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Experimental confirmation of a character-facing bias in literacy development

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Supplementary files

The anonymised data and R analysis code are available under the first author's account, at the Open Science Framework: https://osf.io/chvfw/

Abstract

When learning to write, children often mirror-reverse individual letters. For children learning to use the Latin alphabet, in a left-to-right writing culture, letters that appear to face left (such as J and Z) seem to be more prone to reversal than those that appear to face right (such as B and C). It has been proposed that, because most asymmetrical Latin letters face rightward, children statistically learn this general regularity, and then tend to write any letter rightward when uncertain of the correct direction. The evidence for this character-facing bias is circumstantial, however, because letter facing direction is confounded with other factors that could affect error rates: for instance, J and Z are left-facing, but they are also infrequent. We report the first controlled experimental test of the character-facing bias. We taught 43 Scottish primary schoolchildren (aged 4.8-5.8 years) four artificial, letter-like characters, two of which were left-facing, and two of which were right-facing. The characters were novel, so were not subject to prior exposure effects; and alternate groups of children were assigned to identical but mirror-reflected character sets. The children were three times more likely to mirror-write a novel character that they had learned in a left-facing format, than one that they had learned in a right-facing format. This provides the first experimental confirmation of the character-facing bias in literacy development, and suggests that implicit knowledge acquired from exposure to written language is readily generalised to novel letter-like forms.

Introduction

The production of individual letters or even words in a reversed direction, such that they look normal when viewed in a mirror, has long been noted in the writing of children. Early reports portrayed such reversals as markers of slow intellectual development and/or left-handedness (Fuller, 1916; Gordon, 1921; Schiller, 1932). Recent studies have dispelled these beliefs, indicating that, rather than identifying any specific sub-group of children, mirror-writing characterises a normal stage of literacy development, between learning the letter shapes and learning their orientations. Proposed explanations are that the representation of letter shape is subject to an automatic mirror-generalisation, which must be actively unlearned (Corballis & Beale, 1976; Dehaene, 2010; Dehaene et al., 2010), or that the direction of a writing *action* is learned later than its general shape (Della Sala & Cubelli, 2007). Either account entails a period of directional instability, during which children will be prone to mirror-write.

For children learning to use the Latin alphabet, in a dextrad (left-to-right) writing culture, mirror-reversals are not equally likely for all asymmetrical letters, but are more likely for letters that are 'left-facing' (Fischer, 2011; Simner, 1984; Treiman & Kessler, 2011; Watt, 1983). A typical left- or right-facing letter has its distinguishing features appended to one side of a vertical or semi-vertical stem (e.g. J vs F); though observers also agree about the directionality of some letters that do not fit this stem-and-appendage pattern (e.g. S faces rightward, and Z leftward) (Fischer, 2017b; Treiman, Gordon, Boada, Peterson, & Pennington, 2014).[1] The disproportionate reversal of left-facing characters has been confirmed for uppercase letters, lowercase letters, and digits (Fischer, 2011, 2017a, 2017b, Fischer & Koch, 2016a; Fischer & Tazouti, 2012; Treiman & Kessler, 2011; Treiman et al., 2014), and in left- and right-handed children alike (Fischer & Koch, 2016b).

[1] Of the asymmetrical uppercase letters, only J and Z are clearly left-facing, whilst B, C, D, E, F, G, K, L, P, Q, R and S are all right facing; of the asymmetrical lowercase letters, a, d, g, j, q, y, and z are considered left-facing, and b, c, e, f, h, k, n, p, r, and s are considered right-facing (Treiman et al., 2014).

This asymmetry of errors could be explained by automatic statistical learning of letter forms by children exposed to written language (Fischer, 2011; Fischer & Tazouti, 2012; Treiman & Kessler, 2011; Treiman et al., 2014). Right-facing letters make up the majority of the Latin alphabet - especially uppercase - and it is proposed that children extract this general regularity before they acquire the individual letter directions, and internalise the expectation that letters face to the right. This expectation would bias their writing when uncertain of the correct orientation, promoting the correct writing of right-facing letters, and the reversal of left-facing letters. If this expectation were generalised to other letter-like forms, it could also explain why left-facing Arabic numerals are more often reversed, even though right-facing forms do not predominate amongst the digits (Fischer, 2011, 2017a, 2017b, Fischer & Koch, 2016a, 2016b; Fischer & Tazouti, 2012; Treiman & Kessler, 2011; Treiman et al., 2014).

