



HAL
open science

Character reversal in children: the prominent role of writing direction

Jean-Paul Fischer

► **To cite this version:**

Jean-Paul Fischer. Character reversal in children: the prominent role of writing direction. *Reading and Writing*, 2017, 30 (3), pp.523-542. 10.1007/s11145-016-9688-y . hal-02012597

HAL Id: hal-02012597

<https://hal.univ-lorraine.fr/hal-02012597>

Submitted on 8 Feb 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Dear Author,

Here are the proofs of your article.

- You can submit your corrections **online**, via **e-mail** or by **fax**.
- For **online** submission please insert your corrections in the online correction form. Always indicate the line number to which the correction refers.
- You can also insert your corrections in the proof PDF and **email** the annotated PDF.
- For fax submission, please ensure that your corrections are clearly legible. Use a fine black pen and write the correction in the margin, not too close to the edge of the page.
- Remember to note the **journal title**, **article number**, and **your name** when sending your response via e-mail or fax.
- **Check** the metadata sheet to make sure that the header information, especially author names and the corresponding affiliations are correctly shown.
- **Check** the questions that may have arisen during copy editing and insert your answers/ corrections.
- **Check** that the text is complete and that all figures, tables and their legends are included. Also check the accuracy of special characters, equations, and electronic supplementary material if applicable. If necessary refer to the *Edited manuscript*.
- The publication of inaccurate data such as dosages and units can have serious consequences. Please take particular care that all such details are correct.
- Please **do not** make changes that involve only matters of style. We have generally introduced forms that follow the journal's style. Substantial changes in content, e.g., new results, corrected values, title and authorship are not allowed without the approval of the responsible editor. In such a case, please contact the Editorial Office and return his/her consent together with the proof.
- If we do not receive your corrections **within 48 hours**, we will send you a reminder.
- Your article will be published **Online First** approximately one week after receipt of your corrected proofs. This is the **official first publication** citable with the DOI. **Further changes are, therefore, not possible.**
- The **printed version** will follow in a forthcoming issue.

Please note


After online publication, subscribers (personal/institutional) to this journal will have access to the complete article via the DOI using the URL: [http://dx.doi.org/\[DOI\]](http://dx.doi.org/[DOI]).

If you would like to know when your article has been published online, take advantage of our free alert service. For registration and further information go to: <http://www.link.springer.com>.

Due to the electronic nature of the procedure, the manuscript and the original figures will only be returned to you on special request. When you return your corrections, please inform us if you would like to have these documents returned.

Metadata of the article that will be visualized in OnlineFirst

Please note: Images will appear in color online but will be printed in black and white.

ArticleTitle	Character reversal in children: the prominent role of writing direction	
Article Sub-Title		
Article CopyRight	Springer Science+Business Media Dordrecht (This will be the copyright line in the final PDF)	
Journal Name	Reading and Writing	
Corresponding Author	Family Name	Fischer
	Particle	
	Given Name	Jean-Paul
	Suffix	
	Division	InterPsy Laboratory
	Organization	University Lorraine
	Address	EA 4432, 23 Bd Albert Ier, BP 3397 54015, Nancy Cedex, France
	Phone	+33 83 55 89 47
	Fax	
	Email	jean-paul.fischer@univ-lorraine.fr
	URL	
	ORCID	
	Received	
Schedule	Revised	
	Accepted	
Abstract	<p>Recent research has established that 5- to 6-year-old typically developing children in a left–right writing culture spontaneously reverse left-oriented characters (e.g., they write  instead of J) when they write single characters. Thus, children seem to implicitly apply a right-writing rule (RWR: see Fischer & Koch, 2016a). In Study 1, the reversal of all asymmetrical digits and capital letters by 356 children was modeled with a simple Rasch model, which describes reversal as the outcome of two competing responses, correct writing and writing in the cultural direction of writing. It accounts for the high frequency of reversals of the left-oriented characters (3, Z, J, 1, 2, 7, 9), as predicted by the RWR. Study 2 investigated letter reversals when children spontaneously write their name from right to left. Most of the 204 children in the study radically changed the direction of the RWR by reversing mainly the right-oriented letters (B, C, D, E, F, G, K, L, N, P, R, S). Hence, a more universal formulation of the RWR would be as an implicit rule orienting characters in the writing direction. This reformulated rule is consistent with the “spatial agency bias” model (Suitner & Maas, 2016), according to which writing direction affects thoughts and actions. Visual and motoric statistical learning may favor bootstrapping of the rule. Taken together, these data demonstrate the prominent role of culture in a phenomenon—character reversal or mirror writing—which has often been presented uniquely as biologically determined.</p>	
Keywords (separated by '-')	Mirror writing - Writing direction - Capital letter reversal - Digit reversal - Rasch model	
Footnote Information		

1

3 **Character reversal in children: the prominent role**
4 **of writing direction**

5 **Jean-Paul Fischer¹**

6
7 © Springer Science+Business Media Dordrecht 2016

8 **Abstract** Recent research has established that 5- to 6-year-old typically developing
9 children in a left–right writing culture spontaneously reverse left-oriented characters
10 (e.g., they write ʌ instead of J) when they write single characters. Thus, children
11 seem to implicitly apply a right-writing rule (RWR: see Fischer & Koch, 2016a). In
12 Study 1, the reversal of all asymmetrical digits and capital letters by 356 children
13 was modeled with a simple Rasch model, which describes reversal as the outcome
14 of two competing responses, correct writing and writing in the cultural direction of
15 writing. It accounts for the high frequency of reversals of the left-oriented characters
16 (3, Z, J, 1, 2, 7, 9), as predicted by the RWR. Study 2 investigated letter reversals
17 when children spontaneously write their name from right to left. Most of the 204
18 children in the study radically changed the direction of the RWR by reversing
19 mainly the right-oriented letters (B, C, D, E, F, G, K, L, N, P, R, S). Hence, a more
20 universal formulation of the RWR would be as an implicit rule orienting characters
21 in the writing direction. This reformulated rule is consistent with the “spatial agency
22 bias” model (Suitner & Maas, 2016), according to which writing direction affects
23 thoughts and actions. Visual and motoric statistical learning may favor bootstrap-
24 ping of the rule. Taken together, these data demonstrate the prominent role of
25 culture in a phenomenon—character reversal or mirror writing—which has often
26 been presented uniquely as biologically determined.

27
28 **Keywords** Mirror writing · Writing direction · Capital letter reversal · Digit
29 reversal · Rasch model

A1 Jean-Paul Fischer
A2 jean-paul.fischer@univ-lorraine.fr

A3 ¹ InterPsy Laboratory, University Lorraine, EA 4432, 23 Bd Albert Ier,
A4 BP 3397 54015, Nancy Cedex, France

32 The present research investigated the tendency of 5- to 6-year-old typically
 33 developing children to mirror-reverse some characters, at least occasionally, when
 34 they are learning to write. Our interest in this topic was triggered by the fact that the
 35 mirror-reversal phenomenon has intrigued neuropsychologists and developmental
 36 psychologists for more than a century and by the importance of learning to write
 37 within primary school curricula. In addition, because learning to write has a major
 38 impact on language learning, elucidating the mechanism(s) underlying character
 39 reversal could provide further insight into both the language-learning process and
 40 some of the difficulties associated with it. Most notably, the results of studies into
 41 the character reversal phenomenon may help refine contemporary theories of
 42 language acquisition, such as the cognitive theories of implicit statistical language
 43 learning (e.g., Erickson & Thiessen, 2015) and of language acquisition through
 44 bootstrapping (e.g., Christophe, Millotte, Bernal, & Lidz, 2008). Data on character
 45 reversal could also provide a further test for the psychosocial model of “spatial
 46 agency bias” (Suitner & Maass, 2016).

