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Suzanne Balfour
Sheena Borthwick
Roberto Cubelli
Sergio Della Sala

Mirror writing and reversing single letters in stroke patients and normal elderly

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R. Cubelli (✉)
Dipartimento di Scienze della Cognizione e della Formazione
University of Trento
Cozso Bettini, 31
38068 Rovereto (TN), Italy
E-Mail: roberto.cubelli@unitn.it

S. Balfour · S. Della Sala
Human Cognitive Neuroscience
Psychology
University of Edinburgh
7 George Square
Edinburgh EH8 9JZ, UK
E-Mail: sergio@ed.ac.uk

S. Borthwick
Speech and Language Therapy
Western General Hospital
Edinburgh, UK

Abstract Mirror writing (MW) refers to the production of individual letters or whole word strings in reversed direction. When held to a mirror, these letters or words can be read normally. We observed MW in a considerable number of stroke patients. Of the 86 patients screened 15 (17.5%) showed at least one instance of mirror writing in any of the tasks. Both right (14% of 36 patients) and left (20% of 50 patients) hemisphere damaged patients produced reversed letters only when writing with their left hand, respectively the contralesional and ipsilesional hand. The dissociated performance between the two hands in brain damaged patients is relevant to the interpretation of MW because, unlike all other peripheral dysgraphias, MW affects the non-dominant hand only. Importantly, healthy elderly also showed MW solely when writing with their left hand (6.9% of 86 participants). MW in controls was less frequent but qualitatively similar to that observed in brain damaged patients. This finding is consistent with the motor interpretation of MW that assumes an inability to transform the stored letter forming programmes for left hand writing. However, several cases have been reported in the literature of a more pervasive form of MW whereby patients mirror reverse entire words or sentences. This pattern has been observed in children learning to write but it has never been observed in healthy adult volunteers. We propose that the diagnosis of MW should be limited to the reversal of whole words, multi-digit numbers and full sentences, which reveal a disorder in coding the correct direction of writing rather than an inability to accomplish the correct spatial orientation of single letters.

Key words mirror writing · stroke · left hand writing · apraxia

Introduction

Mirror writing (MW) defines the production of individual letters or whole word strings in reversed direction [12]. When held to a mirror, these letters or words can be read normally. Anecdotes of deliberate mirror writing are reported in biographies of famous people, including Lewis Carroll and Leonardo da Vinci [20]. MW can be unintentional in children learning to write [4] and has also been reported following acquired brain disorders [23]. The reported

frequency of MW in an unselected series of hemiplegic patients varies between 2.4% [8] to 13% [22]. A higher frequency (24%) is reported when only patients with left hemisphere lesions were considered [23], however, none of the available studies on the frequency of mirror writing specifies the selection criteria of the sample [8, 17, 21, 22].

The asymmetry due to the site of lesion is reflected in group studies whereby MW associates with right hemiplegia. Fränkel (1908, quoted by Critchley, p.10) [4] observed mirror writing in 21/58 (36%) right hemiplegics but only in 3/21 left hemiplegics (14%), while Paradowski and Ginzburg [15] reported one case of mirror writing out of 22 right hemiplegics (4.5%), yet observed no instances of mirror writing among a group of 19 left hemiplegics. The association of MW with left-sided lesion and left handed writing is highlighted by the analysis of single cases. The main features of the 31 mirror writers reported in the literature (18 detailed in Della Sala & Cubelli, Table 2 [5] and 13 reported by Oblu et al. [14]) are summarized in Figure 1. Most cases had a left hemisphere lesion encroaching upon the parietal lobe. Thirty of the patients reverse writing with their non-dominant left hand; all those who were not paretic wrote normally with their right hand. The only exception was a patient who mirror wrote with her right hand in Hebrew but wrote normally in Polish and German [21]. The role of left-hand writing in MW has been further stressed by Kuzuya et al. [10] who in an unselected series of 112 brain-damaged Japanese patients, including demented people, observed MW in 75 participants (67%) who were asked to write with their left hand, but never when they were asked to write with their right hand.

