

## REVIEW

# Mirror writing: neurological reflections on an unusual phenomenon

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Mirror writing is an unusual script, in which the writing runs in the opposite direction to normal, with individual letters reversed, so that it is most easily read using a mirror. This writing is seen in healthy individuals; it is also associated with various focal lesions that most commonly involve the left hemisphere, as well as with certain diffuse cerebral disorders. Mirror writing is nearly always undertaken with the left hand, and left-handers, and those whose languages are written leftwards, have an unusual facility for this writing. Concerning possible underlying processes, the implications of using the left hand when writing are considered first. Motor pathways that may be important, the surrogate model of bimanual mirror movements and the contribution of the corpus callosum are then discussed. The reasons why left-handed writing is mirrored, and the factors that tend to inhibit mirroring, are outlined. After commenting on mirrored motor and visual engrams, the possibility that the right hemisphere may play an important part is entertained, and Leonardo da Vinci's unique, habitual mirror writing proves to be of unexpected relevance. Further investigations, ranging from epidemiological to functional imaging studies, may provide valuable insights into mirror writing.

surveyed, then possible underlying processes are considered and finally it is proposed that mirror writing is a topic that warrants further study, and some suggestions for such studies are outlined.

## THE PHENOMENON OF MIRROR WRITING

### The nature of mirror writing

The term "mirror writing" (Spiegelschrift) was introduced by Buchwald<sup>3</sup> to describe "that variety of script which runs in an opposite direction to the normal, the individual letters being also reversed".<sup>4</sup> Mirror writing is unusual as it is sometimes executed by entirely normal people, and at other times is only seen in the wake of a variety of neurological disorders.<sup>4,5</sup> Sometimes mirror writing is undertaken deliberately and at other times inadvertently; sometimes the writer notices the mirrored form, yet at other times it escapes attention. Mirroring can variously affect spontaneous, copied and dictated writing. Particularly when produced spontaneously, mirror writing is a highly heterogeneous phenomenon: the mirroring may range from as small an item as a single reversed letter, through numerous reversed letters but not words, to thousands of pages of mirrored script; the place in the word in which a mirror letter occurs is variable, and numerals may or may not be reversed too. This heterogeneity raises the issue of whether mirror writing comprises a single entity. Thus, reversing a single letter in an otherwise normal script, whether by healthy people or by those with disease, may be a different phenomenon compared with more extensive mirroring, and although mirror writing in general is considered here, emphasis is placed on the more marked and pervasive forms of this writing.

Usually, the line of mirror writing flows from right to left, but sometimes—as in Chinese script—normal leftwards hieroglyphs can be reversed, but not the rightwards ordering of the vertically written lines,<sup>6</sup> and mixtures of orientations of letters, words and lines of writing may be seen.

Other unusual reports of mirror writing include mirror writing in concordant identical twins and in three generations of people<sup>7</sup>; familial, upside-down mirror writing<sup>8</sup>; inverted mirror writing<sup>4</sup>; and acquired mirror writing with either hand.<sup>9</sup>

The prevalence of mirror writing has recently been investigated using a newspaper survey, and the anecdotal report indicating a surprisingly high prevalence of 1 in 6500 Australians suggests that further epidemiological studies are warranted.<sup>7</sup>

Very occasionally mirror writing is accompanied by mirror reading. Although consistent mirror reading is exceptionally uncommon,<sup>10</sup> rare cases

I gave an account of an epileptic girl who used to write with the left hand, in reverse order, and with the forms of the letters reversed as well—and [she wrote] fluently, too—in such a way that what she wrote could only be read when placed before a mirror .... But a few years ago ... I observed a centurion who, having lost his right arm in action, wrote all his letters with the left hand, with order and form similarly reversed, with the highest degree of fluency ... one who wished to read his writing had to hold it to a mirror.<sup>1</sup>

Three hundred years ago, Lentilius described the first known cases of pathologically acquired mirror writing, but mirror writing had been observed a long time earlier. For example, in 1568, in describing the reversed letters of Leonardo da Vinci's script, Vasari<sup>2</sup> reported "whoever is not practiced in reading them cannot understand them, since they are not to be read save with a mirror". This review considers mirror writing from the neurological perspective. Firstly, the various circumstances in which mirror writing occurs are

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of mirror reading (ie, reading of mirrored letters) and reversed reading (ie, reading letters or words backwards) have been reported<sup>11</sup>—either of normally written letters, or mirror-written letters or both. Such associated mirror reading may be congenital or acquired, and when acquired there is often a variety of other visuospatial disturbances and left–right confusion.<sup>12–13</sup>

### When does mirror writing occur?

Mirror writing is seen in normal and pathological circumstances. Developing Critchley's classification,<sup>5</sup> tables 1 and 2 summarise the various occasions when mirror writing typically occurs.

### Mirror writing in healthy people

Table 1 summarises the occasions when mirror writing occurs in healthy people.

