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Brief Report

Inhibition of the mirror generalization process in reading in school-aged children

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ABSTRACT

A striking error in reading is the early and sometimes persistent confusion of mirror letters such as *b* and *d*. These mirror errors are likely a result of the mirror generalization process that allows one to identify a visual stimulus regardless of its presentation side. A previous study demonstrated that preventing mirror errors in reading requires the inhibition of the mirror generalization process in expert adult readers (Borst et al., 2015). Using the same experimental paradigm, the current study aimed at replicating this result in school-aged children. Three age groups—1st, 3rd, and 5th graders—performed a negative priming study in which they were asked to determine on the primes whether two letters were identical and on the probes whether two animals facing opposite directions were identical. All three groups of children required more time to discriminate two letters that were lateral mirror images of one another (e.g., b/d) than two letters that were not (e.g., f/t). Crucially, children required more time to determine that two animals facing opposite directions were identical when preceded by two letters that were lateral mirror images of one another (b/d) than when preceded by letters that were not mirror images of one another (f/t). Importantly, the amplitude of the negative priming effect did not vary with age. Our results suggest that overcoming mirror errors in reading, regardless of the reading proficiency of school-aged children, is rooted in the ability to inhibit the mirror generalization process.

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Introduction

Learning and teaching are two of the most elaborate human abilities. As we learn, we face numerous and diverse sources of errors. Most of the errors disappear with training or with age, but some persist. In certain contexts, systematic errors are believed to be partially related to our tendency to rely on heuristics (i.e., fast, automatic, and holistic strategies) in situations where they interfere with algorithmic strategies (i.e., slow, cognitively demanding, and analytical strategies) (Gilovich, Griffin, & Kahneman, 2002). For instance, in Piaget's (1952) seminal number conservation problem, where two rows of tokens are presented and then one of the rows is transformed in length and the child is asked whether the two rows contain the same number of tokens, children's errors are partially due to their inability to inhibit their tendency to rely on the ''length equals number" heuristic to solve this problem (e.g., Houdé & Guichart, 2001; Poirel et al., 2012). A growing number of studies have shown that a failure to inhibit a misleading heuristic accounts for systematic errors in solving classical Piagetian problems (e.g., Borst, Poirel, Pineau, Cassotti, & Houdé, 2013) in the resolution of arithmetic word problems, such as at school (Lubin, Vidal, Lanoë, Houdé, & Borst, 2013), and in the visual discrimination of letters with lateral mirror-image counterparts (Borst, Ahr, Roell, & Houdé, 2015).

In the current study, we focused on mirror errors and, specifically, on the confusion of letters with lateral mirror-image counterparts, that is, confusing *b* with *d* and confusing *p* with *q*. Mirror errors are common in preschool and school-aged children aged 3 to 7 years (Cornell, 1985; Gardner & Broman, 1979; Hildreth, 1934). Several theories have been proposed to account for these mirror errors in reading. According to several models, mirror errors are a consequence of the symmetrical organization of the brain and notably of the occipito-temporal cortices of the left and right hemispheres (Lachmann, 2002; Orton, 1925). For instance, in Orton's (1925) model, mirror errors occur in reading because neurons of the occipito-temporal cortices are oriented in opposite directions in the left and right hemispheres and, thus, these two brain areas store mirror-image representations of the same letter. According to Lachmann (2002), the mirror generalization process—a process that is applied to all visual stimuli before one learns to read and that allows us to recognize an object regardless of its left–right orientation (e.g., Pegado, Nakamura, Cohen, & Dehaene, 2011)—leads to the co-storage and co-retrieval of the image representation of a letter and its mirror-image representation and, thus, to mirror errors in reading. Note that findings from several studies have challenged the assumption that mirror errors occur because of the symmetrical organization of the brain (see, e.g., Corballis, Miller, & Morgan, 1971; Corballis et al., 2010; Fisher & Camenzuli, 1987; Gregory & McCloskey, 2010; Kosslyn, LeSueur, Dror, & Gazzaniga, 1993; Storandt, 1974).

Because the mirror generalization process has been observed in adults (Dehaene, Nakamura et al., 2010; Dehaene, Pegado et al., 2010), children (Nelson & Peoples, 1974), infants (Bornstein, Gross, & Wolf, 1978), and other species (Rollenhagen & Olson, 2000), new models have argued that mirror generalization is an innate property of the visual system, selected by evolution to facilitate the visual recognition of relevant objects, animals, or places (Rollenhagen & Olson, 2000). Functional magnetic resonance imaging (fMRI) studies have revealed that mirror generalization is a built-in property of the posterior fusiform sulcus and of the parahippocampal place area, object- and building-selective regions of the visual ventral stream, respectively (Dilks, Julian, Kubilius, Spelke, & Kanwisher, 2011). In this study, we focused on lateral mirror-image generalization because lateral mirror errors are more prevalent in reading than mirror errors in other directions (e.g., Bornstein et al., 1978; Cairns & Steward, 1970; Corballis & McLaren, 1984). That said, we acknowledge that the prevalence and origins of lateral mirror-image generalization for objects are still debated (see, e.g., Gregory, Landau, & McCloskey, 2011; Gregory & McCloskey, 2010).

From the evolutionary standpoint, reading is a relatively recent skill. The first images created by humans date from 40,000 years B.C. (Aubert et al., 2014), and the most ancient texts date from 3100 years B.C. (Nissen, 1986). Thus, it is surprising that an area of the brain (i.e., the left lateral ventral occipito-temporal sulcus) is specialized in the visual processing of written symbols in literate people (Cohen et al., 2000; Dehaene & Cohen, 2011; Jobard, Crivello, & Tzourio-Mazoyer, 2003) despite the limited time for evolution to select for such functional specialization. A meta-analysis of fMRI data