

Writing with the Right Hemisphere

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We studied writing abilities in a strongly right-handed man following a massive stroke that resulted in virtually complete destruction of the language-dominant left hemisphere. Writing was characterized by sensitivity to lexical-semantic variables (i.e., word frequency, imageability, and part of speech), semantic errors in writing to dictation and written naming, total inability to use the nonlexical phonological spelling route, and agrammatism in spontaneous writing. The reliance on a lexical-semantic strategy in spelling, semantic errors, and impaired phonology and syntax were all highly consistent with the general characteristics of right hemisphere language, as revealed by studies of split-brain patients and adults with dominant hemispherectomy. In addition, this pattern of writing closely resembled the syndrome of deep agraphia. These observations provide strong support for the hypothesis that deep agraphia reflects right hemisphere writing. © 1991 Academic Press, Inc.

INTRODUCTION

The left hemisphere is dominant for language functions in the majority of right-handed individuals. However, neuropsychological evidence from studies of split-brain patients (Zaidel, 1985) and adults with dominant

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hemispherectomy (Smith, 1974; Burklund & Smith, 1977) suggests that the right cerebral hemisphere, at least in some right-handers, may possess considerable linguistic competence. Converging clinical evidence from these two patient populations has prompted the proposal that the right hemisphere has a unique linguistic profile (Zaidel, 1985). Right hemisphere language is characterized by a rich auditory and a somewhat more limited visual receptive vocabulary (Zaidel, 1976, 1978, 1983). The right hemisphere lexicon appears to be biased toward familiar, high imageability or concrete words and is thought to have "weaker" representations for low imageability or abstract words, functors, and bound morphemes (Zaidel, 1982, 1983, 1985; Schweiger et al., 1989). Although the right hemisphere seems capable of handling a variety of semantic relations, its semantic system may be less precisely organized, making it prone to semantic errors (Zaidel, 1982, 1985). In contrast to its substantial lexical-semantic competence, the right hemisphere has impoverished phonology and syntax (Levy & Trevarthen, 1977; Zaidel, 1977, 1985; Zaidel & Peters, 1981). Furthermore, its generative capacity for linguistic expression is severely limited. The right hemisphere of split-brain patients is unable to generate speech in the vast majority of cases, with only a few notable exceptions to this rule (Levy, Trevarthen, & Sperry, 1972; Gazzaniga, Volpe, Smylie, Wilson, & LeDoux, 1979; McKeever et al., 1981; Gazzaniga, 1983). However, right hemisphere speech in some of these patients has been attributed to the presence of left hemisphere damage in early life and subsequent anomalous development of language lateralization (Gazzaniga, 1983). At the same time, it should be noted that adults with dominant hemispherectomy are able to produce speech from the right hemisphere soon after surgery. Although initially speech is often limited to automatic phrases, expletives, and single words, patients usually develop some ability to produce propositional speech over time (Zollinger, 1935; Smith, 1966; Burklund & Smith, 1977).

Is there evidence for right hemisphere spelling and writing? Following complete surgical sectioning of the corpus callosum, many patients become unable to form legible graphemes with the left hand, demonstrating unilateral apraxic agraphia (Bogen, 1985). However, using the left hand, some split-brain patients were able to copy words, spell simple words by arranging anagram letters, and some could even write the names of common objects presented visually to the right hemisphere (Gazzaniga & Sperry, 1967; Levy, Nebes, & Sperry, 1971; Gazzaniga, LeDoux, & Wilson, 1977; Sidtis, Volpe, Wilson, Rayport, & Gazzaniga, 1981). When the patients were unable to name the word they had just written with the left hand, it was assumed that writing originated from the right hemisphere. As in the case of right hemisphere speech, the general implications of this evidence for right hemisphere writing may be questioned, since some of the patients had a history of early left hemisphere damage.