47 Single-letter or single-digit reversal is sometimes called fragmentary or partial
 48 mirror writing, as the reversed characters appear normally written when held in
 49 front of a mirror. This phenomenon is particularly intriguing in 5- to 6-year-old
 50 typically developing children because these children spontaneously write characters
 51 (letters or digits) they have never seen written in this fashion (see Fig. 1). Where
 52 does this ability come from?

53 For a long time, mirror-reversed writings were attributed to a child’s individual
 54 characteristics, most notably writing with the left hand. For example, Ireland (1881)
 55 wrote of “a physiological tendency with left-handed children to fall into mirror-
 56 writing” (p. 364). In fact, emphasis on writing with the left hand was so great that
 57 Scheidemann (1936) found the reversal of characters by a six-year-old boy who had
 58 no left-handed tendencies to be “noteworthy since all cases of mirror writing thus
 59 far reported have been encountered with left-handed children, and only with
 60 extremely left-handed ones” (p. 492). The primacy of the left-handedness
 61 explanation of mirror reversal continued until the end of the twentieth century,
 62 when Lebrun, Devreux, and Leleux (1989) wrote: “In countries where script
 63 normally runs from left to right, young children who spontaneously produce mirror-
 64 writing are generally left-handers” (p. 356).

65 However, despite its predominance, left-handedness was not the only causal
 66 explanation of mirror reversal in young children. Gordon (1921) concluded his
 67 empirical research by noting: It is “evident that mirror writing is very closely
 68 associated with mental deficiency” (pp. 342–343). Hildreth (1950) subsequently
 69 combined these two views when she stated: “The strongest tendency to mirror write
 70 occurs when left-handedness and mental defect coincide” (p. 74). Gender is also

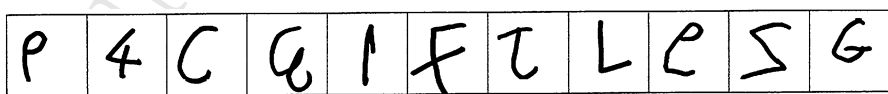


Fig. 1 Writing of the series P, 4, C, 3, 1, 7, J, L, 9, Z and G (dictated characters) by a 6-year 2-month old girl, using her preferred hand (*right*), in an experiment by Fischer and Tazouti (2012)



71 sometimes mentioned as a factor in mirror reversal. In the same review of research
 72 into mirror writing, Hildreth concluded: “Most observers find mirror writing more
 73 common among boys than girls in proportion greater than three to one” (p. 69, but
 74 see Fischer, 2010, p. 231).

75 In contrast with explanations of mirror reversal based on children’s individual
 76 characteristics, recent research has uncovered a quite different source of character
 77 reversals in typically developing young children. Both Fischer and coworkers
 78 (Fischer, 2013; Fischer & Koch, 2014; Fischer & Tazouti, 2012) and Treiman and
 79 co-workers (Treiman & Kessler, 2011; Treiman, Gordon, Boada, Peterson, &
 80 Pennington, 2014) have proposed a link between the reversal of characters and their
 81 shape. They noted that several letters in the Latin alphabet have a vertical or semi-
 82 vertical stem and one or more appendages attached to the right (e.g., b, P, R), which
 83 gives the impression that these letters face right. Furthermore, because writing has a
 84 motor component, Fischer and coworkers emphasized the need to take into account
 85 the dynamics of writing in the cultural environment in which children learn to write.
 86 For example, 5- to 6-year-old French children generally write N by producing an
 87 upward vertical stroke, followed by a right-trending downward stroke, and then
 88 another vertical upward stroke. Given this writing dynamic, N may be categorized
 89 as right-oriented, even though the static form of the finished letter cannot be said to
 90 have any specific orientation. Viewed in this way, all the asymmetrical characters
 91 (digits and capital letters) can be classified as either left-oriented (1, 2, 3, 7, 9, J, and
 92 Z) or right-oriented (all the others).

93 Reversal of the characters is easy to explain via Fischer and Koch’s (2016a, b)
 94 proposed right-writing rule (RWR), which could be acquired by statistical learning
 95 (Treiman & Kessler, 2011; Treiman et al., 2014). Due to mirror generalization by
 96 the brain (Corballis & Beale, 1976; Dehaene, 2010), 4- to 5-year-old typically
 97 developing children know only the shape of the characters but not their horizontal
 98 (left–right) orientation. Consequently, in our left-to-right oriented culture, the RWR
 99 predicts that children should prefer to orient their writing rightwards when writing
 100 the characters from memory; therefore, they reverse mainly the left-oriented
 101 characters (see Fig. 1).

102 Our Study 1 used a simple Rasch mathematical model to confirm the reversal of
 103 left-oriented characters. However, the dependence of reversal on the left–right
 104 direction of writing in the children’s culture raises another question: What happens
 105 when children write from right to left? Study 2 attempted to answer this question by
 106 using, for the first time, a within-subject design.



107 **Study 1: Character reversal when writing from left to right**

108 **Introduction: a Rasch model of reversal**

109 **AQ1** In order to fully discuss character reversal, it is necessary to analyze both the
 110 characteristics of participants and the properties of the items. The logistic item-
 111 response (Rasch) model allows the participant and item locations to be placed in a

112 directly linear relationship on a single oriented line. Therefore, it appears well suited
 113 to modeling data on character reversal by children.

114 The Rasch model is a standard method for modeling success, coded 1, and
 115 failure, coded 0, in test situations. The basic model begins by postulating that
 116 $\ln\left[\frac{p_{pi}}{1-p_{pi}}\right] = \theta_p - \beta_i$, where p_{pi} is the probability of a participant, p , giving a
 117 1-response. In the present research, we attributed a 1-response to a correct writing of
 118 a character and a 0-response to a mirror reversal of a character. Therefore, θ_p can be
 119 considered the writing competency of a participant, p , and β_i the attraction towards
 120 mirror reversal of an item (character), i . Applying elementary mathematics to the
 121 basic equation shows that (a) if a participant's competency, θ_p , is greater than an
 122 item's attraction, β_i , the chance of the participant writing that item correctly is better
 123 than even; (b) if θ_p is less than β_i , the chance of the participant reversing that item is
 124 better than even; and (c) if $\theta_p = \beta_i$, the two chances are the same.

125 Method

126 Because Fischer and Tazouti (2012, Expt 2) involved suitable numbers of both
 127 items ($n = 23$) and participants ($N = 356$), we used data from this experiment for
 128 our Rasch analysis. The items were the 15 asymmetric capital letters (all but A, H, I,
 129 M, O, T, U, V, W, X, Y) and the 8 asymmetrical digits (all but 0 and 8). The
 130 children ($M_{age} = 5.71$ years, $SD = 0.36$, range: 5.00–6.41, 175 girls, 181 boys)
 131 were recruited from “upper section classes” at 18 *écoles maternelles* (kindergarten)
 132 in France. The other features of the participants, materials, procedure, and data
 133 coding can be found in the original paper, so we describe here the only important
 134 change we made. In the original experiment, each child wrote each character one
 135 time only, with the exception of 3, 9, J, and Z, each of which they wrote three times.
 136 In order to homogenize the items, the present analysis includes only the first writing
 137 of each of these four items. Therefore the datasheet contained $23 \times 356 = 8188$
 138 responses, coded 1 (correct writing), 0 (left–right mirror reversal), or NA (not
 139 available).

140 The main weakness of these data is the large number of missing data (NA),
 141 mainly due to an absence of writing (10.2 %)—children who did not know how to
 142 write a character were instructed to put a cross in the response box corresponding to
 143 that character. Fortunately, these missing data do not rule out a Rasch analysis for
 144 two reasons. First, the Rasch functions implemented in the recent R-TAM-package
 145 (Kiefer, Robitzsch, & Wu, 2016; R-Core Team, 2015) process the missing data and,
 146 second, the non-available data were distributed in such a way that all the items and
 147 all the participants could be included in the analysis. This second point is important
 148 because excluding some items or some participants is not without risk (Flieller,
 149 1994), especially when the aim is (as was the case here) to produce an ecologically
 150 valid analysis.

