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When only the right hemisphere is left: Studies in language and communication

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Abstract

An adult of above normal intelligence, BL, underwent left hemispherectomy at age five, and subsequently graduated from college and has been regularly employed. Using standardized neuropsychological instruments, previous extensive testing had revealed optimal performance for a hemispherectomized subject. To probe communicative abilities in greater detail, and to examine current questions about linguistic superiority of the left hemisphere and "crowding" of right hemisphere functions, 12 additional protocols were administered. BL performed at normal or above on nearly all protocols. However, performance on production of phonemically complex words was effortful, and deficits were seen on two tests requiring comprehension of linguistic contrasts in prosody (Linguistic Prosody Test) and syntax (the Active–Passive Test). These findings support previous claims of reduced ability in specific, circumscribed linguistic functions in the left hemispherectomized person, and lead to suggestions for further testing of communicative competence in individuals with a single intact hemisphere.

Keywords: Hemispherectomy; Language; Cognition; Laterality

1. Background

In the first study of 102 children with early onset hemiplegia, 35 of whom underwent hemispherectomy, Basser (1962) concluded from that with respect to speech development, "the left and right hemispheres are equipotential" (p. 451). At about the same time, an overview of 150 cases of persons who had undergone hemispherectomy as a treatment for infantile hemiplegia documented an improvement in "mental capacity" in two-thirds of the patients, regardless of side of surgery (White, 1961). Wilson (1970) also reported no effect of side of surgery on subsequent language development.

Later, however, in studies of children and adults who had early hemispherectomy, two specific effects on cognitive function were found to be associated with side of cerebral injury. First, language skills were found to be relatively more impaired in left-hemispherectomized than right-hemispherectomized patients (Day & Ulatowska, 1979; Satz, Strauss, Wada, & Orsini, 1988; Vargha-Khadem, Isaacs, Papaleloudi, Polkey, & Wilson, 1991; Woods & Teuber, 1973). Even when language function was apparently well established in the maturing individual, on careful testing, syntactic contrasts appeared less developed in left- than right-hemispherectomized persons (Aram & Whitaker, 1988; Dennis & Kohn, 1975; Dennis & Whitaker, 1976; Stiles & Nass, 1991). Of two hemispherectomized subjects, reading was more impaired in the individual with a remaining right hemisphere (Patterson, Vargha-Khadem, & Polkey, 1989). In a comparable population, children with infantile hemiplegia, right hemiplegic (left hemisphere damaged) subjects performed less well than left hemiplegic (right hemisphere damaged) subjects on tests of syntactic awareness (Kiessling, Kenkla, & Carlton, 1983). However, other studies have not always supported this claim, holding instead to the notion of equipotentiality of the hemispheres for language development (Ameli, 1980; Bishop, 1983; Byrne & Gates, 1987; de Bode & Curtiss, 2000; Ichiba & Takigana, 1992; Ogden, 1988).

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The second specific effect of hemispherectomy on cognitive function has been called "crowding." Somewhat paradoxically, inferior performance in visuospatial ability in the remaining "nondominant" hemisphere is commonly observed (Geschwind & Galaburda, 1985; Vargha-Khadem & Mishkin, 1997), along with relatively intact language function, leading to the notion that language representation has crowded out other traditional right hemisphere cognitive functions. Epileptic patients with right hemisphere representation of language as determined by Wada (intracarotid amobarbital) testing also performed more poorly on nonverbal tests than those with left hemisphere representation (Saykin, Gur, Sussman, & O'Connor, 1989; Strauss, Satz, & Wada, 1990). Selective preservation of verbal compared to performance scores in 31 children, regardless of side of unilateral brain injury, was reported by Riva and Cazzaniga (1986).

Greater nonverbal deficits were found in children with pre- and perinatal hemisphere damage, also lending support to the crowding hypothesis (Nass, Peterson, & Koch, 1989; Srinivasan, 1993; Stiles & Nass, 1991). Visuospatial and constructional capacities are more likely to be compromised in left and right hemispherectomized subjects, sparing verbal competence (Marriotti, Invone, Torrioli, & Silveri, 1998; Strauss & Verity, 1983; Verity et al., 1982). Similarly, complex pitch processing, previously shown to be associated with right hemisphere function (Sidtis, 1980; Sidtis & Volpe, 1988), was defective in adolescent subjects with early left as well as right hemisphere focal damage (Nass, Sadler, & Sidtis, 1992).

Separate functional properties attributed to the right and left hemispheres, respectively, in the neurologically normal, right-handed adult have long been asserted and explored (Absher & Benson, 1993; Bever, 1975; Bogen, 1969; Bradshaw & Nettleton, 1983; Critchley, 1962; Jackson, 1874; Liederman, 1988; Martin, 1979; Milner, 1980; Sperry, 1974; Young, 1983). That speech and language functions eventually formulate themselves into the left hemisphere of the overwhelming majority of right-handed and in most left-handed adults has been repeatedly confirmed by lesion studies (Caplan, Hildebrandt, & Makris, 1996; Geschwind, 1970), clinical testing using intracarotid amobarbital (Loring, Meador, Lee, & King, 1992; Rasmussen & Milner, 1977; Wada & Rasmussen, 1960), cortical speech mapping (Abou-Khalil, 1995; Ojemann, 1983; Ojemann & Mateer, 1979; Penfield & Roberts, 1959), and more recently, functional MRI (Springer et al., 1999). Yet many questions remain. Further ambiguities have arisen with the growth of functional brain imaging technologies (Knecht et al., 2000; Sidtis, 2000), which has yielded numerous studies reporting right hemisphere activation during verbal tasks, challenging the model developed from neurological studies.

