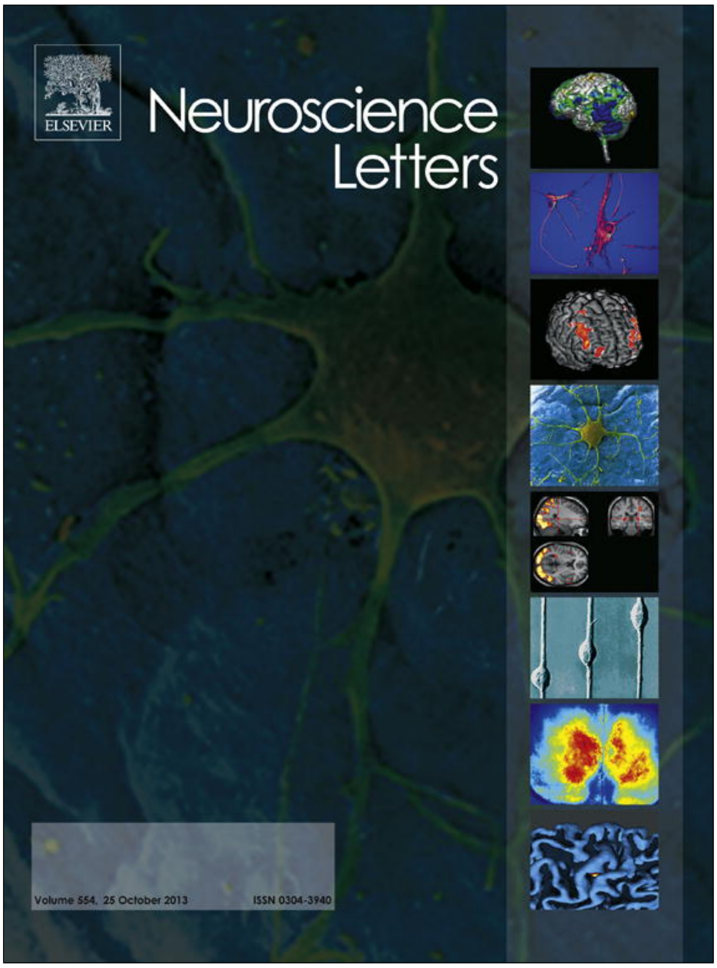
ELSEVIER
Neuroscience Letters
Volume 554, 25 October 2013
ISSN 0304-3940

Neuroscience Letters 554 (2013) 105–109

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

Literacy acquisition reduces the influence of automatic holistic processing of faces and houses

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HIGHLIGHTS

- Holistic processing of faces and houses were studied through composite face tasks.
- Illiterates, ex-illiterates and literates were tested.
- Illiterates were consistently more holistic in dealing with faces and houses.
- Literacy has a broad effect on visual processing style.

ARTICLE INFO

Article history:
Received 28 May 2013
Received in revised form 15 August 2013
Accepted 28 August 2013

Keywords:
Reading
Face processing
House processing
Holistic processing
Analytic processing

ABSTRACT

Writing was invented too recently to have influenced the human genome. Consequently, reading acquisition must rely on partial recycling of pre-existing brain systems. Prior fMRI evidence showed that in literates a left-hemispheric visual region increases its activation to written strings relative to illiterates and reduces its response to faces. Increasing literacy also leads to a stronger right-hemispheric lateralization for faces. Here, we evaluated whether this reorganization of the brain's face system has behavioral consequences for the processing of non-linguistic visual stimuli. Three groups of adult illiterates, ex-illiterates and literates were tested with the sequential composite face paradigm that evaluates the automaticity with which faces are processed as wholes. Illiterates were consistently more holistic than participants with reading experience in dealing with faces. A second experiment replicated this effect with both faces and houses. Brain reorganization induced by literacy seems to reduce the influence of automatic holistic processing of faces and houses by enabling the use of a more analytic and flexible processing strategy, at least when holistic processing is detrimental to the task.