151 **Results**152 *Goodness-of-fit*

153 Because inferences drawn from a poorly fitting model may be invalid (Maydeu-
 154 Olivares, 2013), it is essential to evaluate how well the data fit the model. A basic
 155 idea of the Rasch model is that consistent item parameter estimates can be obtained
 156 from any subgroup of a population where the model holds, so it is important to
 157 verify that no specific items depend on the subgroup being examined. Possible
 158 differences in the functioning of items across subgroups (DIF) can be examined
 159 both on subgroups based on extraneous participant characteristics (e.g., boys vs.
 160 girls) and on subgroups based on raw experimental data (e.g., children with good
 161 writing skills vs. children with poorer writing skills). We tested the 23 items for
 162 possible DIF in subgroups defined by writing hand, gender, and age (subgroups
 163 determined by median split in the latter case). A Fisher exact test on the two
 164 subgroups defined by each of these three participant characteristics indicated 2, 1,
 165 and 3 significant differences (at the .05 level), respectively. However, at the .01
 166 level and, a fortiori, at a level corrected for multiple comparisons (i.e., $.05/$
 167 $23 = .0022$), there were no significant differences between the subgroups (out of 23
 168 characteristics \times 3 subgroups = 69 possible differences).

169 The children's academic performance and their parents' socio-economic status
 170 (SES) were not included in Fischer and Tazouti's (2012) data, so for this particular
 171 comparison we used analogous data from Fischer and Koch (2014), which indicated
 172 these characteristics. For academic performance, we used the mean to split the
 173 sample into two subgroups. For SES, we compared the subgroup of children whose
 174 parents had low SES with the complementary subgroup of children whose parents
 175 had intermediate or high SES (according to a French categorization reported in
 176 Fischer and Koch). For the two subgroups defined by each of these two participant
 177 characteristics, a Fisher exact test led to 0 and 2 significant differences (at the .05
 178 level), respectively. Again, there were no significant differences (out of
 179 $23 \times 2 = 46$) at the .01 level.

180 We used the likelihood ratio global test (LR-test: see Andersen, 1973), as
 181 implemented in the eRm package (Mair & Hatzinger, 2007), to compare the
 182 subgroups determined by the results of the experiment. As well as being able to
 183 detect DIF, this test is a powerful tool for checking sufficiency and monotonicity,
 184 two other conditions determining the applicability of the Rasch model. The test
 185 yielded a LR-value of 28.39; therefore, a Chi-square test with 22 degrees of freedom
 186 was not significant ($p = .163$).

187 In addition, the eRm package includes a graphical procedure that can be used to
 188 detect, a posteriori, a DIF between children with good writing skills and children
 189 with poorer writing skills (dichotomization through the mean). The 23 items were
 190 relatively well aligned around the diagonal of the first quadrant (continuous black
 191 line) and only 2 items (the letters B and N) clearly lie outside the confidence band
 192 shown by the dotted lines (Fig. 2).

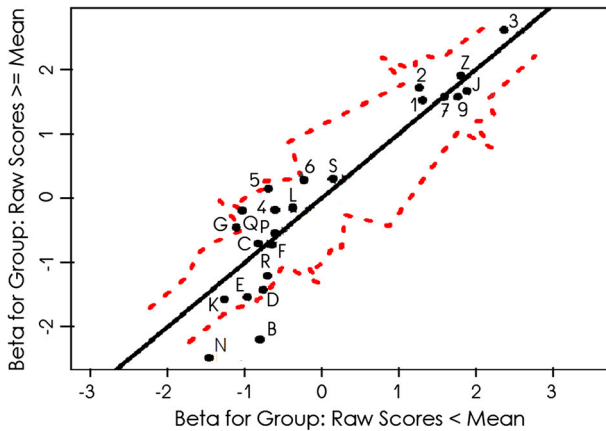


Fig. 2 Graphical check of a possible differential functioning of the items between children with good writing skills and children with poorer writing skills (the *dotted lines* indicate the confidence band)

193 *Items parameter*

194 Table 1 (column 2) shows the beta estimates for all 23 items. These estimates range
 195 from -3.893 (the letter N) to $+0.611$ (the digit 3). Column 4 in Table 1 shows the
 196 recorded frequency of mirror reversals for each character. As would be expected if
 197 the item difficulty is mainly due to the attraction towards mirror reversal, the
 198 correlation between the betas and the reversal frequencies is very high:
 199 $r(22) = 0.976$, $p < .001$ ($r_s = 0.999$ with Spearman's rho).

200 *Depiction on a common scale*

201 Figure 3 shows item attractions as points along a straight vertical line (or band) on
 202 the left (higher values are towards the top). There were too many children in the
 203 sample to show each child's writing competency as a point on the scale, so the right-
 204 hand column in Fig. 3 shows their distribution in intervals of length of .50.

205 Figure 3 shows the children are shifted upwards compared with the items, which
 206 indicates that the items were relatively easy for the children. This is mainly due to
 207 the fact that only two letters (J and Z) attracted the children to write them in the
 208 wrong direction (because of their left orientation).

209 **Discussion**

210 As a general rule, data never fit a Rasch model perfectly and this was the case for
 211 the present study. Because the model's underlying hypotheses—unidimensionality
 212 and local independence—are both difficult to satisfy and hard to verify (Flieller,
 213 1994), it was important to assess how well our data fit the model before applying the
 214 model to the participant's scores. The results of the checks we carried out did not
 215 suggest the model should not be applied.

Table 1 Beta parameter estimates (with SE) and empirical reversal frequencies for the 23 Items

Item (character)	Beta		Reversal frequency (%)
	Estimate	Standard error	
1	-0.454	0.116	40.06
2	-0.340	0.119	42.64
3	0.611	0.121	63.25
4	-2.262	0.177	11.38
5	-2.042	0.170	13.69
6	-1.861	0.166	15.44
7	-0.371	0.123	41.42
9	-0.321	0.132	42.11
B	-3.351	0.298	4.17
C	-2.710	0.217	7.60
D	-3.076	0.261	5.42
E	-3.212	0.252	4.93
F	-2.663	0.227	7.80
G	-2.727	0.265	7.21
J	-0.212	0.126	45.14
K	-3.397	0.344	3.91
L	-2.174	0.176	12.19
N	-3.893	0.361	2.56
P	-2.530	0.203	8.86
Q	-2.463	0.215	9.29
R	-2.939	0.241	6.21
S	-1.704	0.153	17.56
Z	-0.079	0.122	47.86

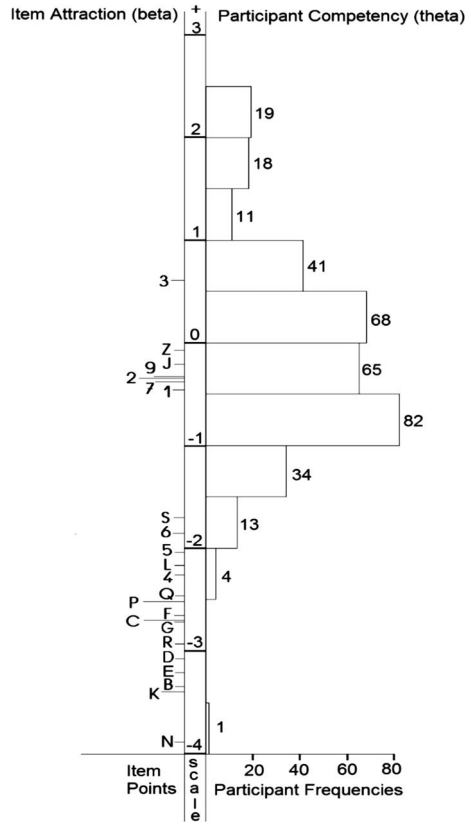
216 Once we had run the Rasch analysis, we verified the consistency of the results
 217 with our reversal theory. As predicted, the item coefficients (see Table 1; Fig. 3)
 218 clearly separated the left-oriented characters from the others. This result supports
 219 the validity of the present Rasch analysis and of a reversal theory based on the left-
 220 right orientation of the characters (Fischer, 2013; Treiman & Kessler, 2011).