Are the processes of lateralized specialization, particularly for language, based on intrinsic or innate features of hemispheric neural tissue and are thus in some sense mandatory? Neurological disruption in the maturational years of childhood has been seen to radically change the expected picture. What is the relationship of cerebral laterality of function, as documented in adult lesion studies, to neural "plasticity" proposed for developmental recovery from neurological disorders? (Bach-y-Rita, 1990; Hertz-Pannier et al., 2002; St. James-Roberts, 1981). Although models and explanations have been proposed (Corballis & Morgan, 1978; Kahn, 1987; Lenneberg, 1967; Nooteboom, 1979), studies of common hemispheric specialization, and its uncommon but revealing anomalies, still do not satisfactorily address these fundamental questions.

A unique opportunity arose to perform neurologic and cognitive evaluations of BL, whose above-average intelligence was represented entirely in a single, right hemisphere. The cooperation of BL enabled us to test some of the claims that have emerged out of previous studies on comparable persons, and to reflect further on assumptions about cerebral laterality of function. In previous, extensive standardized neuropsychological testing reported by Smith and Sugar (1975) performed on two occasions (in 1969 and 1974), neither impoverished language skills nor diminution, and therefore "crowding," of visuospatial abilities was observed. Rather, superior verbal scores coupled with normal-to-superior visuospatial performance scores were obtained. However, tests specific for syntactic and motor speech processing were not included in previous testing (see Nooteboom, 1979).[1] Further, new tests of communicative abilities associated with the right hemisphere, such as nonliteral language, prosody, and personally familiar stimuli had become available.

2. Background: Patient history and evaluation

Following birth by caesarean section on December 6, 1947, BL showed signs of cyanosis for three days, hemiparesis at 5 months, and suffered right-sided seizures beginning at age 3 years (Smith & Sugar, 1975). Speech during the early years to time of surgery was reportedly severely dysarthric with poor intelligibility. A left hemispherectomy, performed on July 28, 1953, when BL was $5\frac{1}{2}$ years of age, involved removal of left cerebral cortex and white matter, reportedly sparing basal ganglia and some ependyma of the temporal horn. An MRI scan showing six axial and coronal views of the adult

[1] Nooteboom (1979) comments on the interesting case of BL, adding "Unfortunately, this man has not received tests specifically aimed at measuring syntactic (á la Dennis) or phonetic (á la Liberman) competence" (p. 328). Our goal was to provide some of these measures.

brain, taken at the time of the testing reported here, can be seen in Figs. 1A and B. Compensatory hypertrophy of the right hemisphere is apparent (Liederman, 1988). In the adult brain, the left mammillary body is atrophic, and a gliotic remnant of thalamus remains; basal ganglia cannot be seen. Apparently these structures have either atrophied or been resorbed.

By four months following surgery, as BL approached age 6, speech reportedly improved to normal. BL was raised and educated in the Midwestern United States and is a native speaker of American English. He attended regular elementary and high school and graduated from college with a Bachelor's degree with a double major in business and sociology. He played the baritone horn in a band. His occupation as an adult included several years as an accountant in international business. He has never married.

At time of neurological testing in July, 1997, BL appeared as a persistently pleasant, $49\frac{1}{2}$-year-old man. He walked with a hemiplegic limp spending more time on his left leg. His right arm hangs limply beside him when he walks. There is no overall facial asymmetry. Auditory acuity was excellent bilaterally. At no time did he evidence any neglect of sounds or sights to his right.[2]

3. Methods and materials

The previous testing of Smith and Sugar (1975) was supplemented using 12 additional tests of communicative function and visuospatial ability. Some are published and standardized, and others are research protocols available in our laboratory. All testing was completed in one session, in a quiet environment, following informed consent. The subject appeared alert, focused, attentive, pleasant, and fully cooperative throughout the testing. At no time did he complain of or indicate fatigue, confusion, resistance or distraction with respect to the tasks before him. The testing session was audiotaped and/or videotaped for later analysis. Performance by BL was compared with age- and education-matched normal-control subjects, whether from published and standardized or custom testing. Tests selected, as well as background and rationale for the selection, are listed below.

3.1. Test instruments

The Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1983) is a standardized confrontation naming task. Among aspects of language processing, confrontation naming is particularly fragile, and performance diminishes with a wide variety of moderate to severe cognitive dysfunction (Kremin, 1988), mild brain damage such as concussion (Goodglass, 1980), and fatigue and normal aging (Thomas, Fozard, & Waugh, 1977).

The Revised Token Test (McNeil & Prescott, 1978) is a published protocol designed to probe grammatical relations; it has been found to correlate with measures of auditory comprehension and language production. The 10 subtests contain commands of varying length and syntactic complexity. However, there is some disagreement about whether this test focuses primarily on syntactic relations or on semantic entities (color, shape, and size). Persons without language dysfunction perform nearly perfectly, but the test is sensitive to deficits in those with mild to moderate aphasia symptoms.

