19 Neuropsychology of Writing

Alfredo Ardila

INTRODUCTION

In this chapter, brain organization of writing and writing disturbances associated with brain pathology will be examined. Initially, it will be proposed that historically writing developed in three different stages, and it is based in three different abilities: visuoconstructive, praxic, and linguistic. The analysis of writing disturbances observed in cases of brain pathology (agraphias) supports the assumption that there are three major types of agraphias corresponding to the impairment in each one of these fundamental abilities. Later in the chapter, contemporary neuroimagining studies are introduced and the patterns of brain activation observed during writing are reviewed. Different writing systems are currently used, and not only brain activation during writing but also clinical characterization of writing disturbances are not totally coincidental among these different writing systems; this question will be examined in the following section of the chapter. Further, it will be emphasized that writing evolution has continued with the introduction of typewriters, and more recently, computers; brain control required for handwriting and for using computers is partially different; and it can be anticipated that toward the future new agraphia syndromes will be described. In the final section, some tentative conclusions are presented.

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ON THE ORIGINS OF WRITING

Viewed in terms of brain-behavior relationships, Ardila (2004) proposed that writing is based in three different abilities: visuoconstructive, praxic, and linguistic. Consistent with this notion, three major disorders in writing can be observed as a result of brain injury or pathology: visuoconstructive (spatial or visuospatial agraphia), ideomotor (apraxic agraphia), and linguistic (aphasic agraphia). Perhaps not coincidentally, the anthropological origins of writing appear to mirror these three different abilities.

In prehistory, writing developed first using a visuospatial modality to create three-dimensional clay tokens to represent objects, which later progressed into drawings. Schmandt-Besserat (1996, 2007) analyzed the impact of literacy on visual arts. This author observed that, before writing development, art of the ancient Near East consisted very specially of repetitive motifs. But, after writing, conventions of the script, including the semantic use of form, size, order, and placement of signs on a tablet was applied to images resulting in specific and complex visual narratives. Art played a crucial role in the evolution of writing from a mere accounting system to literature when inscriptions started to be featured on art monuments. Schmandt-Besserat found evidence in the clay tokens and envelopes unearthed from many different archaeological sites in the Near East. The tokens are marble-sized objects manufactured in a variety of geometric shapes. Groups of tokens have been discovered sealed inside clay envelopes.

Wall paintings appeared during the Paleolithic era, some thirty to thirty-five thousand years ago. Frequently animals, but also people, instruments, and environmental conditions were represented in these paintings. Then, during further evolution in prewriting, specific elements were represented in a standardized written way using a stylized pictorial representation of any given object (i.e., a standard representation of a bird means "bird"). Lecours, Peña-Casanova, and Ardila (1998) pointed out that writing evolved using with concrete pictograms that reflect realities accessible to the senses, particularly to vision. Finally, pictograms further evolved and became abstract, progressively separating from the concrete representation (i.e., the representation of "bird" is progressively more and more distant from a concrete and recognizable bird). This progression was observed in Sumer (contemporary Iraq) about 53 centuries ago, and it is usually regarded as the beginning of writing in human history. At this point, symbols referred to the meaning of the words; thus, these original writing systems are regarded as logographic. Graphemes representing sounds (syllables) appeared later, about 4000 years ago in Phoenicia (Sampson, 1985), and graphemes representing phonemes appeared even later in Greece. The sequence of the evolution of writing in consequence was:

Clay tokens → clay tokens pressed into wet clay to form animpression → drawings → pictograms → logograms → syllabic graphemes → phonemic graphemes

Thus, prewriting began as a *visuoconstructive* ability (i.e., forming clay tokens to represent concrete objects or elements in the real world) and only later did it become became an ideomotor *praxis* ability (i.e., making certain learned and stereotyped sequences of movements with the hand to create a pictogram, or a standardized two-dimensional representation of external elements). Even later, it became a *linguistic* ability (i.e., associating the pictogram with a word, and further analyzing the word in its constituting sounds).

Over the centuries, the diffusion of acquired writing skill was slow to reach wide sectors of society. Although writing began several millennia ago, until the fifteenth century, when the printing press was invented, writing may well have been limited to a few intellectuals and monks. Most were men. Even though no statistics are available, it may be conjectured that perhaps 99% (or even more) of the population was illiterate. Even now, at the beginning of the twenty-first century, approximately 20% of the adult population is illiterate (UNESCO, 2007). Furthermore, it has to be kept in mind that the mean level of education of contemporary man remains very low worldwide (about three or four years of more or less formal schooling), which may not be enough to develop automatic or fluid reading and writing skills.

It becomes evident that writing represents an unusual ability in humans. The overwhelming majority of members of our species who have lived throughout history could not read or write. Reading and writing is obviously far from being a "primary" or "biologically-based" cognitive ability. Clearly, writing represents a cognitive ability that depends on the human cultural evolution (Ardila, 2008; Vygotsky, 1962), although rooted in biologically based brain functions, such as the ability to make cross-modal associations between visual and auditory information.