Patients with naturally occurring callosal lesions (e.g., tumors, hemorrhages, infarctions), however, can be assumed to have a normal pattern of premorbid language lateralization. Unlike surgically induced complete callosotomy, naturally occurring lesions usually result in only partial callosal disconnection. Anterior lesions involving the genu and/or the body of the corpus callosum may produce apraxic agraphia of the left hand or a combination of apraxic and linguistic agraphia (Liepmann & Maas, 1907; Geschwind & Kaplan, 1962; Watson & Heilman, 1983; Graff-Redford, Welsh, & Godersky, 1987; Leiguarda, Starkstein, & Berthier, 1989). Unfortunately, very limited information is available about the nature of the linguistic spelling errors in these patients. On the other hand, lesions involving the posterior half of the body and sometimes also the splenium of the corpus callosum may result in unilateral agraphia of the left hand that is predominantly or exclusively linguistic in nature (Sugishita, Tokokura, Yoshioka, & Yamada, 1980; Yamadori, Osumi, Ikeda, & Kananzawa, 1980; Gersh & Damasio, 1981; Yamadori, Nagashima, & Tamaki, 1983; Kawamura, Hirayama, & Yamamoto, 1989). A qualitative analysis of spelling errors in these patients should be particularly revealing, since the right hemisphere is now disconnected from the linguistic input of the left hemisphere, but is able to express itself in writing because the motor programs for the production of graphemes are presumably able to cross through the more anterior parts of the corpus callosum (Watson & Heilman, 1983). Unfortunately, the agraphia in the patient reported by Gersh and Damasio (1981) was so severe that he could not spell even the most simple words correctly with the left hand. However, three of the four Japanese cases (Sugishita et al., 1980; Yamadori et al., 1980; Yamadori, Nagashima, & Tamaki, 1983) demonstrated an intriguing dissociation: they spelled Kanji characters with the left hand significantly better than Kana. Furthermore, two of these patients made semantic errors when writing Kanji. Kanji characters, originally derived from Chinese script, are ideograms with no systematic relationship to the corresponding spoken sounds (Paradis, Hagiwara, & Hildebrand, 1985). Kanji characters are used to represent major lexical morphemes (although these can also be written in Kana). Kana characters are phonetic symbols, each of which has a one-to-one correspondence with a syllable. Grammatical morphemes are only written in Kana. Whereas the processing of Kanji is closely associated with activation of lexical-semantic representations, the processing of Kana characters is phonologically mediated (Sasanuma, 1980). The better success of the left hand with Kanji characters in the three Japanese patients suggests that the right hemisphere may predominantly rely on a lexical-semantic strategy in spelling and that it has limited ability to use the phonological spelling route. The semantic errors noted in two of these patients are consistent with this view. However, the fourth Japanese patient with a posterior callosal lesion (Kawamura et al., 1989)

showed the opposite dissociation: unilateral left hand agraphia for Kanji but not for Kana. Kawamura et al. (1989) attribute this discrepancy between their case and the other Japanese cases of unilateral left hand agraphia to possible differences in lesion sites or individual differences in callosal function.

In addition to the callosal cases reviewed above, there are also reports of adults with dominant hemispherectomy where the right hemisphere had some limited capacity to write simple words to dictation and write the names of visually presented common objects (Smith, 1966; Burklund & Smith, 1977). However, due to the limited amount of information that is available for most of these patients, the full dimensions and linguistic characteristics of right hemisphere writing remain largely unknown.

We now present a right-handed patient who suffered a massive left hemisphere stroke that resulted in virtually complete destruction of the language-dominant hemisphere. This unique case provided a rare opportunity to conduct a detailed linguistic analysis of right hemisphere writing.

CASE REPORT

GK is a 60-year-old right-handed male with 11 years of formal education. He has no history of early brain damage or family history of left-handedness. In February 1977, GK suffered a massive left hemisphere stroke that resulted in global aphasia, alexia, agraphia, and apraxia, as well as right hemianopia, right hemiplegia, and right hemisensory loss. When he was discharged from the hospital 2 months later, he was only able to produce occasional single spoken words but demonstrated some comprehension of conversational speech and could follow a few simple written commands. He received individual speech and language therapy for approximately 5 years following his stroke, with continued improvement of receptive language skills noted over the course. He also participated in group language therapy for many years and is currently a member of a communication support group for aphasics. GK does not read for pleasure and his writing consists of occasional shopping lists. GK lives alone and is generally able to handle his own affairs. He walks with the aid of a leg brace, but his right arm is essentially plegic with only proximal movement possible at the shoulder. Right homonymous hemianopia and right hemisensory loss are still present.

A recent MRI scan revealed a massive old infarction, involving the distribution of all three major cerebral arteries supplying the left hemisphere (Fig. 1). The lesion resulted in virtually complete destruction of the cortex of all four cerebral lobes as well as the underlying white matter. Small scattered islands of cortical tissue in the primary visual cortex, perirolandic sensorimotor region, paracentral lobule, uncus, and orbitofrontal area appear completely undercut and isolated. The posterior thalamus and most of the basal ganglia structures are also destroyed. The left

