroup with LNDS ≥ 6 show different degrees of left hemisphere dysfunction.

DL test and procedure

The subjects were seated in a quiet room and the DL stimuli were presented via headphones. The experimenter had an extra set of headphones in order to overhear the output. Oral answers were continuously marked on a special scoring sheet. Stimulus materials, test and scoring procedures were taken from the guidelines of Hugdahl (1995). Dichotic stimuli consisted of the six stop consonants paired with the vowel /a/ to form six consonant-vowel (CV) syllables (ba, da, ga, pa, ta, ka). The syllables were paired with each other in all possible combinations, thus giving 36 different syllable pairs (including the 6 homonymic pairs). The dichotic tape was prepared on a computer (Digital Corporation, PDP 11/45), and digital-analog converters and with a digital-analog multiplexer. Each CV-syllable was approximately 450 milliseconds in duration, and the inter-trial interval was approximately 4 seconds. The temporal alignment between channels was set at the energy-release in both the consonant and the vowel segments of the CV-syllable. Maximum-onset difference between the channels was 0.5 milliseconds due to the digital-analog multiplexer resolution and the sampling frequency (minimum, 10 kHz). The syllables were originally recorded from the computer onto a reel-to-reel tape recorder (NAGRA IV), and copied onto a chrome dioxide cassette and played to subjects from a standard cassette player at about 80 dB. The 36 dichotic pairs were recorded three times on the tape with three different randomizations, for each attentional instruction.

There were three different attentional conditions, with different instructions on how to focus attention. In the first condition, the patients were simply told they would be presented with a list of CV-syllables. Thus, no specific instruction regarding attention was presented. This condition was called the non-forced (NF) attention condition. The subject's task was to answer with the syllable they heard on each trial. Thus, one response for each trial was emphasized, even though they might have perceived both syllables on some trials. This was done to eliminate the risk of artificial change in ear-advantages due to comparison of double-responses against single response trials. During the forced-right (FR) attentional instruction, the patients were told to pay close attention to only the right ear syllables, and only to report what they heard in the right ear. During the forced-left (FL) attentional instruction, the patients were told to pay close attention to the left ear syllables, and only to report what they heard in the left ear. The order of presentation was with the NF condition first, and the FR and FL conditions incompletely counterbalanced. Data were scored for each subject as the frequency of correctly recalled syllables for the right and left ear input.

All the statistics are calculated using SPSS 10.0 for Windows NT 4.

RESULTS

In the following, the subgroup with LNDS < 6 has been labeled the "normal" subgroup, and the subgroup with LNDS

Table 1. *Demographic and neuropsychological summary measures in patient groups with (LNDS ≥ 6) and without (LNDS < 6) left hemisphere dysfunction*

	LNDS ≥ 6	LNDS < 6	*t*-value	Sign.
Gender (males/females)	(13/11)	(10/16)		
Age	33.8 (8.6)	33.2 (9.1)	0.26	0.80
FSIQ	95.5 (12.2)	101.6 (10.2)	1.94	0.06
GMI	87.0 (15.5)	93.3 (18.1)	1.30	0.20
GNDS	36.5 (12.5)	25.9 (9.8)	3.36	0.002

Abbreviations: LNDS: Left Neuropsychological Deficit Scale; FSIQ: Full Scale Intelligence Quotient; GMI: General Memory Index; GNDS: General Neuropsychological Deficit Scale; Sign.: level of significance.

≥ 6 the "dysfunctional" subgroup, these labels referring to left hemisphere cognitive functioning. Moreover, the percentage correct responses to right ear signals in DL will be referred to as "RE%", and the percentage correct responses to left ear signals in DL will be referred to as "LE%".

As shown in Table 1, the dysfunctional subgroup had lower full scale IQ than the normal subgroup, but the difference was not statistically significant. However, the dysfunctional subgroup had a significantly higher score on GNDS, suggesting that signs of general brain dysfunction were present to a larger degree in this subgroup.

In the DL NF attention condition, the dysfunctional subgroup showed significantly fewer correct responses to right ear stimuli, and significantly more correct responses to left ear stimuli, than the normal subgroup. Mean RE% in the dysfunctional subgroup was 41.6 (*SD* = 8.9), in the normal subgroup it was 49.3 (*SD* = 11.7), *t*(df = 48) = 2.60, *p* = 0.012. Mean LE% in the dysfunctional subgroup was 44.7 (*SD* = 9.4), in the normal subgroup it was 34.3 (*SD* = 10.7), *t*(df = 48) = 3.65, *p* = 0.001.