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Writing Disorders Associated with Brain Pathology

In 1867, Ogle introduced the term *agraphia* to refer to the writing disorders associated with brain damage. Agraphia can be defined as the partial or total loss of the ability to produce written language due to brain pathology, which may result secondary to tumor resection, stroke, traumatic head injury, or any other similar condition affecting the brain. The ability to write can be impaired as a result of linguistic defects (aphasia), but other nonlinguistic abilities (e.g., motor and spatial) also participate in the writing process.

Of note, in cases of agraphia, letter and word writing is impaired while number writing and written calculation may be spared (Anderson, Damasio, & Damasio, 1990; Starrfelt, 2007), which suggests that the associations between linguistic information (phonemes) and visual symbols (letters) is at least partially independent from the association between quantities (number concepts) and visual symbols (written numbers).

In 1881 Exner proposed that there is a "writing center" located in the second frontal gyrus, in front of the primary motor area controlling the hand movements; in fact, the discussion about the role of this writing area supposedly specialized in writing has continued up to today (e.g., Sugihara, Kaminaga, & Sugishita, 2006). As early as 1891, Déjerine first described the syndrome of "alexia with agraphia," which clinically manifested as kind of acquired illiteracy. In 1940, Gerstmann proposed that agraphia can be observed in association with acalculia, right-left disorientation, and finger agnosia in a single clinical syndrome, usually known as Gerstmann's (or angular gyrus) syndrome.

During the twentieth century, several attempts were made to classify agraphias. Goldstein (1948) distinguished two major agraphia subtypes: apractoamnesic and aphasoamnesic. Luria (1976, 1980) referred to five different subtypes of agraphia: three of them were associated with aphasia (sensory agraphia, afferent motor agraphia, and kinetic agraphia); two others were due to visual-perceptual disturbances. Hécaen and Albert (1978) referred to four different subtypes of agraphia: pure, apraxic, spatial and aphasic.

Currently, a major distinction between linguistic (aphasic) and nonlinguistic (nonaphasic, usually including apraxic and spatial) agraphias is established (Benson & Ardila, 1996). Primary motor abnormalities obviously also impair the ability to perform the writing motor activity (motor agraphia). In recent decades so-called psycholinguistic classifications of agraphias have been proposed (e.g., Roeltgen, 1985), including a major distinction between central (equivalent to linguistic) and peripheral (equivalent to nonlinguistic) agraphias. In addition, difficulties in programming and controlling writing can be observed in cases of prefrontal pathology (dysexecutive syndrome); the term "dysexecutive agraphia" has been proposed to refer to this specific manifestation of the dysexecutive syndrome. Table 19.1 presents a general classification of agraphias.

Aphasic Agraphias

Aphasic patients present a fundamental linguistic defect that can be manifested not only when speaking but also when writing. Agraphia is hence the consequence of this fundamental linguistic defect and parallels the spoken language impairment. Thus, in Broca's aphasia (nonfluent form of aphasia characterized by apraxia of speech and agrammatism) patients have a slow, clumsy, abbreviated, and agrammatical writing. Literal paragraphias (errors in forming and then writing letters and words) are due to anticipations, perseverations, and letter omissions, observed especially in complex syllables. Letters are poorly formed and inadequately distributed on a line or a page. Most often, these patients are hemiparetic (i.e., due to a brain injury, they have a weakness on one side of the body). For those patients who are right-hand dominant and experiencing a right hemiparesis, they are forced to rely on their nonpreferred left hand in writing, which is awkward and represents an additional burden to the writing task. Spelling can be difficult and omission of grammatical elements is usually observed in writing (agrammatism in writing). Figure 19.1 presents an example of this type of agraphia.

Patients with Wernicke's aphasia (fluent aphasia associated with language understanding defects, word-finding difficulties, and paraphasias, anomalous words from the phonological or semantic point of view) have a writing defect characterized by a fluent writing with well-formed letters that

TABLE 19.1
General Classification of Agraphias

APHASIC (LINGUISTIC, CENTRAL) AGRAPHIAS
Different subtypes depending on the impaired level of the language
NONAPHASIC (NON-LINGUISTIC, PERIPHERAL) AGRAPHIAS
Visual-spatial
Apraxic
Motor
EXECUTIVE CONTROL OF WRITING
Dysexecutive

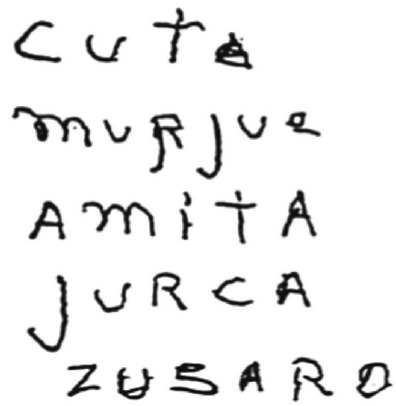

FIGURE 19.1 Example of agraphia associated with Broca's aphasia. Difficulties in forming the letters and incorrect sequences of letters (paragraphias) are observed.