Normal *children* often go through a stage of mirroring of at least certain letters, especially reversible letters such as b and d, during the scribbling period and early stages of learning to write,<sup>10</sup> mainly between the ages of 3 and 7 years.<sup>14</sup> The child often does not appreciate the mirror form of writing because he or she cannot read it. Eighty years ago in English elementary schools, about 0.48% of children mirror wrote when they used their left hand.<sup>15</sup> Beeley's<sup>16</sup> report during the same period that only 0.04% of American elementary school children mirror wrote is likely to be an underestimate, as it was based solely on teachers noting children who were seen to mirror write. Although it is unclear whether these early observations remain valid today, when educational approaches and social circumstances have changed so much, even recently, left-handed children were sometimes forced to use their right hand for writing.<sup>17–18</sup>

With more or less effort, normal *adults* are able to produce some mirror writing at will, including when asked to do so in experimental conditions. Mirror writing can be produced for fun, when writing with both hands simultaneously, or when writing on one's own forehead or the under-surface of a board.<sup>5</sup> Certain writers, notably Lewis Carroll, have produced mirror writing for entertainment.<sup>19</sup> Rarely, mirror writing is said to occur under ill-defined conditions of transiently altered cerebral function, such as hypnosis and anaesthesia<sup>20</sup>; spiritualist mediums are said to be able to mirror write during trances—an anecdotal observation that may relate to the similarly anecdotal report that mediums tend to be left handed.<sup>21</sup>

Mirror writing can be learnt for occupational purposes. In the past, mirror writing was seen in several occupations such as telegraphy. Particularly etchers and lithographers, most famously William Blake,<sup>22</sup> acquire the skill of mirror writing

**Table 1** The occurrence of mirror writing in healthy people

|   |
|---|
| Children  |
| when learning to write  |
| Adults  |
| writing for curiosity, for fun or experimentally                          |
| during transiently altered cerebral function—eg, hypnosis or anaesthesia  |
| after peripheral damage to the preferred right hand                       |
| habitually, probably only by Leonardo da Vinci                            |
| learnt for occupational purposes by telegraphers, etchers, lithographers, |
| etc   |
| undertaken in classical times   |
| in reversed writing before transfer to paper                              |
| inscriptions on monuments and artefacts                                   |
| as a component of boustrophedon script*                                   |

\*Script written in boustrophedon (Greek "as the ox turns") comprises alternate lines written rightwards and leftwards, mirrored.

**Table 2** The occurrence of pathological mirror writing

|   |
|---|
| In children with "mental retardation", learning difficulties or dyslexia                            |
| In focal brain disease  |
| usually involving the left hemisphere (eg, stroke, focal trauma and abscess)                        |
| extremely rarely in lesions of the right hemisphere   |
| In diffuse brain disease  |
| head injury   |
| degenerative brain disease (essential tremor, Parkinson's disease and spinocerebellar degeneration) |
| rarely in adults with learning disabilities   |
| elderly people and people with dementia   |

so that the inscribed plate when printed results in normal script.

Otherwise normal right-handed adults can show transient mirror writing when, from necessity, they write with their unaccustomed hand. This may occur when the usual hand cannot be used as a result of some peripheral injury, and left-handed mirror writing, often for a few letters, sometimes emerges for a brief transitional period.<sup>23</sup>

The ability to mirror write is probably more common than generally realised, as perhaps many potential mirror writers—who are generally left handed—suppress their sinistrality and mirror writing.<sup>24</sup> Suppression has often been instigated by others,<sup>17–25</sup> particularly in the past when sinistrality was considered perverse and often pathological. However, writers themselves have often suppressed their own left-handed mirror-writing tendency. This has been partly because mirror writing was considered peculiar, and partly because it is obviously difficult for others to read. The facility for mirror writing may remain latent, however, as revealed in the mirror-written letter produced just 4 days after the individual realised that she could mirror write (fig 1).<sup>17</sup> Normal people,<sup>24–26</sup> as well as some patients with acquired mirror writing,<sup>27–28</sup> have sometimes commented on the surprising ease with which they can mirror write, and these people are usually originally ambidextrous or left handed.

Habitual mirror writers are exceptionally rare, and perhaps the only recognised example is Leonardo da Vinci, whose mirror writing is discussed later.

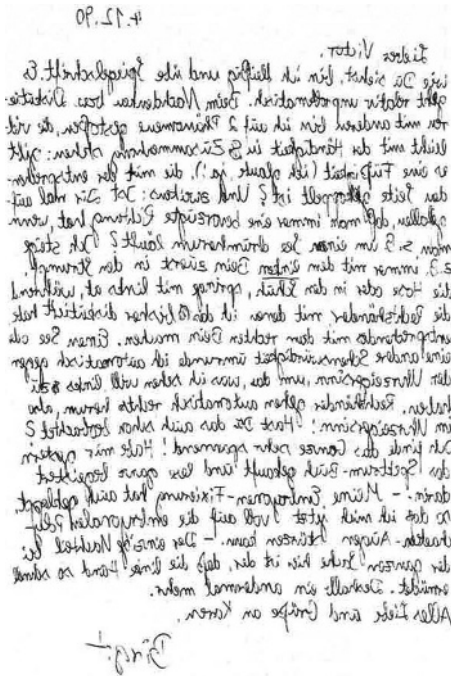
### Mirror writing in pathological conditions

The range of pathological conditions associated with mirror writing in children and adults shows that neither a specific location nor a particular aetiology underlies the phenomenon (table 2).