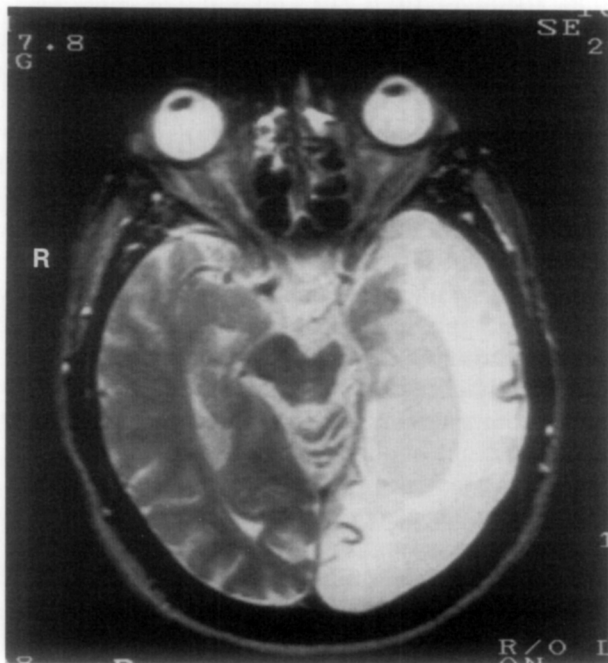
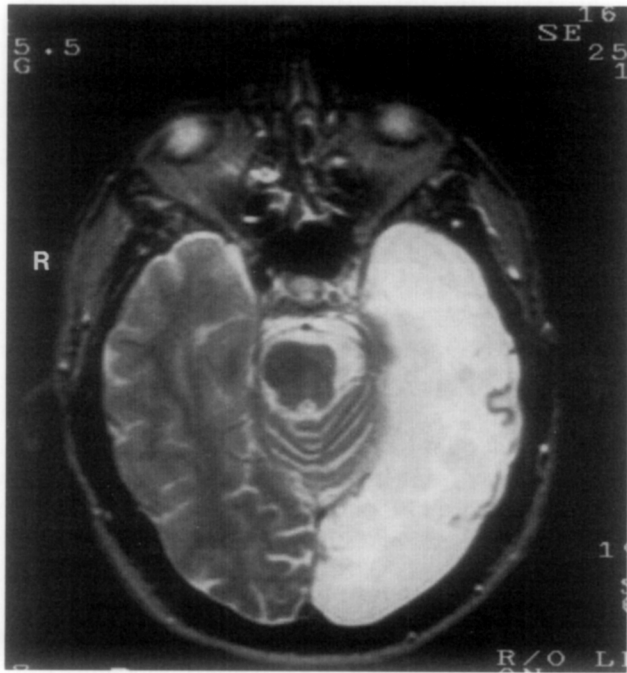


FIG. 1. T₂-weighted MRI scan demonstrating virtually complete destruction of left hemisphere cortex and underlying white matter by the massive infarction. Most of the basal ganglia and posterior thalamus are also destroyed (see text for details).

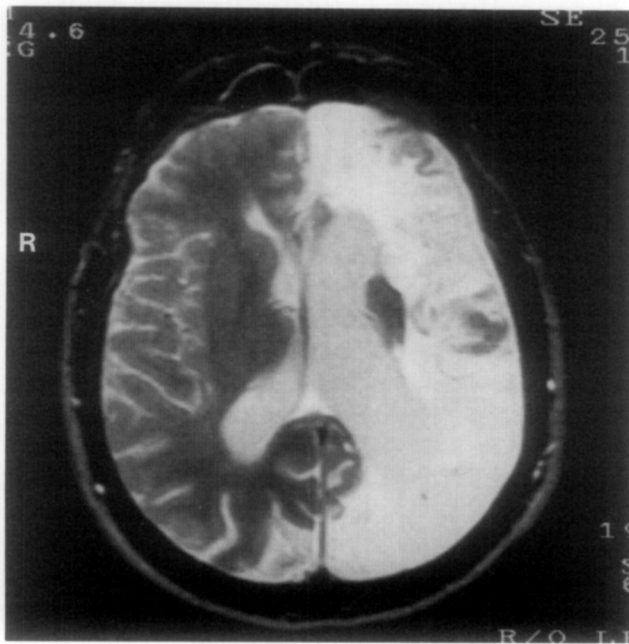
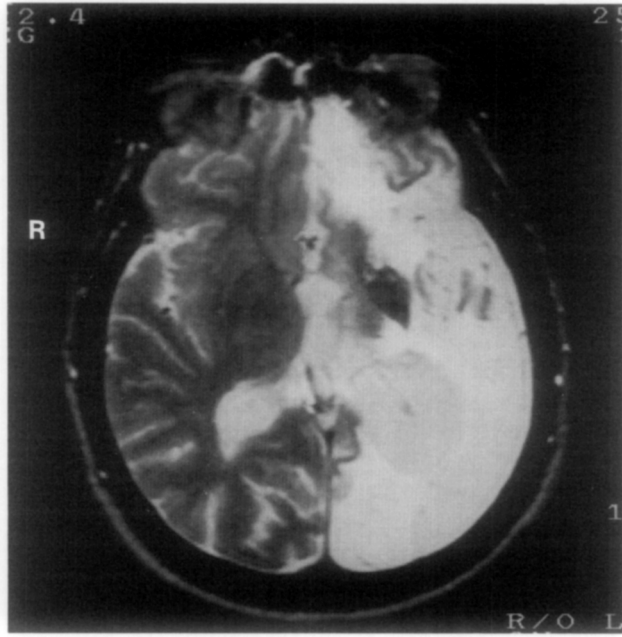


