

## Orthographic coding in illiterates and literates

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## Abstract

We investigated how literacy modifies one of the mechanisms of the visual system that is essential for efficient reading: flexible position coding. To do so, we focused on the abilities of literates and illiterates to compare two-dimensional strings of elements with character-position manipulations. Results from two perceptual matching experiments revealed that literates are sensitive to within-string position and identity alterations, while illiterates are almost blind to these changes. We concluded that letter-position coding is a mechanism that emerges during literacy acquisition and that the recognition of sequences of objects is highly modulated by reading skills. These data offer new insights about the manner in which reading acquisition shapes the visual system by making it highly sensitive to the internal structure of sequences of characters.

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Deciphering written information requires complex visual skills. These, however, are deeply rooted in a language system, and are acquired through intensive explicit training that often implicates phonological decoding (e.g., Frost, 1998; Share, 1995). Here we ask whether the manner by which the human visual system processes sequential orthographic elements is *qualitatively* shaped by literacy.

The role of literacy in orthographic processing is questioned by recent evidence suggesting that non-human primates can handle orthographic material relatively well after extensive training (Grainger, Dufau et al., 2012). Grainger et al. demonstrated that trained baboons were able to discriminate between a large set of words and nonwords in a simple lexical decision task. Furthermore, trained baboons also show flexibility in letter-position coding (e.g., failing to differentiate between DNOE and DONE; Ziegler et al., 2013), somewhat resembling human behavior (but see Frost & Keuleers, 2013, for discussion). In fact, data from humans consistently demonstrate flexibility in coding letter position (see Grainger, 2008, for review), an effect evident even after elementary reading instruction (e.g., Ziegler, Bertrand, Lété, & Grainger, in press). Hence, on the face of it, reading acquisition for humans and orthographic training with baboons seem to result in the emergence and development of similar visuo-orthographic perceptual skills.

In the current study we focused on the etiology of the mechanisms that lead to the observed flexibility in orthographic coding in humans, by investigating the origin of a critical marker of orthographic processing: the transposed-letter (TL) effect (i.e., failing to efficiently differentiate between a known letter-string and another one created by transposing two of its internal elements; e.g., CHOLOCA TE and CHOCOLATE; see Perea, Duñabeitia, & Carreiras, 2008, and Frost, 2012, for reviews). Current models of reading, in general, and of orthographic processing, in particular, offer different explanations for this marker. Some accounts propose that TL effects reflect domain-general, noisy perceptual mechanisms of the

visual system, that apply to orthographic processing just as they apply to visual object recognition (e.g., Norris, 2006; Gómez, Ratcliff, & Perea, 2008). Other accounts tie flexible letter-position coding to the type of orthographic representations that exclusively develop through reading instruction (e.g., Davis, 2010; Grainger & Ziegler, 2011; Whitney, 2001). To date the evidence suggests that some form of orthographic-specificity underlies TL effects (e.g., Duñabeitia et al., 2012; Massol et al., 2013), but the origin of the flexibility in orthographic coding and the nature of transposed-letter effects remain to be clarified.

To shed light on this debate we explored character-in-string position assignment in literates and illiterates. We designed two perceptual matching experiments to examine the sensitivity of literate and illiterate adults to letter and symbol strings that were similar to each other except for the transposition of two internal elements. Comparing performance of illiterates to that of literates will determine whether literacy acquisition leads to qualitative changes in the way letter strings are visually processed, and whether orthographic effects found in baboons and humans are likely to result from similar cognitive mechanisms (see Frost & Keuleers, 2013). If processing the position of characters in a string follows domain-general principles rooted in a noisy object recognition system (e.g., Norris, 2006), then both literates and illiterates will show similar patterns of transposed-letter effects (i.e., difficulty in identifying that NDTF-NTDF are distinct, as compared to a substituted-letter condition like NSBF-NTDF). In contrast, if literacy is (at least partially) responsible for the development of orthographic coding principles based on flexible position assignment mechanisms, literate adults should show sizeable TL effects, while illiterate individuals should exhibit notably reduced effects. This was directly tested in Experiment 1. Since potential between-group differences in the magnitude of TL effects could be partially explained by the obviously unequal exposure of literates and illiterates to letter stimuli, in Experiment 2 we explored the

sensitivity of the same groups of participants to transpositions and replacements in non-linguistic symbol strings, which neither group has extensive experience with.