#### *Mirror writing in children with "mental retardation", learning disabilities or dyslexia*

Over a century ago it was observed that "imbeciles" and children with learning disabilities often mirror wrote, and many of these children were left handed.<sup>25–30</sup> Compared with the 0.48% of normal elementary school children who mirror wrote, the frequency was 8% among children with learning disabilities; among the children with learning disabilities, 30% of left-handed children mirror wrote, compared with about 2% of the right-handed children.<sup>15</sup> There is a paucity of clinical details of the conditions experienced by these children. For instance, the extent and nature of mental impairment were often not characterised other than by terms such as "very 'low grade' feeble minded",<sup>15</sup> and it is difficult to evaluate those early reports now.

Later, it was observed that certain children with selective difficulties in reading often had commensurate writing difficulties; again, mirror writing and left handedness were common,<sup>31–33</sup> but many of these children with developmental



**Figure 1** A letter written 4 days after the author discovered her ability to write mirror script with her left hand. Reprinted with permission from Smetacek.<sup>17</sup>

dyslexia (which had previously been termed congenital word blindness) had normal or indeed superior abilities in other cognitive domains. However, whether people with dyslexia have an increased mirror-writing tendency remains controversial, and has been both confirmed<sup>34</sup> and refuted.<sup>35–37</sup>

**Mirror writing in adults with focal brain disease**

In 1878, Buchwald<sup>3</sup> described three patients with hemiplegia who, when writing with their left hand, did so in mirror form. A few years later, a series of patients who mirror wrote after stroke was reported,<sup>38</sup> and subsequently further cases have been reported. Unfortunately, however, in most instances, the clinical details, investigations and neuropsychological data are scanty or non-existent.

The most frequent circumstance in which acquired mirror writing occurs in adults is after stroke affecting various peripheral and deep locations in the left hemisphere.<sup>28 39–43</sup> Adequate studies are lacking and it is unclear how often such patients mirror write, but the phenomenon has been thought to be uncommon: in a brief report of 50 patients with hemiplegia, only one was found to mirror write, and that right-handed patient with right-sided hemiplegia had dyslexia.<sup>44</sup> One of the largest series of acquired mirror writing carried out with the left hand comprised 13 right-handed patients with left-sided cerebral lesions who had undergone neurosurgery: 4 with penetrating head injury, 3 with cerebral abscess and 6 with an intracranial haematoma.<sup>45</sup> Cases after surgery for a left parietal tumour have also been described.<sup>46 47</sup>

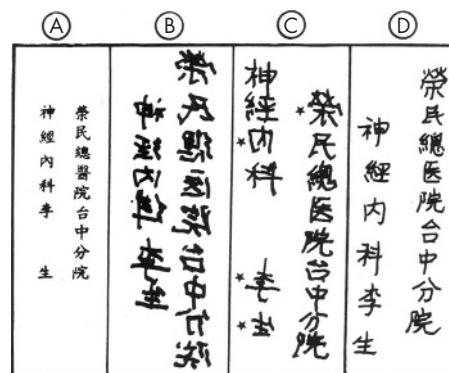
The mirror writing associated with a precipitating neurological event such as stroke is usually transient, lasting a few days or weeks, and is often fragmentary and confined to a few letters, words or sentences. Sometimes there is dysphasia, dysarthria, and directional and spatial confusion,<sup>13</sup> or other accompanying features reflecting the associated deficits, and a case of left-sided alien hand phenomenon associated with ipsilateral, left-handed mirror writing has also been described.<sup>48</sup>

An unusual case of mirror writing has been reported in which a right-handed Chinese patient produced spontaneous mirror writing with the left hand, following a left basal ganglia haematoma with resultant right hemiplegia and aphasia.<sup>6</sup> Ten months later the CT [computed tomography] scan showed low density at the site of the previous haematoma, and the patient showed a severe dysarthria, and occasional reversal of spoken digits during spontaneous speech and after repetition. When writing with his left hand, he spontaneously mirror wrote, reversing the Chinese characters but not the normal right-to-left ordering of the vertical lines of writing. There was then a phase of a combination of conventional and occasional mirrored words when writing with the left hand, but after two years, when the right arm remained paretic and left-handed writing was still being undertaken, he no longer mirror wrote nor reversed the order of spoken digits. Figure 2 illustrates the evolution of this mirror writing.