FIG. 1—Continued

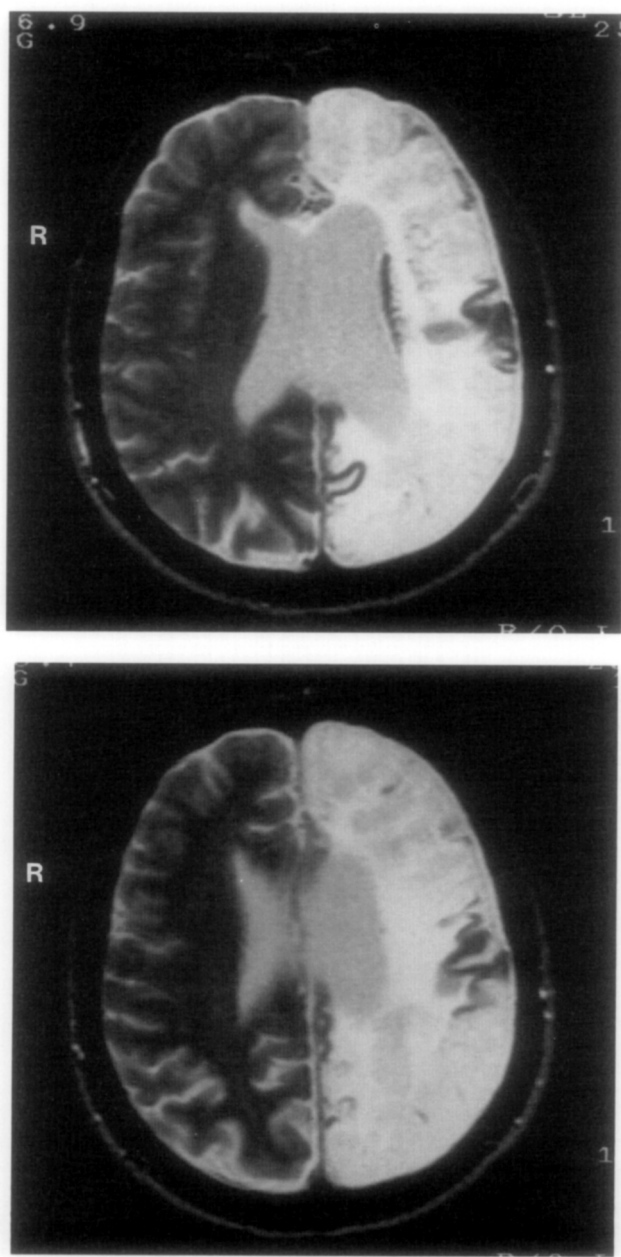


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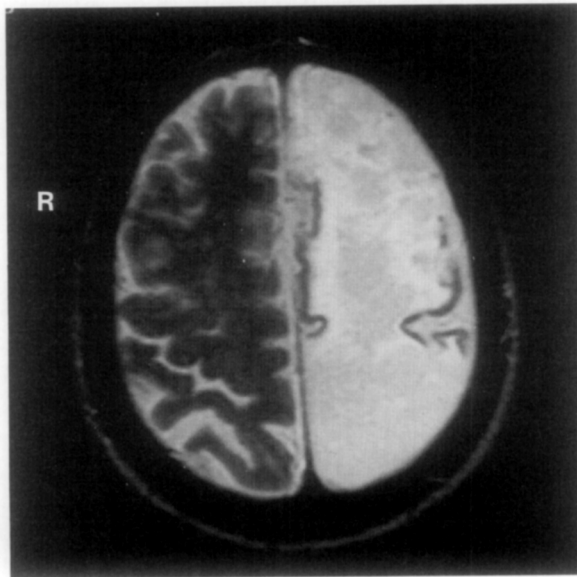
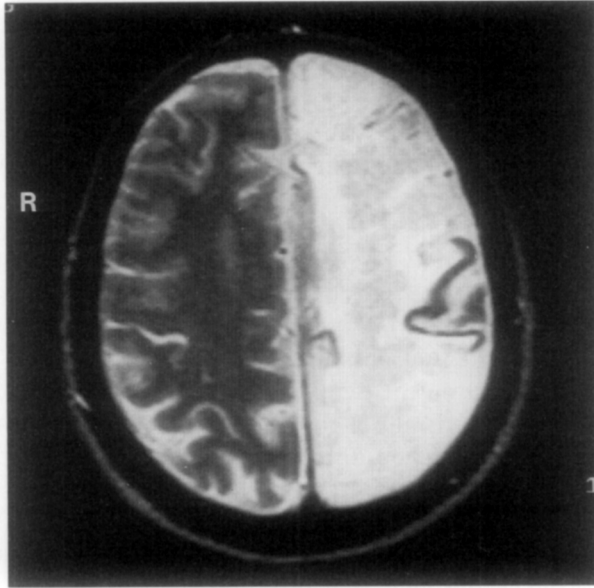


FIG. 1—Continued

cerebral penduncle and left side of the basis pontis are atrophied due to degeneration of the left hemisphere outflow tracts. The right hemisphere appears normal.

LANGUAGE EVALUATION

Oral Language Functions

Thirteen years after the massive stroke, GK's spontaneous speech remains effortful, nonfluent, and slightly dysarthric. His speech output is meaningful but agrammatical, characterized by the omission of functors, the predominant use of uninflected content words, and simplified sentence structure. Comprehension of conversational speech is excellent. GK's scores on the auditory verbal comprehension section of the Western Aphasia Battery (Kertesz, 1982) were as follows: Yes/No Questions: 54/60, Auditory Word Recognition: 52/60, and Sequential Commands: 55/80. His impairment on the Sequential Commands subtest was limited to the longer and syntactically more difficult sentences. That GK's comprehension breaks down when formally tested with syntactically complex sentences was also confirmed on the modified Token Test section of the Multilingual Aphasia Examination (Benton & Hamsher, 1978). GK only achieved a Raw Score of 16, which falls between the 38th and the 52nd percentiles for left hemisphere damaged aphasic patients. GK can repeat single words and nonwords without difficulty, but sentence repetition is impaired. On the Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1983), GK spontaneously named 37/60 (62%) stimuli correctly and was able to name another 12 with phonemic cueing. He produced several semantic errors on this test (e.g., accordion-organ). On the Western Aphasia Battery (Kertesz, 1982), GK's scores were consistent with Broca's aphasia.

