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# Dynamics of mirror writing compared to conventional writing in typical preliterate children

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**Abstract** In left-to-right writing cultures, spontaneous mirror writing of letters and digits in preliterate children appears more frequently on left-than right-facing characters. A compelling theory drawn on neuropsychological evidence of mirror generalization suggests that children resort to a right-orienting/writing rule when learning to write. The aim of the present study was to conceptually replicate and specify recent findings (Fischer, 2017a) on the predominant contribution of writing directionality to mirror writing in preliterate children. A training study was designed to compare on-line production of conventional versus mirror writing of 4-to-5 year-old French children ($n$=30). Over a 4-week period, children were taught to write from memory words and digits. During a subsequent writing-from-memory task, a spatial constraint (Cornell, 1985) was imposed to elicit paired conventional and mirror writing of the words/digits. Spatial and kinematic data were recorded through the use of a digital pen. The results indicate a main contribution of writing directionality to letter and digit reversals. Furthermore, kinematic equivalence between conventional and mirror writing supports the neurological mirror generalization process in children. Overall, these results constitute a further illustration that the manifestation of mirror writing in typically developing children is culture-bound.

**Keywords** Mirror writing · Letter reversal · Digit reversal · Writing directionality · Kinematics

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## Introduction

Mirror writing, which involves letter and digit reversals, is a transitory phenomenon in young children's spontaneous writing. First attempts to explain this phenomenon were mainly based on intrinsic factors such as left-handedness, spatial impairment or learning disabilities. In addition, several theories have relied on pathological cases to propose a unitary account of mirror writing that highlights either perceptual or motor processes (Della Sala & Cubelli, 2007; Heilman, Howell, Valenstein, & Rothi, 1980; Orton, 1925). However, a growing body of studies in typically developing children have ruled out the previous assumptions. For instance, recent empirical studies have shown that letter reversals equally affected right and left-handed children (Cubelli & Della Sala, 2009; Della Sala & Cubelli, 2007; Fischer & Koch, 2016a). Another major finding is that mirror writing is frequent among 3-to-7 year-old typically developed children (Fischer, 2011) and would not be specifically associated with school difficulties or further reading impairments (Johansson, 2005; Fischer & Tazouti, 2012). The transitional nature of letter reversals along typical literacy acquisition is supported by neuropsychological (Cohen et al., 2000, 2003) and behavioural evidence of an unlearning (Pegado, Nakamura, Cohen, & Dehaene, 2011) or an inhibitory (Ahr, Houdé, & Borst, 2016) process of mirror generalization.

In early literacy acquisition, letter and digit processing activates the same brain areas as those involved in the recognition of objects and faces. At this point, children know the graphic components of the shape of letters while their horizontal orientation remains unavailable in memory. Indeed, lateral mirror images are processed as similar due to an inherited property of the visual system (Corballis & Beale, 1976). Mirror generalization is an adaptive mode of visual processing for most objects in the physical world. However, it makes young children at risk for confusions and reversals of letters, especially for pairs of letters whose shapes are identical except for orientation (e.g., b and d). Along literacy instruction, letter-specific processing would be achieved through neuronal recycling of cortical structures, especially in the so-called 'visual word form area' (Cohen & Dehaene, 2004; Dehaene et al., 2010). In expert readers, neurons in this area are tuned to discriminate lateral mirror images for words and letters (Dehaene et al., 2010; Pegado et al., 2011). Thus, mirror writing disappears along literacy instruction as neuronal recycling overcomes mirror generalization for letters and digits.

While neuropsychological hypotheses provide a convincing explanation of the origin of mirror writing, they cannot account for the nature of character reversals. Indeed, letter reversals were found to be selective among characters' shapes. The shapes of Latin letters and Arabic digits are formed with a limited number of graphic units predominantly arranged according to a stem-appendage horizontal structure. Thus, letters and digits can be categorized as either left-facing, with an appendage to the left of the stem (e.g., "d"), or right-facing, with an appendage to the right of the stem (e.g., "b") (Treiman & Kessler, 2011). As print experience increases, children's spontaneous letter reversals affect predominantly left-facing letters (Treiman & Kessler, 2011). According to Treiman, Gordon, Boada, Peterson, and Pennington (2014) and Treiman and Kessler (2011), children make a statistical assumption that most letters are facing right. Thus, when information about orientation is not available in memory, children rely on this implicit knowledge to process both letters and digits.