In the DL FR attention condition, the dysfunctional subgroup showed a non-significant tendency towards fewer correct responses to right ear stimuli, and significantly more correct responses to left ear stimuli, compared to the normal subgroup. Mean RE% in the dysfunctional subgroup was 47.4 (*SD* = 14.1), in the normal subgroup it was 53.7 (*SD* = 10.8), *t*(df = 48) = 1.76, *p* = 0.08. Mean LE% in the dysfunctional subgroup was 39.0 (*SD* = 11.6), in the normal subgroup it was 31.6 (*SD* = 12.2), *t*(df = 48) = 2.20, *p* = 0.033.

In the DL FL attention condition, no significant subgroup differences in correct responses to right ear stimuli were found. The dysfunctional subgroup showed significantly more correct responses to left ear stimuli than the normal subgroup. Mean RE% in the dysfunctional subgroup was 32.9 (*SD* = 12.8), in the normal subgroup it was 34.4 (*SD* = 12.8), *t*(df = 48) = 0.4, *p* = 0.680. Mean LE% in the dysfunctional subgroup was 52.3 (*SD* = 12.6), in the normal subgroup it was 43.5 (*SD* = 13.9), *t*(df = 48) = 2.34, *p* = 0.024. The DL results are summarized in Fig. 1, with significant group differences marked with an asterisk.

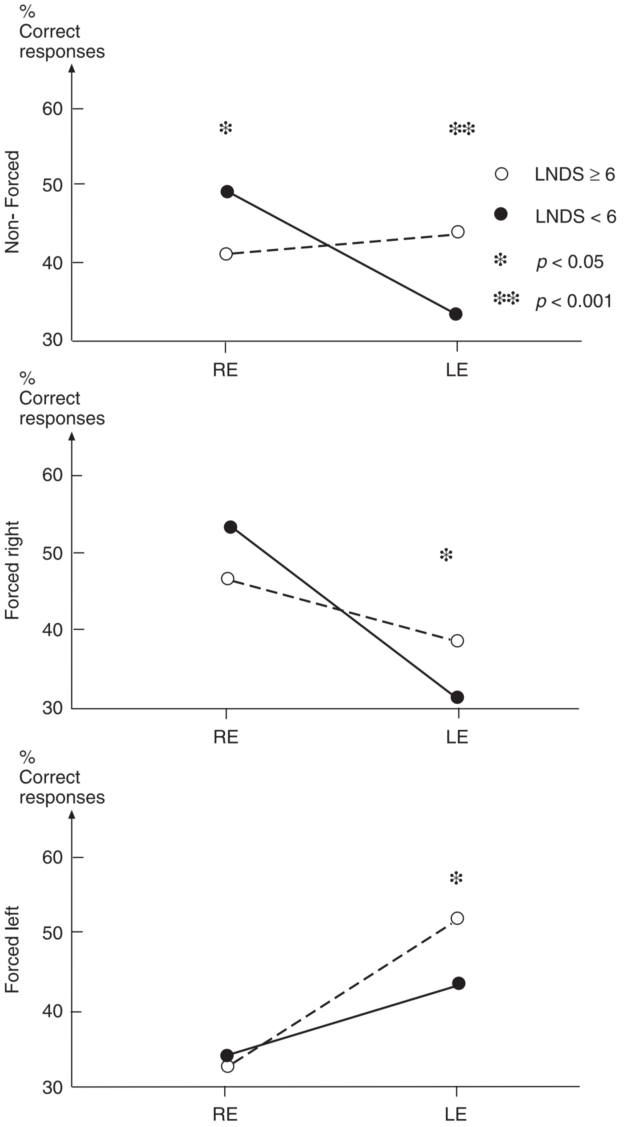

Fig. 1. Dichotic listening results in three different attention conditions, in groups split according to scores over or under cut-off on the Left Neuropsychological Deficit Scale.
Note: Significant group differences are marked with asterisk(s). *Abbreviations*: RE, Right Ear; LE, Left Ear; LNDS, Left Neuropsychological Deficit Scale.

Differences between patients with right and left temporal epileptic foci were also analyzed. There were no significant differences between these subgroups on demographic or neuropsychological summary variables. The subgroup with left focus had significantly fewer correct responses to right ear stimuli than the subgroup with right focus in the DL NF attention condition (*t*(df = 48) = 2.27, *p* = .028). Mean RE% in the left focus subgroup was 42.6 (SD = 9.2), in the right focus subgroup it was 49.5 (*SD* = 12.3). The left focus subgroup had a mean LNDS of 6.6 (*SD* = 4.1), which was higher than the mean LNDS of 5.4 (*SD* = 3.0) in the right focus subgroup, although not significantly so (t(df = 48) = 1.16, $p = 0.251$).