1. Introduction

Learning to read leads to the development of a strong response to written materials in the left fusiform gyrus, in the "visual word form area" (*VWFA*, e.g. [8,11]). Here, we examine whether it also has consequences outside the language domain. In a recent fMRI study comparing illiterate to literate adults [13], we showed that at the VWFA site, learning to read competes with the cortical representation of other visual objects, especially faces. With increasing literacy, cortical responses to faces decrease slightly in the left fusiform region while increasing strongly in the right fusiform face area (*FFA*). Thus, right-hemispheric lateralization for faces is increased in literates compared to illiterates. Further developmental studies corroborate a tight link between reading acquisition and changes in face processing [6,15,20,25,31,32,38].

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http://dx.doi.org/10.1016/j.neulet.2013.08.068

These observations support the existence of competition between the VWFA and FFA [10,11,39], with some displacement of fusiform face-sensitive areas toward the right hemisphere. A similar theoretical perspective [4,33] espouses interplay between cooperation and competition between distributed circuits for face and word recognition.

However it remains unknown whether this brain reorganization has behavioral consequences. Here, we investigate whether face processing is affected by literacy, and particularly whether holistic processing is changed. It is generally accepted that faces are processed differently than other objects, relying considerably on "holistic" processing of the whole face configuration [e.g. 28]. Under the simple view that the right FFA encodes configuration while the left fusiform gyrus encodes features [e.g. 5], one might predict that the stronger right-hemispheric lateralization for face processing with literacy implies a more holistic processing of faces.

However, such tuning might be flexible and dynamic [19,26], and the depth with which a face is holistically encoded may depend on the nature of the task [17,34]. By training the left fusiform gyrus to process letters and their combinations, literacy may enhance an analytic mode of visual processing which would generalize to processing of other visual categories represented at this and nearby cortical sites, thus bringing more flexibility to face processing. Accordingly literate adults would more easily adopt an analytic mode of face processing if the task requires it, while illiterate adults would systematically adopt what may be the default or privileged mode of processing faces in adults, namely holistic processing (this matures as early as after 4 years of experience with faces [14]).

To evaluate these two hypotheses we compared holistic processing in adult illiterates, literates, and ex-illiterates. In Experiment 1, all stimuli were made out of faces. In Experiment 2, we compared faces to another object category, namely houses.

In both experiments participants had to determine if the bottom halves of two sequentially presented composite images were the same while trying to ignore the top halves.