Furthermore, Fischer' recent observations (Fischer, 2017a) highlighted the preeminent role of writing direction in mirror writing. Strong cultural and educative constraints set writing directionality at a topokinetic level (i.e., writing direction along lines) and a morphokinetic level (i.e., letter's writing trajectory). By comparing French children's "conventional" rightward writing to an artefactual leftward writing induced by a spatial constraint (Cornell, 1985), Fischer (2017a) found that the nature of letter reversals depends of the topokinetic directionality. In this study, left-facing characters were more frequently mirror-written in the conventional condition while right-facing characters were more frequently mirror-written in the artifactual condition. This finding supports Fischer and colleagues' proposal (Fischer, 2011, 2013, 2017a; Fischer & Koch, 2016b; Fischer & Tazouti, 2012) that mirror writing in children results from a combination between the orientation of the characters and the directionality of the writing system, which promotes an implicit right-orienting/writing rule in left-to-right writing cultures. As a consequence, this implicit knowledge would lead children to more frequently reverse left-facing characters. This finding also allows the formulation of a universal writing-direction-orienting rule that bias the orientation of the characters towards the topokinetic writing directionality.

It is worth noting that children often learn systematic morphokinetic directionality at school to write individual characters, mainly from left-to-right. For instance, these educative constraints influence the shift from clockwise to counter clockwise preferred morphokinetic directionality (Meulenbroek, Vinter, & Mounoud, 1993). Hence, to what extent morphokinetic directionality or topokinetic directionality specifically contributes to mirror writing has to be clarified.

The present study aimed to compare on-line productions of paired conventional and mirror writing. French preliterate children were trained to write from memory letters and digits that were right-facing, left-facing or symmetrical. The writing outputs (conventional vs. mirror) were manipulated by imposing a spatial constraint (Cornell, 1985) during a writing-from-memory task that elicited either leftward or rightward topokinetic directionality.

This study addressed three main purposes: (1) to empirically test whether the statistical hypothesis or the writing-direction-orienting rule better explains mirror-writing in preliterate children from a left-to-right writing culture; (2) to specify the contribution of writing direction on children's mirror writing by examining morphokinetic directionality, (3) to investigate the involvement of prior knowledge about the orientation of letters and digits through kinematic examinations. According to the statistical learning hypothesis (Treiman et al., 2014; Treiman & Kessler, 2011), children acquire an implicit knowledge about the prevalence of right-facing over left-facing letters. Consequently, left-facing letters would be more frequently mirror written than right-facing letters regardless of the topokinetic directionality primed by the spatial condition. Conversely, the writing-direction-orienting rule (Fischer, 2011, 2013, 2017a; Fischer & Koch, 2016b; Fischer &

Tazouti, 2012) assumes that children write the characters so their orientation correspond to writing direction. Thus mirror writing would be restricted to left-facing characters with rightward topokinetic directionality and to right facing characters with leftward topokinetic directionality. Considering Fischer's recent findings (2017a), we expected the results to corroborate the writing-direction-orienting rule.

Neuroimaging (Cohen et al., 2000, 2003) and behavioural studies (Pegado et al., 2011), raised the assumption that mirror writing is due to mirror generalization in preliterate children. Thus, children are able to recall the proper shape of the characters while they cannot rely on an explicit knowledge of their orientation. Mirror generalization could be reflected in the writing process by kinematic equivalence between conventional and mirror outputs. An alternative, but not mutually exclusive, assumption is raised by the statistical learning hypothesis. According to this view, preliterate children who fail to remember the orientation of the characters can rely on an implicit knowledge of the predominant orientation of letters (i.e., facing right) while writing. Following this assumption, the right-facing outputs could be expected to be written faster and more fluently than left-facing outputs.

## Methods

### Participants

Thirty children (18 boys and 12 girls) aged from 4.25 to 5 years ($M_{age} = 4.63$ years) were recruited from middle sections of three France's public preschools. Their print experience consisted only of informal early literacy and handwriting activities. All children were right handed, as assessed in a laterality task (see below), and spontaneously used their right hand to perform the writing task. None was reported as having any motor, perceptual, language or cognitive impairment, which could affect his/her learning abilities. All standard administrative authorizations and ethical rules for such experiments in schools were respected.

