Mirror Writing, Left-handedness, and Leftward Scripts

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This minireview concerns a new observation on mirror writing. An uncommon form of writing, mirror writing is seen among healthy individuals, but it can also follow a variety of neurological diseases; it is nearly always carried out with the left hand and is more easily undertaken by left-handers. We have found that a particularly high prevalence of left-handed mirror writing has been reported among those whose native languages are traditionally written in a leftward direction, including Chinese, Japanese, and Hebrew. Innate left-handers and those whose languages are written leftward thus share an unusual facility for left-handed mirror writing, an observation that may have implications for understanding hemisphere specialization in relation to handedness.

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Mirror writing runs in the opposite direction to normal and with letters reversed, and it is most easily read using a mirror. It is usually written leftward with the left hand, and its occurrence often appears to be linked to the circumstances in which left-handed writing emerges. The characteristics of mirror writing, the circumstances in which it occurs, and many of the theories thought to explain it were reviewed over 70 years, and subsequent clinical and theoretical aspects have been briefly reviewed more recently.

Transient mirror writing sometimes occurs in both left-handed and right-handed healthy children as a normal phase during writing development. In right-handed adults who write with their left hand, mirror writing can be produced at will and for fun, and it is undertaken by lithographers, printers, and others for occupational purposes. Transient left-handed mirror writing is also sometimes observed when conventional writing is no longer possible in otherwise healthy right-handed individuals, for example, after the right arm has been damaged.

Pathological left-handed mirror writing in children has long been noted to be particularly common in dyslexia or more nonspecific “learning difficulties.” In adults, pathologically acquired mirror writing most commonly occurs in focal diseases affecting the left hemisphere, in particular a stroke that results in a right hemiplegia when writing with the left hand becomes necessary. Extremely rarely, left-handed mirror writing after a right hemisphere stroke has been reported. Mirror writing with the left hand has also been associated with diffuse cerebral disorders, including head injury, and various neurodegenerative processes, including Parkinson disease, essential tremor, and spinocerebellar degenerations.

The reason why mirror writing is usually carried out with the left hand has long been attributed to abductive arm movements being generally considered easier and better coordinated than adductive movements; leftward writing has therefore been held to be the natural direction of writing of the left-hander. Letters formed leftward would then result in the form of the script being mirrored, and this is the most usual explanation for reversal of letters such as b and d, although other letters such as s and N are also often reversed.

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Various theories to account for mirror writing have been proposed, and these have been summarized elsewhere. They include:

1. **The motor center hypothesis**, in which it is postulated that there are motor programs in the brain, with the programs represented bilaterally but in mirror form in the 2 hemispheres. When the left hand carries out writing movements normally carried out by the right hand, it has been suggested that in mirror writing there is a failure to inhibit the natural left-handed tendency to write leftward and in mirror form.

2. **The visual hypothesis**, in which it is similarly envisaged that there are bilateral visual memory traces (engrams) in the brain, the nondominant (usually right) hemisphere engraving being in mirrored form and again normally suppressed. Thus, when suppression is impaired or incomplete, mirror writing with the left hand would result. Conflict between abnormal motor pathways subserving mirror writing and a normal visual monitoring system has also been suggested.

3. **The spatial-orientation hypothesis**, in which it is suggested that there is confusion in respect of direction and orientation of reading and writing, sometimes associated with spatial confusion. These phenomena may merge with other related phenomena, including difficulties in overcoming the left-to-right directional bias of normal writing, right-left perceptual difficulties, different processing of writing in right and left hemisphere, and access to mirrored graphemes when mirror writing is part of more complex mirror and perceptual phenomena.

4. **The involvement of thalamo-cortical circuitry**. Rarely, mirror writing may be seen in essential tremor, Parkinson disease, and spinocerebellar disorders. It has been postulated that disruption of thalamo-cortical pathways may be the common underlying factor in these conditions.

Thus, there are both numerous circumstances in which mirror writing occurs and numerous theories invoked to explain the phenomenon, but the unifying feature is that mirror writing is nearly always carried out with the left hand. Furthermore, left-handers often find mirror writing particularly easy. We now report a new observation indicating that there is another group of individuals who have a particular facility for left-handed mirror writing.