The dissociated performance between the two hands in brain damaged patients is a key feature of MW. However, previous studies investigating the prevalence of MW following brain damage have failed to test the left-handed writing skills of non-paretic patients. This omission may have resulted in an underestimation of the prevalence of MW. Moreover, two cases have been reported [2, 22] of left-hand MW following right hemisphere lesion. Yet, the performance of right-hemisphere damaged patients has been ignored in group studies.

In summary, MW could be more widespread than usually thought, being undetected because writing is rarely assessed with the non-preferred, left hand. The aim of this study was to assess the frequency of MW in an unselected series of left and right-hemisphere damaged stroke patients when writing with their left and whenever possible with their right hand.

Furthermore, MW can sometimes emerge in healthy people when they are asked to write with their non-preferred hand [24]; however, none of the prevalence

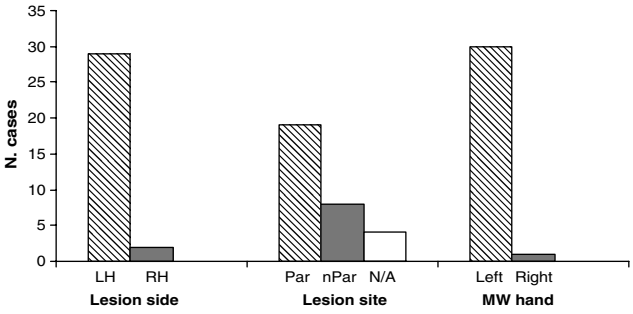

Fig. 1 Number of detailed MW cases from the literature divided according to side of lesion (Left Hemisphere vs. Right Hemisphere), site of lesion (encroaching upon the Parietal lobe vs. sparing the Parietal lobe) and mirror writing hand (left vs. right). LH = Left Hemisphere, RH = Right Hemisphere; Par = Parietal Lobe lesion; nPar = Non Parietal Involvement; N/A = not available

studies on MW following brain damage included healthy matched controls. This omission is relevant insofar as MW has been reported as a frequent occurrence in healthy elderly, varying from 8.1% [23] to 31.4% [9] up to 40% [10]. In the current study the presence of MW was also assessed in a group of controls age-matched with the patients to check the specific role of brain damage in eliciting MW.

Participants and Methods

A consecutive series of 202 stroke patients admitted to the ward for acute stroke at the Western General Hospital in Edinburgh, were considered. Sixty-three were excluded from the study: four because they had a clear bilateral lesion, three because the lesion could not be detected on CT, two because they refused testing, twelve refused to write with their non-preferred hand, twenty-three due to the severity of their medical conditions, nine had visual deficits incompatible with neuropsychological testing, ten were discharged before further assessment could be carried out. A further 53 patients (37 RHD and 16 LHD) were not assessed because of their severe contra-lesional paresis. The left and right hand writing skills of the remaining 86 patients were tested within a month (mean: six days, range: 1–33 days) from their stroke. The average age of patients screened was 73 years (range: 44–92), their mean years of education were 11.0 years (range: 3–18), 41 were male and 45 were female. Eighty-two patients were using their right hand to write while 4 used their left, 4 of the 82 patients using their right hand reported being forced to use their right hand to write with at school. Thirty-six patients had a lesion affecting their right cerebral hemisphere (RHD/pts) while fifty had a left-sided lesion (LHD/pts).

The same test battery was given to 86 healthy elderly people who volunteered to take part in the experiment. They were closely matched in age to the stroke participants with an average age of 74 (range 53–92) and a mean number of years of formal education of 11.9 (range: 9–18). 81 were right handed and 5 were left-handed, 31 were male and 55 were female. They were recruited from friends and relatives of university students, were all living at home without the need of any supervision, and were selected to be age-matched with the patients. The testing protocol was approved by the appropriate ethics committee and the assessment was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All participants gave their informed consent prior to their inclusion in the study.