## Experiments

**Participants.** After a careful sample selection process (including several experimental assessments of reading abilities; see SOM-R), 19 Mexican illiterates and 19 literate adults were tested. These participants were carefully matched for age, socio-economic status, gender, and working memory. All participants were recruited from 8 municipalities of the Mexican state of Morelos, where the adult illiteracy rate is 7% (INEGI, 2014). The National Institute of Adult Education, INEA, granted access to all the illiterate and literate participants, and care was taken to select the appropriate control (i.e., literate) participants from the exact same neighborhoods as the illiterate participants, hence controlling for the potential impact of different socio-demographic origins.

**Materials.** Two perceptual matching tasks that included pairs of identical or different character strings were created (90 pairs in the “*same*” condition and 90 pairs in the “*different*” condition in each experiment). The “*different*” pairs modified the internal characters of one string, either interchanging their position (i.e., transposed-characters; 45 pairs per experiment), or substituting by other characters (i.e., replaced-characters; 45 pairs per experiment). Experiment 1 involved letter strings made of consonants (letters K/G/L/N/B/D/S/T/F), and Experiment 2 involved symbol strings (symbols %/&/?/£/</\$/(/€/+/). Similar to previous studies, flexibility in character-position coding was assessed by comparing performance in the transposed-character conditions to performance in the replaced-character conditions. The set of materials was taken from Duñabeitia et al. (2012), and illustrative examples are shown in the Table. Two lists were constructed for

counterbalancing purposes. The order of the experiments and the presentation of the items were randomized across participants.

**Procedure.** Participants were tested individually. Stimuli were presented on a computer at a distance of 70 cm (1024x768 resolution, 90Hz), in black Courier New font on a white background. Each trial started with the presentation of a fixation cross in the center of the screen for 500ms. Next, the reference stimulus was presented for 300ms, horizontally centered above the center of the screen. After the reference, the target was displayed horizontally centered below the center for a maximum of 5000ms or until response. The ISI was set to 500ms. Participants were instructed to press one of two buttons on a gamepad when the two strings were identical and the other when they were different. Participants were asked to respond as accurately as possible once the target had appeared on the screen, with no time pressure.

## Results

ANOVAs were run on the error rates in the “*different*” responses following a 2x2 design (*Group*: literates/illiterates; *Type*: transposed/replaced). Mean error rates for Experiment 1 (letters) and Experiment 2 (symbols) are presented in the Figure and in the Table. We focused on the percentages of errors, given that participants were instructed to prioritize accuracy over speed of response (note that timeout was set to 5000ms since participants had little experience with computers). The short display time used for the references (300ms) yields sufficiently high error rates to allow for between- and within-group analyses (Duñabeitia et al., 2012; Massol et al., 2013).

**Table.** Mean error rates (percentage) and standard deviations in each condition tested in Experiment 1 (letter strings) and Experiment 2 (symbol strings), together with the transposed-character effects (mean error rate in the

transposed-characters conditions minus mean error rate in the replaced-characters conditions), and d-prime ( $d'$ ) and beta ( $\beta$ ) indices of discriminability and decision bias.