To further explore the relative impact of epileptic focus and left hemisphere cognitive dysfunction, a two-way analysis of variance was performed, where effects of LNDS (normal and dysfunctional subgroups) and side of epileptic focus (subgroups with left and right sided focus) on RE% were tested. A significant main effect of LNDS ($F = 5.29$, df = 1, $p = 0.026$) and a significant main effect of side of focus ($F = 4.30$, df = 1, $p = 0.044$), was found. The interaction effect was not significant. Thus, both epileptic focus and LNDS influenced RE%, independent of each other. The effect of LNDS was slightly stronger than that of side of epileptic focus. No significant effect of side of epileptic focus was found on any other DL variable.

Because the normal and dysfunctional subgroups on the LNDS differed also on other cognitive measures, the data were further analyzed in two ways. First, correlations between DL variables and neuropsychological variables were calculated. Then, multiple regression analyses were performed with DL measures as dependent variables. In the first model, LNDS and GNDS were included as independent variables in the regression analysis. Then, FSIQ and GMI were also included to test the amount of additional explained variance contributed by these variables. The results from the correlational analysis are presented in Table 2, and the results from the regression analyses of the first model are presented in Table 3.

From Table 2 it can be seen that LNDS showed significant correlations with both DL measures in the NF attention condition. No other correlation was significant and correlations with other measures than LNDS were quite low. In the FR and FL attention conditions, correlations with the other neuropsychological measures were higher, and more frequently significant. In particular, correlations between GNDS and DL results were always significant. Significant correlations were also found between FSIQ and RE% in the FR attention condition, and between GMI and RE% in the FL attention condition.

Table 2. *Correlations between dichotic listening results and neuropsychological summary measures*

		FSIQ	GMI	GNDS	LNDS
NF	RE%	0.11	−0.01	−0.01	−0.44**
	LE%	−0.05	0.09	−0.02	0.36*
FR	RE%	0.29*	0.16	−0.29*	−0.30*
	LE%	−0.25	−0.14	0.30*	0.29*
FL	RE%	−0.20	−0.38**	0.30*	−0.13
	LE%	0.14	0.26	−0.28*	0.15

Abbreviations: NF: Non-forced attention condition;
FR: Forced right attention condition; FL: Forced left attention condition; RE%: Percent correct answers to right ear items; LE%: Percent correct answers to left ear items; FSIQ: Full Scale Intelligence Quotient; GMI: General Memory Index; LNDS: Left Neuropsychological Deficit Scale; GNDS: General Neuropsychological Deficit Scale.
** $p < 0.01$, * $p < 0.05$.

Table 3. *Regression analyses with LNDS and GNDS as predictors of dichotic listening results*

Dependent variable		Predictor	Beta	*R* Square
NF	RE%	LNDS	0.61	0.26
		GNDS	0.32	
	LE%	LNDS	0.53	0.20
		GNDS	0.31	
FR	RE%	LNDS	0.21	0.11
		GNDS	0.18	
	LE%	LNDS	0.19	0.12
		GNDS	0.20	
FL	RE%	LNDS	0.42	0.21
		GNDS	0.52	
	LE%	LNDS	0.44	0.22
		GNDS	0.52	

Abbreviations: See Table 2.

The positive-negative direction of the correlations may also be noted. For FSIQ and GMI, better performance predicted higher scores. For GNDS and LNDS, dysfunctional performance lead to higher scores. Thus, one would expect correlations with GNDS and LNDS to be in the opposite direction compared to FSIQ and GMI. This was the case for the correlations between GNDS and DL measures. However, correlations between LNDS and DL in the FL attention condition were in the opposite direction of those for GNDS. That is, contrary to the GNDS, higher scores on LNDS were associated with lower RE% and higher LE% in the FL attention condition.

As can be seen from Table 3, the regression model with LNDS and GNDS as predictors explained about 20% of the variance in the NF attention condition, about 10% of the variance in the FR attention condition, and about 20% of the variance in the FL attention condition. In the NF attention condition, the beta weights show that LNDS was a better predictor than GNDS for both DL measures. In the FR attention condition, the beta weights show that the relative contribution of LNDS and GNDS was about similar. In the FL attention condition, the beta weights show that GNDS was a better predictor than LNDS for both DL measures.