Fischer (2011) proposed the term, 'right-writing rule' to capture this idea. However, the original formulation has been updated by observations that suggest a pivotal role of current writing direction. Fischer (2017a) retrospectively examined data from 579 children who had written their name on two separate sheets of paper, the layout of which promoted left-to-right writing on one sheet and right-to-left writing on the other (method adapted from Cornell, 1985). Fischer identified 204 children with at least one reversible letter in their name, who had written their name in uppercase in both directions. When writing left-to-right, children more often reversed left-facing letters; but when writing right-to-left, the pattern flipped, such that right-facing letters were more often reversed. This suggests that the true internalised expectation is that letters face *in the direction of writing*. In a dextrad writing culture, the typical manifestation would be the greater reversal of left-facing characters.

However, the key evidence for the character-facing bias is still circumstantial, because it derives from spontaneous reversals amongst children using natural language. Character-facing direction is a strong candidate cause of the bias, but other factors that could potentially influence the likelihood of errors. For instance, the most often reversed uppercase letters (J and Z) are left-facing, but they are also infrequent. Treiman and Kessler (2011) considered several possible confounding influences, including letter frequency, number of segments, and the presence of descenders (parts below the line), and found no evidence that these varied in ways that could account for the pattern of reversals. They also emphasised that the tendency to reverse left-facing forms holds between pairs of letters that are similar in reflection (such as d and b, or q and p), which seems to rule out a causal role for aspects of shape other than facing direction. Fischer's (2017a) analysis of the influence of writing direction also seems to exclude factors other than character-facing, since the letters most often reversed when writing rightward were least often reversed when writing leftward. Even so, *experimental* evidence for the causal role of character-facing direction is still lacking.

We report the first experimental test of the character-facing bias. We achieved this by creating a set of asymmetrical letter-like characters, half of which were left-facing and half right-facing. We taught English-speaking children to write these novel characters, and then tested the prediction that characters taught in a left-facing orientation would more often be reversed. Because the characters were novel, they were not subject to prior frequency effects; and we counterbalanced the specific shapes by assigning alternate groups of children to identical but mirror-reflected stimulus sets, so that the left-facing characters for one child were the right-facing characters for another, and vice-versa. The characters taught in a left-facing orientation were indeed more often reversed. This confirms the determining role of character-facing direction, and suggests that statistical patterns extracted from exposure to letter stimuli are readily applied to novel shapes. Our method also allows for a relatively uunbiased estimate of the size of the effect in typically-developing five-year old children.

Method

Participants

Forty-three children in the entry class of a Scottish Primary school took part in this study (18 girls, 25 boys; aged 4.8-5.8 years, mean 5.48 years, SD 0.29). These children were at the upper stage of the early level of the Scottish 'Curriculum for Excellence', in which they learn to form lowercase and uppercase letters, to spell familiar words, and to read and to write in a left-to-right (and top-to-bottom) direction. Written informed consent was obtained from a parent or guardian for every child, and the study was approved by the University of Edinburgh Psychology Research Ethics Committee, and the City of Edinburgh Council.

Stimulus materials

The stimuli for this study were two sets of four novel letter-like characters (Figure 1). Each character had a name, which was used when teaching the children to write it. The names were palindromic words of symmetrical letters: OXO; WOW; OMO; VOV (International Phonetic Alphabet: ɒksoʊ; waʊ; ɒmoʊ; vɒv). The formation of each character was taught with a specific movement sequence (Figure 1). In each stimulus set, two of the characters were left-facing and two were right-facing, and the two sets were mirror-reflections of one another. Children received a workbook (size A4 = 210*297 mm) for each character in the set they had been assigned. Sticker rewards were used to encourage the children to complete the workbooks.