It is evident that the location of these left-sided lesions associated with mirror writing is extremely variable, and have variously included deep and superficial structures—for instance, the basal ganglia<sup>6</sup> together with posterior temporal region<sup>11</sup>; multiple areas in the parietal cortex<sup>39</sup>; temporal, temporoparietal, and frontotemporoparietal cortex<sup>45</sup>; occipitoparietal cortex, the striatum and internal capsule<sup>43</sup>; and thalamus.<sup>28</sup> Thus, although interruption of motor pathways or other networks may be relevant, any specific focal lesion in the left hemisphere is probably not directly responsible for mirror writing.

Mirror writing after *bifrontal* vascular damage has been described,<sup>49</sup> and at least two cases associated with a *right* hemisphere lesion have been reported:

Chan and Ross described a right-handed Chinese man who normally wrote in Mandarin Chinese and who developed a left hemiplegia complicated by other features including lack of spontaneous speech and incontinence.<sup>50</sup> A CT scan showed an infarct affecting the right anterior cingulate gyrus, anterior supplementary motor area, and posterior medial prefrontal cortex, with minimal involvement of the corpus callosum. Two weeks after the stroke, he had



**Figure 2** Mirror writing with the left hand by the right-handed Chinese patient who sustained a left basal ganglia haematoma. The Chinese script normally runs vertically and right to left, with individual characters written from left to right. (A) Normal script (in translation “Veterans General Hospital Taichung Neurology Section Lee San”); (B) mirror writing, at onset of illness; (C) normal script intermixed with few mirror-written words (indicated by \*), 10 months after onset of illness; (D) normal script, 2 years after onset of illness. Reproduced from Chia and Kinsbourne.<sup>6</sup>

impairment of bimanual tasks that required non-mirror movements and, whilst his writing with his right hand was normal, when writing with his left hand he did so in mirror fashion from right to left, and both characters and Arabic numerals were mirrored. When reassessed 8 months later, all these mirror phenomena had resolved.

A further case of a right-handed Japanese patient who mirror wrote with his left hand after a right middle cerebral artery territory infarct has also been described.<sup>28</sup> The mirror writing of this patient (case 28) was exceptionally well formed, and the patient believed he had always had a facility for mirror writing, raising the possibility that he may originally have been left handed.

#### *Mirror writing in adults with diffuse brain disease*

Mirror writing very rarely follows head injury, and can be transient<sup>51</sup> or persistent.<sup>9</sup>

Perhaps the most remarkable case is the patient reported by Streifler and Hofman.<sup>52</sup> These authors described a woman who had sustained an 'apparently slight brain concussion' as a result of a road traffic accident. She was right handed, but there was evidence to suggest she was originally left handed. She was born in Poland and learnt to speak Polish as an infant, but the first script she learnt was Hebrew, and following her later emigration to Israel, Hebrew became her main everyday language. After the accident she was able to write and copy correctly in Latin script. Hebrew, however, was written in mirror script and in the reversed direction, from left to right, and she had difficulty in reading Hebrew script unless it was presented in mirror form. She also displayed other impairments including dyscalculia, a variety of difficulties in reading, memory disturbances, and spatial and temporal confusion. The authors suggested the clinical features were reminiscent of an incomplete parietal lobe syndrome. The diffuse nature of the cerebral injury, lack of neurological signs and the few investigations undertaken preclude localization of the cerebral lesion(s). In respect of the discussion below, however, the salient features are the selective mirror phenomena associated with Hebrew script with sparing of Latin script.

More recently, Tashiro *et al*<sup>28</sup> observed the high incidence of mirror writing in patients with certain diffuse degenerative brain diseases, namely, essential tremor, Parkinson's disease and spinocerebellar degeneration, with some patients producing fragmented reversals—termed by the authors as "partial" mirror writing. The authors also commented that left-handedness was reportedly more common than expected in patients with essential tremor. Apart from their first patient, whose mirror writing may have been spontaneous, the left-handed writing in the other patients was "induced".

Although we have little information on mirror writing in elderly people, left-handed mirror writing may be more common in those of advanced age, especially in the presence of cognitive impairment.<sup>53 54</sup>

#### **The occurrence of an unusual facility for mirror writing**

There are two groups of people who seem to have a particular facility for mirror writing: innate left handers and those whose languages are written leftwards.

##### **Innate left handers**

The propensity for mirror writing among left-handed school children was noted by Ireland<sup>25</sup> more than a century ago, and

others have confirmed this. For reasons discussed earlier, the left-handed tendency and accompanying mirror writing then become suppressed, only to re-emerge when this suppression is overcome. An example is provided by Smetacek's<sup>17</sup> patient referred to earlier. It has been repeatedly observed that it is those who are left-handed, ambidextrous or who somehow believe they are inherently left-handed, who retain their unusual left-handed mirror writing facility—a facility, or advantage, that has been both confirmed<sup>55 56</sup> and refuted<sup>57 58</sup> in experimental studies in normal people.