### Laterality task

Several demonstrations hand and eye tasks were used to assess lateral preference. These tasks were taken from a French standardized scale of lateral preference for children (*Test de Latéralité Usuelle*, Auzias, 1975). Hand preference was determined through the hand spontaneously used while children were asked to perform graphic tasks (drawing the sun and writing their name) and everyday tasks (including throwing a ball, erasing, inserting a needle in a bead, using a table-tennis racket, cutting with scissors, shaking a maraca, hitting with a toy hammer and unscrewing a cork). Eye preference was based on the eye spontaneously used to look through a keyhole. A single laterality score was obtained for each child using a conventional Laterality Index (*LI*; McManus, Sik, Cole, & Mellon, 1988), computed from the following equation:

$$LI = [n(R) - n(L)]/[n(R) + n(L)];$$

in which $n(R)$ and $n(L)$ are the number of tasks respectively performed with the right or the left side of the body. This score indicates both the laterality direction (left vs. right) from the median value and degree from the deviation to extremes values. Participants in the study demonstrated a consistent right preference for lateral preference ($M_{LI} = 0.86$; $SD = 0.11$).

## The learning of characters

Children were taught how to write from memory 11 alphanumeric characters: 9 uppercase letters and two digits. Among them, five were right-facing (B, E, N, R, S), four were left-facing (1, 3, J, Z) and two were symmetrical (O, U) as categorized by student participants in a previous study (Fischer, 2017b). Uppercase letters were chosen since they are more familiar and easier to write for 4-to-5 year-old children. The nine letters were included in five words that did not exceed five letters in length so that preschool children were able to memorize their spelling easily: BISES (kisses), NEZ (nose), OURS (bear), JOUE (cheek), ROSE (pink). In order to make the learning more attractive, words and digits were included in a meaningful short story: 'QUAND ON LUI DONNE 3 BISES SUR LE NEZ, PETIT OURS A 1 JOUE ROSE' (When you give him 3 kisses on the nose, Little Bear has 1 pink cheek).

Learning was performed through four group sessions (4–5 children) over a 4-week period and consisted of one half-hour session per week. A preschool teacher helped in the design of the four learning sessions. All of them were intended to train children to complete the targeted writing-from-memory task (see below). They were designed to provide a cross-modal training of words and digits through visual-auditory matching (session 1) and writing tasks (sessions 2 and 4). Moreover, they were composed of several tasks including writing, a memory game and assembling magnetic letters aimed at drawing children's attention on the letters/digits and their shape.

The first session consisted of a visual exposure to uppercase printed words and digits. As the experimenter told the story, pictures depicting words and digits were presented in their appearance on separate cards as a visual support to the story (Fig. 1). Also, words and digits in uppercase letters printed on separate cards were shown. Then, children had to pronounce aloud the story while the experimenter showed the cards. The second session was aimed at manipulating the constitutive letters of words. Each child received successively the eight printed cards and had to assemble magnetic letters on a magnetic board to form the target words. Then, he/she had to copy the words by hand. The third session consisted of a memory game. Children were asked to match a target picture by selecting a printed word/digit

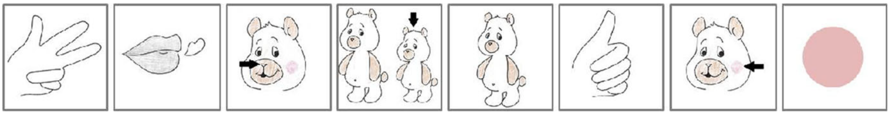

**Fig. 1** The eight picture cards that served as a visual support to the story

among two distractors visually close. For example, the printed word JOUE (cheek) had to be found among the words JOUR (day) and BOUE (mud). In the final session, children were asked to write on a sheet of paper the word as it was dictated by the experimenter and depicted on the picture card.