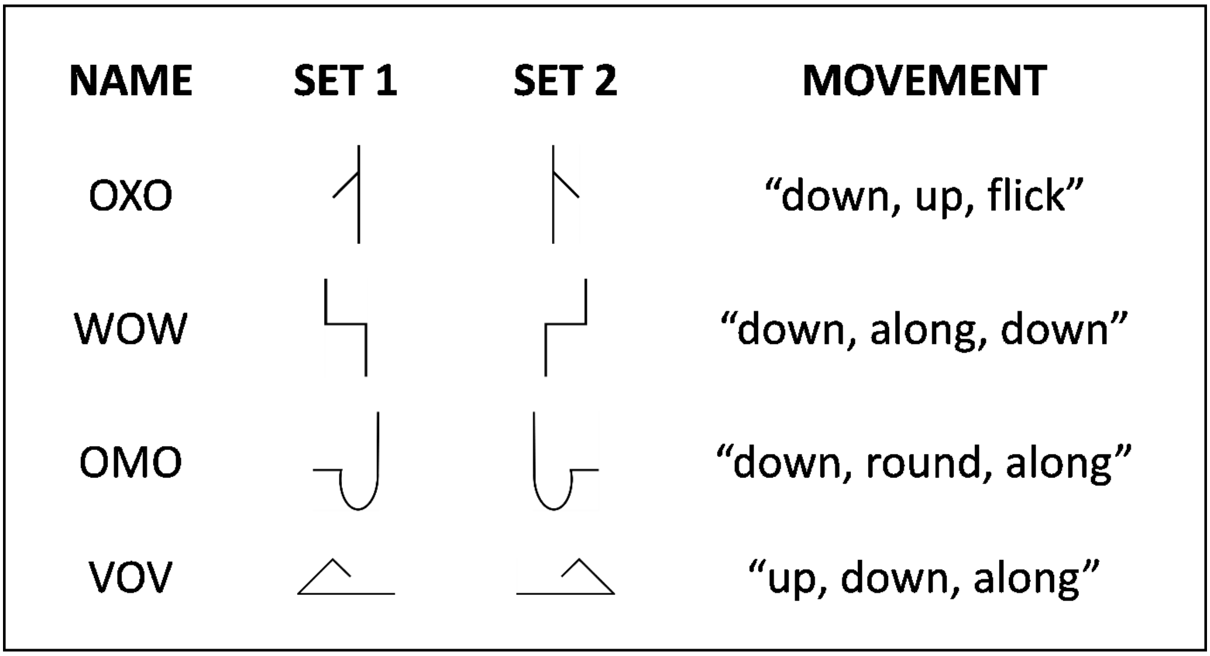

Figure 1. *The two alternate stimulus sets of four novel letter-like characters, and the movement descriptions used in teaching children to write them. In Set 1, the characters OXO and OMO are left-facing, and the characters WOW and VOV are right-facing: in Set 2, the characters OXO and OMO are right-facing, and the characters WOW and VOV are left-facing. Sets 1 and 2 are mirror-image versions of one-another.*

Procedure

The children worked under the close supervision of the experimenter, in groups of three or four, in a quiet room outside of the main classroom. The experimenter distributed the workbooks for the first character in the set, and then showed a (size A6 = 105*148 mm) card of that character to the group. The experimenter introduced the character by name (e.g. "*this shape is called OXO*"), holding the card in the left hand so that it faced the children. They then traced the shape with the index finger of the right hand, speaking the movement sequence as they did so (e.g. "*down, up, flick*"). The children joined in repeating this action and verbal sequence three times with the experimenter. The children then had to individually complete Stage 1 of the workbook for that character. The first page, which had the character name printed at the top, was a training page. This involved tracing the character over three dotted outlines in the top half of the page, then writing the character twice starting from two dots in the bottom half of the page. The next three sheets were blank, and the children had to write the character once on each sheet from memory, without looking back through the workbook. The workbooks were then collected, and this process was repeated for the other three characters, alternating between characters of opposite facing directions.

After Stage 1 had been completed for all four characters, the experimenter gave out a Stage 2 workbook for the first character. The first page had the character name printed at the top, and a dotted outline to guide the child in tracing the character once. The children were then required to write the character from memory on each of three subsequent blank sheets. The workbooks were then collected, and this Stage 2 process was repeated for the other three characters, in the same order as at Stage 1. This two-stage design was intended to break up the repetitions of each character, to reduce stereotyped responding. In total, each child wrote each of the four characters six times from memory.