#### **Those whose languages are written leftwards**

As is evident from the reports cited above, many *individual* cases of acquired mirror writing are reported in Chinese and Japanese people. There is also further confirmation of the high prevalence of left-handed mirror writing among *groups* of diverse people, but all of whose languages are written (and read) leftwards.<sup>59</sup> These groups include normal Hebrew-speaking American<sup>16</sup> and Chinese<sup>43</sup> school children, cognitively impaired Chinese school children,<sup>43</sup> Chinese and Japanese<sup>39-43</sup> patients who have had stroke involving the left hemisphere, healthy elderly Chinese<sup>53</sup> and elderly Japanese people with dementia.<sup>54</sup>

Although further numerical details are provided elsewhere,<sup>59</sup> the different groups, studied in different circumstances and in different eras, do not allow the overall prevalence to be estimated. Furthermore, these findings need to be interpreted with some caution, as the definition of leftwards direction of language is complex, and variables include the directions of the vertical and horizontal lines of script, letters and hieroglyphs, and changes in direction of written language over time. Nevertheless, these observations have implications when considering the mechanisms that are discussed in the following section.

#### **MECHANISMS**

Acknowledging that sometimes mirror writing in young children is carried out with the right hand,<sup>30</sup> and that there are very rare instances of acquired right-handed mirror writing in adults,<sup>60 61</sup> nevertheless, mirror writing is otherwise nearly always carried out with the left hand. This fact must surely be pivotal, and raises two questions: (1) what is the link between mirror writing and the left hand? and (2) what leads to the mirrored form of that writing?

As a preface, mirror writing is considered here to be a motor phenomenon rather than a cognitive phenomenon. As is evident from the data summarised above, mirror writing may occur in association with immaturity, ageing, dementia, learning disabilities and various ill-defined forms of cognitive impairment, dyslexia and some acquired instances of confusion and disorientation; yet, clearly, none of these conditions is sufficient or necessary for mirror writing to occur. Rather, it is suggested that they represent epiphenomena and provide the circumstances in which left handedness and left-handed mirror writing persist or emerge. As discussed later, the right hemisphere may perhaps sometimes be enlisted in the production of mirror writing, but it is argued that this would be through effects mediated by motor processes rather than by cognitive processes.

#### **The left hand and mirror writing**

At least in the most common cases of acquired mirror writing, those due to damage to the left hemisphere with right hemiplegia, the subject is "forced" to use the unaccustomed left hand for writing. The same situation arises in those who need to switch to their left hand after peripheral damage to their right hand, and in those who choose (rather than have) to write with their left hand in the setting of diffuse brain

dysfunction, or similarly when writing with the left hand for fun or in the laboratory. Hardly surprisingly, innate left handers accomplish their customary left-handed writing quite readily. Thus, the reason for using the left hand when writing is immaterial: it is the circumstances in which left-handed writing persists, develops or returns that leads to the persistence, development or return of mirror writing.

Accepting the importance of the left hand, what motor processes generate that writing? Mirror writing in normal people is likely to involve normal motor processes; however, in those who switch from right-handed to left-handed writing, as in those who are forced to use their non-dominant right hand,<sup>18</sup> presumably unaccustomed motor and other cortical processes are engaged. No experimental data are available on the processes specifically subserving mirror writing, and we are therefore dependent on speculative possibilities suggested by other motor phenomena.

**Bimanual mirror movements**

Perhaps the most relevant surrogate model is the phenomenon of bimanual associated movements of the upper limbs,<sup>62</sup> which has several features in common with mirror writing (table 3). Furthermore, at least one patient simultaneously acquired mirror writing together with bimanual mirror movements.<sup>50</sup>

By analogy with mirror movements in general, and congenital mirror movements in particular, mirror writing with the left hand may implicate various motor processes which may be pertinent to mirror movements. Recently summarised by Farmer and Carr,<sup>63</sup> these include:

*Transcallosal pathways*

It seems likely that motor commands and responses are inherently bilateral, but in certain circumstances the normal suppression of ipsilateral motor pathways from the contralateral cortex via transcallosal pathways may be impaired. This has been suggested as a mechanism for the mirror movements that are seen in the immaturity of childhood and in pathological conditions such as Kallmann’s syndrome. Mirror writing has been associated with frontal damage that involved the corpus callosum,<sup>50</sup> and some other acquired cases also may have involved the corpus callosum, the role of which is discussed later.

*Ipsilateral pathways*

Ipsilateral corticospinal pathways are thought to be implicated in many conditions associated with mirror movements, including craniocervical junction abnormalities such as Klippel–Feil syndrome, Kallmann’s syndrome and congenital

mirror movements. These ipsilateral pathways are likely to be implicated in motor recovery after stroke,<sup>64 65</sup> and could “drive” the left hand when mirror writing.