### Writing task

Children had to write previously learned words and digits under dictation on a sheet of paper bisected by a vertical ink line (Cornell, 1985). Each word/digit had to be written twice. In the normal condition, writing was performed from a point about one centimetre to the right side of the line that elicited rightward topokinetic directionality. In the constraint condition, writing was performed from a point about one centimetre to the left side of the line that elicited leftward topokinetic directionality. The spatial condition imposed by the starting point favoured conventional writing in the normal condition and mirror writing in the constraint condition. The location of the starting point was counterbalanced for each word between children so that half of the participants had to first write a stimulus in the normal condition and then in the constraint condition and conversely for the other half. Also, the location of the starting point was counterbalanced for words within children so that approximately half of the stimuli were first written in the normal condition then in the constraint condition and conversely for the other half. The experimental task was performed by means of a digital pen (Anoto®) on a plain paper printed with digital microdots Anoto-Seldage®. All writing movements and pauses made along the writing course were recorded by the pen through its built-in optic lens using Anoto® technology. All kinematics and spatial data were monitored and analysed using Elian software® which provides both visual and numeric displays of the writing production.

### Coding

Letters and digits were coded individually according to the writing output and the morphokinetic directionality. *Writing output*: Writings of asymmetrical letters and digits were classified into two categories: (1) conventional writing, (2) mirror writing (left–right reversal). *Morphokinetic directionality*: The coding of morphokinetic directionality was based on the writing trajectory for each character. Morphokinetic directionality was coded as either left-to-right or right-to-left for characters that have a stem-appendage structure (i.e., B, E, J, N, R, 1). Morphokinetic directionality was coded as either clockwise or counter clockwise for characters that have a curvy or a concave shape (i.e., S, Z, 3, U and O). To code the morphokinetic directionality of the letters S and Z, we considered the first movement initiated as it is known to be the most relevant feature regarding orientation (Primus, 2004). The coding was based on a visual coloured display provided by Elian Software where different shades of colours along the strokes indicated the movement direction. Velocity and fluency were kinematic parameters recorded for each character. *Velocity*: The velocity (mm/s) was directly extracted in a numerical format from Elian Software. *Fluency*: The fluency measure corresponded to the number of acceleration alternations per centimetre provided by Elian Software on a graph. The lower the score was, the better was the fluency.

## Results

Two series of analysis were conducted on each letter independently. The first analysis focused on the effect of the spatial condition on the writing output (conventional vs. mirror), the morphokinetic directionality (left-to-right or clockwise vs. right-to-left or counter clockwise), the velocity and the fluency. The second analysis examined the association between the writing output and both the morphokinetic directionality and the kinematics.

### Spatial condition

It is worth noting that, in the writing task, some characters were presented more than once (i.e., E, O, R, S, U) as they appeared in several target words. Considering these letters, the variables writing output and morphokinetic directionality were highly polarized between extreme values across both spatial conditions. In other words, all exemplars in a given spatial condition usually follow the same trend. Thus, these two variables have been dichotomized along median value. For instance, the letter E that appears four times in the writing task within each spatial condition was coded as conventionally written once the written production contained less than two "Ǝ". McNemar's paired tests showed an effect of the spatial condition on the writing production ($p_s < .005$), except for the letter Z ($p = .18$). The direction of this effect varied as function of the orientation of the characters: left-facing characters (1, 3, J) were more frequently mirror-written in the normal condition while right-facing characters (B, E, R, N, S) were more frequently mirror-written in the constraint condition (Fig. 2). An illustration of this trend is provided in Fig. 3, showing an actual participant's writing outputs.

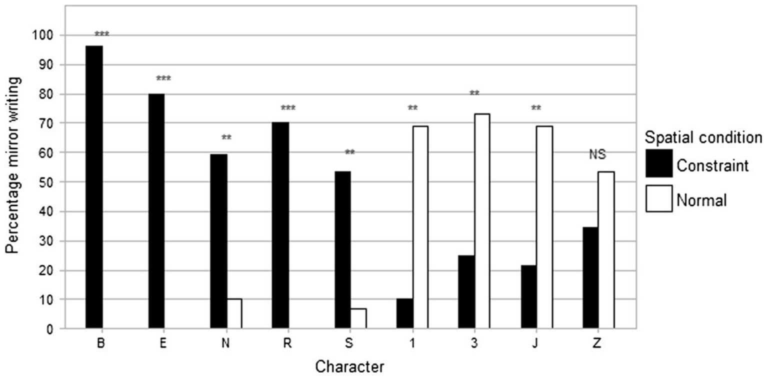


**Fig. 2** Percentages of mirror writing as a function of the spatial condition. *Note* ***$p < .001$; **$p < .01$; $^{NS}p > .05$