221 Does the model describe the data well? Take the case of the 34 children within
 222 the $[-1.5, -1]$ interval on the scale in Fig. 3. According to the model, the mean
 223 probability the children will correctly write each of the 23 characters is greater than
 224 .50 for all the characters except for 3 ($p = .142$), Z ($p = .248$), J ($p = .273$), 9
 225 ($p = .295$), 2 ($p = .299$), 7 ($p = .306$), and 1 ($p = .324$). These estimated
 226 probabilities are a good reflection of the data, as more than 50 % of the 34
 227 children's writings of each character were correct for all the characters except 3
 228 (17 %), Z (31 %), J (25 %), 9 (29 %), 2 (30 %), 7 (15 %), and 1 (19 %).

229 Because the Rasch model's common scale is an interval scale, it does not show
 230 only whether different values are bigger or smaller, it also indicates how much



Fig. 3 Item distribution (*left side*) and histogram of children's writing competencies (*right side*) on a common scale



231 bigger or smaller they are. As an illustration, the distance between the group of 68
 232 children and the item K is greater than the distance between the group of 34 children
 233 and the item P. Accordingly, the model estimates that the mean probability the
 234 group of 68 children will correctly write K ($p = .974$) will be greater than the mean
 235 probability the group of 34 children will correctly write P ($p = .791$). The
 236 corresponding empirical frequencies, 100 and 79 %, were in line with the model's
 237 estimates.

238 However, the value of a model also resides in its ability to make predictions.
 239 Analogous data compiled by Fischer and Koch (2014) allowed us to verify many of
 240 the present Rasch model's predictions. First, the beta estimates reported in Table 1
 241 should correlate with the percentage of reversals in Fischer and Koch. This
 242 prediction was clearly confirmed, as $r(21) = .923, p < .001$. Second, because the
 243 items {3, Z, J, 9, 2, 7, 1} are clearly the most attractive (see Fig. 3), these seven
 244 items should be the seven most frequently reversed items in Fischer and Koch's
 245 data. This was the case. Third, because the model's estimates clearly placed the digit
 246 3 at the top of the scale and the letter N at the bottom of the scale, we expected them
 247 to occupy the same positions in Fischer and Koch's data. Again, this was the case.
 248 However, one prediction was not confirmed. Because the digit 3 exerts the greatest

249 attraction, we predicted that children who reversed just one character would reverse
 250 the digit 3. This was not the case in Fischer and Koch's data, as the most common
 251 character reversed by the 19 children who reversed only one character was the letter
 252 L. The rarity of character reversals by these 19 children suggests that they were
 253 further advanced in learning to write than most of the other children. This
 254 observation led us to hypothesize that many of these 19 children had confused the
 255 letters L and J, as these letters tend to be better (but not totally) consolidated in the
 256 declarative memory of more advanced learners, compared with less advanced
 257 learners.

258 Because the data from Fischer and Koch (2014) that we used to verify some of
 259 the model's predictions were compiled by the same research group as the data used
 260 to compute the beta estimates, we felt it was important to test the model's
 261 predictions on data compiled by an independent research group. Unfortunately, no
 262 recent data on both digit and capital-letter reversals by 5-year-old children are
 263 available. However, Ritchey's (2008, Fig. 1)¹ graphical data allowed us to test the
 264 predictions for the 15 asymmetrical capital letters. The correlation we obtained was
 265 positive and highly significant, $r(13) = .72, p < .005$, although it was slightly lower
 266 than the correlation obtained using Fischer and Koch's (2014) data.

267 In summary, the Rasch model simply describes the curious phenomenon of
 268 character reversal in writings by 5- to 6-year-old typically developing children. We
 269 used the Rasch model approach in order to describe character reversal as a result of
 270 competition between two possible responses to a lack of knowledge about the
 271 direction in which characters are oriented (Wilson & De Boeck, 2004). The first
 272 response arises from a child's ability to write correctly. However, the standard
 273 direction of writing in the cultural environmental also exerts an attraction over a
 274 child's writing. Thus, in a left-right writing culture this second response competes
 275 with the first in the case of the left-oriented characters. The sign and value of the
 276 basic difference $\theta_p - \beta_i$ in the Rasch model, where θ_p is a child's writing
 277 competency and β_i is the attraction of the item in a false direction, provide a
 278 probabilistic solution to the conflict.²

279 Study 2: Letter reversal when writing from right to left

280 Introduction

281 The Rasch model adequately describes and accounts for reversals of characters
 282 when children write normally, that is, from left to right in a left-right (L-R) culture.
 283 But what happens when the writing direction changes radically, that is, when
 284 children write from right to left?

1FL01 ¹ The percentages of reversed and correct writings were manifestly inverted in Ritchey's (2008, p. 37)
 1FL02 graph (or in the legend). For comparison, we estimated the percentage of reversals by measuring on the
 1FL03 graph the number of reversals and the absence of writings (correct or reversed) for each of the 15
 1FL04 asymmetrical capital letters.

2FL01 ² The probability of a participant, p , reversing an item, i , can be derived from the basic formula given at
 2FL02 the beginning of Study 1: $p_{pi} = [\exp(\theta_p - \beta_i)]/[1 + \exp(\theta_p - \beta_i)]$.

285 One way of approaching this question would be to carry out a comparative
 286 analysis of writings by children from two different reading/writing cultures (L–R
 287 and R–L). However, it is very difficult, if not impossible, to establish a systematic
 288 and comparative statistic on reversals of single (capital) letters. Indeed, the letters in
 289 R–L writing cultures generally have very different shapes to those in Western, L–R
 290 writing cultures, and these shapes can vary across both geographic areas and time
 291 (Suitner & Maass, 2016). In addition, participants who write different scripts (e.g.,
 292 in two different countries) cannot be randomly assigned to groups, which makes it
 293 difficult to explore the causality of the writing direction effect.

294 Two recent studies have examined the influence of mirror reading on adults. In an
 295 experiment by Casasanto and Bottini (2014), Dutch speakers were asked to perform
 296 space–time congruity tasks with the instructions and stimuli written in standard,
 297 mirror-reversed, or rotated orthography. In one block, they were instructed to press a
 298 button if the stimulus–phrase referred to an interval of time in the past and another
 299 button if it referred to an interval of time in the future. In the other block, the
 300 mapping between the two buttons and past/future phrases was reversed. In fact,
 301 when participants judged temporal phrases written in standard orthography, their
 302 reaction times were consistent with a rightward-directed mental timeline, but after
 303 brief exposure to mirror-reversed orthography, their mental timelines were reversed.
 304 In another experiment, Román, Flumini, Lizano, Escobar, and Santiago (2015)
 305 asked Spanish students to draw the contents of auditory descriptions such as “the
 306 square is between the cross and the triangle” immediately after reading a short text.
 307 The text in one condition was mirror written. The directionality of the drawings in
 308 the mirror-reading condition clearly showed a reduction in the standard L–R bias
 309 found in the normal reading condition.

310 Although these experiments on adult participants show the considerable impact
 311 of writing/reading direction on the spatial bias, they do not clarify the influence of
 312 writing direction on letter reversals when young children write spontaneously. There
 313 are at least three major reasons for this. First, in these experiments mirror writing
 314 had a contextual function and its influence was studied only on tasks not related to
 315 writing. Second, unlike adults, 5- to 6-year-old children have not automatized
 316 writing and reading. Third, with respect to letter reversal, writing differs
 317 considerably from reading because when reading children see the letters’
 318 orientations. To the best of our knowledge, no experiments have been conducted
 319 to investigate the influence of writing direction on letter reversal by children. Maass,
 320 Suitner, and Deconchy (2014) also commented on this curious lack of research,
 321 noting that “the role of writing direction in writing/reading errors among non-
 322 clinical populations is at the moment at best under-investigated and further studies
 323 are needed to clarify the role of writing direction in mirror writing and letter
 324 inversion phenomena” (p. 83).

