Can literacy change brain anatomy?

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Several studies have postulated that education and/or literacy may not only protect against the effects of biological ageing (Albert et al., 1995; Christensen & Henderson, 1991; Orrell & Sahakian, 1995), but also against the clinical manifestation of cerebral neuropathology (Katzman, 1993; Stern, 2002; Stern, Gurland, Tatemichi, Tang, Wilder, & Mayeux, 1994; Zhang et al., 1990). In clinical neuropsychology, much debate has centred on whether the brain is more likely to degenerate as a result of overuse or underuse; while some epidemiological studies have suggested that active engagement in intellectual, social, and physical activities may delay the cognitive deterioration associated with normal ageing (Scarmeas, Levy, Tang, Manly, & Stern, 2001), other studies have emphasized that the protective effect of education is not always observed but depends upon the specific cognitive ability that is measured (Ardila, Ostrosky-Solís, Rosselli, & Gómez, 2000; Ostrosky-Solís, Ardila, Rosselli, López, & Mendoza, 1998). Ostrosky-Solís (2002) points out that protection or age-related decline attenuation in well-educated subjects is highly related to verbal abilities; thus, education and verbal advantage could serve as a means of compensatory strategies, such as using verbal cues to aid recall or encoding visuospatial tasks with language. These are the strategies provided by formal education. The use of these strategies could mask otherwise similar rates of biological ageing among different educational groups, and this advantage, coupled with the effects of several important variables such as good health, appropriate occupation, and active engagement with the surrounding environment, could explain why cognitive stimulation can provide some moderating influence on the complex changes in cognitive performance associated with ageing.

It has also been reported that Alzheimer's disease not only has a later onset but that it is less severe in highly educated people (Katzman, 1993; Stern et al., 1994). This association of high education with late age of onset of dementia has been considered as an evidence of cognitive and/or brain reserve (Katzman, 1993; Mortimer, 1988; Satz, 1993; Stern, 2002).

The articles presented in this Special Issue analyse the impact of literacy on the anatomic and functional organization of the adult brain. Cognitive neuroimaging studies, event-related potentials, neuropsychological data of literate and illiterate subjects, and discussion regarding the origins and evolution of reading and writing are presented.

Stern, Scarmeas, and Habeck point out that the cognitive reserve model suggests that variables such as education and IQ are associated with cognitive reserve (CR) and may mediate differential susceptibility to age-related memory changes. They propose two complementary facets to CR: *reserve*—individual differences in the capacity to perform task—and *compensation*—the use of alternate brain networks or cognitive processes to cope with brain pathology. However, up to now the neurophysiologic substrate of CR has not been established. Therefore in order to explore the anatomical basis for CR in healthy young and old individuals, they used H215O PET to analyse the relationship between CR and task-related activation during the performance of a nonverbal recognition memory test. The first two studies focused on young subjects, and found either brain areas or brain networks where the amount of increased activation correlated with CR. The third study compared activation patterns of young and elderly individuals and found locations where the relation between activation and CR differed

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across the two groups. They suggest that these may represent areas where *compensation* for the effects of ageing has caused a functional reorganization of the neural substrate for task performance. For the young subjects this brain network may be used to cope with increasing task demands, and may represent a neural manifestation of *reserve*. These exploratory analyses suggest that it is possible to identify the neural substrate for these two aspects of cognitive reserve.

In a series of pioneering research dating back to 1976, Castro-Caldas and colleagues have used illiteracy as a tool to understand the way the brain adapts to information. Using behavioural and neuroimaging studies, they have shown that learning how to read and write during childhood affects the functional organization of the adult brain. In his article, Castro-Caldas describes two types of effects that can be related to the exposure of the stimulation that is involved in the complex process of schooling: a diffuse effect and a focal effect. He defines the diffuse effect as the one related to the adaptation to a rich environment, such as that present in school, and which introduces several changes in brain function, like the increase of abstract thinking and the development of parallel processing of information. The focal effect is related to the learning of specific skills and operations that constitute the mastery of reading and writing and which may change particular areas of the brain involved in these operations. Castro-Caldas reviews, both from the functional and from the anatomical point of view, how the knowledge of reading and writing has effects on several cognitive process including visual processing, cross-modal operations (audiovisual and visuotactile), and interhemispheric crossing of information. Using the results of neuroimaging studies, he reports differences between groups of literate and illiterate subjects in several areas: the corpus callosum is thinner in the illiterate group in the segment where the parietal lobe fibres cross; the parietal lobe processing of both hemispheres is different between groups; and the occipital lobe processes information more slowly in individuals who learned to read as adults compared to those who learned at the usual age. While dealing with phonology, a complex pattern of brain activation was only present in literate subjects.