To counterbalance character-facing against other aspects of character shape, alternate groups of children were assigned to character Set 1 and Set 2. For each character set, we alternated whether a left- or a right-facing character was taught first. Because the children were tested in groups of three to four, and an odd number of groups was tested, the final matching was close rather than exact: 23 children received character Set 1 and 20 children received character Set 2; 23 children were taught a left-facing character first, and 20 children were taught a right-facing character first.

Scoring

Each writing was classified as correct in form if the shape was judged correct, independent of horizontal orientation. Each correct form was classified as either forward or mirror-reversed, according to its horizontal orientation (there were no vertical inversions). An initial sample was double-coded by both experimenters (RH and EA), who compared scores and classification criteria. Their judgements were closely concordant, so double-coding was not deemed necessary for the full dataset. The experimenters instead marked one half of the workbooks each, and any writings considered borderline were resolved by discussion.

Results

To summarise the main patterns, we calculated, for each child, for each character, the percentage form errors, and the percentage of reversals amongst the correct forms. These were averaged across the two characters for each facing direction, to give a marginal mean error rate, unweighted by differences in the number of observations per character. Twenty-one children made at least one form error. Figure 2a shows the form error rates for these children for each character-facing direction, and the paired differences between left- and right-facing characters. Form errors did not differ systematically between left- and right-facing characters, Wilcoxon signed-rank test $V = 110$, $p = .86$. Twenty-five children produced at least one reversal, and Figure 2b shows the reversal rates for these 25 children for each character direction, and the paired differences. Left facing characters were more prone to mirror-reversal than right-facing characters, Wilcoxon signed-rank test $V = 214.5$, $p = .02$. This is consistent with the proposed character-facing bias.

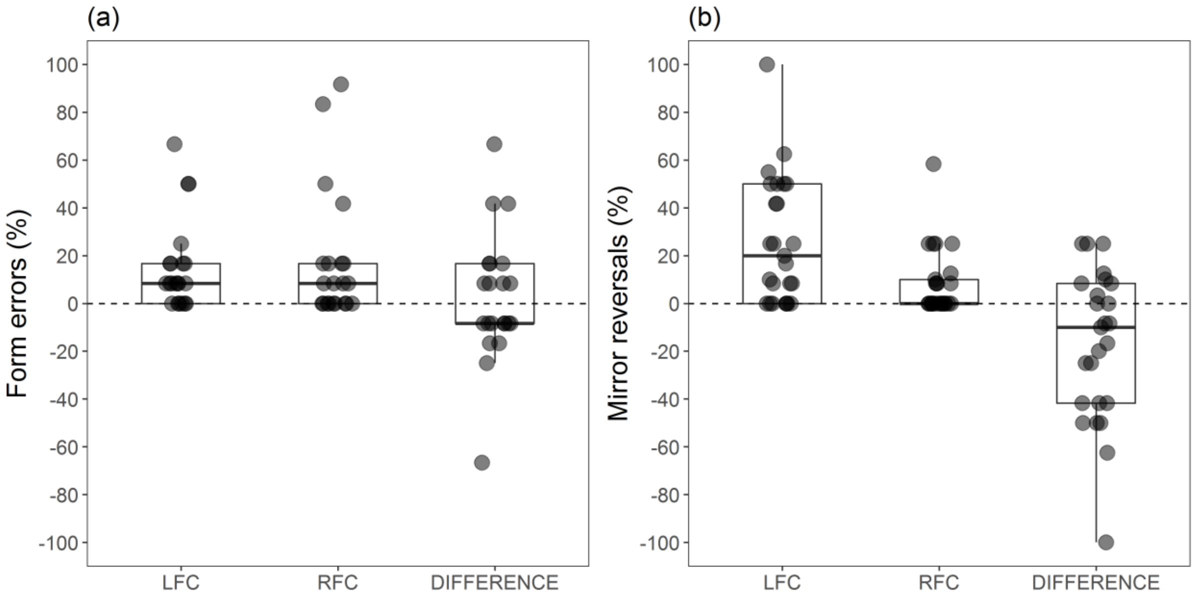

Figure 2. (a) *Marginal mean error rates per child for left-facing characters (LFC) and right-facing characters (RFC), and paired differences (RFC-LFC). There is no difference in rates of form error, according to character direction.* ***(b)*** *Marginal mean reversal rates amongst correct forms per child, showing elevated reversal rates for LFC relative to RFC, supported by the negative group shift in the difference score (RFC-LFC).*