The Linguistic Prosody Test (Van Lancker, 1992a, 1992b) evaluates production and comprehension of noun phrases and noun compounds, which differ only in placement of the accent (e.g., gréenhouse and green hoúse; móving van and moving ván). Phrasal stress contrasts form only a peripheral grammatical process in American English compared to other languages, such as Norwegian and Finnish. Besides the noun phrase/compound pairs mentioned above, noun and verb pairs (e.g., ímport, impórt) are also distinguishable by accent alone. Accent placement on contrastive pairs in English is a productive rule, and is part of the competence of the grammar of the normal native speaker. In the present study, comprehension was measured by presenting 24 tape-recorded utterances with a four-item response card in a picture-matching protocol; two of the items represented the two choices contrasted by accent alone, two of the items were semantically related distracters. For the production task, the subject produces each of 24 utterances after reading the word on a card and a definition indicating appropriate pronunciation. For the production task, the tape-recorded responses were later evaluated by two independent raters. For this test, the normal-control group consisted of 21 adults ages 20–68 (mean age 46.4), with 12–24 years of education (mean = 17.4 years), all native speakers of English. Two children ages 6 and 7 were also tested. On the comprehension subtest, the mean performance of the adult group was 81.3 (±3.5 SEM), and on the production subtest, 92.0 (±3.44 SEM).

The Kempler Comprehension Task (Kempler, 1986) requires matching of one of two line drawings to verbal expressions of increasing syntactic complexity, which include passive voice and embedded clauses. Healthy subjects perform at ceiling on this 24 item test.

Semantic Picture Selection (Van Lancker, 1992a, 1992b) tests specificity of meaning recognition. In a ten-item auditory recognition test format, four response choices are made up of semantically related items. This test of word/meaning comprehension was selected to

[2] Detailed neurological, ophthamological, and auditory testing is described in Bogen et al. (1998).

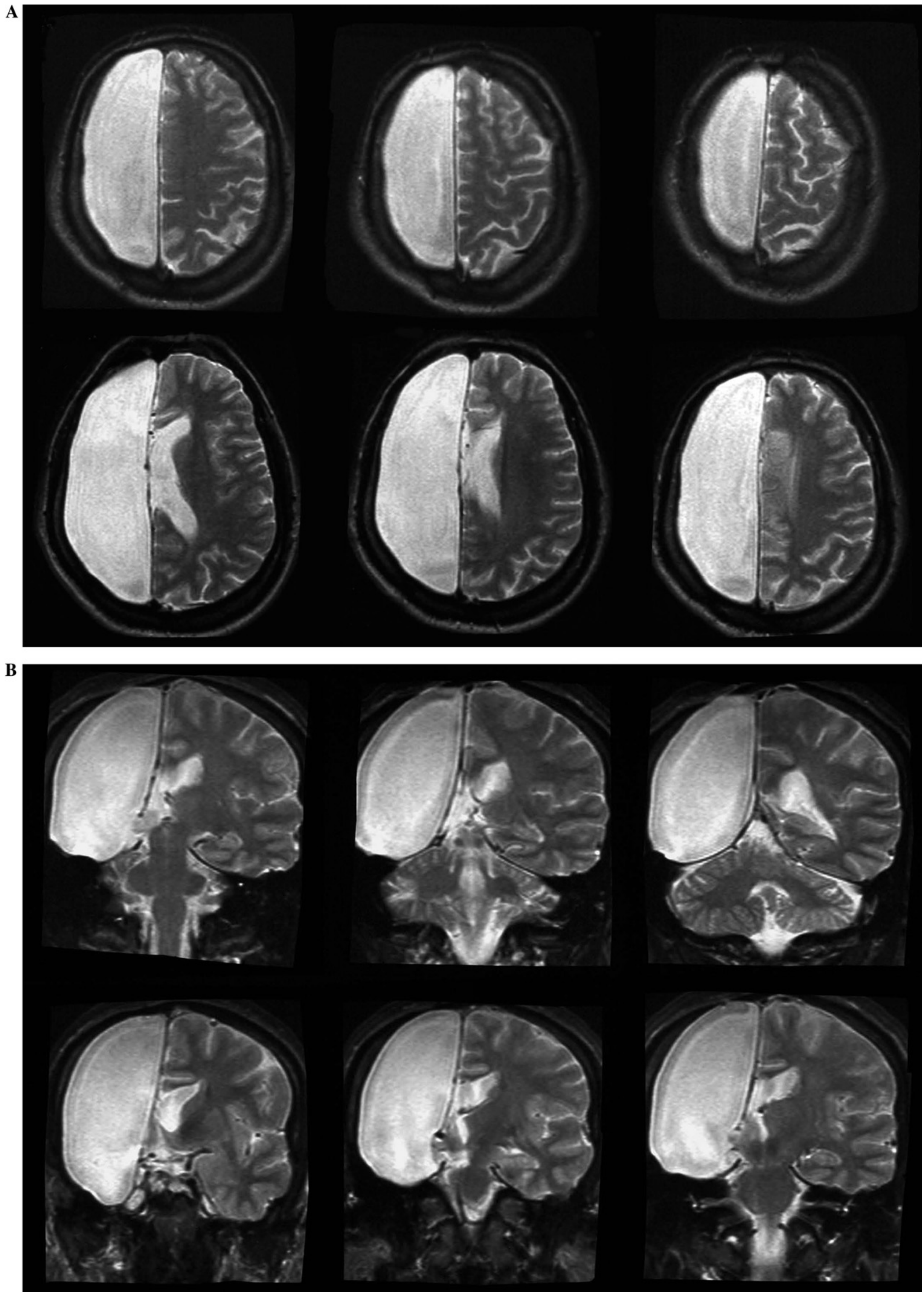


Fig. 1. (A) MRI scan of BL: axial view. (B) MRI scan of BL: coronal view.