Table 1 Frequency of mirror writers among right and left hemisphere damaged patients writing with their right or left hand.

	Presence of mirror writing			
	Absent	Right hand only	Left hand only	Both hands
RHD/pts (n. 36)	31	0	5 (14%)	0
LHD/pts (n. 50)	40	0	9 (18%)	1 (2%)
Controls (n. 86)	80	0	6 (6.9%)	0

Each participant was tested individually with a short battery of tasks composed of four different tasks: signature, copy, writing to dictation, and writing a description of a scene depicting a group camping in the countryside. Four kinds of stimuli were used in copying tasks (capital letters: B,F,S; numbers: 3,4,9; upper case words: KEEN, GRIEF; lower case cursive words: speed, bicep) all evenly spaced and printed in font Times New Roman, size 72. Three individually presented words were used in the dictation task (apple, pencil, beef), no specific instruction was given to use printing or cursive writing. For the scene description task no time constraint was given, but the participants were encouraged to write a few short sentences. Half of the patients and half of the controls were tested with their right hand first, the other half with their left hand first.

Results

Of the 86 patients screened 15 (17.5%) showed at least one instance of mirror writing in any of the tasks (see Table 1). They were all right-handed, their mean years of formal education (10.7, range 9–15) overlapped with that of the whole group.

All five RHD/pts wrote normally with their right hand, four of them show apraxic difficulties when writing with their left hand producing badly formed letters and reversing number "3" (all four) and capital letter "S" (one instance) in the copying task only. The fifth patient reversed his entire signature, but did not produce any other mirror reversed responses. The lesions of these five RHD/pts were subcortical in two cases, affecting the territories of the middle cerebral artery in the other two, and of the posterior cerebral artery in the fifth. One RHD patient showed clinical signs of left-sided visuo-spatial perceptual neglect.

One of the LHD/pts showed instances of reversal writing in the copying task both with his right hand (lower case "d") and his left (capital "S", and lower case "d"). The other nine patients did not mirror reverse letters or words with their right hand; four wrote normally, while five presented with spelling or writing difficulties, failing to produce the correct sequence of letters in words including omissions, additions and substitutions (four patients) or to form the correct shape of individual letters hampering their identification, i.e. apraxic dysgraphia (1 patient). All showed mirror writing with their left hand, albeit eight in the context of apraxic difficulties. This was coupled in four cases with dysgraphic errors like deletions or substitutions of individual letters. Only one patient presented with pure mirror writing. At odds with the right hand performance, mirror writing was observed in signature (3 patients), dictation (1), and spontaneous writing (3) as well as in copying tasks (all). The lesions of the LHD/pts affected the territory supplied by the medial cerebral artery in six cases, the posterior cerebral artery in one case, the subcortical territory in two cases and the remaining case could not be specified. Eight LHD patients were affected by language deficits.

Moreover, notwithstanding the fewer words generated in spontaneous writing when considering all tests together, LHD/pts produced on average more reversed letters than RHD/pts (2.7 vs. 1.25). The mean number of letter reversal errors committed by the MW patients in each task is detailed in Table 2.

Interestingly, instances of MW were observed also in the elderly controls when writing with their left hand though never when writing with their right hand. None of the volunteers mirror wrote entire words, nor did they mirror reverse letters in their signature or under dictation, probably due to the more automatic nature of these tasks. However, 6 normal elderly (6.9%) mirror reversed individual letters (mean: 1.83, range: 1–3). Their mean years of formal education (12.2, range 9–18) overlapped with that of the whole group. Two controls reversed letters in both copying and spontaneous writing tasks, 2 showed reversals when copying only and 2 showed reversals in the spontaneous condition alone. Left hand mirror writing was less frequent in normal controls than in brain damaged patients ($\chi^2 = 4.394$; $p < .05$), but it was qualitatively similar, with the letter S as the most involved in errors. The mean number of letter reversal errors committed by the MW controls in each task is reported in Table 2.