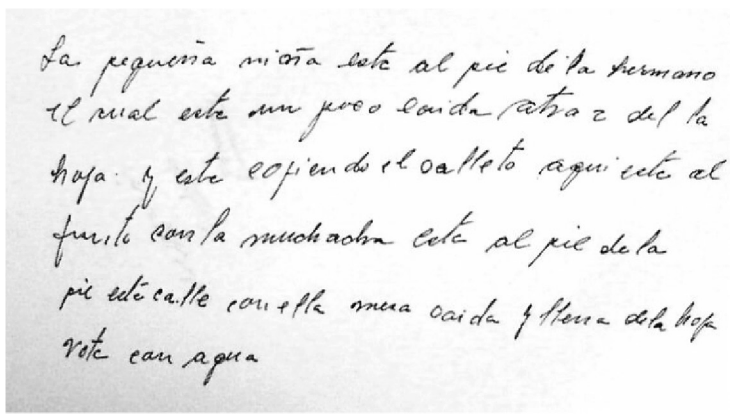

FIGURE 19.2 Example of agraphia associated with Wernicke's aphasia. Letters are well formed and calligraphy is normal. Nonetheless, there are letter and word substitutions and the text is difficult to understand.

are nevertheless combined incorrectly. Literal paragraphias (letter additions, omissions, and substitutions) and verbal paragraphias (word substitutions) are abundant. Sometimes, words are simply unrecognizable in meaning because the patient has neologized words by making new words, using new words or creating new meanings for words whose significance is known only to the patient (neologisms). Grammatical elements are used and even overused; often these grammatical elements are incorrectly selected (paragrammatism). Run-on sentences are common; nouns tend to be under-represented. As is the case with their spoken language, patients with Wernicke's aphasia produce copious amounts of written language, but for the above reasons their written language is seldom comprehensible in that it makes little logical sense to the reading audience (jargonagraphia). Figure 19.2 presents an example of agraphia associated with Wernicke's aphasia.

In cases of word deafness, spontaneous writing is preserved, but of course, writing by dictation is impossible. This neuropsychological syndrome is characterized by severe deficits in understanding spoken language, but patients have a preserved ability to understand written language and produce written language.

Agraphia associated with conduction aphasia is characterized by language repetition defects, associated with a relatively well-preserved language understanding and spontaneous language production. This complex defect is not yet well understood. Luria (1976, 1980) referred to this type of agraphia as "afferent motor agraphia." In this type of agraphia, spontaneous writing is better than writing to dictation. Literal paragraphias are abundant in words containing complex phonological sequences as well as in low-frequency words and particularly pseudowords (made-up words that are spelled and can be pronounced as if they were real words). These patients recognize that the word she or he wrote is written incorrectly, but when attempting to correct it, new errors are added; writing, consequently, often contains a significant amount of corrections, missteps and crossed-out words. The patient demonstrates that s/he assuredly knows the word (and can even repeat it to him or herself) but cannot remember how to write it (Ardila & Rosselli, 2007; Benson & Ardila, 1994). Writing is slow and painstaking. Associated ideomotor apraxia is frequently a co-occurring condition. Letters are poorly formed, but both grammar and word selection are correct. With extended lesions, and because of the location of the damage (usually, left parietal lobe) the writing defect may represent an evident apraxic agraphia (impaired ability to select and sequence the series of strokes necessary for legible writing). In such cases, the patient is unable to write letters, and when attempting to write, only unintelligible scribbles are produced. Figure 19.3 presents an example of agraphia associated with conduction aphasia.

Extrasylvian (transcortical) sensory aphasia is characterized by fluent irrelevant speech output, very poor comprehension, and well-preserved repetition. In these cases, the patient presents overt noun-finding difficulties; verbal paragraphias may be abundant in writing; nonetheless, some difficulties in forming the letters are frequent because of the potential extension of the damage in the parietal lobe. By contrast, extrasylvian (transcortical) motor aphasia is characterized by reduced spontaneous speech, with preserved auditory comprehension and repetition. Writing is scarce and perseverations are common, which means that the patient tends to write the same letters or words over and over again.

Mixed extrasylvian (transcortical) aphasia is a combination of both the motor and sensory type of transcortical aphasia. For these patients, their copying ability may be relatively preserved, while spontaneous writing and writing by dictation is impossible. In the case of global aphasia, a condition which is associated with extensive damage in the brain's language areas (the brain area around the lateral fissure in the left hemisphere), writing is usually limited to some isolated strokes that do not constitute whole or accurate letter formation or isolated letters that do not form whole or accurate words.