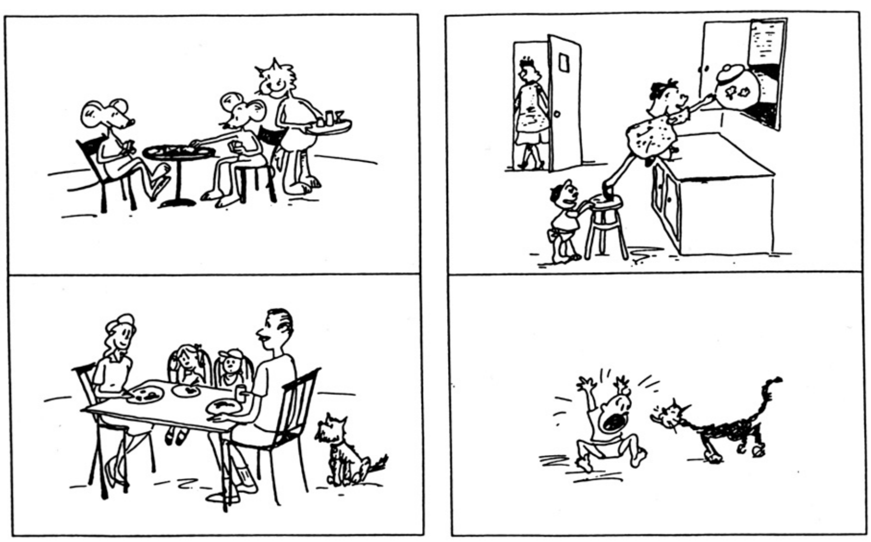
augment the Peabody Picture Vocabulary Test, on which BL gave a superior performance, by designed semantically similar responses for each word, thus presenting a greater challenge to ability to identify word meanings. Healthy subjects perform at ceiling on this protocol.

The Active–Passive Test (Dennis & Kohn, 1985) was designed to measure the ability of normal and brain-damaged children to understand four different but closely related grammatical forms (active affirmative, passive affirmative, active negative, and passive negative). Using a verbal response (saying "A" or "B" as quickly as possible) the subject selects one of two line drawings which matches a sentence presented orally by the examiner. Results in the form of accuracy and latency data for 50 children ages 5–14 (10 in each group of 6-, 8-, 10-, 12-, and 14-year-old children) are published (Dennis & Kohn, 1985).

The Motor Speech Evaluation is a standard clinical test of speech production. It includes assessment of spontaneous speech, measures of oral symmetry, length and quality of vowel production, articulation and rate of syllable production, and word and phrase repetition. Scoring is both quantitative (durations and syllable counts) and impressionistic (voice quality and articulatory ability).

The Formulaic and Novel Language Comprehension Test (FANL-C) (Kempler & Van Lancker, 1996) contains 20 formulaic expressions (idioms, speech formulas, and proverbs) and 20 matched novel expressions in a picture matching task. Subjects hear the test item spoken by the examiner, and point to one of four line drawings as a response (see examples in Figs. 2A and B). Persons with unilateral hemisphere damage following stroke (Van Lancker & Kempler, 1987) show a "double dissociation" on this test: left hemisphere damaged subjects

A



B

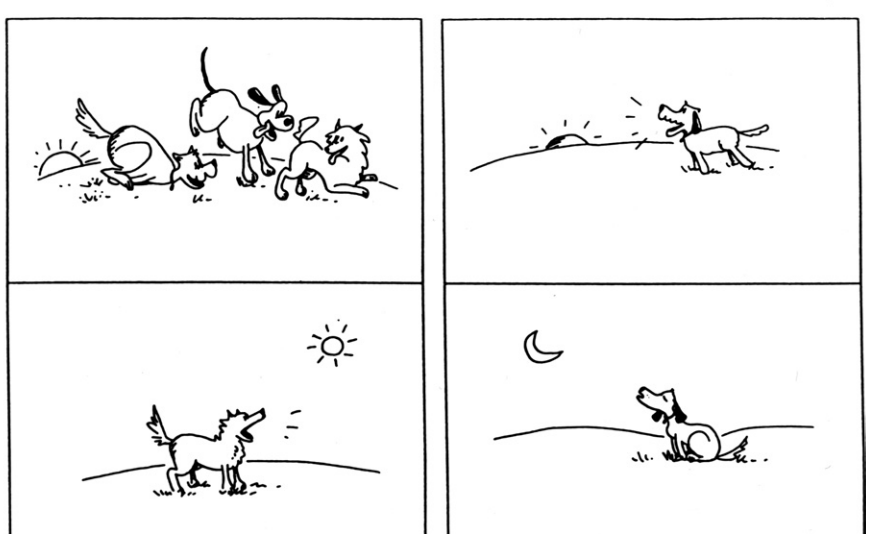


Fig. 2. Response sheet for FANL-C (Formulaic and Novel Language Comprehension Test). (A) Sample formulaic item (top figure): "While the cat's away, the mice will play." (B) Sample novel item: (bottom figure): "Whenever the sun sets, the dog barks."