325 The data compiled by Fischer and coworkers (Fischer & Koch, 2014, 2016a;
 326 Fischer & Tazouti, 2012) provide interesting material that has not yet been exploited
 327 for examining this issue. These data were gathered in naturalistic situations, as
 328 attending school is an almost universal part of growing up in France, the culture in
 329 which the data were collected. More than 500 5-year-old children were asked to
 330 carry out both a character-writing task, in which they had to write all the

331 asymmetrical capital letters and digits under dictation, and a name-writing task. The
 332 name-writing task included a condition (adapted from Cornell, 1985) in which the
 333 children were encouraged by spatial constraints to write their name from right to left
 334 and a condition inducing normal writing. Hence, the role of writing direction in the
 335 capital-letter reversal process can be studied, at least in the children who reversed
 336 the L–R direction of writing, by comparing the writing of the asymmetrical letters in
 337 the character-writing task and in the name-writing task.

338 Method

339 Participants

340 Encouraging R–L writing by applying spatial constraints, but without explicitly
 341 telling children to write from right to left, is far from always being productive. In
 342 order to obtain a sufficiently large sample, we combined data from three
 343 experiments (Fischer & Koch, 2014, 2016a; Fischer & Tazouti, 2012, Expt 2) in
 344 which children were encouraged to write their name from right to left. These three
 345 experiments involved 579 children, 349 of who wrote their name from right to left
 346 (generally in the condition encouraging R–L writing) and who were, therefore,
 347 potentially eligible for inclusion in our analysis sample. However, as Fig. 4 shows
 348 (first column of name writings), some of these children reversed all the reversible
 349 letters in their name (e.g., ALDIN and LEANE), some reversed some of the
 350 reversible letters but not all (e.g., HADJER and JULIETTE), and some did not
 351 reverse any of the reversible letters (e.g., JAROD and MAXENCE).

352 Because the aim of the study was to compare within-participant letter reversals
 353 during right-to-left spontaneous name writing and during normal (L–R) writing of
 354 single letters and words, all the children included in the sample had to have written
 355 their name in both directions and in capital letters. In addition, each child's name
 356 had to contain at least one reversible capital letter. Consequently, our final sample
 357 comprised 204 children ($M_{\text{age}} = 5.60$ years, $SD = 0.35$, range 5.00–6.35, 70 girls,
 358 134 boys) who fulfilled all these conditions. Thirty of these children wrote with the
 359 left hand. Most of the children were attending “upper section” classes in *écoles*
 360 *maternelles* (kindergarten) in northeast France.

361 Material

362 The children had to write (in capital letters) three series of nine or ten dictated
 363 characters. The characters were written in squares (one character per square) on one
 364 side of a sheet of paper (half A4 format), moving from left to right (see Fig. 1). The
 365 precise series and details of the procedures are described in Fischer and Tazouti
 366 (2012, Expt 2) and Fischer and Koch (2014). What is important here is that all 15
 367 asymmetrical capital letters (B, C, D, E, F, G, J, K, L, N, P, Q, R, S, and Z) were
 368 dictated once.³ The children wrote their name on the other side of the sheet of paper,

3FL01 ³ The letters (J and Z) were dictated three times: only the first writing was included in the data. The digit
 3FL02 writings are not analyzed in this study.

Writing Child ^(a)	Right to left Name ^(b)	Normal (Left to right)	
		Reversible letters of the name ^(c)	Name ^(b)
Boy, 5 y. 4 m.	ALDIN	D L N	ALDIN
Girl, 6 y. 1 m.	LEANE	E L N	LEANE
Boy, 5 y. 10 m.	HADTER	D E T R	HADTER
Girl, 6 y. 2 m.	JULIETTE	E T L	JULIETTE
Boy, 5 y. 8 m.	DJARA	D J R	DJARA
Boy, 6 y. 2 m.	MAXENCE	C E N	MAXENCE



Fig. 4 Name writings as a function of direction of writing and normal writings of the single reversible letters included in their name by six of the children in our sample. The *dot* described in the Material section can be seen to the left (*first column* of name writings) or to the right (*last column*) of the vertical line

369 either before or after writing a series of characters. This side of the paper was
 370 bisected into two boxes by an ink line. Two name-writing conditions were used. On
 371 the first and third sheets of paper, an ink dot was positioned about 1 cm to the left of
 372 the median line (dot-left condition: see first column of name writings in Fig. 4). On
 373 the second sheet of paper, this dot was about 1 cm to the right of the median line
 374 (dot-right condition: see the last column of Fig. 4).

375 Procedure

376 In both conditions of the name-writing task children were instructed to write their
 377 (first) name “as beautifully as possible”, beginning at the ink dot. In order to get
 378 reasonably spontaneous writings from the children, even if their writings were not
 379 truly spontaneous, the experimenter did not correct children who took the starting
 380 dot as the finishing point for their writing (or who crossed the bisecting line).
 381 Consequently, because the dot-left condition implicitly encouraged R–L writing, the
 382 children had two main opportunities to momentarily change the normal direction of
 383 writing.

384 Details of how the writings were coded are provided in Fischer and Tazouti
 385 (2012, Expt 2) and Fischer and Koch (2014). The sample of writings shown in
 386 Fig. 4 shows that reversal judgments of capital letters were unambiguous.

387 *Operationalized predictions*

388 We used the three writings—single characters, R–L names, and L–R names—to
 389 compute three correlations: (1) between individual letter reversals in normal writing
 390 of single characters and in R–L writing of the name; (2) between individual letter
 391 reversals in normal writing of single characters and in L–R writing of the name; and
 392 (3) between individual letter reversals in R–L name writing and in L–R name
 393 writing. These correlations are not independent but because of the non-transitivity
 394 of correlations all three are reported.

395 If statistical learning (e.g., Erickson & Thiessen, 2015; Spencer, Kaschak, Jones,
 396 & Lonigan, 2015; Treiman et al., 2014) results in children retaining in their implicit
 397 memory that the letters face right, they should reverse the same letters (mainly J and
 398 Z) irrespective of the writing direction. Therefore, letter reversals should positively
 399 and strongly correlate between any pair of writings. Thus, this statistical learning
 400 (fundamentally visual) predicts that correlations 1, 2, and 3 should be positive and
 401 strong.

402 However, if statistical learning results in children memorizing that the letters face
 403 the writing direction, they should reverse the right-oriented letters when writing
 404 from right to left. Such statistical learning would lead to a negative correlation 1,
 405 with letter reversals in the single-character writing task correlating negatively with
 406 letter reversals in R–L name writing, a positive correlation 2, with letter reversals in
 407 the single-character writing task correlating positively with L–R name writing, and
 408 a negative correlation 3. The level of activation of Fischer's (2013) postulated
 409 implicit RWR is a function of the individual and of the context. Therefore,
 410 activation of the rule should be weaker when children write from right to left. In
 411 fact, as Fischer and Koch (2016a, p. 115) noted, "the rule may disappear or the child
 412 may even transform it into an implicit left-writing rule". The correlations predicted
 413 by such an adaptation of the rule to the direction of writing are the same as those
 414 predicted by statistical learning of the letter's orientation in the direction of writing.

415 If children turn the letters in the direction of writing, they should reverse the
 416 right-oriented letters more frequently than the left-oriented letters (J and Z) when
 417 they write their name from right to left. In contrast, when they write the single
 418 letters (in their name) or their whole name in the "normal" direction (L–R), they
 419 should reverse the left-oriented letters more frequently than the right-oriented
 420 letters.