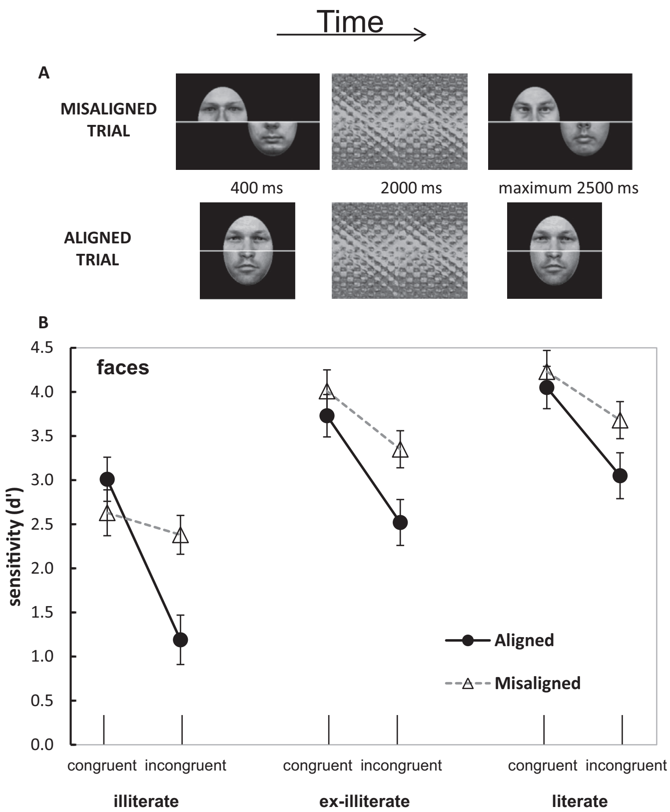

Fig. 1. Design and results of Experiment 1 (faces). (A) Experimental design. Participants were asked to say aloud if the bottom part of the test face was either the same or different from the study face. (B) Results. Average *d'* scores (error bars SEM) for aligned and misaligned, congruent and incongruent trials, separately by group. Lines provide a graphic depiction of congruency effect/HP index for aligned (black line) and misaligned (gray line) conditions.

2. Experiment 1: composite face task

2.1. Materials and methods

2.1.1. Participants

Three groups of 22 participants each were examined: literates (16 females; average age 54.7 ± 13.2 yrs), ex-illiterates (16 females; average age 54.8 ± 7.8 yrs), and illiterates (16 females; average age 56.1 ± 12.3 yrs). All were recruited through non-governmental agencies participating to social projects in a small town on the outskirts of Lisbon, Portugal. They were matched as closely as possible on cultural and socio-economic characteristics, and came from similar households. All had normal or corrected-to-normal visual acuity (Snellen chart for illiterates) and were fully functional in their daily lives. Ex-illiterates and illiterates had received no early schooling during childhood. Among them, we considered as ex-illiterates those who had fulfilled adult alphabetization courses, while illiterates were still unable to read even simple words (but could identify some letters; see Supplementary Table 1 for results on letter identification and reading tests). Literate participants had benefited from regular education (including literacy) at an early age and were all normal readers. All participants gave their informed consent (the consent form was read aloud and explained to illiterates) which is archived by the first author. The experiment was approved by the Deontological Committee – Faculty of Psychology (University of Lisbon) and conformed to the Declaration of Helsinki.

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.neulet.2013.08.068.

2.1.2. Material

Stimuli were constructed from 28 male faces (8 for training) from the MPI face database [44], converted to gray scale and cut in half. Stimuli were composites made out of the top- and bottom-half of different faces. A line separated face halves. To eliminate cues derived from the shape of the head or chin, we presented faces inside an oval within a black rectangle (see Fig. 1A).

For the sequential matching task (of bottom-halves) we used the complete design, with four types of trials: congruent *same* (both halves of study and test faces were identical), congruent *different* (both halves of study and test faces were different), incongruent *same* (only the bottom halves of the study and test faces were identical, the top halves were different) and incongruent *different* (only the bottom halves of the study and test faces were different, the top halves were identical). Study and test faces were either both aligned (bottom and top halves were spatially aligned) or both misaligned (bottom halves were spatially offset from the top halves); we used strongly misaligned faces to facilitate attention to the target part.

Two aligned and two misaligned blocks were counterbalanced and followed interactive training. Each block comprised 80 trials, 40 congruent and 40 incongruent (in both cases, half *same* and half *different*).

2.1.3. Procedure

On each trial, a fixation cross appeared in the center of the screen for 500 ms followed by a study face shown for 400 ms. After a 2000 ms mask stimulus, a test face appeared. Participants were instructed to match the bottom parts of the composites while ignoring the top parts. They had to say aloud if the bottom part of the test face was either the same or different as that of the study face. The experimenter registered the response by pressing either one of the two keys. The test face was presented for a maximum of 2500 ms, disappearing as soon as a response was provided.

2.2. Results

We analyzed all trials on sensitivity, using *d'* scores adapted for same–different comparison designs [27]. To avoid infinite *d'* scores, for participants with 100% correct performance (and no false alarms: one illiterate, two ex-illiterates, one literate) we followed the suggestion of Macmillan and Creelman [27] and adjusted proportions of 0 and $1-1/(2N)$ and $(1-1/(2N))$, respectively (N being the number of trials on which the proportion is based).