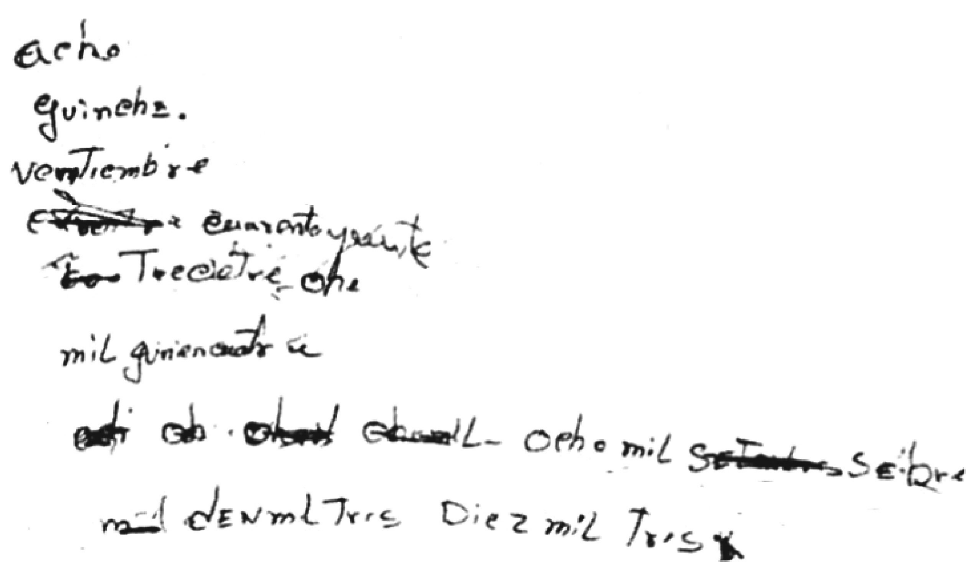

FIGURE 19.3 Example of agraphia associated with conduction aphasia. Letters are poorly formed; literal paragraphias are observed; when attempting to correct errors, new errors are added; a significant amount of corrections, missteps, and crossed-out words are observed.

Finally, it is important to emphasize the syndrome of alexia with agraphia mentioned before and first described in the nineteenth century by Déjerine (1891). In these cases, there is a significant impairment in the writing ability. Associated language disturbances are diverse and can include elements of Wernicke aphasia, extrasylvian sensory aphasia, and so-called Gerstmann's (angular gyrus) syndrome, which features acalculia, right-left disorientation, finger agnosia, and probably semantic aphasia (Ardila, Concha, & Rosselli, 2000; Benton, 1992).

Nonaphasic Agraphias

Writing is not only a linguistic, but also a visual-spatial and motor ability; consequently, spatial disturbances and motor programming defects can also impair writing skill. For most individuals who are right-hand dominant, these visuo-spatial brain functions tend to be located in the right hemisphere. Thus, right hemisphere pathology is usually associated with general spatial difficulties, defects in the recognition of places, and visuocontructive impairments. Spatial or visuo-spatial agraphia is regarded as a nonaphasic writing disturbance, which impairs orientation and correct sequencing in writing (Benson & Ardila, 1996). It is supposed to represent a defect in graphic expression due to impairment in spatial perception, usually associated with right hemisphere pathology.

According to Hécaen and Albert (1978), visuo-spatial agraphia is characterized by four deficits: (1) some graphemes are written with additional strokes; (2) lines in writing are not horizontal but rendered instead in ascending and/or descending strokes; (3) a left-sided visuo-spatial neglect which results in writing that is concentrated in right side of the page; and (4) blank spaces are included in the middle of the words, disorganizing the words and destroying the unity. Frequently, spatial agraphia is associated with spatial alexia, spatial acalculia, left hemi-spatial neglect, constructional apraxia, and general spatial difficulties. Close to 75% of the patients with right retro-Rolandic (that means behind the central or Rolandic fissure) pathology and 50% of the patients with lesions in the right pre-Rolandic (that means in front of the central or Rolandic fissure) cortex present some degree of visuo-spatial agraphia. Ardila and Rosselli (1993) proposed that the spatial agraphia has seven characteristics: (1) omissions of strokes and letters, but also additions of strokes and letters; (2) inability to correctly use spaces to join and separate words; (3) difficulty maintaining a horizontal direction in writing; (4) progressive increase of the left margin (cascade phenomenon); (5) spatial disorganization in writing; (6) disautotomatization and changes in the writing style (cursive writing may be difficult); and (7) constructional apraxia for writing. Figure 19.4 presents an example of spatial agraphia.

It is interesting to emphasize that the ability to use cursive writing can be affected in cases of right hemisphere pathology, even though the left hemisphere is typically dominant for language