	LITERATES		ILLITERATES	
	Mean	SD	Mean	SD
<b><i>Experiment 1</i></b>				
(Target: <i>NDTF</i> )				
<b>Same responses</b>	14.70%	10.40	24.67%	14.09
(Reference: <i>NDTF</i> )				
<b>Transposed-letters</b>	39.04%	24.31	62.41%	24.24
(Reference: <i>NTDF</i> )				
<b>Replaced-letters</b>	20.48%	17.33	62.08%	26.34
(Reference: <i>NSBF</i> )				
<b>Effect</b>	<b>18.56%</b>		<b>0.33%</b>	
<b><math>d'</math></b> (discriminability)	1.80		0.40	
<b><math>\beta</math></b> (bias)	0.72		1.03	
<b><i>Experiment 2</i></b>				
(Target: ?&ℓ<)				
<b>Same responses</b>	14.16%	10.47	29.91%	13.67
(Reference: ?&ℓ<)				
<b>Transposed-symbols</b>	43.77%	19.92	60.56%	19.57
(Reference: ?ℓ&<)				
<b>Replaced-symbols</b>	30.05%	19.18	57.15%	22.49
(Reference: ?\$%<)				
<b>Effect</b>	<b>13.72%</b>		<b>3.41%</b>	
<b><math>d'</math></b> (discriminability)	1.56		0.35	
<b><math>\beta</math></b> (bias)	0.59		0.93	

Results from Experiment 1 (letters) showed a main effect of Type ( $F_1(1,36)=22.76, p<.001, \eta^2_{\text{partial}}=.387$ ;  $F_2(1,88)=37.47, p<.001, \eta^2_{\text{partial}}=.299$ ) and a main effect of Group ( $F_1(1,36)=19.81, p<.001, \eta^2_{\text{partial}}=.355$ ;  $F_2(1,88)=494.56, p<.001, \eta^2_{\text{partial}}=.849$ ), but more importantly, the interaction between the two factors was significant

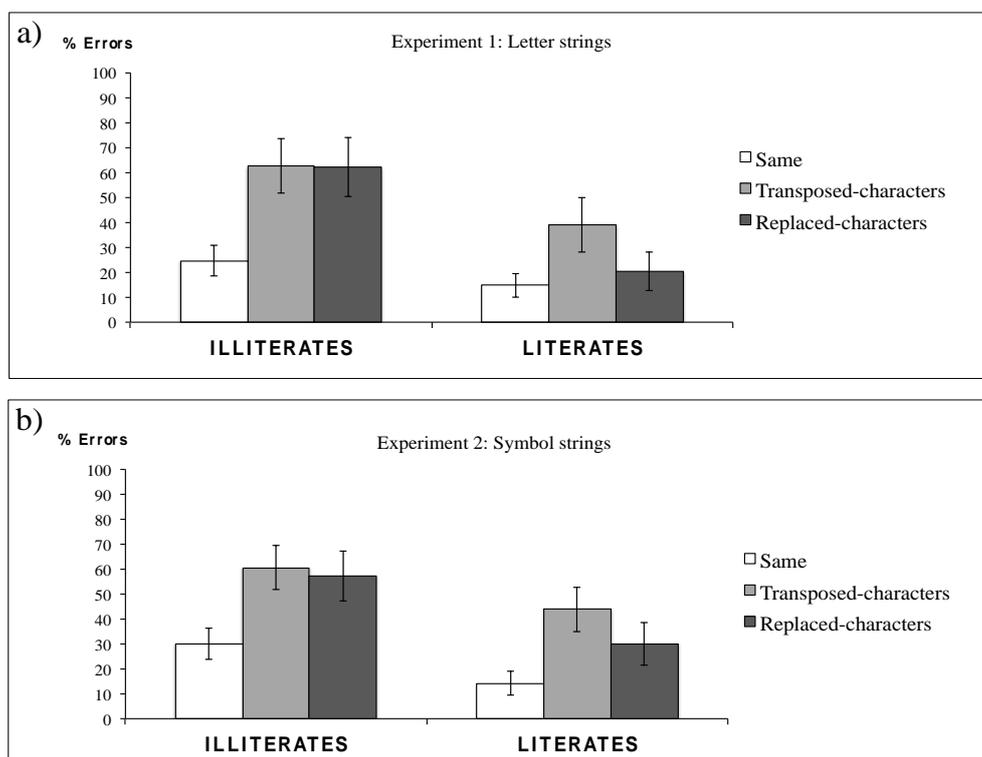
( $F_1(1,36)=21.17, p<.001, \eta^2_{\text{partial}}=.370$ ;  $F_2(1,88)=38.82, p<.001, \eta^2_{\text{partial}}=.306$ ), showing that while literates clearly made more errors in the transposed-letter than replaced-letter condition ( $t_1(18)=5.55, p<.001$ ;  $t_2(88)=9.16, p<.001$ ), illiterates showed no significant differences between these conditions ( $t_{1,2}<1, ps>.85$ ).