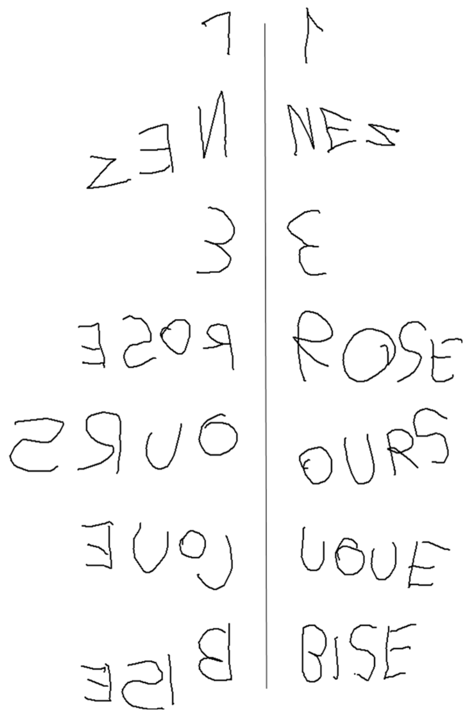

**Fig. 3** The writing outputs recorded for an actual participant as a function of the spatial condition. The left column shows writing outputs in the constraint condition with all left-facing characters conventionally written and all right-facing characters mirror written. The right column shows writing outputs in the normal condition with all left-facing characters mirror written and all right-facing characters correctly written

McNemar's paired tests also showed an effect of the spatial condition on morphokinetic directionality for eight characters (B, E, J, N, R, U, 1 and 3; $p_s < .009$). No effect was found for the remaining three characters (O, S and Z; $p_s > .72$). The characters with a stem-appendage structure (B, E, J, N, R and 1) showed more occurrences of a left-to-right morphokinetic directionality in the normal versus constraint condition. Conversely, the right-to-left morphokinetic directionality was more frequent in the constraint versus normal condition

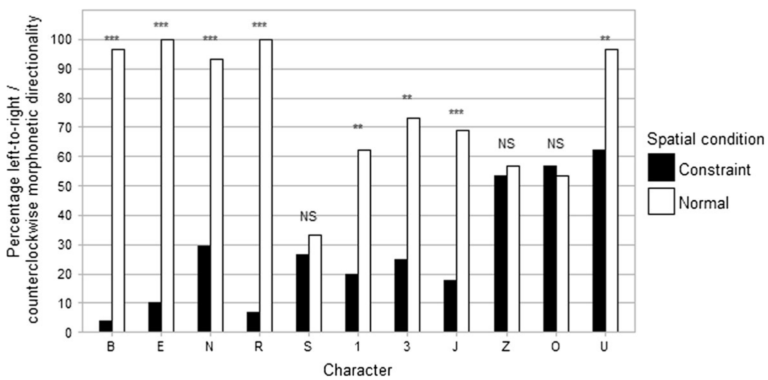


**Fig. 4** Percentages of left-to-right and counterclockwise morphokinetic directionality as a function of the spatial condition. *Note* ***$p < .001$; **$p < .01$; $^{NS}p > .05$

(Fig. 4). The concave letter U was more often performed by using a counter clockwise directionality in the normal condition (vs. constraint) and a clockwise directionality in the constraint condition (vs. normal).

### Writing output

Phi correlations revealed a significant association between the writing output and morphokinetic directionality for all characters ($p_s < .001$) but the S ($p$=.21). It is worth noting that these associations are strong and differed as a function of characters' orientation. 89.17% of the mirror written productions of left-facing characters (1, 3, J) were associated with left-to-right or counterclockwise morphokinetic directionality. Conversely, 84.21% of the mirror written productions of right-facing characters (B, E, N, R, S) were associated with right-to left or clockwise morphokinetic directionality (Table 1).