Evaluation of Writing and Oral Spelling

Although writing with the left hand was slow and laborious, GK could form clear and legible graphemes. He was able to write 23/26 (88%) letters of the alphabet to dictation when given their names, but could only write 5/22 (23%) when given their characteristic sound.

Writing to dictation was further assessed with a total of 344 words. This corpus included lists of nouns (matched for length) that were constructed to allow an independent evaluation of the effects of word frequency (Kucera & Francis, 1967) and imageability (Paivio, Yuille, & Madigan, 1968) by varying one dimension while the other was held constant. Part of speech effects were evaluated with lists of nouns, verbs, and adjectives matched for frequency and length, as well as with a list of functors. Finally, the effect of orthographic regularity was assessed by using lists of regular and irregular nouns matched for length, frequency, and imageability.

Of the the 344 words, GK spelled 122 correctly (35%). He spelled high frequency nouns better than low frequency nouns ($\chi^2 = 14.93$; $p < .001$). There was also a significant advantage for high imageability nouns over low imageability nouns ($\chi^2 = 27.11$; $p < .001$). Nouns were spelled significantly better than functors ($\chi^2 = 12.13$; $p < .001$). Nouns were also spelled better than verbs ($\chi^2 = 11.27$; $p < .001$) and adjectives ($\chi^2 = 13.12$; $p < .001$). Orthographic regularity, on the other hand, had no significant effect on spelling.

GK's spelling errors (Table 1) included semantic errors (e.g., grass-lawn) and morphological errors (e.g., work-working). Morphological errors on suffixed words included both suffix deletions (e.g., opened-open) and suffix substitutions (e.g., ships-shipping). Several functor substitution errors were also noted (e.g., however-without). In addition, many of GK's spelling errors were visually but usually not phonologically similar to the target words, suggesting partial lexical/orthographic knowledge (e.g., secret-securt). These errors were characterized by letter substitutions, omissions, transpositions, reversals, and additions.

GK was also asked to spell to dictation 25 pronounceable nonwords consisting of four to seven letters (e.g., flig). Although he was able to repeat the nonwords both before and after his attempts to write them, he could not spell a single nonword correctly. His errors on nonwords usually had little visual or phonological resemblance to the targets (e.g., flig-enps; mofer-hocsk).

In contrast to written spelling, GK was unable to spell even the most simple words orally. He attempted this task by first repeating the target word and then producing letter names seemingly at random and rejecting each in turn, including the correct ones. He got easily frustrated with this task and often started tracing the correct letters with the index finger of the left hand instead.

Written naming was evaluated with the Boston Naming Test (Kaplan et al., 1983). GK correctly spelled the names of 19/60 items (32%). He made some semantic errors on this task (e.g., igloo-eskimo) and several of his responses showed partial lexical/orthographic knowledge of the target words (e.g., octopus-octpush).

To evaluate spontaneous writing, GK was asked to describe the picnic scene picture from the Western Aphasia Battery (Kertesz, 1982). His written narrative was agrammatical, consisting mainly of uninflected content words combined with only a limited number of functors to create simple phrases and incomplete sentences.

Reading

The analysis of GK's reading was based on a total of 1411 single word oral reading responses that included the word lists used for testing writing, as well as several additional published word lists (e.g., Brown & Ure,

TABLE 1
 EXAMPLES OF GK'S SPELLING ERRORS IN WRITING TO DICTATION AND WRITTEN NAMING

Semantic errors		Morphological errors	
Stimulus	Response	Stimulus	Response
grass	lawn	soul	souls
product	result	ships	shipping
igloo	eskimo	opened	open
bowl	pot	work	worked
lesson	spell	ringing	rings
noose	loop	driving	drive
walking	move	half	halves
knot	tight	cooked	cook
rage	hateful	notice	notices
come	go	ship	shipped
Partial lexical knowledge		Functor substitutions	
Stimulus	Response	Stimulus	Response
guitar	guilat	while	who
secret	securt	because	both
helicopter	helicophet	from	to
pretzel	prezter	however	without
octopus	octpush	ever	he
receipt	repeit	already	through
justice	jutrice	whose	which
pyramid	pymind	why	all
snail	srail	in	at
biscuit	bucsilt	though	although

1969; Dunn & Dunn, 1981; Rothi, Coslett, & Heilman, 1984). GK correctly read 1092/1411 (77%) words. He read high imageability nouns significantly better than low imageability nouns ($\chi^2 = 15.84$; $p < .001$). However, there was no statistically significant effect of word frequency, orthographic regularity, or part of speech.

