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From hand to eye: The role of literacy, familiarity, graspability, and vision-for-action on enantiomorphy

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ABSTRACT

Literacy in a script with mirrored symbols boosts the ability to discriminate mirror images, i.e., *enantiomorphy*. In the present study we evaluated the impact of four factors on enantiomorphic abilities: (i) the degree of literacy of the participants; (ii) the familiarity of the material; (iii) the strength of the association between familiar objects and manipulation, i.e., *graspability*; and (iv) the involvement of vision-for-action in the task. Three groups of adults – unschooled illiterates, unschooled ex-illiterates, and schooled literates – participated in two experiments. In Experiment 1, participants performed a vision-for-perception task, i.e., an orientation-based same–different comparison task, on pictures of familiar objects and geometric shapes. Graspability of familiar objects and unfamiliarity of the stimuli facilitated orientation discrimination, but did not help illiterate participants to overcome their difficulties with enantiomorphy. Compared to a baseline, illiterate adults had the strongest performance drop for mirror images, whereas for plane rotations the performance drop was similar across groups. In Experiment 2, participants performed a vision-for-action task; they were asked to decide which hand they would use to grasp a familiar object according to its current position (e.g., indicating left-hand usage to grasp a cup with the handle on the left side, and right-hand usage for its mirror image). Illiterates were as skillful as literates to perform this task. The present study thus provided three important findings. First, once triggered by literacy, enantiomorphy generalizes to any visual object category, as part of vision-for-perception, i.e., in visual recognition and identification processes. Second, the impact of literacy is much stronger on enantiomorphy than on the processing of other orientation contrasts. Third, in vision-for-action tasks, illiterates are as sensitive as literates to enantiomorphic-related information.

1. Introduction

1.1. Theoretical background

Reading is a highly demanding visual task that requires adapting the existing cognitive and neural architecture. Consequently, learning to read does not only creates a specific circuitry for processing written material in the ventral occipitotemporal region (*vOT*) including the "visual word form area" (*VWFA*, e.g., Cohen et al., 2000; Dehaene & Cohen, 2011), but also deeply impacts on non-linguistic visual processing. This has been shown through studies comparing schooled literate adults to both *illiterate* adults, who did not attend school nor learn to read or write due to socioeconomic reasons, and unschooled *ex-illiterates*, who are from the same socioeconomic background as illiterates but learned to read and write as adults in special alphabetization courses. These studies have shown that at the brain level, learning to read induces a broad enhancement of occipital responses to non-letter stimuli and leads to neural competition in the left vOT between written words and other visual categories, in particular faces (Dehaene et al., 2010). At the behavioral level, learning to read improves contour integration (Szwed, Ventura, Querido, Cohen, & Dehaene, 2012) and boosts the ability to discriminate lateral mirror images (Kolinsky et al., 2011).

The latter ability, also called *enantiomorphy*, was the topic of the present work. Enantiomorphy may be considered as running against a large tendency among humans and animals to consider mirror images as equivalent (see a review e.g., in Corballis & Beale, 1976). This tendency, called *mirror-image generalization* or *mirror invariance*, is considered as evolutionarily advantageous for processing natural objects, which are mostly symmetric (Gross & Bornstein, 1978), and hence, remain the same under lateral reflection. However, mirror invariance needs to be "broken" in order to learn a script with mirrored symbols such as "b" vs. "d" (Gibson, 1969).

In our former work (Kolinsky et al., 2011), we showed that illiterates displayed poor enantiomorphy abilities; for example, they presented far

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poorer performance than schooled literates and ex-illiterates when asked to judge whether two simultaneously or sequentially presented geometrical or blob-like shapes were in the same or in different orientations. In contrast, ex-illiterates were as able as schooled literates to discriminate mirror images (henceforth, *enantiomorphs*). Illiterates' poor results did not reflect general visual processing troubles, as they were quite able to discriminate other orientation contrasts like rotations in the plane (henceforth, *plane rotations*) as well as other dimensions of the stimuli like size, shape, or color. Furthermore, data from literates in a script with no mirrored symbols, namely the Tamil syllabary, refute the idea that the illiterates' results were due to extraneous factors as motivation to the task, for the Tamil literates displayed as poor enantiomorphy as illiterates (Danziger & Pederson, 1998; Pederson, 2003). Thus, the available evidence shows that it is learning to read a script with mirrored symbols that triggers enantiomorphy, an ability that generalizes to novel non-linguistic material.

Nevertheless, several issues remain hitherto unclear as regards the emergence of enantiomorphy. First, to our knowledge, no prior study has evaluated whether enantiomorphy would also generalize to familiar non-linguistic objects (e.g., pictures of tools and clothes), as previous work has only used geometric or blob-like shapes (Danziger & Pederson, 1998; Kolinsky et al., 2011; Pederson, 2003). One could argue that illiterate adults are less familiar with this kind of material than the literate groups, making impossible to disentangle the role of material familiarity from that of literacy on enantiomorphic performance. Yet, rather than being deleterious, material unfamiliarity may in fact benefit enantiomorphy, or, more generally, orientation discrimination. Indeed, participants are extremely sensitive to orientation variations of novel shapes, but not of familiar objects (see e.g., Tarr & Pinker, 1989). Familiar objects have been seen from many viewpoints, allowing observers to develop either orientation-invariant representations (e.g., object-centered structural descriptions: Biederman & Gerhardstein, 1993) or multiple orientation-specific representations (Tarr & Bülthoff, 1995). Thus, they are represented relatively independently of orientation, whereas novel shapes (as geometric and blob-like shapes) seem to be coded in a view-dependent, orientation-specific manner (Tarr & Bülthoff, 1995; Tarr & Pinker, 1989). Although this would hold true for both literates and illiterates, it may thus be the case that illiterates would present even stronger difficulties to discriminate orientation contrasts of familiar objects than of novel shapes.