Table 2 Mean number of individual letters reversed by participants writing with their left hand in the four different tasks. Average number of letters and their range for signature and spontaneous writing are given in parentheses for each of the group tested.

	Writing tasks			
MW participants	Signature	Copy (25 letters)	Dictation (15 letters)	Spontaneous writing
RHD/pts (n. 4)*	0* (8.6; 6–13)	1.25	0	0 (21.6; 14–22)
LHD/pts (n. 10)	0.3 (9; 5–14)	1.70	0.1	0.6 (21.7; 4–48)
Controls (n. 6)	0 (10.6; 6–15)	0.83	0	1.0 (26.3; 16–37)

*The RHD/pt who mirror reversed his whole signature has been excluded from this table

Discussion

Mirror writing (MW) was observed in a considerable number of stroke patients. Both RHD/pts and LHD/pts produced reversed letters only when writing with their left hand, respectively the contralesional and ipsilesional hand. The dissociated performance between the two hands in brain damaged patients is relevant to the interpretation of MW because it is at odds with all other peripheral dysgraphias[1](which in the absence of an associated callosal lesion affect both hands) [6], MW affects the non-dominant hand only. Importantly, healthy elderly also showed MW solely when writing with their left hand. The frequency of MW of individual letters in the current sample of elderly controls is remarkably similar to that reported by Wang et al. [24] who found seven mirror writers (producing an average of 1.90% reversed Chinese ideograms or numbers) in a sample of 86 healthy participants aged over 70 (8.1%) tested in spontaneous writing only.

Relevant to the interpretation of MW is the similarity of left hand reversal errors between patients and controls. On the whole, copying tasks proved the most sensitive in eliciting mirror writing both in the patient groups and in the healthy controls. All participants who mirror wrote produced reversed individual letters but never systematically mirror reversed whole words (with the exception of the RHD/pt who only mirror reversed his signature). Taken together, the present data suggest that MW of individual letters within normally written words should be traced back to the unskilful use of the left hand in right-handed people that is further worsened following brain damage. Indeed, reversal of individual letters within otherwise normal writing has been observed in people forced to use their left hand because of severe peripheral damage to their preferred right hand [19]. For example, due to amputation (as in the historical case reported by Rosinus Lentilius, 1698, quoted by Critchley [4]), writer's cramp (Marinesco, as reported by Laveran [11] and cited by Russell [16]) or in right-handers with extra-pyramidal disorders instructed to write with their left hand [22]. In all these cases, whether stroke patients, healthy elderly asked to write with their left hand, right-hand amputees or people unable to write with their dominant hand, the habitual motor programme to form individual letter shapes has to be transformed into a new programme for the use of the left hand. This transformation requires considerable cognitive resources, and would be susceptible to attentional lapses (Wernicke, 1906[2]) [25]. Consider for example, writing a reversible letter like "F", with the right hand one has to produce a vertical line and two horizontal segments away from the body. To produce a correct "F" with the left hand calls for an attention-dependent "transforming mechanism" that translates the programme into one vertical line and two horizontal segments *towards* the body. A slip of this transformation mechanism would result in the default use of the "F" programme producing a reversed "F" with the left hand. This interpretation coincides with the "motor hypothesis" which has been put forward to account for MW [2, 7] and could account for mirror reversal of individual letters within a word correctly written from left to right.