perform significantly worse on novel than on formulaic items, while those with right hemisphere damage perform significantly worse on formulaic than novel items. Maturationally, performance on formulaic items lags considerably behind performance on novel sentences in children from 3 to 15 years of age, and normal adults perform at ceiling (Kempler, Van Lancker, Marchman, & Bates, 1999).

The Affective Prosody Test (Van Lancker, 1988) was designed to evaluate recognition emotional categories (happy, angry, sad, and surprised) expressed in speech intonation. The subject hears 16 tape-recorded utterances (four each of happy, angry, sad, and surprised) and points to one of four line drawings depicting the four facial expressions, with the appropriate word written underneath. Persons with left cortical, right cortical, and subcortical brain damage have been found deficient on this and like protocols (Cancelliere & Kertesz, 1990; see Van Lancker & Breitenstein, 1999; for review). Normal-control performance data are available in Van Lancker and Sidtis (1992).

Famous Names and Faces (Van Lancker, Drake, Pachana, & Sudia, 1997) contains 24 target famous faces in a picture pointing task; half are African-American and half are Caucasian. This test was designed to probe questions of processing of famous proper nouns, faces, and personal relevance, which have been associated with right hemisphere function (Ohnesorge & Van Lancker, 2001; Van Lancker, 1991). Significant differences were found between performance scores on same-race versus other-race items in a normal adult population (Drake, Pachana, & Van Lancker, 1997). For this assay, 31 Caucasian adults (15 males, 16 females) with an age range of 22–80 (mean of 51.3 years), with 12–22 years of education (mean of 15.7 years), all born and educated in the United States, were tested. These normal-control subjects scored a mean of 21.96 (±1.1 SEM).

The Test of Facial Recognition (Benton, Hamsher, Varney, & Spreen, 1983) is a standardized face discrimination test of increasing difficulty, requiring the matching of a target black/white photograph to an array of like photographs in different lighting and configurations.

The Visual Closure Test is a compilation of incomplete figures representing objects of scenes compiled from previous sets of the Street Completion Test (Street, 1931) and Closure Faces Test (Mooney & Ferguson, 1951). Twenty-eight black and white figures are shown, and the subject is required to perform a perceptual closure task and name the figure. In identifying each incomplete figures, subjects received a score of 0, 1, or 2, depending on accuracy and specificity. Twenty-two health normal control subjects (13 males, 9 females) were used as a comparison group. They ranged in age from 24 to 67 (mean = 42.9 years) and had 14–20 years of education (mean 18.2 years). Occupations varied and included sales persons, business analysts, clerical, academic and clinical employees, librarians, and students. The mean performance for this group was 33.1 (±2.1 SEM).

4. Results

Results of testing of BL and age- and education-matched normal-control subjects are provided in Table 1. BL's performance ranged from high normal to impaired. High normal performance occurred on the Boston Naming Test, Famous Names and Faces, the FANL-C *novel* items subtest, and the Visual Closure Test.

Normal performance was observed on the Revised Token Test, the Linguistic Prosody *Production* subtest, and the Kempler Comprehension Test.

Low normal scores were seen on Affective Prosody Comprehension and Production subtests, the FANL-C *formulaic* items subtest, and Benton Facial Recognition.

BL's spontaneous speech contained the full range of sounds, grammar, and semantics. A typewritten transcript of conversational interaction during the testing session revealed normal speech, language, and communicative performance (see Appendix A for speech samples). Examples of complex sentences appear in lines 4, 6, and 12 of Appendix A. Competent turn taking is seen throughout the speech sample. Response to context occurs in lines 13–16 and in line 28, when BL evaluates the voice quality of the announcer on the prosody test tape. BL's comment in line 25, where he likens the fragmented visual closure figure to Guernica (by Picasso), offers an example of sophisticated verbal humor. Appropriate formulaic exemplars appear in lines 6, 8, and 27. No grammatical "gaps" or errors in morphosyntactic forms were observed at any time in verbal interaction with BL. In the spontaneous speech classification system designed by Curtiss, de Bode, and Mathern (2001), BL's speech ranks at "mature grammar" (Spoken Language Rank, or SLR, 6), the highest rating on their scale.[3]

On the clinical Motor Speech Evaluation, a speech production task, BL's performance was normal, except that increased effort was observed on velar consonant (ka) syllable repetition, and on production of phonemically complex phrases (e.g., "Methodist Episcopal").

Deficient performance was seen in the Linguistic Prosody Comprehension subtest (Fig. 3). BL had

[3] No further descriptive indicators or criteria are offered for SLR 6. For SLR 5, the authors specify that "a child has fluent speech plus embeddings of all types... some 'gap' in morphosyntax may persist... (e.g., errors with the passive past participle)" (p. 387). No morphosyntactic errors were observed in the conversational, spontaneous speech of BL, leading to the SLR 6 ranking.