421 Because the debate between perceptual and motor explanations of mirror-writing
 422 is omnipresent in the literature (see McIntosh & Della Sala, 2012), it should be
 423 emphasized that assuming children orient the letters in the direction of writing does
 424 not mean that learning is based only on a child's motor movements. In fact, many
 425 lines of evidence in adults point to close links between the perceptual and motoric
 426 representations of actions in the brain (Oosterhof, Wiggett, Diedrichsen, Tipper, &
 427 Downing, 2010). When parents or teachers (at least in France's *écoles maternelles*)
 428 in a L–R writing culture "read" picture books to 3- or 4-year-old children, they
 429 usually point to the pictures, moving their finger from left to right (even if they just
 430 point to the pictures on the left-hand page before the pictures on the right-hand
 431 page). Whether or not the accompanying text is read (and tracked with the finger),



432 this practice gives the child an opportunity to see (and therefore implicitly learn)
 433 that the letters of the text are generally oriented in the direction in which their
 434 parent's or teacher's finger moves.

435 Results

436 *Percentages of reversals for the 15 individual letters*

437 Table 2 shows the percentages of reversals for each of the 15 asymmetrical capital
 438 letters in the character-writing and name-writing tasks. Because occurrences of each
 439 letter in the children's names differ greatly, Table 2 also reports the number of
 440 opportunities for writing each of these letters in the name-writing task. Some letters
 441 (e.g., E) occurred frequently in the children's names; others were much rarer. For
 442 example, the letter Q occurred in only two children's names and was therefore
 443 excluded from our correlation coefficient computations. The number of relevant
 444 writings of each letter is indicated in the last column of Table 2. These numbers are
 445 much greater than the numbers of occurrence of the letters in the children's name,
 446 although the children appear to have had difficulties writing the letter G, resulting in
 447 this letter having the lowest number of relevant (correct or reversed) writings.

Table 2 Comparison between reversals of individual letters in normal (L–R) writing of the single letters and writings of the same letters in a R–L or L–R writing of the child's name

Percentage reversal	Name		Number of opportunities ^a	Letter (normal writing)	Number relevant ^b
	Right–left	Left–right			
B	100.0	0.0	8	7.2	152
C	92.9	0.0	28	13.6	162
D	68.4	0.0	19	5.6	160
E	84.4	0.8	122	8.8	194
F	66.7	0.0	6	10.4	144
G	60.0	20.0	5	9.5	95
J	33.3	33.3	18	51.0	153
K	66.7	0.0	6	1.9	107
L	95.8	1.4	72	9.0	167
N	74.2	0.0	95	3.5	170
P	75.0	0.0	8	10.1	168
Q	0.0	0.0	2	14.5	131
R	77.6	0.0	49	7.6	172
S	36.3	5.9	51	20.8	173
Z	0.0	16.7	6	55.6	162

^a The number of opportunities was the same for both R–L and L–R name writing

^b All 204 children were asked to do the character-writing task, but some of them could not write certain letters or produced a writing other than the correct or reversed form of the capital letter in question

448 *Correlational analyses*

449 Correlation 1, between single letter reversals in the character-writing and R–L
 450 name-writing tasks, was significant and negative, $r(12) = -.82, p < .001$. Although
 451 we excluded the letter Q from the computation (which only slightly diminished the
 452 strength of the correlation), many other letters we did include were poorly
 453 represented in the children’s names. Consequently, we computed the same
 454 correlation on the 253 children who had completed these two tasks adequately.
 455 This slightly more representative sample confirmed the strong negative correlation,
 456 $r(12) = -.84, p < .001$.

457 Correlation 2, between single letter reversals in the character-writing and L–R
 458 name-writing tasks, was significant and positive, $r(12) = .78, p < .001$. The large
 459 number of null percentages (8 out of 14) indicates a probable floor effect for this
 460 measure, so we also computed a point-biserial correlation after coding all non-zero
 461 percentages “1”, $r_{pb} = .56, p < .05$.

462 Correlation 3, between letter reversals when the name was written from left to
 463 right and letter reversals when the name was written from right to left, was
 464 significant and negative, $r(12) = -.67, p < .01$. For the same reason as in
 465 correlation 2, we also computed a point-biserial correlation, $r_{pb} = -.49, p < .10$.

466 *Global analyses*

467 On a more global level, we compared the weighted mean percentage of reversals of
 468 the right-oriented capital letters (B, C, D, E, F, G, K, L N, P Q, R, and S) with the
 469 weighted mean percentage of reversals of the left-oriented capital letters (J and Z).
 470 The first percentage was greater than the second percentage (77 vs. 25 %) when the
 471 children wrote their name from right to left, but when the children wrote their name
 472 normally (L–R) and when they wrote the single letters of their name, the first
 473 percentage was smaller than the second percentage (1 vs. 29 and 4 vs. 53 %, respectively).
 474

475 **Discussion**

476 Data gathered by Fischer and coworkers (Fischer & Koch, 2014, 2016a; Fischer &
 477 Tazouti, 2012) offered an opportunity to examine, for the first time, which (capital)
 478 letters children in a L–R writing culture tend to reverse when they spontaneously
 479 write from R–L. The findings were very clear.

480 First, R–L name writing leads to a considerable number of reversals, whereas L–
 481 R writing of the same names leads to very few reversals (Table 2, first column of
 482 name writings). The letter E, which occurred in most of the 204 children’s names,
 483 was reversed on more than 84 % of occasions (i.e., less than 16 % correct Es) when
 484 it was included in a R–L name writing, but on only 0.8 % of occasions (i.e., more
 485 than 99 % correct Es) when it was included in a L–R name writing.

486 Second, if the children orient the letters in the writing direction, the three
 487 correlations we obtained conform perfectly to our predictions. These correlations
 488 were both significant (in the predicted direction) and strong. This was especially



489 true for the negative correlation (correlation 1, $r = -.82$) between reversals of
 490 single characters when written in the normal (L–R) direction and their reversals
 491 when included in a R–L writing. This correlation, which can be considered “very
 492 large” according to the nomenclature introduced by Cohen (1988), seems to
 493 considerably weaken the hypothesis that children implicitly memorize (mostly
 494 visually) letters as facing right, and then use this implicit knowledge when writing.
 495 Indeed, children who do not know a letter’s orientation generally write that letter so
 496 its orientation coincides with the direction of writing. Such behavior could be
 497 favored by the motor dynamics of writing. Transforming the right-orienting/right-
 498 writing rule into a writing-direction-orienting rule reveals the RWR to be a special
 499 case of the more universal rule that applies to L–R writing cultures. Although most
 500 of the digits are turned towards the left (the opposite direction to our writing
 501 direction), the primacy of reading picture books (with the help of parents or
 502 teachers) means it is possible for children to assimilate the rule by statistical
 503 learning (Treiman et al., 2014).

504 Even though the left-oriented capital letters (J and Z) provide only a small
 505 amount of material for studying the comparison between reversals of the left- and
 506 right-oriented characters, they confirm the result of a similar comparison with the
 507 digits. In fact, there are more left-oriented digits (1, 2, 3, 7, and 9) than right-
 508 oriented digits (6, 5, and 4, if one takes into account writing dynamics), and all the
 509 left-oriented digits were reversed more frequently than the right-oriented digits in a
 510 normal (L–R) writing task (in our Study 1 and in Fischer, 2013).

511 In addition to the small number of left-oriented letters, our study has a number of
 512 other limitations. First, it was based, essentially, on children’s writings of their
 513 name. Two inconvenient consequences of this are that (a) some letters (notably the
 514 letter Q) are under-represented and that (b) the percentage reported for each of the
 515 15 asymmetrical letters is based on a (partially) different (and often small) sub-
 516 sample of children. Avoiding this problem would be difficult because at the
 517 developmental age at which children spontaneously mirror write, the only word
 518 most children can write from memory is their name.