*Aberrant motor control at the cortical level*

In contrast with normal people, bilateral activation of motor cortices after unilateral hand movements is another possible mechanism subserving mirror movements, such as those seen in congenital cases, Kallmann’s syndrome and other examples of mirror movements. Similarly, bilateral activation of motor cortices could be enlisted in mirror writing.

Other motor pathways that may subserve mirror writing, particularly in those in whom it occurs in the setting of diffuse brain disease, immaturity or ageing, include thalamocortical<sup>28 66</sup> and other extrapyramidal pathways. The latter pathways have been implicated in mirror dystonia<sup>67</sup> and mirror movements in Parkinson’s disease.<sup>68</sup>

**The role of the corpus callosum?**

As the initiation of movements is generally thought to be generated bilaterally,<sup>69</sup> those movements of the unwanted side will normally be suppressed,<sup>70</sup> and one relevant mechanism may comprise transcallosal deactivation of contralateral crossed pathways.<sup>71 72</sup> Apart from mirror writing associated with callosal damage due to stroke and possibly head injury, it is also possible that left-handed mirror writing normally disappears during childhood maturation, as a result of inhibition associated with callosal myelination which takes place at around the same time. Conversely, age-related declining callosal inhibition<sup>73</sup> might account for the reappearance of mirror writing with dementing processes and ageing.

The controversial issues surrounding dyslexia have been discussed earlier. In dyslexia, stuttering, in addition to left handedness and mirror writing, may occur,<sup>33</sup> and, among a variety of different possible underlying mechanisms, dysfunction of the corpus callosum has been postulated.<sup>74</sup> Thus, Webster<sup>74</sup> found that when performing bimanual letter writing, both right-handed and left-handed people who stuttered made more mirror reversals with the non-dominant hand compared with fluent speakers, and their writing was of poorer quality and slower. He suggested that there was an impairment of “callosal gating” between the two hemispheres, in particular the two supplementary motor areas (see below).

Arguing against the involvement of the corpus callosum is the fact that congenital abnormalities of the corpus callosum, and callosotomy in either left handers<sup>75</sup> or right handers,<sup>76</sup> are not associated with mirror writing.

**Table 3** Mirror writing compared with bimanual mirror movements

| Mirror writing   | Bimanual mirror movements  |
|--|--|
| Nearly always affects left hand  | Involves both hands; may be asymmetric   |
| Voluntary  | Voluntary or (particularly in congenital mirror movements) involuntary   |
| Only affects writing   | Affects non-specific hand movements  |
| More common in left handers, and those whose languages are written leftwards   | No relationship to handedness or direction of language   |
| Suppressible   | Completely or partially insuppressible   |
| Often present in childhood, usually disappearing before teenage years  | Often present in childhood, usually disappearing before teenage years  |
| Sometimes seen in normal adults in various specific circumstances  | Occasionally seen in normal adults—for example, on effort; with bimanual activities  |
| Present in pathological processes: focal (usually left hemisphere) disease, especially stroke; diffuse cerebral disease; ?ageing | Present in pathological processes: usually congenital (corpus callosal disorders, Klippel–Feil and other craniocervical junction abnormalities); occasionally after stroke; in Parkinson’s disease |
| Inheritance: rarely familial   | Inheritance: rarely familial   |

### The mirrored form of writing

To most observers, mirror writing seems not only curious but also difficult to read. More than a century ago, however, Vogt,<sup>77</sup> and soon others,<sup>78</sup> viewed it as the natural script of the left hander, and this view remains compelling. The evidence that mirror writing is the natural script of the left hander arises from everyday observations that abductive movements are generally more natural, and also more accurate,<sup>79</sup> than adductive movements. Writing with a pen held in the left hand will therefore be more readily undertaken leftwards; the script, too, would then be reversed compared with the conventional rightward-directed script—that is, mirrored.

Thus, mirror writing with the left hand is not a bizarre form of writing at all, but predictable, and presumably a form of writing that is normally suppressed or superseded by conventional writing in order to be read.

### Factors that suppress mirror writing

Factors which tend to suppress or conflict with mirror writing can be of various types.

#### Motor influences

Sometimes, an apparent conflict between movements subserving mirrored and conventional writing can be demonstrated. Examples have included a patient's difficulty with left-handed writing in the *conventional* form after a stroke<sup>80</sup>; a patient's mirror-writing left hand "leading" the right hand, dominant but impaired as a result of hemiplegia, resulting in normal script<sup>27</sup>; and a patient's use of their half-paralysed right hand to form correct rightwards writing with the mirror-writing left hand.<sup>81</sup>

#### Visual influences

Normally, mirroring would be corrected by the conventional appearance of writing. Children often seem neither to perceive mirror differences in letters<sup>82</sup> nor to notice their mirror writing. Curiously, adults who mirror write with their left hand after a stroke, and others too, often do not notice their mirror writing. Presumably, correcting visual influences either do not obtain or are insufficient to override the mirrored form.