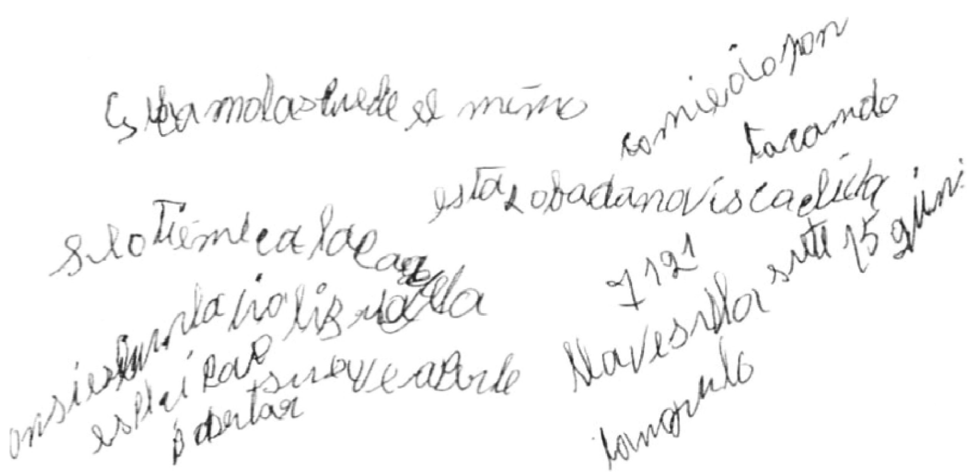

FIGURE 19.4 Example of visuo-spatial agraphia associated with right hemisphere pathology.

functioning in those who are right-hand dominant. Recently, Popescu and Vaidya (2007) reported a patient who was right-hand dominant and had ischemic damage to the parietal and occipital lobes bilaterally who exhibited a writing disorder strictly limited to cursive writing.

According to Hécaen and Albert (1978), apraxic agraphia refers to the inability to form graphemes correctly; strokes and letter inversions as well as distortion in the formation of letters and words are found in this type of writing deficit. The patient can spell the words and form words by arranging letters preprinted on cards; yet, when asked to write freehand, the patient typically makes spelling errors, and iterations are also frequent. On occasion, the patient can write short phrases, but paragraphic errors are evident. Sometimes apraxic agraphia is called "pure agraphia" because it is not associated with aphasia and alexia. Hécaen and Albert (1978) proposed two different types of apraxic agraphia: in one type, the patient does not present with associated aphasia and alexia; instead, these patient presents with an ideomotor apraxia observed in the left hand and apraxic agraphia in the right hand. In other patients, however, apraxic agraphia is associated with other parietal symptomatology, including alexia and some language understanding difficulties. In such cases, however, agraphia does not depend on aphasia, but both agraphia and aphasia depend on an inability to program the movements required to form letters and words.

Motor Agraphias

Motor disturbances in writing can appear as a consequence of central nervous system pathology involving the basal ganglia, cerebellum, and corticospinal tract of the pyramidal system or as a consequence of lesions affecting the peripheral nerves and the mechanical movements of the hand (Benson & Ardila, 1996). Different types of motor agraphia can be distinguished. Damage in the lower motor neurons of the pyramidal system can affect the muscles of the upper right limb; in those cases, flaccidity will be found. Damage in the upper motor neuron is associated with spasticity. A patient with a paretic hand will tend to write using poorly formed and letters that are exaggerated in size. Extrapyramidal pathology can be manifested in hypokinesis, as observed in Parkinson's disease, or in hyperkinesis, as found in chorea, athetosis, and dystonia. By the same token, cerebellar tremor can also affect the ability to write. So-called writer's cramp is a focal dystonia affecting the fingers, hand, and/or forearm; symptoms usually appear when a person is attempting to perform a task that requires fine motor movements, such as writing longhand for an extended time.

Dysexecutive Agraphia

Although many types of writing disorders associated with brain pathology have been described throughout medical history, there is relatively sparse mention of writing disturbances associated with prefrontal pathology. Prefrontal pathology affects executive functioning, which includes self-monitoring,

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Clinical observations of patients not only with focal prefrontal pathology but also with other conditions affecting the frontal lobe system (e.g., traumatic head injury, dementia) confirm the assumption that these patients present an overt decrease in the ability to express threads of logical ideas in writing. It can be argued that complex aspects of writing, such as planning, narrative coherence, and maintained attention, are significantly disturbed in cases of impairments of executive functions (dysexecutive syndrome). Frontal lobe patients not only have difficulties maintaining attentional effort required for writing, but also they have deficits in organization and planning necessary for the transmission of ideas into written text. The term *dysexecutive agraphia* (Ardila & Surloff, 2006) has been proposed to refer to this specific writing disorder.

Brain Activation during Writing

The use of contemporary neuroimagening techniques has significantly advanced the understanding of the brain organization of writing (see www.fmriconsulting.com/brodmann/). This technology has enabled researchers to observe that writing is associated with an extended pattern of brain activity, usually including a diversity of anterior and posterior, right and left hemispheric areas. Indeed, writing is a complex act, requiring not only linguistic but also motor and spatial abilities.

Functional studies have demonstrated that writing single letters is associated with a significant activity of Brodmann's areas 37 (temporal-occipital area, related with auditory-visual associations) and 7 (superior parietal lobe) (Rektor et al., 2006). Other parietal areas are also active during writing including the border between the parietal superior and inferior lobuli Brodmann's area (Brodmann's areas 2 and 40), deep in the intraparietal sulcus, with a surprising right-sided dominance. The right parietal activation may reflect the spatial dimension of writing.