Participants who performed the task at chance level (three illiterates) were excluded from the analyses.

The results of the $3 \times 2 \times 2$ mixed ANOVA with congruency and alignment as within-participants factors and group as the between-participants factor, is presented in Supplementary material. Importantly, the three-way interaction was significant. To interpret this interaction, we computed a congruency effects/Holistic Processing, HP index corresponding to the *d'* scores difference between incongruent and congruent trials, separately for aligned and misaligned stimuli (Fig. 1B). Larger HP scores reflect a stronger tendency to process the whole stimulus rather than just the bottom-part. The planned contrast comparing HPs between aligned vs. misaligned trials for illiterates vs. literates was significant [$F(1, 60) = 6.56$, $p < .01$], as well as that comparing illiterates vs. ex-illiterates [$F(1, 60) = 5.49$, $p < .05$]. HP scores were thus higher for illiterates when faces were aligned. If the stronger congruency effect for aligned than misaligned stimuli reflects holistic processing, then illiterates rely on holistic processing more than ex-illiterates and literates.

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3. Experiment 2: composite face vs. house tasks

Thus far our results are consistent with the hypothesis that acquiring literacy enables to partly reduce reliance on holistic processing. However, is strong holistic reliance a general processing mode in illiterates, or is it specific to faces? To approach this question we devised a new composite task, comparing face to house processing in fresh participants. Houses were chosen as control stimuli because, like faces, they have a canonical orientation, possess a reliable set of parts, and tend to share a common configuration. However, houses preferentially activate the parahippocampal place area – PPA [3] and lingual gyrus [1,2], a region not affected by literacy [13]. We therefore predicted no effect of literacy on the holistic processing of houses. On the other hand, recent fMRI evidence [9] during a same–different task with faces and houses showed first-order perceptual differentiation at the right FFA/occipitotemporal cortex that was not specific for faces. Some researchers propose that many of the regions typically attributed to face processing may be involved in making fine distinctions among stimuli within visually homogeneous categories [18]. Accordingly, literate participants may develop an analytic mode of visual discrimination that may influence faces and even houses.

3.1. Materials and methods

3.1.1. Participants

A new pool of 71 participants was tested, with characteristics equivalent to those of Experiment 1 (see Supplementary Table 1 for details on letter identification and reading tasks): 21 illiterates (16 females; average age 40.4 ± 15.4 yrs), 24 ex-illiterates (13 females; average age 41.0 ± 9.6 yrs), and 26 literates (18 females, average age 43.2 ± 13.411 yrs).

Participants gave their informed consent (the consent form was read aloud and explained to illiterates), which is archived by the first author. The experiment was approved by the Deontological Committee – Faculty of Psychology (University of Lisbon) and conformed to the Declaration of Helsinki.