#### Motor and visual interactions

In addition to conflicting motor and visual influences on mirrored and conventional writing, there are conflicts between the motor and visual influences themselves. More than a century ago, such an interaction was suggested to be pertinent in adults.<sup>78</sup> In children, there is a tendency for very young, left-handed school children to scan from right to left,<sup>83</sup> and oculomotor control when reading, at least in the early stages, may be a right-hemisphere specialisation.<sup>84</sup> A right-hemisphere bias to the control of eye movements when reading would favour leftwards reading and hence writing, and consequent conflict with the rightwards direction of writing (and reading) of Western languages—leading to the view that confusions are especially likely to occur when eye movements are controlled by one hemisphere and hand movements by the other.<sup>85</sup>

#### Cultural factors

Linked to these visual influences is the role of written language. The evidence that those whose languages are written leftwards have an increased tendency to mirror write has been discussed above, but the implication from this observation is that learning and practice of leftwards writing entrains, and is entrained by, the eye and the hand in a leftwards direction, and thus potentially the mirrored form of writing when the left hand is used.

### Spatial and orientational factors

Left-handed mirror writing occurs when healthy people write in unusual spatial situations, and also pathologically in the presence of acquired directional and spatial confusion. In these circumstances, presumably normal spatial and orientating correcting influences are thwarted and mirror writing emerges. However, proposed interactions between motor control of the contralateral hand with spatial and attentional systems subserving action in the contralateral space<sup>86</sup> may be more simply explained by the mechanical factors involved when writing with the left hand in either hemisphere.

### Mirrored writing: a non-specific mirrored motor phenomenon

Supporting the view that mirroring is itself not abnormal is that mirroring with the left hand is far from specific to writing. For example, mirror writing can occur even when Chinese "illegal" pseudocharacters are written.<sup>58</sup> Furthermore, those who retain normal cerebral function but, after injury, have to undertake left-handed tasks, such as using a screwdriver or turning a door knob, sometimes do so in mirror fashion,<sup>23</sup> and people who have had limbs amputated occasionally experience phantom mirror movements of their missing limbs.<sup>87</sup> These examples show that mirroring seems to be an unselective feature of dextrous left-handed movements—that is, mirror writing may simply represent a specific example of a mirror movement, both perhaps enlisting the same motor processes that were discussed earlier.

### Mirroring processes at the cortical level?

If abductive, leftwards hand movements generated through various motor pathways are characteristic of writing movements with the left hand, are there also motor and visual processes in the hemispheres that are specifically concerned with mirroring? When discussing mirror writing, the term "engram" has often been used; this term, meaning those neural changes that constitute stored memories, is perhaps now outdated, but will be retained here as the traditional shorthand for those ill-understood memory processes thought to be applicable to mirror writing.

#### Mirrored motor engrams

Brain<sup>88</sup> envisaged

The fact that learning to write includes an unconscious education in mirror-writing, especially with the left hand, implies the establishment, probably in the right hemisphere, of graphic motor-schemas which are the mirror-images of those which underlie normal writing in the left hemisphere.

This ability to "educate" the opposite hand in a mirror task had been previously demonstrated—for example, in a maze-tracing task<sup>89</sup>—but the evidence for *mirror* image motor engrams for writing remains inconclusive. If, however, such engrams exist, the mirroring would usually have to be suppressed, and it has been suggested that the right supplementary motor area may be responsible for this normal suppression.<sup>50</sup> This suggestion recalls the involvement of the supplementary motor areas and the interconnecting callosal pathways, envisaged in the context of stuttering discussed earlier.<sup>74</sup>

#### Mirrored visual engrams

Orton<sup>90</sup> invoked the concept of visual engrams to explain why many mirror writers were left-handed children with dyslexia and a variety of other perceptual difficulties. There had been earlier speculation that there might be mirrored images in the brain, "like the negative of a photograph",<sup>25</sup> and Orton and

later others postulated that visual engrams for writing are not only stored in both hemispheres but are also in mirror form.<sup>12 58 90</sup>

Evidence in animals<sup>91</sup> and humans<sup>92</sup> suggests that visual images are transferred across the corpus callosum in mirror image form. More recently, the concept of “mirror generalisation” as an intrinsic property of the primate visual system has been proposed, and there is evidence for specific interhemispheric point-to-point pathways that might be relevant to activation of mirrored forms.<sup>93</sup> However, Corballis and Beale<sup>94</sup> tersely comment “Orton’s theory is wrong”. They rightly point out that by implying that the dominant hemisphere would record events with the correct orientation and the non-dominant hemisphere would record them in reversed orientation, the conclusion follows that whenever the dominant hemisphere was inactivated, mirror phenomena would necessarily emerge—and this clearly does not occur.

Thus, although visual factors are doubtless of considerable importance, particularly when children learn to read, and in the context of direction of written language, mirrored visual engrams have not been established as being inherent in mirror writing.