### Kinematics

Kinematics were analysed regarding the effect of the spatial condition and their association to writing output. Paired t-tests did not show any significant difference between writing conditions (normal vs. constraint) on both the velocity ($p_s > .10$) and the fluency ($p_s > .29$). Furthermore, the writing output did not correlate significantly with the velocity (point biserial: $p_s > .06$) nor with the fluency (point biserial: $p_s > .27$) (respectively, Fig. 5a, b).

## Discussion

The aim of the present study was to investigate the factors on which preliterate children rely when producing the orientation of letters. The participants had to write both right-facing and left-facing characters from memory according to two spatial conditions that primed opposite topokinetic directionality (Cornell, 1985). Conventional and mirror outputs were analysed across the spatial conditions and compared on morphokinetic directionality and kinematics. The moderate sample size ($n$=30)

**Table 1** Mean percentages and association statistics of left-to-right or counterclockwise morphonetic directionality as a function of the writing output

| | Conventional | Mirror | $\phi$ |
|---|---|---|---|
| B | 96.55 | 0.00 | − .96*** |
| E | 69.05 | 0.00 | − .90*** |
| J | 3.23 | 92.31 | .89*** |
| N | 89.19 | 10.53 | − .77*** |
| R | 82.05 | 0.00 | − .78*** |
| S | 76.19 | 55.55 | − .21 |
| Z | 21.87 | 73.07 | .51*** |
| 1 | 8.33 | 91.30 | .82*** |
| 3 | 0.00 | 100.00 | 1*** |

***$p < .001$

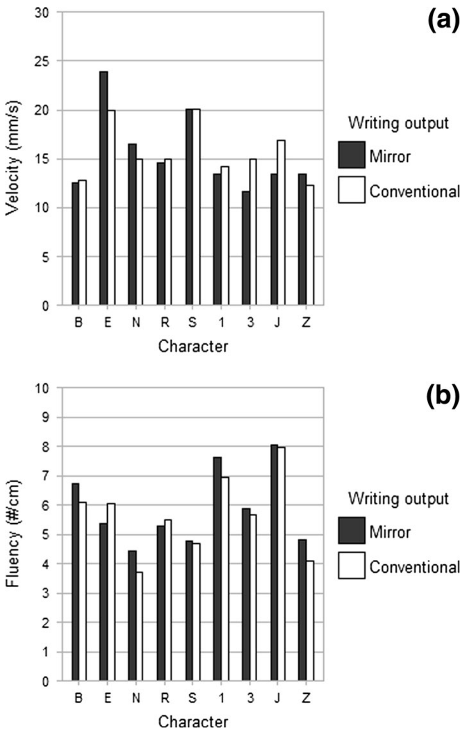


**Fig. 5** Mean velocity (**a**) and fluency (**b**) as a function of the writing output

and the limited material (only seven out of the 26 letters from alphabet and two of the 10 Arabic digits) represent potential limitations of the study.

Spatial conditions resulted in conventional and mirror writings as a function of characters' intrinsic orientation. The normal condition, which primed rightward topokinetic directionality, led to conventional writing for right-facing characters (B, E, N, R, S) and mirror writing for left-facing characters (1, 3, J). This result reflects common observations in spontaneous writings of preliterate children in a left-to-right writing culture: left-facing letters are more frequently mirror-written than right-facing letters (e.g., Treiman & Kessler, 2011). A similar trend was found for digits (Fischer, 2013). Two theoretical theories have been put forward to account for left–right character reversals. According to Treiman et al. (2014) and Treiman and Kessler (2011), children rely on an implicit knowledge about the prevalence of right-facing when orientation is not available in memory. Fischer and colleagues (Fischer, 2011, 2013, 2017a; Fischer & Koch, 2016b; Fischer & Tazouti, 2012) assumed that implicit right-orienting/writing rule is not only promoted by the predominant orientation of letters but mostly by the writing directionality. The constraint condition, which primed leftward topokinetic directionality, is informative regarding this theoretical debate. The statistical learning hypothesis predicts similar results to the normal condition. In other words, left-facing characters would be more frequently mirror written whatever the conditions of production. However, a reversed pattern of results can be predicted following Fischer's proposal (2017a):

right-facing characters would be more frequently mirror written such as characters ‘orientation correspond to writing direction. As they revealed a conventional writing for left-facing characters and a mirror writing for right-facing characters in the constraint condition, the present results provide new evidence to the writing-direction-orienting rule. Thus, it is unlikely that children only resort to an implicit knowledge of letter orientation (i.e., most letters are facing right) in their writing samples as postulated by Treiman et al. (2014) and Treiman and Kessler (2011). As previously pointed out by reference to Fischer (2017a), writing direction plays a major role in preliterate children’s spontaneous mirror writing.