Comparing the brain activity observed during writing and drawing, a relatively similar pattern of activation for both has been reported (Harrington et al., 2007) including bilaterally the premotor, inferior frontal, posterior inferior temporal, and parietal areas. Significant differences between the two activities (writing and drawing) are found in areas of the brain known for language processing (perisylvian area, located in). Greater activation for writing is observed in the left hemisphere, which is typically dominant for language functions in those who are right-hand dominant. For drawing, greater right hemisphere activation is found in homologous areas, particularly Brodmann's area 46 (part of the prefrontal cortex–anterior middle frontal gyrus) and 37 (temporal-occipital).

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Sugihara, Kaminaga, and Sugishita (2006) recorded the brain activation while writing with the right and the left hand using Japanese Kana (phonograms representing syllables). Three areas were found to be activated: (1) the posterior end of the left superior frontal gyrus, which is superior and posterior to the so-called Exner's area (an area just above Broca's area and anterior to the primary motor control area, initially described as the "writing center"); (2) the anterior part of the left superior parietal lobule; and (3) the lower part of the anterior limb of the left supramarginal gyrus. In the single-subject analysis, whereas the first two of the above three areas were found to be crucial for writing in all individuals, an inter-individual inconsistency of involvement with writing was observed in last area: the lower part of the anterior limb of the left supramarginal gyrus (60% involved); the right frontal region (47%); and the right intraparietal sulcus (47%).

Writing in Different Systems

Few papers have approached the question of the potential similarities and differences in agraphia clinical manifestations across different writing systems. Some studies have approached the comparison of writing disturbances and brain activation patterns in Japanese Kana and Kanji. More recently, studies of agraphia in other languages have become available.

Indeed, Japanese represents a unique language using two different writing systems: Kana is a phonographic system and symbols represents syllables; Kanji is a logographic system and symbols represent meanings (morphograms). Various types of alexia with or without agraphia in the Japanese language cause specific types of Kanji/Kana dissociation; it has been further proposed that there is a semantic reading pathway via Brodmann's area 37 on the inferior border of the left temporal lobe and a phonological reading pathway via middle portion of the left lateral occipital lobe (Iwata, 2004).

Yaguchi, Yaguchi, and Bando (2006) reported a case of pure (apraxic) agraphia observed both in Kana and Kanji writing to dictation and copying. Most errors in Kana and Kanji writing to dictation and copying involved the inability to write. The patient, however, was able to write numerals from 1 to 12 precisely. Magnetic resonance imaging showed a cerebral infarction in the left parietal lobe, which included a part of superior parietal lobule and supramarginal gyrus. That means the apraxic agraphia was similarly affecting both writing systems, Kana and Kanji. Sakurai, Mimura, and Mannen (2008) analyzed two patients with lesions of the left posterior middle temporal gyrus. Patient 1 first presented with pure alexia more impaired for Kana after an infarction in the left middle and inferior occipital gyri and right basal occipital cortex, and after a second infarction in the left posterior middle temporal gyrus adjoining the first lesion, he showed alexia with agraphia for Kanji and worsened alexia for Kana; Kanji alexia recovered over the following 6 to 10 months.

Patient 2 presented with alexia with agraphia for Kanji following a hemorrhage in the left posterior middle and inferior temporal gyri, which resolved to agraphia for Kanji at 2 months after onset. In both patients, Kanji agraphia was mostly due to impaired character recall. The authors concluded that damage to the left posterior middle temporal gyrus alone can cause agraphia for Kanji. If the adjacent mid fusiform/inferior temporal gyri (Brodmann's area 37) are spared, the Kanji alexia is transient. This report also demonstrates that agraphia for Kana and for Kanji can be at least partially dissociated.

Ihori and colleagues (2006) reported the case of a right-handed patient who exhibited right unilateral jargonagraphia after a traumatic callosal hemorrhage. The lesions involved the entire corpus callosum, except for the lower part of the genu and the splenium. The patient's right unilateral jargonagraphia was characterized by neologisms and perseveration in Kanji and Kana, and was more prominent in Kana than Kanji. The authors propose that at least two factors seem to explain that Kana was more defective than Kanji. First, writing in Kana, which is assumed to be processed mainly via a subword phoneme to grapheme conversion route, might depend more strongly on lateralized linguistic processing than writing in Kanji. Second, Kanji, which represent meaning as well as phonology, with much more complicated graphic patterns than Kana, are assumed to be processed in both hemispheres.

Fukui and Lee (2008) reported three patients with progressive agraphia. Initially, these patients complained primarily of difficulties writing Kanji while other language and cognitive impairments were relatively milder. It was proposed that agraphia was generally more prominent, although not exclusive, for Kanji, probably because of later acquisition and larger total number of Kanji symbols, leading to lower frequency of use and familiarity per symbol. For comparison purposes, it is worthy to mention the case of progressive agraphia in a Spanish-speaking woman reported by Ardila, Matute, and Inozemtseva (2003). This patient presented a progressive deterioration of writing abilities, associated with acalculia and anomia. An MRI disclosed a left parietal-temporal atrophy. Using Spanish orthography was the initial writing difficulty noted in this woman. The correct use of orthography (i.e., selecting between two or more homophone alternatives) represents for normal people the most difficult aspect in Spanish writing, and it is not surprising to find it was the writing ability that proved most vulnerable in this patient.