The data were also analysed by mixed-effects binary logistic regressions, across all trials for included children, with fixed effects of character-facing direction (right-facing, left-facing) and character identity (OXO, WOW, OMO, VOV). Child identity was included as a random factor (intercept model), to control for unequal numbers of observations across children. For form errors, the binary dependent variable was whether the general form was correct (0) or not (1). For reversals, the dependent variable was whether the character was written forward (0) or reversed (1).

There was no significant influence of character-facing direction on form errors, $\beta = 1.32$, $z = 1.50$, $p = .14$. But form errors did differ across characters, with OXO being subject to lower error rates than any of the other characters: WOW, $\beta = 3.05$, $z = 4.17$, $p < .001$;

OMO, $\beta = 2.43$, $z = 3.46$, $p < .001$; or VOV, $\beta = 3.95$, $z = 5.40$, $p < .001$. Character identity affected reversals similarly, with fewer reversals for OXO than any of the other characters: WOW, $\beta = 2.33$, $z = 5.11$, $p < .001$; OMO, $\beta = 0.94$, $z = 2.03$, $p = .04$; or VOV, $\beta = 1.67$, $z = 3.54$, $p < .001$. The critical outcome was the effect of character-facing direction on reversals, which was significant, $\beta = 1.32$, $z = 4.30$, $p < .001$. To get a more intuitive effect size, we converted the logodds β (1.32) to relative risk, taking the marginal mean reversal rate for right-facing characters (8.57%) as the baseline risk (Zhang & Yu, 1998). This indicated a relative risk of 3.02, 95% CIs [1.88, 4.54]; the central estimate exactly matches that obtained by directly dividing the marginal mean reversal rate for left-facing characters (25.90%) by that for right-facing characters (8.57%). Children were thus three times more likely to mirror write a character if it was taught to them in a left-facing rather than a right-facing orientation.

Finally, although not part of our original design, a further prediction can be explored. If reversal errors are driven by a tendency to orient letters in a specific direction, then the more likely a child is to reverse left-facing characters, the less likely they should be to reverse right-facing characters. This predicts a negative correlation between reversals for the two character directions, in contrast to the positive correlation expected if mirror-writing were due simply to a poor knowledge of character-facing direction. For the 25 children making reversals, the correlation between reversal rates for left and right facing characters was indeed negative, Spearman's $\rho = -.47$, $p = .02$ (see also Fischer, 2013; Fischer & Koch, 2016a).

Discussion

This study is the first experimental test of the influence of character-facing direction on mirror-writing errors in children (Fischer, 2011; Simner, 1984; Treiman & Kessler, 2011; Watt, 1983). Our results confirm that children learning to write in English more often reverse a character that faces leftward than an otherwise identical character that faces rightward. This gives converging support for a statistical learning account, that children automatically extract the prevalent properties of written language, and it suggests that the biases acquired are readily generalised to novel letter-like forms (Fischer, 2011, 2017a, 2017b, Fischer & Koch, 2016a, 2016b; Fischer & Tazouti, 2012; Treiman & Kessler, 2011; Treiman et al., 2014).

This controlled approach, using artificial characters, also allows for a relatively unbiased estimate of the effect size: left-facing characters were three times more likely than right-facing characters to be reversed. Even so, this estimate relates to the present character set and sample of children, in the context of writing individual characters, and the bias may be modulated across different situations. Prior data from an individual letter writing task indicate that left-facing uppercase letters (J and Z) were mirror-written about half the time (Fischer, 2011), compared with about 9% for right-facing letters, suggesting a somewhat stronger bias, perhaps due to the rarity of the letters J and Z. Name-writing errors suggest an even more extreme bias, with J and Z reversed around twelve times more often than right-facing letters (25 vs 2%) (Fischer, 2017a). This could reflect a major influence of motoric script direction, which is stronger when writing whole words. Right-facing letters became more often reversed than left-facing letters when writing in the opposite direction, but reversal rates were overall higher, with a less extreme relative bias (69 vs 17%). These examples mainly highlight that the factors at play may be complex. Controlled, artificial characters may thus be a useful simplifying tool for comparing the character-facing bias under different response conditions, at different stages of literacy development, or in different cultures.