Reading errors (Table 2) included visual errors (e.g., fact-face), morphological errors (e.g., truth-truthful), and some functor substitutions (e.g., whether-until), although most functor errors were also visually similar to the target (e.g., above-about). GK produced only a single error that was semantically but not also visually related to the target stimulus (weak-sick). A small proportion of his errors (4%) consisted of responses that were both visually and semantically related to the target word (e.g., escalator-elevator).

From the list of 25 pronounceable nonwords, GK could not read a single one correctly. On occasion, his response was a real word that was visually similar to the nonword stimulus (e.g., gove-give).

TABLE 2
EXAMPLES OF GK'S READING ERRORS

Visual errors		Morphological errors		Functor substitutions	
Stimulus	Response	Stimulus	Response	Stimulus	Response
fact	face	admit	admittance	whether	until
span	spank	truth	truthful	once	upon
despise	despite	learned	learn	without	with
acorn	accord	dismay	dismayed	in	on
prose	poise	shining	shine	because	beside
divine	divide	worked	working	of	from
fringe	finger	agreed	agreement	under	until
mitten	kittens	kindness	kindly	ever	even
torture	tortoise	access	accessible	above	about
esteem	seem	childless	child	they	there
Visual/semantic errors		Semantic error			
Stimulus	Response	Stimulus	Response		
escalator	elevator	weak	sick		
flush	blush				
attack	action				
fight	fright				
telegram	telegraph				
defeat	defend				
ritual	spiritual				
apparition	appearance				
medley	melody				

GK achieved maximum score on the reading comprehension subtests of the Western Aphasia Battery (Kertesz, 1982). Precision of reading comprehension was further assessed with a 40-item version of the written word-to-picture matching test devised by Bishop and Byng (1984). This test requires subjects to match a written word to one of five pictures that include the correct item, a visually similar distractor, a close semantic distractor, a distant semantic distractor, and an unrelated item. GK was first asked to match the stimulus word to the appropriate picture and then to read the word out loud. He selected the correct picture on 36/40 (90%) trials and his four incorrect responses were all semantic errors (three close and one distant). However, GK correctly read aloud all stimulus words, including the ones for which he incorrectly selected a semantic distractor in reading comprehension.

DISCUSSION

GK's left hemisphere was virtually completely destroyed by the massive infarction, therefore, it seems reasonable to assume that speech as well

as the linguistic and motor components of writing must be generated by the right hemisphere.

Linguistic analysis of GK's writing revealed that he is completely unable to spell nonwords to dictation. The fact that he could repeat the nonwords both before and after his attempts to write them indicates that this deficit cannot simply be attributed to imperception of the stimuli or limited phonological short-term memory. Instead, GK's inability to spell nonwords suggests that the nonlexical phonological spelling route that relies on phoneme-grapheme translations¹ (Ellis, 1982) was not available to him. The impairment of the phoneme-grapheme conversion procedure is also demonstrated by GK's poor performance in writing letters to dictation when given their characteristic sound.

GK's spelling of real words was significantly affected by lexical-semantic variables (i.e., word frequency, imageability, and part of speech) but not by orthographic regularity. These observations, as well as the presence of semantic errors in writing to dictation and written naming, suggest that GK's writing depended on the use of the lexical-semantic spelling route. This procedure involves the activation of word-specific visual/orthographic information from the orthographic output lexicon in response to a semantic code (Ellis, 1982). GK frequently produced written responses that reflected only partial lexical/orthographic knowledge. Errors of partial lexical knowledge suggest that certain entries in the orthographic output lexicon may only contain incomplete information about the identity and/or the serial ordering of graphemes, or that orthographic information cannot always be activated in an all-or-none fashion (Ellis, 1982, 1988; Patterson, 1988). Alternatively, these errors may reflect the rapid decay of orthographic information from the graphemic output buffer (Nolan & Caramazza, 1983). The graphemic output buffer is a working memory system that temporarily stores abstract graphemic representations for conversion into letter names (i.e., oral spelling) or letter shapes (i.e., written spelling) (Ellis, 1982; Miceli, Silveri, & Caramazza, 1985; Caramazza, Miceli, Villa, & Romani, 1987). Under normal circumstances, the information in the graphemic output buffer can be "refreshed" by input from the phonological output buffer via the nonlexical phoneme-grapheme conversion process (Ellis, 1982, 1988; Nolan & Caramazza, 1983; Miceli et al., 1985). GK's complete inability to utilize phoneme-grapheme conversion pre-

¹ Whether the nonlexical phonological spelling system performs subword level phonological-to-orthographic translations based on individual phonemes and graphemes only or whether larger units are also involved is currently a subject of debate (Patterson, 1988). It has also been suggested (Campbell, 1983) that the procedures involved in spelling nonwords may not be entirely nonlexical and may instead be based on analogy with familiar words. In any case, GK's total failure to spell nonwords demonstrates a complete inability to use either subword level phonological-to-orthographic translations or the lexical analogy procedure.