Highly similar results were obtained in Experiment 2 (symbols). Main effect of Type was significant ( $F_1(1,36)=20.89, p<.001, \eta^2_{\text{partial}}=.367$ ;  $F_2(1,88)=20.46, p<.001, \eta^2_{\text{partial}}=.189$ ), as was Group effect ( $F_1(1,36)=12.04, p<.01, \eta^2_{\text{partial}}=.251$ ;  $F_2(1,88)=184.01, p<.001, \eta^2_{\text{partial}}=.677$ ). The interaction between these two factors was again significant, showing that the transposed-character effect was different for literates and illiterates ( $F_1(1,36)=7.55, p<.01, \eta^2_{\text{partial}}=.173$ ;  $F_2(1,88)=9.23, p<.01, \eta^2_{\text{partial}}=.095$ ). The transposed-character effect was significant for literates ( $t_1(18)=4.66, p<.001$ ;  $t_2(88)=5.26, p<.001$ ), but not for illiterates ( $t_{1,2}<1.5, ps>.13$ )<sup>1</sup>.

**Figure.** Mean error rates for the group of literate and illiterate participants in Experiment 1 (letter strings, upper panel) and Experiment 2 (symbol strings, lower panel). Error bars represent 95% confidence intervals.

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<sup>1</sup> The difference between the TL effects for literates in letter strings and in symbol strings (18.56% vs. 13.72%) is in line with the results observed by Duñabeitia et al. (2012) and Massol et al. (2013). However, this 5% difference was not significant in the current study, most probably due to the sample size.



We also ensured that all participants performed reasonably well in these experiments by contrasting the individual sensitivity indices against chance-level distributions. Binominal tests on the accuracy rates in “*same*” responses for each participant were significant (all  $p_{\text{binomial}} < .05$ ). Also, considering the nature of the same-different task, we analyzed participants’ discriminability indices and their decision bias according to Signal Detection Theory.  $d'$  indices for discriminability and  $\beta$  scores for decision biases were calculated for literates and illiterates in each of the experiments.  $d'$  scores were larger for literates than for illiterates<sup>2</sup> (see Table), and this observation was supported by  $t$  tests comparing the two groups of participants in Experiment 1 ( $t(36) = -4.68, p < .001$ ) and in Experiment 2 ( $t(36) = -5.45, p < .001$ ). Accordingly,  $\beta$  scores were significantly lower for literates than for illiterates (Experiment 1:  $t(36) = -2.64, p < .02$ ; Experiment 2:  $t(36) = 4.19, p < .001$ ), validating the more

<sup>2</sup> Considering the high number of errors elicited by the transposed-character conditions, we also computed  $d'$  indices including data from all the “*same*” and only the “*different*” trials consisting of character replacements. While the results for the illiterate group remained similar (0.39 in Experiments 1 and 2),  $d'$  scores for the literate group increased substantially (2.18 in Experiment 1 and 1.79 in Experiment 2).

conservative (i.e., less guessing) nature of the responses of the literates as compared to the illiterates.

### Discussion

This pattern of results suggests clear-cut dissimilarities in the way literates and illiterates process a sequence of visual elements, and in their skills to code the identity and position of the elements conforming two-dimensional sequences. In contrast to the significant transposed-character effects found for the group of literates, illiterates did not show any specific differential discrimination cost between transposed- and replaced-character conditions. This was shown in a perceptual matching experiment including letter strings (Experiment 1), and using symbol strings (Experiment 2). The identical pattern of results in both experiments suggests that the differences between literates and illiterates are not due to the greater exposure of literates to printed sequences of letters, thereby generalizing the findings to other types of visual elements that rarely form strings. Therefore, the first critical finding from this study is the total absence of transposed-character effects in this group of illiterates.