519 The second limitation comes from the difficulty of obtaining spontaneous mirror
 520 writings. The “spontaneous” mirror writings in our sample were not truly
 521 spontaneous, as they were prompted by a spatial constraint. However, as shown
 522 by the number of children excluded from the initial sample, the children were never
 523 “forced” or explicitly instructed to write from right to left.

524 A third limitation arises from our decision to focus entirely on capital letters. We
 525 did this because French children are quickly taught to write in a cursive style, using
 526 connected, lower-case letters. Hence, many children mirror wrote their name in this
 527 way (see, for example, Fischer & Tazouti, 2012, Fig. 3). Because cursive mirror
 528 writing implies reversing all the letters, it made no sense to study reversals of
 529 individual letters in names written using this style of writing. As a result, many
 530 children who wrote their name in this way were excluded from the initial sample.

531 **General discussion**

532 Before concluding, we discuss how our present findings may relate to, and thereby
 533 contribute to the discussion of three more general ideas or theories. Our results
 534 indicate that children in a western culture tend to orient the characters, correctly or
 535 erroneously, toward the right (Study 1). This raises the question of the historical
 536 origins of this choice of preferred direction. Interestingly, the results of our Study 2
 537 suggest a partial answer to this epistemological question, as the analysis was based
 538 on data from single experimental sessions involving two conditions in which
 539 children were encouraged to write their names from L–R and from R–L. In the dot-
 540 right condition (encouraging L–R writing), many children wrote their name from
 541 left to right while orienting all the letters toward the right, whereas in the dot-left
 542 condition (encouraging R–L writing), they wrote their name from right to left while
 543 turning all the letters toward the left. If “ontogeny recapitulates phylogeny”, as
 544 postulated by Haeckel (quoted in Shuttlesworth, 2010, p. 40), the genesis of an
 545 individual’s knowledge would be expected to follow the same course as the genesis
 546 of human knowledge. Hence, the alternating behavior shown by children should be
 547 found in early human writings. This is, in fact, the case for the Boustrophedon
 548 writing system, which was used in ancient Greece around the 6th century BC. In this
 549 system, successive lines of text run in opposite directions, left to right, then right to
 550 left, then left to right, etc., with the orientation of the individual characters also
 551 being reversed from one line to the next.

552 Second, the recent spatial agency bias (SAB) model (Suitner & Maass, 2016)
 553 postulates that human agency follows the script direction prevalent in a given
 554 cultural context. Writing direction is the first moderator and “plays a founding role
 555 in defining both the direction and the intensity of the SAB” (p. 280). A possible
 556 explanation is that, in cultures in which text is written from left to right, reading and
 557 writing encourage a scanning habit that also runs from left to right. The SAB model
 558 postulates that this left to right habit generalizes to a much larger spectrum of
 559 actions than just reading and writing. For example, if an individual is asked to depict
 560 an actor (i.e., the agentic person) performing an action on an object, the SAB model
 561 predicts that the actor is likely to be depicted to the left of the object. Nevertheless,
 562 the SAB is also sensitive to short-lived changes in writing direction (Suitner, 2009)
 563 and is therefore compatible with both reversal of the left-oriented characters and
 564 reversal of the right-oriented characters when momentarily writing from right to left
 565 in a L–R writing culture. The compatibility of the present findings with the SAB
 566 model appears to extend the domain of application of this model because all prior
 567 observations of the influence of SAB have been in tasks unrelated to writing.⁴
 568 Furthermore, an essential feature of agency, that is, acting autonomously in a given
 569 environment, holds for our observations: When children do not know which way a
 570 letter is oriented, they use a self-initiating process, with no apparent help, to

4FL01 ⁴ For example, in visual motion drawing (e.g., Maass, Suitner, & Nadhmi, 2014), aesthetic preference
 4FL02 (Chokron & De Agostini, 2000; but see Treiman & Allaith, 2013), and line bisection (Chokron,
 4FL03 Bartolomeo, Perenin, Helft, & Imbert, 1998).



571 improvise its orientation (see Fischer & Koch, 2016b, note 5). These improvisations
572 may be rooted in implicit statistical learning (Treiman et al., 2014).



573 Third, our empirical studies contribute to the central debate in the cognitive
574 sciences over the nativist hypothesis, according to which the universal features of
575 behavior reflect a biologically determined cognitive substrate. Indeed, the ease with
576 which many children reverse the right spatial bias when they write from right to left
577 shows that a weak, culturally induced bias is easily defeasible, as Thompson, Kirby,
578 and Smith (2016) suggested for cognition in general.

579 In summary, our first study used a basic Rasch model to investigate character
580 reversal as the outcome of two competing responses: correct writing and writing in
581 the cultural direction of writing. The model confirmed that 5- to 6-year-old children
582 reverse mainly the left-oriented characters in a L–R writing culture, when
583 orientation is defined taking into account the dynamics of writing. A partial
584 explanation for these reversals is provided by children's implicit knowledge
585 (obtained by visual learning) that the asymmetrical capital letters face right.

586 However, this memorized learning cannot account for the fact that, in a second
587 study, the children reversed mainly the right-oriented letters when they wrote from
588 right to left. These reversals show that the implicit right writing rule (Fischer &
589 Koch, 2016a), which accounts for the reversal of the left-oriented characters in a L–
590 R writing culture, should be more universally seen as an orienting in the writing
591 direction rule.
592

593 References

- 594 Andersen, E. B. (1973). A goodness of fit test for the Rasch model. *Psychometrika*, 38, 123–140. doi:10.
595 1007/BF02291180.
- 596 Casasanto, D., & Bottini, R. (2014). Mirror reading can reverse the flow of time. *Journal of Experimental*
597 *Psychology: General*, 143, 473–479. doi:10.1037/a0033297.
- 598 Chokron, S., Bartolomeo, P., Perenin, M. T., Helft, G., & Imbert, M. (1998). Scanning direction and line
599 bisection: A study of normal subjects and unilateral neglect patients with opposite reading habits.
600 *Cognitive Brain Research*, 7, 173–178. doi:10.1016/S0926-6410(98)00022-6.
- 601 Chokron, S., & De Agostini, M. (2000). Reading habits influence aesthetic preference. *Cognitive Brain*
602 *Research*, 10, 45–49. doi:10.1016/S0926-6410(00)00021-5.
- 603 Christophe, A., Millotte, S., Bernal, S., & Lidz, J. (2008). Bootstrapping lexical and syntactic acquisition.
604 *Language and Speech*, 51, 61–75. doi:10.1177/00238309080510010501.
- 605 Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). New York, NY: Taylor
606 & Francis.
- 607 Corballis, M. C., & Beale, I. L. (1976). *The psychology of left and right*. New York, NY: Erlbaum.
- 608 Cornell, J. (1985). Spontaneous mirror-writing in children. *Canadian Journal of Psychology*, 39,
609 174–179. doi:10.1037/h0080122.
- 610 Dehaene, S. (2010). *Reading in the brain*. New York, NY: Penguin Viking.
- 611 Erickson, L. C., & Thiessen, E. D. (2015). Statistical learning of language: Theory, validity, and
612 predictions of a statistical learning account of language acquisition. *Developmental Review*, 37,
613 66–108. doi:10.1016/j.dr.2015.05.002.
- 614 Fischer, J. P. (2010). Vers une levée du mystère des écritures en miroir (des chiffres) chez l'enfant [Digit
615 mirror-writing in children: Towards an unlocking of the mystery]. *L'année psychologique*, 110,
616 227–251. doi:10.4074/S0003503310002034.
- 617 Fischer, J. P. (2013). Digit reversal in children's writing: A simple theory and its empirical validation.
618 *Journal of Experimental Child Psychology*, 115, 356–370. doi:10.1016/j.jecp.2013.02.003.