Table 1
Overview of test scores

Test	Results	Norms	Assessment
Visual Closure Test	36/56 (64%)	33.2/56 (59.3%) (±2.1 SEM)	Normal
Boston Naming Test	60/60 (100%)	Adults 40–49, 54.40 (SD 3.47) (90.7%)	Normal
Familiar Names and Faces Test	24/24 (100%)	21.96 (91.5%) (±1.1 SEM)	Normal
Motor Speech Evaluation and Speech Screening	Normal exam; mild L > R mouth asymmetry (WNL); mild effort on velar consonant repetition & phonemically complex items	N/A	Normal with qualification
FANL-C (see Fig. 2A)	Novel: 20/20 (100%)	Novel: 100%	Normal
Linguistic Prosody Test	Production: 21/24 (88%)	92.0% (±3.4 SEM)	Normal
Kempler Comprehension Test	23/24 (96%)	96%	Normal
Semantic Picture Selection	10/10 (100%)	100%	Normal
Revised Token Test	Mean score for 4 most difficult subtests: 14.83/15 (99%)	NC 54%-ile LBD 87%-ile RBD 94%-ile	Normal
FANL-C (see Fig. 2b)	Formulaic: 18/20 (90%)	98% (ceiling)	Low normal
Affective Prosody*	Affective: 14/16 (88%)	94% (range: 88–100%)	Low normal
Benton Facial Recognition Test	43/54 (80%)	41–54 (normal range)	Low normal
Linguistic Prosody Test	Comprehension: 14/24 (58%) (see Fig. 3)	81.3% (±3.5 SEM)	Deficient
Active–Passive Test**	(see Fig. 4)		Deficient

WNL, within normal limits; FANL-C, Formulaic and Novel Language Comprehension Test.
* Van Lancker and Sidtis (1992).
** Dennis and Kohn (1985).

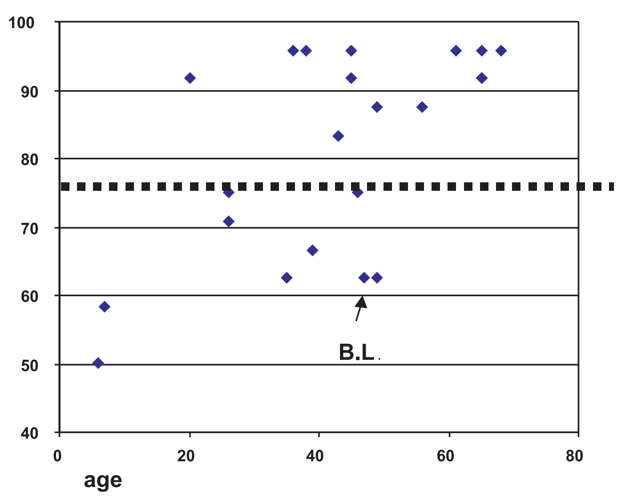


Fig. 3. Percentage correct of linguistic-prosodic contrasts for normal subjects and BL, given by age.

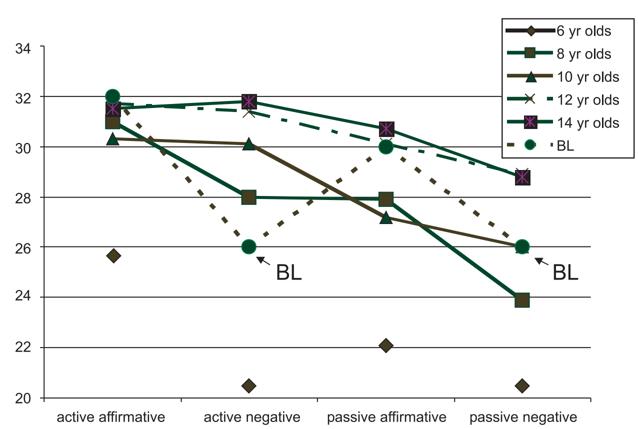


Fig. 4. Discrimination scores on the Active–Passive Test.

considerable difficulty distinguishing between spoken representations of pairs with contrasting stress patterns, such as "yellow jacket" and "yellowjacket." While he was confident during other testing, he expressed uncertainty in his responses during this protocol.

Similarly, BL's performance on the Active–Passive Test was relatively poor, compared to his performance on other tests. As can be seen in Fig. 4, BL's accuracy scores resembled those seen in younger children.

5. Discussion

Regarding speech, language, and communicative function, BL's performance appears grossly normal in pronunciation, grammar, semantics, and usage. By the language rating system devised by Curtiss et al. (2001), our findings are in agreement with theirs; using this ranking scale, they found no effect of left versus right hemisphere removal. Thus, this study of BL, a left hemispherectomized individual with the highest spontaneous speech rating, agrees with their failure to confirm an effect of left hemisphere removal on language, as measured by their Spoken Language Scale. However, focused speech and language testing performed on BL did uncover linguistic deficits. On motor speech testing, increased effort was noted for production of phonemically complex phrases. In findings that may support this perspective, greater impairments on reading and spelling following left than right hemispherectomy were reported (Ogden, 1996; Patterson et al., 1989). To discover relative speech production deficits in abnormal populations, tests especially designed to challenge linguistic competence are likely necessary.