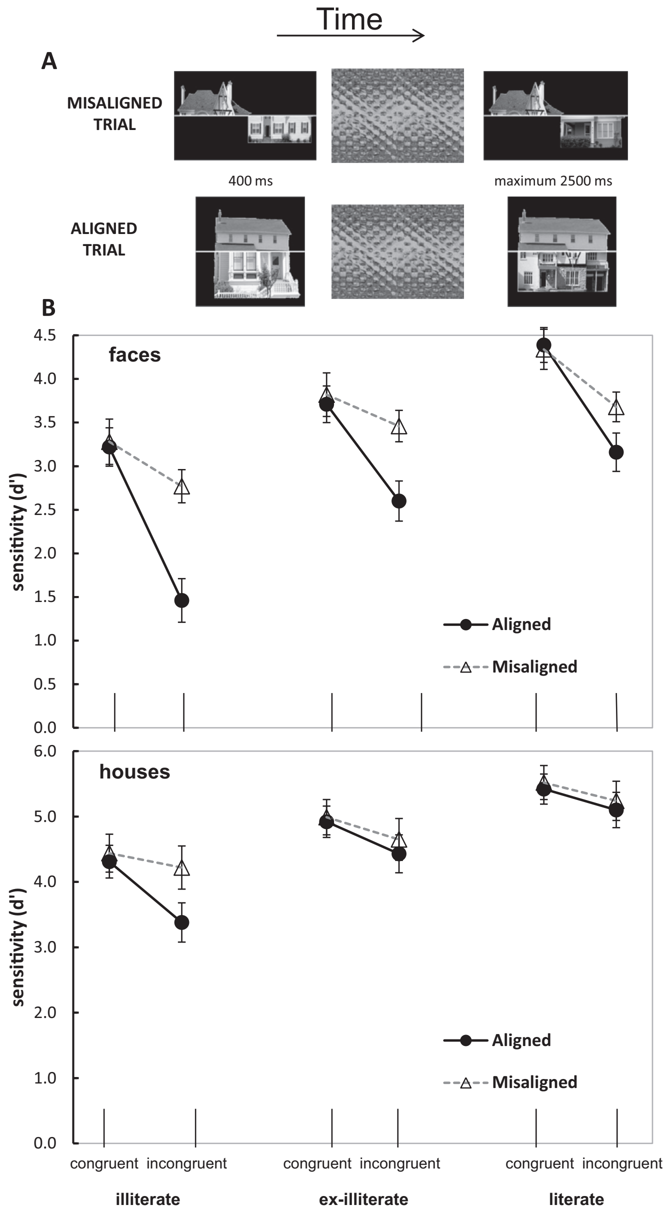

Fig. 2. Design and results of Experiment 2 (faces and houses). (A) Experimental stimuli for the house composite task. Participants were asked to say aloud if the bottom part of the test house was either the same or different from the study house. (B) Results. Average *d'* scores error bars SEM) for aligned and misaligned, congruent and incongruent trials, separately by group and material (faces or houses). Lines provide a graphic depiction of congruency effect/HP index for aligned (black line) and misaligned (gray line) conditions.

3.2. Material and procedure

House stimuli were constructed from 28 houses (8 for training; see Fig. 2A). Except for this, material construction, the face stimuli, and procedure were the same as in Experiment 1. Order of face and house blocks was counterbalanced.

3.3. Results

We analyzed *d'* scores adapted for same–different comparison designs and adopted the same procedure as in Experiment 1 to avoid infinite *d'* scores [27] (for faces: one illiterate and four literates; for houses: three illiterates and six literates).

Participants with average *d'* scores below 1 and performance at chance in the easiest conditions (congruent trials) were excluded (two illiterates, 3 ex-illiterates, three literates).

The results of the $3 \times 2 \times 2 \times 2$ mixed ANOVA with material (faces vs. houses), congruency and alignment as within-participants factors and group as the between-participants factor are presented in Supplementary material. As in Experiment 1, we computed congruency effects/HP indexes separately for aligned and misaligned stimuli, and for each material (Fig. 2B). The results of the analyses performed on HP mirror those on *d'* scores. In particular, material interacted with alignment [$F(1, 60) = 6.42$, $p < .05$], indicating higher HP scores for faces than for houses only in the aligned condition [$F(1, 60) = 22.45$, $p < .0001$], not in the misaligned condition [$F(1, 60) = 2.13$, $p > .10$]. As in the analysis on *d'* scores, these effects were not modulated by group [$F < 1$]. Alignment interacted with group [$F(2, 60) = 4.0$, $p < .05$]: HP scores were higher for illiterates compared to the other groups for the aligned stimuli [$F(1, 60) = 8.94$, $p < .005$, not for the misaligned ones [$F < 1$]. Yet, this interaction was not modulated by material [$F < 1$]. Thus, the analyses do not support a specific effect of literacy on face processing.