In a further evaluation two years after the initial symptomatology, the patient demonstrated not only orthographic (homophone) errors, but also letter omissions and additions and even nonhomophone errors. It is noteworthy that, regardless of her inability to write spontaneously or by dictation, her ability to copy preprinted writing was virtually perfect. It was conjectured that merely copying written letters and words does not really represent a linguistic ability, but rather visuoperceptual and visuoconstructive ability. That's because copying written text is not equivalent to the original production of written expression, which requires a concert of brain activities including language functions, executive functions, and visuo-motor and fine motor skills.

Lin and colleagues (2007) using fMRI examined the neural correlates for Chinese writing, by comparing the writing of logographic characters and that of Hanyu Pinyin, the most commonly used phonetic notation system for Mandarin Chinese characters. The temporal profile of the activations indicated that the middle frontal gyrus, superior parietal lobule, and posterior inferior temporal gyrus reflected more central processes for writing. Although pinyin writing elicited greater activity overall than character writing, the critical finding was that the two types of symbols recruited neurons in essentially the same brain regions.

Liu and colleagues (2007) trained native English speakers with no knowledge of Chinese in recognizing 60 Chinese characters. Following the training, fMRI scans taken during passive viewing of Chinese characters showed activation in brain regions that partially overlap the regions found in studies of skilled Chinese readers, but typically not found in alphabetic readers. Areas included the bilateral middle frontal (Brodmann's area 9), right occipital (Brodmann's area 18/19), and fusiform (Brodmann's area 37) regions. The results suggest that learners acquired skill in reading Chinese characters using a brain network similar to that used by Chinese native speakers.

Meschyan and Hernandez (2006) compared the pattern of brain activation during single word reading in a group of English/Spanish bilinguals. Participants were slower in reading words in their less proficient language (Spanish) than in their relatively more proficient language (English). fMRI revealed that reading words in the less proficient language yielded greater activity in the articulatory motor system, consisting of supplementary motor area/cingulate, insula, and putamen. Orthographic transparency also played a neuromodulatory role. More transparent Spanish words yielded greater activity in superior temporal gyrus (Brodmann's area 22), a region implicated in phonological processing, and orthographically opaque English words (that is, words that cannot be read phonologically, such as *yacht*) yielded greater activity in visual processing and word recoding regions, such as the occipital-parietal border and inferior parietal lobe (Brodmann's area 40).

Writing toward the Future

Most of the cognitive brain syndromes (e.g., aphasia, alexia, agraphia, acalculia, apraxia, spatial orientation disturbances, prosopagnosia, visuoconstructive disturbances) were described during the late nineteenth and early twentieth century. Nonetheless, contemporary culture and living conditions have dramatically changed during the last 100 years. Writing no longer simply means using a pencil and a paper, but rather using a variety of means, including a computer keyboard, word processing programs, or texting using a hand held device often the size of a credit card.

Contemporary literate man is using handwriting less and less, and relying on computers more and more. In an informal survey to 40 people with a college-level education, they reported using a computer about 90% of the time when writing, and handwriting only 10% of the time. Obviously, this sample does not represent all of humankind, and computers are still not readily available to a large percentage of the human population living in the developing world. Nevertheless, this sample seems to illustrate that everyday writing is evolving away from handwriting toward increasing reliance on typing on a computer word processor or handheld device with a keyboard.

Handwriting demands significantly different cognitive and motor abilities than keyboarding tasks. During handwriting, fingers are maintained in a relatively steady position while the hand moves. In typing, the opposite pattern is observed. When typing, one hand does not move from one side to the other and back as in handwriting, but the hands remain relatively stationary and only the fingers are moved. Letters are not written but selected. Both hands have to be used in a similar way when typing. Because of using both hands, we have to assume that a major interhemispheric integration is required. It is obvious to assume that right-hemisphere lesions located in the frontal and parietal areas should significantly impair the typewriting ability of the left hand. Similarly, the use of the space is different. The normal spatial distribution of the words on the page is automatic on the computer and, hence, writing in this way cannot be spatially disorganized, as may be the case in handwriting. By the same token, letters are neatly written and easily recognizable. When typing, we are not using a space that is directly manipulated with the hands ("constructional space"), but only a "visual space."