In BL, from the array of evaluation protocols administered in this and previous testing (Smith & Sugar, 1975), frank diminution in performance was seen only on tests which involved subtle linguistic contrasts: the Linguistic Prosody Comprehension subtest (Fig. 3) and the Active–Passive Test (Fig. 4). Note that the deficient linguistic-prosodic performance was observed in the comprehension, not the production subtest. This score discrepancy (higher performance on production than comprehension of the test items) was also observed in normal subjects. These observations suggest that in some domains of language competence, comprehension may be a subtler probe of the intrinsic linguistic ability of the left hemisphere than production. Our findings for the comprehension tasks are in agreement with Stark, Bleile, Brandt, Freeman, and Vining (1995), who reported greater deficits in subjects following left- than right-hemispherectomy, using syntactic comprehension and rapid-rate auditory processing.

On both of the linguistic-contrast measures utilizing a comprehension mode (prosodic and active–passive contrasts), BL exhibited abilities more consistent with performance at an earlier developmental stage, suggesting that although his production competence as observed in spontaneous speech represented a "mature grammar," his comprehension competence did not.

Regarding the Active–Passive test, there has been controversy in linguistic theory about the active–passive contrast[4] and the negative particle ("not"). The debate has questioned whether these are primarily syntactic or semantic elements. In some approaches, the demarcation between syntax and semantics is less distinct (see Van Lancker, 2001a, 2001b for review). Whatever the perspective, the developmental data reported by Dennis and Kohn (1985) suggest that younger children make more errors on the negative examplars of both active and passive voice, while in older children, active sentences, whether affirmative or negative, show similar accuracy scores, (higher than passive sentences). BL's accuracy scores reveal a pattern similar to that of younger children (ages 6 and 8).

[4] Note that in Curtiss et al. (2001); production errors on the "passive past participle" sufficed to rank a child's speech at less that "mature grammar" (p. 387).

BL performed better than the normal-control group on same- and other-race famous names/faces; therefore, no deficits in personal relevance, associated in other studies with intact right hemisphere function, are suspected (Van Lancker, 1991).

Relative low-normal scores on Affective Prosody Comprehension, the FANL-C formulaic expressions subtest, and Benton Facial Recognition were observed, in comparison to BL's high normal performance on other testing. These tasks—Benton Facial Recognition (Hamsher, Levin, & Benton, 1979), Affective Prosody Comprehension (Ryalls, 1988; Van Lancker & Sidtis, 1992), and the FANL-C formulaic subtest (Brown & Paul, 2000; Paul, Van Lancker, Schieffer, Dietrich, & Brown, 2003; Van Lancker, 1990) have all been found to involve both hemispheres for normal performance. For the Linguistic-Prosodic test, previous studies using comparable materials have yielded inconsistent results regarding the role of hemispheric specialization, although a role of the left hemisphere is suggested (Behrens, 1988; Blumstein & Cooper, 1974; Heilman, Bowers, Speedie, & Coslett, 1984; Hird & Kirsner, 1993; Ouellette & Baum, 1993; Pell, 1998; Shapiro & Danly, 1985). Of domains of linguistic competence examined in laterality studies, only phonological and syntactic processes have been shown to be strongly localized to the left hemisphere, and only these yielded diminished performance in BL.

Communicative abilities of the right cerebral hemisphere more recently proposed (see Van Lancker, 1997; for a review; Myers, 1998), such as personal relevance (Cutting, 1990; Van Lancker, 1991) especially as seen in famous proper noun recognition (Van Lancker & Ohnesorge, 2002), the various functions of prosody (Pell, 1998) and voice recognition (Van Lancker, Kreiman, & Cummings, 1989), unique lexical semantics (Chiarello, 1988; Drews, 1987; Landis & Regard, 1988; Zaidel, 1977) including emotional words (Bowers, Bauer, & Heilman, 1993; Rapcsak, Kaszniak, & Rubens, 1989; Wechsler, 1973), and topics within pragmatic studies such as nonliteral language, maintenance of topic, and humor (e.g., Borod et al., 2000; Joanette & Brownell, 1990), and other aspects of social discourse (Bryan & Hale, 2001) remain to be investigated in more depth in persons with a single hemisphere.

By our casual observation in social situations, such as dinner at restaurants and site seeing, BL's socially exhibited prosodic and pragmatic language skills, including grasp of situational context, conversation, interactional humor, and turn taking, were fully intact. However, although grammatical competence also appeared informally intact, formal testing suggested a diminution, and therefore it is possible that deficits suggesting subtle effects of crowding might be seen also when pragmatic communicative abilities are carefully tested by well designed instruments.

Although subtle linguistic deficits were uncovered in two carefully constructed comprehension tasks and in formal clinical speech testing, the otherwise above normal language abilities of BL challenge the usual understanding of hemispheric specialization of function. The possibility that BL was "naturally left handed," developing language in the right hemisphere, cannot be completely eliminated. From the medical history, left hemispheric damage was likely perinatal in etiology. Statistics weigh against predisposed left handedness in BL, and he was reported to be speaking with severe dysarthria until his damaged left hemisphere was removed, indicating a significant role of the left hemisphere in speech in early development. However, his rapid postsurgical recovery of normal speech and language behavior indicates at least early readiness of the right hemisphere for linguistic communication. This, in fact, could reflect the normal condition. Maturational schedules for establishment of laterality are not well understood (McFie, 1975; Thatcher, Walker, & Giudice, 1987), and it is not clear which hemisphere predominates for what kinds of language behaviors at different early phases of child language acquisition, but a role of the right hemisphere at the earliest stages has been suggested by behavioral (e.g., Kempler et al., 1999; Thal et al., 1991), electrophysiological (Molfese & Molfese, 1988), and functional imaging studies (Chiron et al., 1997).