To our knowledge, the present study is the first to show that kinematics do not vary as a function of the writing output in preliterate children. Each character was produced with the same ease whether it was conventionally or mirror written, as velocity and fluency remained stable. A better performance could have been expected for conventional writing since participants have been exposed to this writing output during the learning phase. Under dictation, they were able to recall the proper shape of the letters while they failed to orient them correctly. Through the learning sessions, the shape of the characters was available in children’s memory but their orientation was not. Kinematic equivalence of mirror shapes written from memory provides further empirical evidence of mirror generalization in preliterate children. A better performance could have been also expected for right-facing output regardless of characters’ intrinsic orientation as implied by the statistical learning hypothesis. If an implicit knowledge about a predominant orientation was activated during writing, this might result in a more efficient production process. In this regard, results on kinematics weaken the statistical learning hypothesis. Further research tracking changes on both the writing kinematics and the prevalence of letter reversals in spontaneous writing across ages would be of interest to investigate the time course of unlearning or inhibiting mirror generalization.

As far as we know, the present study is the first to present a recording of morphokinetic directionality in mirror writing research. Morphokinetic directionality was aligned on the topokinetic level and thus led to opposite patterns across the spatial conditions. On one hand, the characters were produced with right-to-left and clockwise morphokinetic directionality in the normal condition (i.e., rightward topokinetic directionality). On the other hand, the characters were produced with left-to-right and clockwise morphokinetic directionality in the constraint condition (i.e., leftward topokinetic directionality). Thus, during the early stages of writing acquisition, morphokinetic directionality is strongly constrained by the topokinetic level that ontologically precede its development (Chartrel & Vinter, 2004). Participants had not enough experience of handwriting activities to have set up a motor program that hold in memory the specific trajectory of letters and digits. The same applies for the learning sessions that were not devised and did not provide adequate conditions to this end. The three letters O, S and Z did not show any changes at the morphokinetic level as a function of the topokinetic level. The primitive graphic O benefits for a long time practice in drawing circles and a rote production might explain the present result (Goodnow & Levine, 1973). The special case of the letters S and Z will be discussed below. Also, morphokinetic directionality was strongly associated with writing production: The shapes with left-to-right or clockwise morphokinetic directionality faced to the right when produced rightward and the same shapes faced left when produced leftward. These findings specify the influence of writing directionality on the production of characters' orientation. In left-to-right writing cultures, the occurrence of left facing characters' mirror writing along literacy acquisition would result from the constraints imposed by the writing direction (topokinetic directionality) to the movement of hands and fingers (morphokinetic directionality).

Two letters, S and Z, did not always fall into the previous cited trends. Differences in results may pertain to their particular shapes, with no stem-appendage structure, which make their orientation puzzling and require alternation of clockwise and counterclockwise morphokinetic directionality. Further research investigating the perceived orientation of S and Z among preliterate children would be needed.

The present findings support and specify Fischer's proposal (Fischer, 2011, 2013, 2017a; Fischer & Koch, 2016b; Fischer & Tazouti, 2012) about the contribution of writing direction to letters' and digits' production, especially mirror writing. They provide an empirical illustration of mirror writing in preliterate children occurring as a culture-bound manifestation. The present results are in line with a large body of research indicating that the cortical representation of letters in the visual system does not only depend of visual experience (Reich, Szwed, Cohen, & Amedi, 2011) but recruits a complex sensory-motor network (James & Gauthier, 2006; James, 2010) involved in letter learning (Bara, Gentaz, Colé, & Sprenger-Charolles, 2004; Longcamp, Zerbato-Poudou, & Velay, 2005). Thus, writing directionality has a main role in the processing of orientation in written production. Further research would be of interest to investigate the specific contribution of writing directionality to the recognition of characters orientation.

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