The characters created for this study were arbitrary letter-like forms with a horizontal directionality. They were not explicitly intended to differ in difficulty, but we nonetheless saw clear variations in form errors and reversals, with OXO producing the fewest errors, and WOW and VOV the most. This serendipitous result suggests that aspects of character shape other than facing direction modulate the likelihood of reversal in ways that may be hard to predict, as discussed by Treiman and Kessler (2011). This could contribute to sizeable variations in mirror-writing rates for different characters in studies using real alphanumeric forms (e.g. Fischer, 2011, 2017a, Fischer & Koch, 2016b; Fischer & Tazouti, 2012). Future investigations using artifical characters might seek to develop character sets of more consistently-matched difficulty, to minimise influences other than the factors of interest.

This study targeted a narrow prediction concerning character reversal, but it may inform broader issues of statistical learning in cognitive development. Statistical learning is a powerful, automatic, domain-general mechanism, by which humans (and other animals) can learn about regular structures in the world (Aslin, 2017; Krogh, Vlach, & Johnson, 2013; Saffran, 2009). Within developmental science, an initial focus was on the segmentation of words from auditory speech streams (e.g. Aslin, Saffran, & Newport, 1998; Saffran, Aslin, & Newport, 1996), but further work showed that visuo-spatial regularities can similarly be extracted through visual exposure (Fiser & Aslin, 2002; Wu, Gopnik, Richardson, & Kirkham, 2011). It was subsequently proposed that children extract the regularity that Latin letters face rightward, through exposure to writing in their environment, perhaps even before knowing what the forms represent (Fischer, 2011; Fischer & Tazouti, 2012; Treiman & Kessler, 2011; Treiman et al., 2014). One potential problem with this account is an apparent conflict with the idea of an automatic mirror-invariance in form perception, which must be actively unlearned during literacy development (Corballis & Beale, 1976; Dehaene, 2010; Dehaene et al., 2010; Pegado, Nakamura, Cohen, & Dehaene, 2011). How could young children statistically extract a prevailing rightwardness if mirror-orientation is not yet represented within their perceptual systems?

In fact, a recent demonstration of the pivotal role of writing direction in determining whether left- or right-facing characters are more prone to reversal implies that the regularity that is actually learned is not that letters face rightward, but that they face *in the direction of writing* (Fischer, 2017a). If so, the stimulus for statistical learning would be the higher-order relation between the direction of letters and the direction of reading and writing actions. This would be relatively unavailable to young children through mere exposure, but would become available under instruction, for instance if a parent traces the words with a finger when reading to a child. The relation would become salient when children were explicitly taught to read and write from left-to-right, and then ubiquitous once these directional habits were acquired. Given that automatic learning is accelerated for attended input (Toro, Sinnett, & Soto-Faraco, 2005; Turk-Browne, Jungé, & Scholl, 2005), the predominance of 'action-facing' forms might be very rapidly extracted once literacy instruction begins.

This predicts an interesting relationship between the nature of a child's mirror-writing, and their level of certainty over the general direction of writing in the culture. When a child is uncertain over the global script direction, they will less consistently learn how characters tend to be oriented with respect to that direction, so they may reverse the global script direction and/or individual letters, but relatively at random. As their global direction stabilises, the learning stimulus will become more consistent, and individual character reversals should become less common but more specific to those (left-facing) characters that oppose the global (rightward) direction. During this period, specific manipulations that coerce the child into reversing the direction of writing may reverse the expression of the character-facing bias, so that right-facing characters that oppose the global (leftward) direction become most often reversed (Fischer, 2017a). Finally, once the individual character orientations are acquired, an adult pattern will be established in which mirror-reversals appear only under certain extreme conditions, such as following brain injury or at times of great anxiety (Critchley, 1927; Della Sala, Calia, De Caro, & McIntosh, 2015; McIntosh & Della Sala, 2012).

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