### Mirrored and non-mirrored forms of writing

When writing with the unaccustomed left hand, right-handers’ writing is often poorer than their usual writing. By comparison, when innate left handers or ambidextrous people who write with their right hand switch to left-handed writing, their writing is often immediately well formed and easily elicited. Furthermore, their conventional and mirrored scripts are often,<sup>19 24 26 78</sup> but not always,<sup>95</sup> remarkably similar except for the mirroring. This suggests that left handers may have intrinsically different patterns of cerebral organisation and facility for using different motor pathways, at least with respect to writing.

### The role of the right hemisphere?

Even allowing for the contribution of ipsilateral pathways, left-handed writing is likely to be predominantly mediated by motor processes subserved by the contralateral right hemisphere. Additional supporting evidence comes from those people discussed earlier who have an enhanced facility for left-handed mirror writing—innate left handers and those whose languages are written leftwards.

Thus, recent data from functional imaging studies show that, in parallel with their greater bilateral or right-hemisphere language activation compared with right handers,<sup>96</sup> not only do left handers show the expected right hemisphere activation when writing with their left hand, but also “converted” left handers when writing with their right hand show unusual symmetrical functional activation.<sup>97</sup>

In those whose languages are written leftwards, the possible influence of the right hemisphere in control of leftward-directed eye movements has been referred to earlier. Importantly, however, the languages involved are both phonetic (Hebrew) and ideographic (Japanese and Chinese),<sup>98</sup> indicating that it is the leftwards direction in which they are written, and hence the link with right-hemispheric control of movement, rather than the structural or visuospatial aspects of the languages, which is important.

### Leonardo da Vinci: his mirror writing and his right hemisphere

Intriguingly, aside from interest in arguably the world’s most famous polymath, Leonardo da Vinci’s writing provides an unusual and unlikely source of information on mirror writing, and probably represents the only known instance of truly habitual mirror writing.<sup>99 100</sup> An example is shown in fig 3. From



**Figure 3** Leonardo da Vinci: examples of mirror writing, mirror numbers and conventional numbers. *Arundel MS 263, f 280, verso*. Reproduced with permission from the British Library.

the background evidence listed in table 4, we can conclude that, as predicted, the innate left hander, unrestrained by external factors, indeed writes in mirror fashion.

Furthermore, it may be conjectured that after his stroke, Leonardo’s preserved mirror writing ability, documented by the visiting Cardinal’s Secretary de’ Beatis, indeed resided in Leonardo’s right hemisphere. Whether this conclusion can be extended to other mirror writers is obviously unknown.

## CONCLUSIONS

Mirror writing is nearly always undertaken with the left hand, and occurs in healthy people and after disease whenever the left hand is called into action—just as Lentilius noted 300 years ago.<sup>1</sup> But mirror writing remains remarkably little explored, and even epidemiological information about its occurrence in the

**Table 4** Leonardo da Vinci’s mirror writing: the background

- |   |
|---|
| His left handedness: the evidence                           |
| ● contemporary written accounts                             |
| ● direction of shading on certain pictures                  |
| ● examples of right-justified margins of text               |
| His writing: its nature                                     |
| ● thousands of pages of writing extant                      |
| ● nearly, but not all, in mirror script                     |
| ● numerals variably mirrored                                |
| His left-handed mirror writing: its characteristics         |
| ● dated from age 21 years or earlier, thus probably innate  |
| ● written for himself and not for others                    |
| ● suppression by cultural and educational influences absent |
| His probable stroke: the witnessed features                 |
| ● occurrence before the age of 65 years                     |
| ● paralysis of the right arm                                |
| ● unimpaired speech   |
| ● unimpaired left-handed painting and mirror writing        |

normal population remains sparse. The potential value of such investigations is exemplified by surely the most extraordinary, albeit incidental, observations on mirror writing that were recorded by Conklin<sup>101</sup> when studying the Mindoro tribes in the Philippines. He reported that the direction of their writing was in columns directed away from the body, and was bottom to top and left to right when written with the right hand, and in columns from right to left and in inverted mirror style when written by left handers, remarkably showing the links between handedness, direction of writing and mirror writing.

The time now seems opportune for further studies of mirror writing. These might range from detailed population studies, assessing the prevalence, patterns of inheritance and features of mirror writing in the healthy population and in various disease states, to a variety of experimental investigations. Such investigations might include functional imaging studies of mirror and conventional writing in left handers and right handers, in normal people and in those with different pathologies, and in those whose languages are written rightwards and leftwards. But mirror writing itself could also be used as a tool to provide insights into organisation and reorganisation of the nervous system with respect to motor processes, writing and handedness, exploiting Allen's<sup>26</sup> prescient observations a hundred years ago:

mirror writing is often a symptom of nerve disease; but the disease need not be the cause of the existence of the faculty, but only the cause of its discovery.

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