cludes this interaction between the phonological and the graphemic output buffers. Consequently, information in the graphemic output buffer specifying the identity and ordinal position of graphemes cannot be "re-freshed" and may be subject to rapid decay, leading to errors of grapheme omission, substitution, transposition, and reversal (Nolan & Caramazza, 1983). That information from the phonological output buffer exerted no influence on GK's spelling is also demonstrated by the fact that most partial lexical knowledge errors were visually but not phonologically similar to the targets (e.g., pretzel-prezter; yacht-yath). GK's reliance on a "visual" spelling strategy is further supported by certain behavioral observations and by his own introspection. When spelling words to dictation, GK closed his eyes after hearing the word and seemed to be concentrating intensely. He informed us that he had to "see" the word before he could attempt to write it and that simply repeating the word to himself was of no help. That GK may have been trying to "read off" letters from a visual/orthographic representation was also suggested by the observation that on occasion he wrote the initial letters of a word followed by letters from the end of the word and subsequently filled in the space left in the middle. Once he had written a word, he was frequently able to detect spelling errors. However, his attempts to correct the errors were usually unsuccessful.

Whereas GK could write correctly a substantial number of words, he was unable to spell orally even the most simple words. Since it is generally assumed that the same orthographic representations are utilized in oral and written spelling (Ellis, 1982), GK's difficulty is likely to reflect an inability to convert orthographic representations into letter name codes for oral spelling with preserved ability to convert them into graphic motor patterns for written output (Ellis, 1982). That GK's problem with oral spelling is not due to an oral production deficit was confirmed by his intact ability to recite the alphabet and repeat letter names and his relatively good performance in naming single letters on visual presentation (22/26 or 85% correct for lowercase and 24/26 or 92% correct for uppercase letters).

Several features of GK's spelling are consistent with the general characteristics of right hemisphere language, as revealed by studies of split-brain patients and adults with dominant hemispherectomy (Zaidel, 1985). These include sensitivity to lexical-semantic variables (i.e., word frequency, imageability, and part of speech), the presence of semantic errors, inability to utilize the nonlexical phonological spelling route, difficulty with bound morphemes, and agrammatism in spontaneous writing. Although different languages are involved, there are also certain similarities between GK's writing and the writing produced by the left hand in three Japanese patients with partial callosal lesions (Sugishita et al., 1980; Yamadori et al., 1980, 1983). Even more striking is the close resemblance

between GK's pattern of writing and the syndrome of deep agraphia (Bub & Kertesz, 1982; Nolan & Caramazza, 1983; Van Lancker, 1990). Deep agraphia is characterized by reliance on a lexical-semantic spelling strategy and the inability to use the nonlexical phonological spelling route (Bub & Kertesz, 1982). Consequently, spelling is affected by word frequency, imageability/concreteness, and part of speech but not by orthographic regularity (Bub & Kertesz, 1982; Nolan & Caramazza, 1983). Spelling errors include semantic paraphasias, morphological errors, and functor substitutions. The severe impairment of oral spelling relative to written spelling has also been documented (Bub & Kertesz, 1982).

The fact that deep agraphia in GK is clearly the product of writing with the intact right hemisphere raises the possibility that deep agraphia in other patients may also reflect right hemisphere writing. Deep agraphia usually follows extensive damage to the left hemisphere, suggesting that at least in some cases writing may indeed be mediated by the right hemisphere. A right hemisphere hypothesis for deep dyslexia, a similar impairment in the reading system, has already been proposed by several investigators (Coltheart, 1980a; Saffran, Bogyo, Schwartz, & Marin, 1980). Although GK's reading showed certain features of deep dyslexia (i.e., imageability effect, visual and morphological errors, some functor substitutions, inability to read pronounceable nonwords), there was no significant part of speech effect and there was a striking paucity of semantic errors (although he made a few errors that were both visually and semantically related to the target). Since in GK all language functions are carried out by the right hemisphere, the finding that he made semantic errors on other language tasks such as oral and written naming and writing to dictation suggests that the right hemisphere lexical-semantic system is intrinsically somewhat unstable and is prone to semantic errors. Consequently, if GK's reading depended *exclusively* on the use of the semantic reading route (i.e., a routine where the phonological representation corresponding to the printed word is accessed indirectly via a semantic code), he should produce semantic errors in oral reading as well. Some instability of the semantic reading route was in fact demonstrated by GK's occasional semantic errors on the Bishop and Byng (1984) test of reading comprehension. However, it has been proposed that an unstable or imprecise semantic reading route alone is not sufficient to produce semantic errors in oral reading; there must also be damage to the other routes by which reading aloud can be accomplished (Morton & Patterson, 1980; Newcombe & Marshall; 1980, Coltheart, Patterson, & Marshall, 1987). These include the nonlexical phonological route that presumably utilizes subword level grapheme-phoneme conversion and the lexical but nonsemantic reading route that relies on direct transcoding between entries in the orthographic input lexicon and corresponding representations in the phonological output lexicon (Morton & Patterson, 1980; Coltheart, 1980b;