However, several MW cases of brain damaged patients reported in detail in the literature present with more pervasive MW, which encompasses reversal of whole words, multi-digit numbers and full sentences. For instance the Italian patient MF following a left hemisphere stroke presented with overt MW when writing with her left hand. This occurred both in spontaneous writing and in direct copying of words, sentences and multi-digit numbers [5]. Moreover, when presented with several sets of alphabetic tiles, she composed words from right to left in mirror reversal fashion when using her left hand, misspelling single nouns (e.g. SEGA [saw] became AGEZ; MAIALE [pig] became EENAIAM). Nineteen cases similar to MF could be gleaned from the literature from1900 to date (see summary in Della Sala & Cubelli, Table 2 [5]). The overwhelming reversal writing behaviour observed in these cases is clearly not confined to the scarce mis-oriented letters reported in the present study and observed in non brain-damaged people writing with their left hand. The motor hypothesis, which interprets MW as resulting from the default use of predetermined motor programme with the non-dominant hand, could not account for MF's reversal writing with tiles. Furthermore, the motor hypothesis

[1]Cognitive models of spelling and writing typically distinguish between "central" and "peripheral" processes [18]. Central processes generate the abstract orthographic representation of the individual words, which specify the identity and the order of the constituent letters. These representations are either retrieved from the orthographic lexicon or assembled by means of the phoneme-to-grapheme conversion rules. Peripheral processes translate the abstract orthographic representations of the words into sequences of names (in oral spelling) or forms of letters (in handwriting, typing, and letter blocks assembling).

[2]Wernicke (1906) [25] stated: "If one concedes that the optic images of alphanumeric symbols stored in the right hemisphere inform the motor centre of the left arm in the same way as the graphic representations stored in the left hemisphere direct the motor centre of the right arm, it derives that the normal writing pattern with the left arm should be in mirror fashion...Writing movements of the left arm could be informed by representations of alphanumeric symbols stored in the left hemisphere...However, this type of rightward writing with the left hand would require more mental effort and exertion of considerably more will power that mirror writing, which could capitalize on an available, pre-formed route".

would run into difficulties in explaining the dissociating patterns of MW observed in polyglots depending on the hand used and the language. The patient reported by Streifler and Hofman [21] was a polyglot who mirror wrote with her right hand in Hebrew yet continued to write normally in Polish and German, hence writing in all languages from left to right. Marinesco (quoted by Russell [16]) also reported on a man who mirror wrote in Hebrew but not in French with his right hand, yet he produced the opposite pattern (MW in French but not in Hebrew) when writing with his left hand. These polyglot cases demonstrate that the direction of writing is the critical feature of MW rather than the difficulty in executing motor programmes for letter formation. In sum, although the motor hypothesis accounts for the left hand reversal writing of individual letters, it cannot account for the full-blown MW sometime observed after brain damage.

Finally, the motor hypothesis also fails to account for the hemispatial effect in MW reported by Buxbaum et al. [1]. When asked to write with their left hand, two MW patients produced significantly more reversal errors when starting in the right rather than in the left hemispace. A sheer difficulty of re-programming movements for individual letters within normally oriented words should be independent from the side of space upon which one enacts. The assumption is that an abstract representation of direction is inherent with the action to be learned. A lesion to such representation, due to stroke or brain injury, would leave the arm movements at the mercy of its natural abduction tendency, particularly evident in writing – *abductionschrift* [4, 13, 24], hence bringing forth left hand MW in Western languages and right hand MW in Semitic.

Pre-school children who are learning to write also show frequent instances of single letter reversal or full MW, but with their dominant hand [3, 5]. These reversal errors in children are transitory and last as long as they need to acquire the abstract representation specifying the orientation of individual letters or numbers and the direction of script. A brain lesion could impair the learned directional representation resulting in true MW; however the scant single letter reversal could result from a faulty conversion of the letter forming programme for left hand execution, possibly caused by slips of attention not by a deficit in direction representation.

In conclusion, the behaviour of mirror reversing individual letters which occurs when adult people attempt to write with their non-dominant hand should be kept separate from the full-blown manifestations of reversal writing associated with brain damage whereby the location of the starting point and the direction of writing are impaired. The diagnosis of MW as a peripheral hand-writing disorder should be limited to this latter case.

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