In spite of the reasonable performance by the illiterates in the “*same*” conditions (different from chance), they showed significant difficulties in responding accurately to the “*different*” trials (i.e., performance around chance level). This demonstrates that illiterate adults struggle when comparing strings of visual elements on the basis of their internal constituents. Hence, the second important finding corresponds to the surprising inability of illiterate adults to successfully identify individual characters that are embedded within strings. These data unambiguously demonstrate that the skills related to the processing of internal characters’ identities and positions are inherently dependent on literacy acquisition.

Nevertheless, the current manipulations involved internal characters exclusively, and future research should clarify whether these effects can be reproduced with manipulations involving external characters.

These data offer new insights that could help to refine current models of orthographic coding. If character-position coding processes are inherently dependent on literacy, then the underlying principles guiding flexible orthographic coding cannot be fully explained by assuming a generic noisy perceptual mechanism that processes all visual stimuli, letters and objects, alike (e.g., Norris, 2006; Gómez et al., 2008; see Carreiras et al., 2014, for a discussion). Rather, transposed-character effects are the consequence of the letter-specific visual coding mechanisms that develop during reading acquisition (see Duñabeitia et al., 2012, for review).

Furthermore, the importance of the current set of data extends well beyond the scope of models of orthographic coding. We demonstrated that the impact of literacy on visual perception is not limited to reading (see also Szwed et al., 2012). The current results add to a growing body of evidence suggesting that literacy produces substantial anatomical and functional changes in the human brain (e.g., Carreiras et al., 2009; Dehaene et al., 2010), and that the visuo-perceptual and spatial abilities of the literate brain are not functionally comparable to those of the illiterate brain (e.g., Kolinsky et al., 2011; Reis et al., 2001; see Ardila et al., 2010, for review). The apparent inefficiency of the visual system of illiterate adults to access the individual constituents of strings of characters emphasizes the benefits derived from literacy for identifying and processing short sequences of characters.

Finally, there are important theoretical consequences of the parallelisms and discrepancies between the present results and the data from non-human primates. Literates who have acquired the orthographic code over and above a preexisting spoken linguistic code show a high level of flexibility in character-position coding. Animals who lack a spoken

language and have been intensively trained with orthographic material seem to show a flexible coding strategy too (Ziegler et al., 2013). In sharp contrast, illiterate adults with a spoken code show negligible effects. Thus, intensive training with visually presented sequences of letters could be thought to be the most determinant factor for the acquisition of orthographic coding skills and consequently for the emergence of transposed-character effects. However, a closer look at the performance of baboons, literates and illiterates in the *replaced-character* conditions leads to a different conclusion. Interestingly, illiterates and non-human primates show a similar pattern in their responses to these conditions, showing chance-level performance (Experiment 1: 62% errors; Experiment 2: 57% errors; Ziegler et al.: 56% errors). In contrast, human literates show much better performance (Experiment 1: 20% errors; Experiment 2: 30% errors). Hence, considering the difficulty shown by baboons in identifying replaced-characters (similar to illiterates' performance), the transposed-character effects found are likely to result from different cognitive mechanisms. This suggests that orthographic coding skills do not emerge merely from intensive training with visually presented sequences of letters or any other visual objects, ruling out explanations exclusively grounded on a familiarity-based visual discrimination of the visual stimuli (see Vokey & Jamieson, 2014). As argued by Frost and Keuleers (2013), a flexible letter-position coding system assumes that the internal constituents of letter strings are accurately detected in the first place. We suggest that the flexibility in character-position coding requires *both* the preexistence of a linguistic system *and* the emergence of an orthographic coding system as a consequence of literacy training.

This study suggests that literacy provides readers with a granular visuo-orthographic coding approach, thus enhancing their skills for discriminating the individual elements that constitute a multi-character string, and at the same time, increasing their tolerance to minimal disruptions in the order of these elements. The emergence of TL effects appears to depend on

the effective establishment of a written orthographic code, as also suggested by recent developmental data showing that the magnitude of TL effects increases as a function of children's reading experience (see Ziegler et al., in press). In contrast to theories advocating that the generic positional noisy coding of the domain-general visual system explains the high degree of flexibility of the orthographic coding system, our data suggest that the etiology of these orthographic coding skills should be fully ascribed to literacy.