**NEW INSIGHTS**

We have observed that a surprisingly large number of reported left-handed mirror writers are those whose native languages have traditionally been written and read leftward. This is evident from various individual reports of Japanese and Chinese patients, most of whom mirror wrote after (usually) left hemispheric vascular lesions, and the polyglot who, following head injury, selectively mirror wrote and read Hebrew script, while normal reading and writing of Polish remained.

More revealing than individual case reports, however, are findings in groups of subjects, including normal individuals and patients with a variety of disorders. In children, mirror writing was observed in 43% of 60 “mentally retarded” Chinese schoolchildren, compared with only 8% of 1350 English children with mental retardation, a highly significant difference ($P<.001$, $\chi^2$ test). Among the normal children in these 2 studies, mirror writing was seen in 10% and 0.5%, respectively, again a highly significant difference ($P<.001$, $\chi^2$ test). In a report of more than 106000 American schoolchildren, only 42 mirror writers were identified, all of whom were left-handed. Of these, 6 were “American Hebrew” and another, described as “Russian Jewish,” was “mentally deficient”; these 17% of the mirror writers would presumably all have read and written Hebrew in a leftward direction.

In adults, 16 (25%) of 63 right-handed Japanese patients mirror wrote following various left hemisphere vascular disorders, 14 using their left hand; 9 (24%) of 37 Chinese patients with left hemispheric stroke mirror wrote, all with the left hand. These findings contrast with the single (dyslexic) mirror writer among 41 right hemiplegics in a study from the United States. In the elderly, in whom comparable studies of rightward-directed languages are lacking, 6 (21%) of 28 healthy Chinese older than 80 years of age mirror wrote. Among 112 elderly Japanese, mirror writing increased with increasing dementia, and 17 of 18 severely demented patients mirror wrote with their left hand.

**CONCLUSIONS**

The reports presented here are inevitably subject to study and selection bias and to changing educational and other social factors over the past century. Writing customs change over time, and the characteristically leftward and vertical directions of much Asian writing are now becoming less common. Furthermore, mirror writing is often a heterogeneous phenomenon, and the direction of letters and ideograms may be different from the direction of the line of writing. Nevertheless, the high prevalence of mirror writing reported in healthy individuals and in patients whose languages are typically written and therefore also read from right to left is striking.

This finding cannot be attributed to population differences in handedness. Left-handedness is no more frequent among Asians than Westerners, and right-handedness has predominated in all cultures for at least 5000 years. Both consonantal phonetic (Hebrew) and ideographic (Chinese and Japanese) languages are implicated. This suggests that, although ideographic languages are extensively processed in the right hemisphere, it is less the structure and more the leftward direction of these languages that is important and that drives, or is driven by, the contralateral right hemisphere. In addition, as was postulated in the case of ancient Semitic mirror writing, it may well be not only the direction of writing itself but also the right hemisphere involvement in leftward direction of eye movements and the left visual fields that are important. Consistent with the present hypothesis, left-handedness and its association with involvement of the right hemisphere in producing the script of the world’s most famous habitual mirror writer, Leonardo da Vinci, has been postulated on the basis of historical evidence.

The high prevalence of left-handed mirror writing in those whose languages are written leftward recalls the facility for mirror writing among innate left-handers. In
both groups, there is a suggestion that the right hemisphere may have an important role in mediating left-handed mirror writing, and, in the case of left-handers, there is supporting evidence for greater right hemisphere or bilateral activation compared with right-handers.\textsuperscript{13,14} Functional neuroimaging has been used to investigate finger and hand movements in left- and right-handers, including left-handers who write with their right hand,\textsuperscript{14} and also to investigate mirror reading\textsuperscript{5} but not, to our knowledge, mirror writing. These imaging techniques might prove valuable in studying mechanisms underling mirror writing in left- and right-handers and in those whose customary languages are written in different directions. Such studies in turn may further understanding of the links between hemisphere specialization, handwriting, and handedness.

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