Furthermore, typing is not a constructional task in that we do not have to construct the letters and space them correctly on a page, but it is rather more a motor-spatial task. Many people type using a spatial memory for the position of the letters in the keyboard. This is a type of memory not required in handwriting, and it probably depends on right hippocampal and parietal activity (Moser, Hollup, & Moser, 2002). Some people have to look at the keys to select the letters when typing. In this latter case, literal reading is a prerequisite for writing. During typing, letters have to be visually recognized before they are written. In handwriting, we use a mental representation of the visual form of the letters. Interestingly, few people—if any, regardless of how well they can type—are able to reproduce (i.e., describe verbally or by drawing) how the different letters are arranged on the keyboard. Memory for the location of letters on a keyboard or keypad seems to be a form of purely spatial and motor memory of which we are seldom consciously aware. For typing some special symbols (e.g., interrogation marks) and letters (e.g., the Spanish "ñ"), some relatively sophisticated motor maneuvers are required, sometimes involving the use of special keys or sequences of movements. In handwriting, however, special symbols are written using the mental forms that we have learned and then have to retrieve from memory. When typing, if a letter needs to be lower or upper case, a key has to be pushed. No other change to the movement is made. We can also select different writing styles and letter sizes using some special commands and menus, all without changing the sequences of the hand movements.

One obvious question is, in cases of brain damage, how is typewriting impaired? To the best of my knowledge, only one case of agraphia for typewriting has been published up to date (Otsuki, 2006; Otsuki et al., 2002). Nonetheless, it can be assumed that different types of brain pathology may affect the ability for typing on a keyboard. One could conjecture the following three types of disturbances: (1) An anterior callosal lesion would impair the ability to coordinate the movements between the hands. Furthermore, the left hand would be isolated from the linguistic left hemisphere, and would be unable to write. Left-hand hemiagraphia in callosal lesions has been observed (Benson & Ardila, 1996). (2) By the same token, it has been observed that damage in the supplementary motor area results in disturbances in the coordinated movements between both hands (Middleton & Strick, 2001). We can anticipate supplementary motor area typing agraphia. (3) Spatial memory disturbances should result in difficulties in recalling the positions of the letters on the keyboard. Typing would be slow and would require a continual search for the letters.

Otsuki et al. (2002) reported on a 60-year-old, right-handed Japanese man who showed an isolated persistent typing impairment without aphasia, agraphia, apraxia, or any other neuropsychological deficits. The researchers proposed the term "dystypia" for this peculiar neuropsychological manifestation. The symptom was caused by an infarction in the left frontal lobe involving the foot of the second frontal convolution (Exner's area) and the frontal operculum. The patient's typing impairment was not attributable to a disturbance of the linguistic process, since he had no aphasia or agraphia. Nor was the typing deficit attributable to an impairment of the motor execution process, given that the patient had no apraxia. Thus, it was deduced that his typing impairment was based on a disturbance of the intermediate process where the linguistic phonological information is converted into the corresponding performance. The authors hypothesized that the foot of the left second frontal convolution and the operculum may play an important role in the manifestation of "dystypia."

Using a computer is somehow equivalent to using a new writing system recently developed through cultural and technological innovations. Obviously, there is no brain area related to typing on a computer, as there is no single localized brain area related either to the concert of skills needed for writing longhand. Rather, there are basic cognitive abilities (preadaptative abilities) that are required for the use of these new cultural elements, for example, certain visuoperceptual abilities and cross-modal associations for reading, phonological awareness, some fine movements for writing, and so on. Using computers is notoriously more complex, yet we can assume a "functional system" that our brain uses to participate in their use. It can be conjectured that using computer word processors requires at least the following abilities: (1) a conceptual ability (executive functioning) to understand the principles governing the functioning of a computer; (2) some visuoperceptual abilities to recognize icons, windows, and so on; (3) some skilled movements to type on the keyboard and maneuver the mouse correctly; (4) some spatial abilities to handle the working space (monitor screen); and (5) some memory abilities to learn programs, to use the spatial position of the keys, and so on. Obviously, the ability to use computers can potentially be disrupted as a consequence of a failure in any one of these abilities ("acumputuria syndrome"?). In the future, apart from "dystypia," more complex disturbances in the ability to use computers will probably be observed, reported, and analyzed.

CONCLUSIONS

In this chapter, it was initially proposed that historically writing developed in three different stages, and it is based in three different abilities: visuoconstructive, praxic, and linguistic. The analysis of agraphias seems to corroborate the assumption that there are three major types of agraphias—visuo-spatial, apraxic, and aphasic—corresponding to the impairment in each one of these fundamental abilities. Writing also requires a motor support and executive control; some mention to motor and dysexecutive agraphia was also presented.

Later in the chapter, contemporary neuroimagining studies of writing were reviewed, concluding that during writing a complex pattern of brain activation involving a diversity of brain areas is observed. Although some differences in the brain organization of writing in different writing systems (e.g., English and Chinese) have been pointed out, writing depends on a complex pattern of brain activity including diverse cortical areas, usually involving the left frontal, right parietal, left temporal, and left occipital lobes. Complex writing (e.g., spontaneous writing, text writing) also represents an executive function, and it is not surprising that a decrease in the ability to express ideas in writing is observed in cases of prefrontal pathology (dysexecutive agraphia). In the final section it was proposed that writing is rapidly changing due to the introduction of new writing devices. Writing nowadays relies in somehow different abilities than observed only a few decades ago. It can be anticipated that toward the future, new agraphia syndromes will be described as new technology makes new demands upon us.

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