Inclusion of FSIQ and GMI into the equation resulted in a 4% increase in explained variance in both RE% and LE% in the NF attention condition. In the FR attention condition, inclusion of FSIQ and GMI into the equation resulted in a 3% increase in explained variance in RE%, and no increase in explained variance in LE%. In the FL attention condition, inclusion of FSIQ and GMI resulted in more substantial increases in explained variance. Results of the expanded regression model with all four cognitive measures (LNDS, GNDS, FSIQ and GMI) as independent variables, and DL measures in the FL attention condition as dependent variables, are given in Table 4.

Table 4. *Regression analyses with LNDS, GNDS, FSIQ and GMI as predictors of dichotic listening results in the forced-left attention condition*

Dependent variable		Predictor	Beta	*R* square
FL	RE%	LNDS	0.43	0.31
		GNDS	0.53	
		FSIQ	0.29	
		GMI	0.42	
	LE%	LNDS	0.45	0.27
		GNDS	0.61	
		FSIQ	0.31	
		GMI	0.29	

Abbreviations: See Table 2.

As can be seen, this model explained about 30% of the variance for the DL measures in the FL attention condition. The beta weights show that GNDS in each DL measure explained the largest amount of variance, and that LNDS in each DL measure explained more variance than FSIQ and GMI.

We also investigated the impact of RNDS scores on DL results. One significant correlation between RNDS and DL performance was found. The correlation between RNDS and LE% in the FL condition was –0.41. However, when entered into the regression equations, the RNDS only led to marginal increases in explained variance on this variable. The combined model of LNDS, GNDS and RNDS explained 23% of the variance, and the beta weights were 0.34, 0.36 and 0.17, respectively. The combined model of LNDS, GNDS, FSIQ, GMI and RNDS explained 30% of the variance, and the beta weights were 0.30, 0.30, 0.28, 0.36 and 0.28, respectively.

DISCUSSION

This study confirmed that left hemisphere cognitive dysfunction influenced DL performance to a larger degree than having a left-sided temporal epileptic focus. However, a left-sided epileptic focus independently reduced the number correct responses to right ear stimuli in the NF attention condition. This subgroup difference may imply that the subgroup with left hemisphere cognitive dysfunction displayed more clear-cut left hemisphere impairment than the subgroup with a left-sided temporal focus. The process underlying a left hemisphere cognitive deficit may involve structural changes to a larger degree than the electrophysiological process underlying a left-sided temporal focus. The cognitive dysfunction also may involve other left hemisphere structures than the temporal lobe, and thus larger cerebral areas. Increased bilateral dysfunction in the subgroup with left-sided focus can probably be ruled out as an explanation of the difference, because this was only present in a minority of the patients.

The specific effect of left hemisphere cognitive dysfunction was strongest in the NF attention condition. Thus, the effect was strongest for lateralization of perceptual processing rather than for effortful processing as in the FR and FL attention conditions. This is what would be expected in a patient group with dysfunction localized to the temporal lobes, since verbal auditory information is primarily processed in this area.

Two mechanisms may explain the effect of left hemisphere cognitive dysfunction in this study. First, a suppression of the right ear signal may explain the significant reduction in correct reports of right ear signals by the subgroup with left hemisphere cognitive dysfunction in the NF attention condition. The correlational analyses indicated that a similar suppression also could have occurred in the FR and FL attention conditions, although group differences were non-significant. This finding may be explained by difficulties in processing of right ear stimuli by the left hemisphere in this subgroup, an effect often reported in patients with structural left hemisphere lesions (Kimura, 1967; Niccum & Speaks, 1991; Hugdahl, 1995).

In addition, deficient suppression of left ear stimuli has probably been present in the subgroup with left hemisphere cognitive dysfunction. This may explain the findings of significantly more correct left ear responses in this subgroup in all three attentional conditions. This also may explain the seemingly paradoxical positive correlation between correct reports of left ear signals and LNDS in the FL attention condition. Thus, left hemisphere dysfunction may facilitate reports of left ear items also when the subject is specifically instructed to report these items, leading to “supra-normal” performance compared to patients with normal left hemisphere function. The strength of this association, and the finding that the effect was present under all three attention conditions, suggests that deficient inhibition of left ear stimuli may be a quite large effect in patients with left hemisphere cognitive dysfunction, perhaps overriding the suppression of right ear stimuli.