The paper by Ostrosky-Solís, Arellano Garcia, and Perez explores the issue of language lateralization in illiterates. Although some studies reported that lesions in the right hemisphere resulted in a greater incidence of language difficulties in illiterate stroke victims than in their literate counterparts, and that aphasia was less severe in left-stroke illiterate patients, other studies did not replicate these findings and found left-hemisphere dominance in illiterates. Up to now, the question remains as to whether the functional balance between the two cerebral hemispheres while processing oral language could be modified by the knowledge of orthography; thus literacy could play a significant role in language lateralization. Using neurophysiological techniques the authors recorded cortical evoked potentials to a probe click stimulus to assess the extent of activation of the two cerebral hemispheres during a verbal memory task in literate and illiterate subjects. They found a left-hemisphere attenuation during the experimental condition in both groups.

However, during the verbal memory task, significant intrahemispheric differences between groups were found at parietotemporal areas. Results seem to indicate that learning how to read and write demands an intrahemispheric specialization with an important activation of parietotemporal areas. These data support the view that the brains of illiterate subjects show patterns of activation that are different to those of literate subjects, thus suggesting that environmental conditions can influence brain organization.

A large number of studies have found that level of education has been proven to have an important impact on the cerebral organization of cognitive skills and on performance in neuropsychological tests, and it has been suggested that the development and organization of psychological processes such as abstraction, inference, and memory depends on the type of symbols (i.e., written system) used by the individuals in their environment. As suggested by Vygotsky (1978) many years ago, reading and writing are cognitive tools that, once acquired, change the way in which stimuli are memorized and conceptualized, thus stimulating abstract thinking. Manly, Byrd, Touradji, Sanchez, and Stern analysed the effects of literacy on neuropsychological test performance among ethnically diverse elders from Northern Manhattan, NY. Instead of years of education, literacy was assessed by using a reading measure; they concluded that reading level is a more sensitive predictor of baseline test performance, and also that literacy skills are protective against memory decline. They point out that differences in organization of visuospatial information, lack of previous exposure to stimuli, and difficulties with interpretation of the logical functions of language are possible factors that affect test performance of elders with low levels of literacy.

Although culture and education are factors that significantly affect cognitive performance, it is often difficult to distinguish between the effects of education and the effects of culture, since educational level influences the sociocultural status of an individual. Ostrosky-Solís, Ramirez, Lozano, Picasso, and Vélez analysed the influence of education and of culture on the neuropsychological profile of an indigenous and a nonindigenous population. They studied the Maya group, who live in the state of Yucatan in the Mexican Republic. Results showed that indigenous subjects showed higher scores in visuospatial tasks and that level of education had significant effects on working and verbal memory. No significant differences were found in other cognitive processes (orientation, comprehension, and some executive functions). They concluded that culture dictates what is important for survival and that education could be considered as a type of subculture that facilitates the development of certain skills over others. They emphasized that culture and education affects cognitive skills, so that accurate assessment of cognitive dysfunction is dependent on both education and cultural skills.

In a thought-provoking article, Ardila has analysed the origins of reading and writing in human history; he points out that the origins of writing can be traced to early cave paintings. Writing (or pre-writing) was initially a visuoconstructive ability, later involving some stereotyped movements to represent pictograms, and finally involving spoken language. Writing has had a long evolution since the cave painting of Palaeolithic times. Different strategies have been used to visually represent spoken language (ideograms, alphabets, etc.). Writing, however, has continued to evolve since its invention. Evolution has continued with the development of different technical instruments for writing: the feather, the pencil, the typewriter, and the computer. Brain representation of written language has necessarily changed in some ways, too. Ardila suggests that in the future new neuropsychological syndromes resulting from new living conditions will be described.

In human history, writing only dates back some 5000 to 6000 years, and just a few centuries ago, reading and writing abilities were uncommon among the general population. The acquisition of reading and writing skills has changed the brain organization of cognitive activity in general, as well as specific abilities. The papers reported in this issue provide pioneering hard evidence on how culture changes the brain and how the environment can influence brain development; however, many questions remain to be answered regarding idiosyncratic adaptations to diverse cultural influences, the identification of variables that promote cognitive reserve, and the future evolution of the human brain.

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