Second, all the results reported so far were gathered in situations requiring *vision-for-perception*, known to rely massively on the visual ventral stream (including the VWFA) dedicated to object recognition, namely, on the *what* stream projecting from striate cortex to inferotemporal cortex (Goodale & Milner, 1992). Neither this task trait nor the motor-related characteristics of the material were considered as potentially relevant factors.

Task characteristics may be relevant as visual processing depends not only on the ventral stream but also on the dorsal stream, namely on the *how* stream projecting from striate to posterior parietal cortex, responsible for *vision-for-action* (Goodale & Milner, 1992). Although the two streams may operate simultaneously during object recognition, even in passive viewing conditions (e.g., Valyear, Culham, Sharif, Westwood, & Goodale, 2006), they present quite different properties (Creem & Proffitt, 2001): whereas the vOT is sensitive to identity changes and insensitive to orientation changes (Valyear et al., 2006), the lateral occipito-parietal junction, (*lOPJ*), part of the dorsal stream, shows the reverse pattern (for nonhuman primate evidence, see e.g., Murata, Gallese, Luppino, Kaseda, & Sakata, 2000). The two streams also differ by the type of referential frame. While the processes subserved by the ventral pathway use object-centered *allocentric* representations suitable for view-independent object recognition, those subserved by the dorsal pathway use viewer-centered *egocentric* representations appropriate to the moment-to-moment interaction with objects (Goodale, Jakobson, & Keillor, 1994; Milner & Goodale, 1993, 2008). As illiterates are likely to deal correctly with familiar objects in everyday life (they do not seem to have more problems than literates, for instance, in putting the right shoe on the right foot), even though they have troubles with enantiomorphy in vision-for-perception tasks (Danziger & Pederson, 1998; Kolinsky et al., 2011; Pederson, 2003), it would be worth checking whether they perform as well as literates in a vision-for-action task requiring sensitivity to enantiomorphic-related information.

The motor-related characteristics of the material may be relevant as well, even in vision-for-perception tasks. Indeed, in a task that did not involve any object-directed action (an upright/inverted judgment), it has been shown that action-related information is automatically invoked by *graspable* objects, for which there is a strong relationship between shape and manner of being grasped (e.g., a frying pan), leading to stimulus–response compatibility effects (Tucker & Ellis, 1998). Coherently, in a same–different orientation-based comparison task on sequentially presented objects, sensitivity to mirror-image changes in the lOPJ was observed only for graspable objects, not for *non-graspable* objects like a tractor or a sofa (Rice, Valyear, Goodale, Milner, & Culham, 2007; see also Valyear et al., 2006, for similar evidence in passive viewing). Hence, orientation judgments might be more easily performed for graspable than for non-graspable familiar objects.

Finally, we may wonder whether literacy impacts specifically on enantiomorphy or also modulates other orientation judgments. Neuropsychological data have shown that different processing mechanisms supported by largely different brain areas are engaged by plane rotations and mirror reflections (for evidence on the double-dissociation see e.g., Turnbull & McCarthy, 1996; Turnbull, Becshin, & DellaSala, 1997). Furthermore, neuron recordings in monkeys showed that inferotemporal cells are sensitive to plane rotations but not to enantiomorphs (Baylis & Driver, 2001; Logothetis & Pauls, 1995; Logothetis, Pauls, & Poggio, 1995), and brain imaging data in humans showed that the ventral pathway is originally mirror-invariant, with the VWFA remaining largely so for natural objects (Dehaene et al., 2010; Pegado, Nakamura, Cohen, & Dehaene, 2011). The impact of literacy acquisition may thus be stronger on enantiomorphy than on other, non-enantiomorphic, orientation discriminations. Although our former data were coherent with this suggestion (Kolinsky et al., 2011), as illiterates' difficulties were particularly severe with enantiomorphs, literates were in fact better able than illiterates to discriminate orientation contrasts overall. It would thus be worth exploring this point more systematically. Noteworthy, in the Latin alphabet, a few plane rotation contrasts are used to differentiate between letters, and with lower case-letters only 180° rotations are pertinent (e.g., "d" vs. "p"; "u" vs. "n"). To our knowledge, no study has hitherto compared the discrimination of 180° plane rotations to enantiomorphy of geometric shapes, nor of real objects, a comparison which would add the additional benefit of controlling for the angular difference (which is the same as in the out-of-plane flip involved in enantiomorphs).

1.2. Overview of the present study

We examined these issues by testing the impact of four factors on enantiomorphy: the degree of literacy of the participants, the familiarity of the material, the strength of the association between familiar shapes and manipulation, and the nature of the task, involving either vision-for-perception or vision-for-action. To this aim, three groups of adults – unschooled illiterate and ex-illiterate, and schooled literate – participated in two experiments.

In Experiment 1, we used as vision-for-perception task an orientation-based same–different comparison task, using sequential presentation of the stimuli as most prior studies (Dehaene, Nakamura, et al., 2010; Kolinsky et al., 2011; Pegado et al., submitted for publication). We examined for the first time the degree of generalization of enantiomorphy, as consequence of literacy acquisition, by using three types of asymmetrical material: geometric shapes, graspable familiar objects, and non-graspable familiar objects. *Graspability* referred here to the fact that the orientation of the object in the picture strongly signaled the use of one particular hand to grasp it. This was