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## Orthographic coding in illiterates and literates

### Supplementary Online Material Revised (SOM-R)

#### Additional information regarding the selection of the participants

The 19 Mexican literate adults and the 19 Mexican illiterates from the same communities who took part in the experiments were native Spanish speakers, had normal or corrected-to-normal vision and were right-handed (see SOMR\_Table\_1). The 8 municipalities from the state of Morelos involved in the current study were Cuernavaca, Huitzilac, Coatlán del Rio, Emiliano Zapata, Xochitepec, Tepoztlán, Tlayacapan and Zacatepec. The two groups of participants were matched for age ( $p=.79$ ), socio-economic status (using a normative questionnaire from the Mexican National Statistical Institute;  $p=.19$ ), gender (18 females in each group), and working memory (using direct and inverse versions of the digit-span test;  $p=.25$  and  $p=.13$ , respectively). Furthermore, an adapted version of the MMSE ensured that none of the participants manifested the presence of cognitive impairment.

**SOMR\_Table\_1.** Characteristics (means and standard deviations) of the participants.

	LITERATES		ILLITERATES	
	Mean	SD	Mean	SD
Age (in years)	39.00	10.11	39.95	11.59
SES (points)	29.53	18.85	37.84	19.87
Digits direct (span)	5.68	1.86	5.05	1.47
Digits inverse (span)	2.89	1.76	2.05	1.54
MMSE (over 17)	17.00	0.00	16.26	0.93
Number of females	18		18	

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<u>Experiment 1</u>				
Same responses	14.70%	10.40	24.67%	14.09
Transposed letters	39.04%	24.31	62.41%	24.24
Replaced letters	20.48%	17.33	62.08%	26.34
<i>Effect</i>	<b>18.56%</b>		<b>0.33%</b>	
<u>Experiment 2</u>				
Same responses	14.16%	10.47	29.91%	13.67
Transposed letters	43.77%	19.92	60.56%	19.57
Replaced letters	30.05%	19.18	57.15%	22.49
<i>Effect</i>	<b>13.72%</b>		<b>3.41%</b>	

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In order to ensure that literates were skilled readers whereas illiterates did not know how to read, all participants underwent a complete reading assessment. First, all participants completed the 40-nonword reading subtest in PROLEC (a Spanish reading test developed by Cuetos et al., 2007). None of the illiterates was able to read aloud a single nonword, while literates performed reasonably well (mean time=75.79secs, SD=36.89; mean accuracy=85.53%, SD=9.6; between-group  $p < .001$ ).

Second, all participants were given a computerized lexical decision test including 40 Spanish words and 40 nonwords. The 40 Spanish words were selected from B-Pal (Davis & Perea, 2005). All these words were disyllabic (e.g., “nariz”, translated as nose), and had a mean length of 4.75 letters and a mean frequency of 38.26 appearances per million words. The mean number of orthographic neighbors (N) of these words was 4.52. Additionally, a parallel set of 40 nonword targets was created by rearranging the initial and final syllables of the real words (e.g., “selor”). Participants were presented with the whole list of 80 items (40 words, 40 nonwords) in a randomized order after a short practice with 4 trials (2 words, 2 nonwords). They were instructed to press one of two buttons in order to indicate whether each of the strings displayed corresponded to an existing Spanish word or not. Illiterates were asked to respond intuitively if they did not know the correct answer. Presentation of the

stimuli and data collection was carried out using DMDX (Forster & Forster, 2003). Every trial started with the presentation of a fixation mark for 500ms, immediately followed by the centered presentation of the visual string in Courier New font for a maximum of 3500ms or until response. While illiterates clearly performed around chance level in this task (mean error rate=58.75%, SD=11.44, min=44%), literates completed the task correctly (mean error rate=9.67%, SD=7.76, max=28%; between-group  $p < .001$ ).