Schwartz, Saffran, & Marin, 1980; Patterson & Shewell, 1987). The ability to convert print to sound by either of these "peripheral" routines produces a phonological code that can serve to constrain the response generated by the unstable semantic reading route to the correct phonological form and thus can *block* potential semantic errors in oral reading (Newcombe & Marshall, 1980; Coltheart, Patterson, & Marshall, 1987). Since GK is completely unable to read nonwords, it is unlikely that he can use the nonlexical route to compute a phonological code. Consequently, we believe that it is probably GK's ability to activate representations in the phonological output lexicon directly via the lexical but nonsemantic reading route that is responsible for his apparent success in blocking semantic errors in oral reading. The blocking of potential semantic errors in oral reading could be directly observed on the few occasions when GK correctly read aloud stimulus words for which he selected incorrect semantic foils on the Bishop and Byng (1984) test of reading comprehension. According to the right hemisphere hypothesis of deep dyslexia, semantic reading errors remain "unchecked" because the right hemisphere cannot derive phonology from print by either the nonlexical or the lexical but nonsemantic reading route and is therefore unable to "stabilize" the error-prone semantic route (Coltheart, 1980a; Saffran et al., 1980; Coltheart et al., 1987). Our observations in GK suggest that there are significant individual differences in the right hemisphere's ability to perform phonological encoding via the lexical but nonsemantic reading route and that the availability of this route may be sufficient to block potential semantic errors and may also eliminate the anticipated part of speech effect in oral reading.

Although there is evidence that in some aphasics with large left hemisphere lesions the right hemisphere is capable of taking over certain language functions (Nielsen, 1946; Kinsbourne, 1971; Cummings, Benson Walsh, & Levine, 1979; Heilman, Rothi, Campanella, & Wolfson 1979), the relatively high level of right hemisphere linguistic competence demonstrated by GK is decidedly unusual. GK is strongly right-handed for all skilled manual activities and does not have a family history of left-handedness or a history of left hemisphere damage in early life. Thus, there are no obvious factors to suggest anomalous development of language dominance. That the left hemisphere was dominant for language is also supported by the observation that following the massive left hemisphere infarction, GK became globally aphasic, alexic, and agraphic. However, right hemisphere language capacity may vary widely across individuals (Nielsen, 1946; Sidtis et al., 1981; Gazzaniga, 1983; Zaidel, 1978, 1985). Therefore, it is possible that premorbidly GK had "standard" left hemisphere language skills but above average linguistic competence in the right hemisphere.

It has also been proposed that in the normal brain the expression of

right hemisphere linguistic competence may be under left hemisphere control, possibly mediated through cross-callosal inhibition (Sperry, Gazzaniga, & Bogen, 1969; Kinsbourne, 1974; Moscovitch, 1976; Zaidel, 1986). Consequently, left hemisphere damage or callosotomy might be expected to release the right hemisphere from inhibition and allow full expression of its linguistic capacity. Although left hemisphere inhibition of right hemisphere linguistic functions may still be present in patients with smaller left hemisphere lesions, there is indeed some evidence for the release of right hemisphere linguistic processing with larger lesions (Landis, Regard, & Serrat, 1980; Landis, Regard, Graves, & Goodglass 1983). Complete surgical sectioning of the corpus callosum eliminates cross-callosal inhibition, but even in split-brain patients the left hemisphere may still be capable of interfering with the right hemisphere's attempts at linguistic expression (Levy et al., 1971; Levy et al., 1972; Levy & Trevarthen, 1977). Dramatic examples of left hemisphere inhibition of right hemisphere speech and writing in split-brain patients, presumably exerted through dominant subcortical motor control of the vocal apparatus and ipsilateral control of the left hand, are provided by Levy et al. (1971). These observations suggest that only virtually complete destruction of the left hemisphere (as seen in GK) or dominant hemispherectomy would be expected to completely release the right hemisphere from left hemisphere inhibition and permit full expression of its linguistic abilities.

Survival after the kind of massive hemispheric infarction suffered by GK is distinctly uncommon. Therefore, we need to consider the possibility that GK's substantial right hemisphere language skills are the product of continued linguistic development made possible by his prolonged survival. In this regard, it is important to note that continued improvement of language skills is well-documented in adults following dominant hemispherectomy (Smith, 1966; Burklund & Smith, 1977). Hemispherectomy in adults is usually performed for the treatment of malignant brain tumors and unfortunately most patients die from tumor recurrence within 2 years (St. James-Roberts, 1981). As Smith (1974) pointed out, the extent to which right hemisphere language skills might have improved with continuing survival remains unknown. The progressive increase of right hemisphere linguistic competence is also well-documented in split-brain patients where in some cases it culminated in the production of right hemisphere speech (Gazzaniga et al., 1979; Gazzaniga 1983). These observations suggest considerable neuronal plasticity for language development in the right hemisphere of the adult brain. As GK is now 13 years after his stroke, his language performance probably represents the upper limits of right hemisphere linguistic capacity. However, GK's case also illustrates that despite individual variations in the absolute level of right hemisphere linguistic competence and the evolution of language skills over time, right hemisphere language seems to follow a distinct general pattern.

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