- 619 Fischer, J. P., & Koch, A. M. (2014). La magie computationnelle de la voie ventrale est-elle à l'origine de
620 l'inversion des lettres et des chiffres chez l'enfant de cinq à six ans ? [Does the reversal of the letters
621 and digits by the five to six-year-old child originate in the computational magic of the ventral
622 stream?]. *Revue de Neuropsychologie*, 6, 230–237. doi:10.1684/nrp.2014.0318.
- 623 Fischer, J. P., & Koch, A. M. (2016a). Mirror writing in 5- to 6-year-old children: The preferred hand is not
624 the explanation. *Laterality: Asymmetries of Body, Brain and Cognition*, 21, 34–49. doi:10.1080/
625 1357650X.2015.1066383.
- 626 Fischer, J. P., & Koch, A. M. (2016b). Mirror writing in typically developing children: A first longitudinal
627 study. *Cognitive Development*, 38, 114–124. doi:10.1016/j.cogdev.2016.02.005.
- 628 Fischer, J. P., & Tazouti, Y. (2012). Unraveling the mystery of mirror writing in typically developing
629 children. *Journal of Educational Psychology*, 104, 193–205. doi:10.1037/a0025735.
- 630 Flieller, A. (1994). Méthodes d'étude de l'adéquation au modèle logistique à un paramètre (modèle de
631 Rasch) [Methods of assessment of Rasch's model-data fit: A review]. *Mathématiques et Sciences
632 Humaines*, 127, 19–47.
- 633 Gordon, H. (1921). Left-handedness and mirror writing, especially among defective children. *Brain*, 43,
634 313–368. doi:10.1093/brain/43.4.313.
- 635 Hildreth, G. (1950). The development and training of hand dominance: IV. Developmental problems
636 associated with handedness. *Journal of Genetic Psychology*, 76, 39–100. doi:10.1080/08856559.
637 1950.10533526.
- 638 Ireland, W. W. (1881). On mirror-writing and its relation to left-handedness and cerebral disease. *Brain*,
639 4, 361–367. doi:10.1093/brain/4.3.361.
- 640 Kiefer, T., Robitzsch, A., & Wu, M. (2016). *Package 'TAM': Test analysis modules* (version 1.16-0).
641 Retrieved from: <https://cran.r-project.org/web/packages/TAM/TAM.pdf> on February 6, 2016.
- 642 Lebrun, Y., Devreux, F., & Leleux, C. (1989). Mirror-writing. In P. G. Aaron & R. M. Joshi (Eds.),
643 *Reading and writing disorders in different orthographic systems* (pp. 355–378). Dordrecht: Kluwer
644 Academic Publishers.
- 645 Maass, A., Suitner, C., & Deconchy, J. P. (2014).  *Writing in an asymmetrical world: How writing
646 direction affects thought and action*. London: Psychology Press.
- 647 Maass, A., Suitner, C., & Nadhmi, F. (2014).  What drives the spatial agency bias? An Italian–Malagasy–
648 Arabic comparison study. *Journal of Experimental Psychology: General*, 143, 991–996. doi:10.
649 1037/a0034989.
- 650 Mair, P., & Hatzinger, R. (2007). Extended Rasch modeling: The eRm package for the application of IRT
651 models in R. *Journal of Statistical Software*, 20(9), 1–20. doi:10.18637/jss.v020.i09.
- 652 Maydeu-Olivares, A. (2013). Goodness-of-fit assessment of item response theory models. *Measurement:
653 Interdisciplinary Research and Perspectives*, 11(3), 71–101. doi:10.1080/15366367.2013.831680.
- 654 McIntosh, R. D., & Della Sala, S. (2012). Mirror-writing. *The Psychologist*, 25, 742–746.
- 655 Oosterhof, N. N., Wiggert, A. J., Diedrichsen, J., Tipper, S. P., & Downing, P. E. (2010). Surface-based
656 information mapping reveals crossmodal vision-action representations in human parietal and
657 occipitotemporal cortex. *Journal of Neurophysiology*, 104, 1077–1089. doi:10.1152/jn.00326.2010.
- 658 R Core Team. (2015). *R: A language and environment for statistical computing*. Vienna (Austria): R
659 Foundation for Statistical Computing. <https://www.R-project.org/>.
- 660 Ritchey, K. D. (2008). The building blocks of writing: Learning to write letters and spell words. *Reading
661 and Writing: An Interdisciplinary Journal*, 21, 27–47. doi:10.1007/s11145-007-9063-0.
- 662 Román, A., Flumini, A., Lizano, P., Escobar, M., & Santiago, J. (2015). Reading direction causes spatial
663 biases in mental model construction in language understanding. *Scientific Reports*, 5(18248), 1–8.
664 doi:10.1038/srep18248.
- 665 Scheidemann, N. V. (1936). Inverse writing: A case of consistent mirror writing. *The Pedagogical
666 Seminary and Journal of Genetic Psychology*, 48, 489–494. doi:10.1080/08856559.1936.10533745.
- 667 Shuttleworth, S. (2010). *The mind of the child: Child development in literature, science, and medicine,
668 1840–1900*. Oxford: Oxford University Press.
- 669 Spencer, M., Kaschak, M. P., Jones, J. L., & Lonigan, C. J. (2015). Statistical learning is related to early
670 literacy-related skills. *Reading and Writing: An Interdisciplinary Journal*, 28, 467–490. doi:10.
671 1007/s11145-014-9533-0.
- 672 Suitner, C. (2009). *Where to place social targets? Stereotyping and spatial agency bias*. Retrieved from
673 http://paduaresearch.cab.unipd.it/1756/1/tesi_suitner.pdf on April 8, 2016.
- 674 Suitner, C., & Maass, A. (2016). Spatial agency bias: Representing people in space. *Advances in
675 Experimental Social Psychology*, 53, 245–301. doi:10.1016/bs.aesp.2015.09.004.



- 676 Thompson, B., Kirby, S., & Smith, K. (2016). Culture shapes the evolution of cognition. *PNAS*, *113*,
 677 4530–4535. doi:[10.1073/pnas.1523631113](https://doi.org/10.1073/pnas.1523631113).
- 678 Treiman, R., & Allaith, Z. (2013). Do reading habits influence aesthetic preferences? *Reading and*
 679 *Writing: An Interdisciplinary Journal*, *26*, 1381–1386. doi:[10.1007/s11145-012-9424-1](https://doi.org/10.1007/s11145-012-9424-1).
- 680 Treiman, R., Gordon, J., Boada, R., Peterson, R. L., & Pennington, B. F. (2014). Statistical learning, letter
 681 reversals, and reading. *Scientific Studies of Reading*, *18*, 383–394. doi:[10.1080/10888438.2013.](https://doi.org/10.1080/10888438.2013.873937)
 682 [873937](https://doi.org/10.1080/10888438.2013.873937).
- 683 Treiman, R., & Kessler, B. (2011). Similarities among the shapes of writing and their effects on learning.
 684 *Written Language and Literacy*, *14*, 39–57. doi:[10.1075/wll.14.1.03tre](https://doi.org/10.1075/wll.14.1.03tre).
- 685 Wilson, M., & De Boeck, P. (2004). Descriptive and explanatory item response models. In P. de Boeck &
 686 M. Wilson (Eds.), *Explanatory item response models: A generalized linear and nonlinear approach*
 687 (pp. 43–74). New York, NY: Springer.

Journal : **11145**
Article : **9688**



Springer

the language of science

Author Query Form

Please ensure you fill out your response to the queries raised below and return this form along with your corrections

Dear Author

During the process of typesetting your article, the following queries have arisen. Please check your typeset proof carefully against the queries listed below and mark the necessary changes either directly on the proof/online grid or in the 'Author's response' area provided below

Query	Details Required	Author's Response
AQ1	Please confirm the section headings are correctly identified.	