Third, we asked participants to complete a regular Stroop color-naming task. Considering that this paradigm has been classically employed to highlight effects associated with reading automation, we expected to see significant interference and congruence effects for the literate group, while no significant differences are to be expected in the illiterate group in the absence of orthographic knowledge. The Stroop test included 24 congruent items (e.g., the word “rojo” in red ink), 24 incongruent items (e.g., the word “rojo” in blue ink), 24 neutral word items (e.g., the word “sala” in red ink), and 24 neutral symbols (e.g., the string “%” in red ink). Eight Spanish words were used in this task. These words corresponded to the names of the colors green, red, blue and yellow (“verde”, “rojo”, “azul” and “amarillo” in Spanish), and four pairwise-matched words with a similar length, frequency and syllabic structure that did not correspond to color names (“torno”, “sala”, “olor” and “uniforme”, translated as drill or lathe, lounge, smell and uniform, respectively). These words were then arranged to create the Congruent, Incongruent and Neutral Word conditions. The Congruent condition (24 trials) was created by presenting each of the color names printed in the color that matched the lexical entry (e.g., the word “verde” printed in green ink). In the Congruent condition each color name was presented six times (i.e., 4 color names x 6 presentations = 24 trials). The Incongruent condition (24 trials) was created by presenting each color name printed in a color that did not match the color represented by the lexical entry (e.g., the word “verde” printed in red ink). To this end, each color name was presented printed

in each of the other colors twice (i.e., 4 words x 3 colors x 2 presentations = 24 trials). The Neutral Word condition (24 trials) was created by presenting the non-color words in the ink color that corresponded to their pairwise-matched counterparts from the color name set. As in the Congruent condition, each word was presented six times (i.e., 4 words x 6 presentations = 24 trials). Finally, we also included a Control Symbol condition (24 trials) in order to be able to explore potential differences between groups with a minimal influence from reading-related processes. To this end, strings of percentage symbols (e.g., “% % % % %”) were presented in the four possible ink colors (i.e., 4 colors x 6 presentations = 24 trials). Hence, each participant was presented with a total of 96 experimental trials. The trial presentation order was randomized across participants.

The experiment was run using DMDX (Forster & Forster, 2003) and verbal responses were collected through Sennheisser PC151 headsets. Participants were instructed to name the color of the ink of each of the strings presented on the screen. After the instructions, participants completed a short familiarization phase that included four trials (one per condition), and received feedback regarding their accuracy in the practice trials. Immediately after this, participants were presented with the 96 experimental trials. Participants first saw a fixation mark that was briefly displayed in the center of the screen for 300ms and once the fixation mark disappeared, the visual display containing the experimental item was presented until a verbal response was given or for a maximum of 3500ms. All the strings were presented in uppercase Courier New font on a black background. The precise RGB-scale values for each of the colors of the ink of the strings were as follows: green=0,255,0; blue=0,0,255; red=255,0,0; yellow=255,255,0. The whole experimental session lasted around 8 minutes.

**SOMR\_Table\_2.** Mean reaction times (in ms) and error rates (percentage) in all conditions tested in the Stroop experiment for the literate and illiterate groups.

	Reaction times						
	Conditions				Effects		
	Congruent	Incongruent	N. Word	N. Symbol	Stroop	Congruency	Incongruity
Literates	892	1193	988	865	-301	96	-205
Illiterates	944	967	923	921	-23	-21	-44