4. Discussion

Literates were consistently less holistic than individuals without any reading experience. Indeed, the effect is not specific to faces, but extends to houses. Literacy thus seems to induce a generic shift in the ability to deploy analytic visual strategies, over and above any specific effect that it may have on face processing. By differentially training the left and right fusiform regions, literacy brings more flexibility to visual object processing, partly reducing the influence of default holistic processing, at least when detrimental to the task. The improvement of analytic performance observed here in literate participants adds to a growing list of visual enhancements induced by reading acquisition [12,16,24,35,36,42,43].

Holistic processing has different meanings and can be operationalized by different measures [37,40,41]. Here we used the complete-design composite task to examine holistic processing as a failure of selective attention to a face (or house) part. Literates (including ex-illiterates) were better able than illiterates to follow the instructions that called for selective attention to the bottom halves of both faces and houses in the aligned condition, probably as a consequence of enhanced analytic processing. Thus, literacy reduces the influence of holistic processing when it is detrimental to the task by enabling the use of a more analytic and flexible processing strategy [cf. also 47].

The fact that we found a generalized effect of literacy on both face and house processing deserves further comments.

First, it is not usual to compare holistic processing of faces and other objects [7]. Yet, without testing non-face objects, one cannot determine whether holistic processing reflects what is special to face recognition rather than more general properties of object recognition [41]. We found larger composite effects for faces than for houses, although the effect was significant for both categories. These effects may thus reflect, at least in part, domain-general object recognition abilities. Future studies should thus compare face processing to that of different object categories [29].

Second, whether the generalized effect induced by literacy reported here extends to other markers of analytic/holistic processing is a matter of future research. Former studies have already reported processing differences that may be partly related to literacy [22, 23; see also 21, 30, 45]. However, in these studies, ex-illiterates showed the same response patterns as illiterates. On the contrary, here, ex-illiterate and literate adults did not differ on holistic processing, and both differed from illiterates, for both faces and houses. Thus, the present results do not point to an effect of early schooling and/or early literacy acquisition, as did the former data [22,23,45]. Whether the same holds true for other measures of holistic processing of faces (e.g., the inversion effect, [46]) would be worth examining.

Third, what neural mechanisms may underlie the behavioral changes that we observed? Our research was initially motivated by the fMRI observation that, in the fusiform gyrus, face activation is partially shifted toward the right hemisphere in literates compared to illiterates [13]; see also [5,15,20,25,31,32,38]. However, the present results reveal a similar behavioral change for faces as for houses. The latter category primarily activates the parahippocampal rather than the fusiform gyrus, a site where no significant change was induced by literacy in fMRI [13]. This finding reduces the plausibility that a change in FFA lateralization underlies the behavioral change from holistic to more analytic processing reported here in literates.

Finally, it is already known that face processing matures as early as after 4 years of experience with faces [14]. Data from our study may even suggest that holistic processing is the default processing mode that is modified by literacy and (possibly) by other aspects of learning.

5. Conclusions

Literacy impacts face processing, probably as a consequence of enhanced analytic processing. It brings more flexibility in reducing the influence of automatic holistic processing. This effect is not specific to faces, but is also observed for houses. Literacy acquisition thus has a broad effect on visual processing style, which generalizes well beyond the narrow domain of letter and word recognition.

Acknowledgments

We thank Isabel Gauthier and Jennifer Richler for their suggestions, comments, and kindness, and Brad Duchaine and Kirsten Dalrymple for comments on a previous version of the manuscript. We also thank the two non-governmental agencies collaborating in this study: AMUCIP (Olga Mariano) and K'cidade (Cristina Simões and Mário Palma). PV is supported by an FCT grant (PTDC/PSI-PCO/0999526/2008). RK and JM are supported by the Fonds de la Recherche Scientifique – FNRS under grant FRFC 2.4515.12 and by a Interuniversity Attraction Poles grant "IAP 7/33", Belspo; RK is Research Director of the Fonds de la Recherche Scientifique – FNRS, Belgium. SD and LC were supported by INSERM, CEA, Collège de France, Fondation Bettencourt-Schueller, and Agence Nationale de la Recherche grant CORELEX.

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