Such a finding could also have been explained by an increase in the relative activation of the right hemisphere. However, the measure of right hemisphere dysfunction used in this study in general showed insignificant correlations with DL results. The only significant correlation lost most of its explanatory power when controlled for by other measures. Therefore, we conclude that right hemisphere function is less important than left hemisphere function in explaining the results of this study. This is in keeping with the structural model of DL with verbal stimuli, where the right hemisphere primarily is regarded as a relay station for left ear stimuli, which need to be transferred to the left hemisphere for processing (Kimura, 1967, Sparks & Geschwind, 1968).

The anatomical structures involved in deficient inhibition of left ear stimuli may be different than those involved in the suppression of right ear stimuli (Rouiller & de Ribaupierre, 1985), although we leave open the possibility that the two mechanisms may not be entirely independent.

The temporal lobe is not a unitary structure, and aspects of lesion location within the temporal lobe may affect DL results. Preliminary data suggest that lateral, neocortical lesions may have a larger impact on DL results than mesial temporal lesions (Haettig, Burckhardt, Bengner & Meencke, 2003). However, the data in the present study do not allow any thorough analysis of this phenomenon. Only 9 patients showed exclusively lateral foci, and the statistical power of such an analysis would be too low to draw firm conclusions. However, this question needs to be further investigated, and we plan to address it in later studies.

Correlation and regression analyses suggest that the general integrity of the hemispheres, as expressed in the GNDS scale, may independently affect DL performance under conditions of forced attention. This is what would be expected, based on the notion that forced attention is an example of "top-down" processing that may be particularly dependent upon an intact brain. The findings do not lead to any specific hypothesis about structural localization of this processing in the brain. A particular role of the frontal lobes have been suggested (Thomsen, Rimol, Ersland & Hugdahl, 2004), but the present study has not addressed this issue. The data support the idea that larger cerebral networks are involved in forced attention than those that are involved in the more purely perceptual processing in the NF attention condition.

The regression analyses showed that LNDS and GNDS always were the best predictors of DL results. FSIQ and GMI contributed to the prediction of DL results in the FL attention condition, but showed only marginal independent prediction of DL results in the NF and FR attention conditions.

Interestingly, cognitive variables influenced performance in the FR and FL attention conditions to a different degree. In the FR attention condition, cognitive variables showed relatively poor prediction of DL performance. In contrast, cognitive variables showed relatively good prediction of DL performance in the FL attention condition, explaining about 30% of the variance. These results indicate that the FR and FL attention conditions may not be identical, and that level of cognitive functioning is more important for effective performance in the FL than in the FR attention condition of DL. This has also been shown in other populations (Beaton, Hugdahl & Ray, 2000; Hugdahl, Bodner, Weiss & Benke, 2003; Hugdahl, Rund, Lund *et al.*, 2003). The task of overriding an existing perceptual asymmetry may require larger cognitive resources than simply increasing an existing asymmetry.

IAT testing was only done in 21 of the 50 patients to validate side of speech dominance, including two patients tested at another institution. This may represent a methodological weakness. However, only right-handed patients were included, and no significant demographic or cognitive differences were found between the patients with documented left-sided speech dominance and the other patients. Only 11 patients had an early age of seizure onset, before speech is firmly established and localized (Rasmussen & Milner, 1977), and left hemisphere speech dominance was demonstrated by IAT in five of those patients. Thus, we believe that left hemisphere language dominance probably was present in a large majority of the patients in the study.

In conclusion, the results lend support to our previous finding (Gramstad *et al.*, 2003), that left hemisphere cognitive dysfunction is a more potent predictor of DL results than left-sided temporal epileptic focus, although there was evidence that a left-sided epileptic focus independently led to suppression of right ear stimuli in the NF attention condition. In the forced attention conditions, left hemisphere dysfunction affected performance in the same direction as in the non-forced condition, with facilitated perception of left ear stimuli as the strongest effect. Thus, the data supported the idea that influence from extratemporal brain structures is too weak to completely override the effect of temporal lobe perceptual mechanisms in this patient group.

General cognitive function was more important for performance in the forced-attention conditions than in the non-forced condition. In particular, general cognitive function was more important for DL performance in the forced left than in the forced right attention condition. These findings are compatible with the idea that larger cerebral networks may be involved in the task of conscious, effortful processing than in the task of automatic perceptual processing. They are also compatible with the idea that larger cognitive resources are needed to override a perceptual asymmetry than simply to increase an already existing asymmetry.

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