However well attested is lateralization of speech and language function to the left hemisphere with the accompanying right handedness, how and why this happens has not been explained. A genetic explanation will have difficulty with the simplistic question that arises: in the hemispherectomized person, how does the developing right hemisphere "know" that the left hemisphere is not going to do this work? Perhaps the "demands of several levels of interpersonal communication underlying language" (Trevarthen, 1996, p. 583) actuated by gesturing and triggering cerebral asymmetry are responsive to changes brought about by motor insufficiencies of the damaged hemisphere. Another proposal considers plasticity to be a mechanism that governs cognitive priorities (Levy & Kavé, 1999).

The answer to the question posed by Code (1996, 1997): "Can the right hemisphere speak?" is "yes," to lesser or greater extent, when given autonomy in the developing brain, because of damage to or removal of the left hemisphere (e.g., Boatman et al., 1999) but only very little in the normally developed brain (Bogen, 1997; Burklund, 1972; Burklund & Smith, 1977; Hillier, 1954; Smith, 1966, 1974; Smith & Burklund, 1966; Zangwill, 1960; Zollinger, 1935) or when the left hemisphere can play even a severely reduced role, as seen in children as well as in aphasia patients. These observations impinge on unanswered questions about the role of the left hemisphere in inhibiting the right (Landis, Regard, Graves, & Goodglass, 1983; Marshall & Patterson, 1983).

The scenario whereby one hemisphere relatively successfully takes over the functions of two does not provide support to current notions of "modules" of cognitive function in the mind with their implied predictable correspondence to specifiable brain structures (Bogen & Berker, 2002). Given the achievement of the single, nondominant hemisphere in language competence, the mystery of human language development in ontogeny and phylogeny cannot be convincingly unmasked by the proposal of a species-unique "language organ" (Chomsky, 1997), unless this is meant as a metaphor without implied cerebral localization or predicted, definable anatomical properties. Notions of the corpus callosum as essential communication link between functional systems, enabling human behavior (Gazzaniga, 2000), and the search for self-recognition abilities of the left hemisphere (Turk et al., 2002) or of the right hemisphere (Keenan, Nelson, O'Connor, & Pascual-Leone, 2001), as essential for self-awareness (Morin, 2001), might well gain a different perspective from observations of BL and other hemispherectomized persons with full adult competence.

The numerous observations on cognitively intact persons hemispherectomized in childhood bring to mind the report of Lorber (1983) on hydrocephalic adults, whose brains are constituted of only a thin layer of cerebral tissue, and yet who enjoy normal or superior motor and cognitive abilities. Although "localization of function" has been a useful heuristic for analysis of brain–behavior correlations, factors contributing to "cerebral plasticity" are complex and powerful, and remain to be understood.

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Appendix A

Interview with neurosurgeon:

1. JB: You're not taking any medicine.
2. BL: I don't take any medicine.
3. JB: And you can't remember having any seizures, as far as you can...
4. BL: Not since the operation. I know that I haven't had any since the operation. I don't remember. I

don't even remember my seizures, to tell you the truth. And I don't remember what they were like.

. . .

5. JB: Okay, well, you go on. We're going to see the room all the way at the end. I'll be right behind you.
6. BL: Okay. And, ah, you're not going to photograph me as I walk down here, are you?

. . .

7. JB: When did you get the driver's license?
8. BL: Oh, let's see. I guess it was probably 1968 or 1969. I… Just after I turned twenty-one.
9. JB: … And you had a car for…
10. BL: I had a car from 1974 until 1979. And then I got…
11. JB: Five years.
12. BL: I got rid of the car when we had the big snow storm in Chicago.

Testing sessions with author:

13. BL: That's an awful picture of you, by the way.
14. DS: Oh, is it?
15. BL: Is… Is that really you?
16. DVL: Well, I guess I had long hair.

Visual closure test

17. BL: (looking at a response sheet) I am not sure. Don't have any idea about this one either.
18. DS: Okay.
19. BL: Looks like a frog.
20. DS: Uh, huh.
21. BL: That's definitely a girl.
22. DS: Uh huh. Uh huh.
23. BL: I was trying to see if it was a boy.
24. DS: Uh huh.
25. BL: (viewing a fragmented picture) And… I can't tell on this one. Looks like Guernica.
26. DS: (Laughs. Although BL appeared to have completed the test, there are additional test items) Isn't there another one?
27. BL: Oh, I'm sorry. Forgive me.

Affective prosody test

28. BL: (after listening to an audio recording with a female voice announcing the numbers of each test item) Those, eh, the girl was more sad saying the numbers I think than…
29. DS: I know, yeah, I know, that's…
30. BL: She seemed more happy and sad than anybody.

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