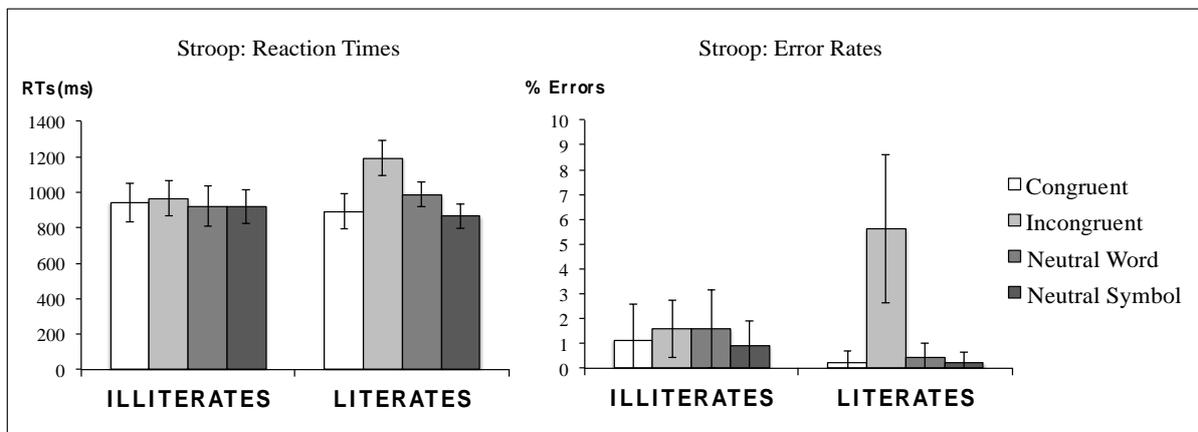
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	Error rates						
	Conditions				Effects		
	Congruent	Incongruent	N. Word	N. Symbol	Stroop	Congruency	Incongruity
Literates	0.23	5.61	0.44	0.22	-5.38	0.21	-5.18
Illiterates	1.15	1.59	1.58	0.90	-0.44	0.43	-0.01

Individual verbal responses were collected and resulting data were preprocessed and corrected for incorrect voice key triggering with the help of CheckVocal (Protopapas, 2007). Incorrect responses and reaction times below or above 2.5 standard deviations from the mean in each condition for each participant were excluded from the latency analysis. The mean latencies for correct responses and error rates are presented in SOMR\_Table\_2. Results confirmed that the literate group displayed a main Condition effect (3 levels: Congruent, Incongruent, Neutral Word) in the RTs and in the error rates ( $F_{1RT}(2,36)=43.44, p<.001$ ;  $F_{2RT}(2,71)=110.71, p<.001$ ;  $F_{1error}(2,36)=12.43, p<.01$ ;  $F_{2error}(2,71)=26.77, p<.001$ ). In contrast, no Condition effect was found for illiterates (all  $F_s<1.5$  and  $p_s>.23$ ; note that the interaction between Group and Condition was significant:  $F_{1RT}(2,72)=13.14, p<.001$ ;  $F_{2RT}(2,69)=50.54, p<.001$ ;  $F_{1error}(2,72)=7.17, p<.01$ ;  $F_{2error}(2,69)=14.30, p<.001$ ). Follow-up analyses confirmed that whereas illiterates showed no differences across conditions, literates showed neat classic Stroop, congruency and incongruity effects in the RTs (all  $t_{1RT}>7, df=18, p_s<.01$ ; all  $t_{2RT}>4, df=36, p_s<.001$ ), and Stroop and incongruity effects in the error rates (all  $t_{1error}>3, df=18, p_s<.01$ , all  $t_{2error}>5, df=36, p_s<.001$ ; see SOMR\_Table\_2 and SOMR\_Figure). Besides, we performed a between-group comparison for the data in the

Neutral Symbol condition, since no a priori differences should be observed between literates and illiterates in this condition, given that those stimuli were not intelligible by reading and bore no (in)congruency. Results showed that the two groups did not significantly differ in their RTs and error rates in this condition (independent-sample  $t_{RT}(36) < 1$ ,  $p > .35$ ,  $t_{error}(36) < 1.2$ ,  $p > .24$ ).

**SOMR\_Figure.** Mean reaction times and error rates for the group of literate and illiterate participants in the Stroop test. Error bars represent the 95% confidence intervals.



Hence, according to this exhaustive assessment of implicit and explicit reading, we ensured that the two groups displayed qualitative differences in their reading skills. While illiterates were unable to read nonwords, performed at chance in a visual lexical decision task and showed no effects in the Stroop task, literates correctly read most of the nonwords, performed well in the lexical decision task and showed typical Stroop effects.

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