CHAPTER 25

How Learning to Read Influences Language and Cognition

Régine Kolinsky

Abstract

As illustrated in this handbook, a substantial body of work now exists that examines which factors and functions affect reading acquisition and reading proficiency, and which brain areas are involved. The converse relationship—namely, which functions and brain areas are affected by literacy—has received far less attention, probably because reading acquisition lags speech and vision by several years and because the crucial comparison of illiterate adults with people who learned to read as adults is difficult to undertake. However, this chapter illustrates that learning to read has profound influences on the processing of spoken language and beyond the domain of language, in particular on visual nonlinguistic perception. The chapter discusses research with literate adults in these areas, including the influence of spelling knowledge on speech perception. It also covers research with illiterate adults and on people who first learned to read as adults.

Key Words: literacy effects, spelling knowledge effects

Introduction

Is it the case, as declared by Frith (1998, p. 1011), that literacy is "literally changing the brain," and that "culture change(s) basic brain anatomy?" Activities linked to literacy (reading books, magazines, etc.) certainly lead to increased knowledge. But literacy per se—the ability to read and write[1]—may induce other, more fundamental changes. Here, the chief issue under discussion is whether literacy modifies cognition qualitatively beyond visual word recognition processes; that is, whether it changes the principles and organization of knowledge.

Learning to read enables the emergence of mechanisms (e.g., Grainger, Tydgat, & Isselé, 2010) and brain networks (e.g., Cohen et al., 2000) tuned to the processing of written strings, which must be connected with both the visual and the spoken language systems. Presumably, direct or indirect connections are also established with the semantic, reasoning, and executive functioning systems, so that reading acquisition might in principle influence all of these functions. Recently it has been proposed that learning to read modulates other systems not only by establishing new functional links (e.g., between orthography and phonology) but also by altering the intrinsic organization of some of these systems through a process of *neuronal recycling* (Dehaene & Cohen, 2007). According to this view, previous brain circuits involved in visual object recognition and spoken language processing must adapt to perform the new task of reading. In this chapter these potential effects of reading acquisition are examined first as regards the most studied domain of language, and then beyond language, for vision and some higher-level cognitive domains.

Obviously, the effects of reading acquisition must be distinguished from those of age and neural maturation as well as from those of formal education and culture. Estimating the proper effects of reading acquisition requires the comparison of groups that do not differ by age or cognitive performance correlated with maturation differences. As regards formal education, although school attendance and learning to read are usually associated in an individual's life, we can gain insight into the specific effects of literacy by comparing adults who remained illiterate for socioeconomic reasons with *late literates* (also called *ex-illiterates*), that is, people who first learned to read as adults in special literacy classes organized by the government, the Army, or industry, many having been encouraged to do so by their employer or supervisor. Contrary to *early literates*—adults who learned to read as children and attended school for several years—illiterates and late literates never attended school in childhood. Moreover, as illiterates and late literates are from the same socioeconomic background, any performance or brain difference between them should not be contaminated by sociocultural factors. A distinctive approach is to study, in literates, the effects of script directionality or of the relation between phonological segments and their spelling.

The Effects of Reading Acquisition on Spoken Language

Script Directionality Influences Listening to Speech

The first experimental evidence of the impact of reading acquisition in a purely aural context came from a study showing that script directionality influences the perceived temporal position of an extraneous noise (a click) relative to the constituents of a spoken sentence. Previous work had shown that click location is influenced by the relative positions of the click and the sentence in the auditory space: the click is judged more often as occurring simultaneously with an earlier part of the sentence (i.e., is located earlier than its objective position) when it is perceived as being on the left of the speech in auditory space than when it is perceived as being on the right of the speech (Bertelson & Tisseyre, 1972; Fodor & Bever, 1965). Bertelson (1972) found that this effect is inverted if, rather than using English or French as in previous experiments, the experiment uses Hebrew (with Israelis), which is written from right to left. In addition, the Israeli participants in that study showed the same pattern as native speakers of French when tested in French (a language they did understand and read). Thus when presented with spoken sentences, literate people "listen from left to right versus right to left" (Bertelson, 1972) according to the directional properties of graphical representation and scanning habits linked to a specific language, which influence the spatial coding of heard speech. In the following years, several experimental studies showed that reading acquisition also changes the very nature of the representations of speech.

Reading Acquisition Induces New Explicit Representations of Speech

Texts are relatively independent of the context that characterizes effective oral communication and can be reviewed, refined, and reformatted, allowing readers to overcome the limitation on the amount of conscious reflection that can be done on spoken materials (e.g., Donald, 1993; Ong, 1982). Literacy would thus favor the "decontextualization" (Denny, 1991) or "objectification" (Olson, 1991) of language, and consequently the development of *metalinguistic abilities*, namely a reflective attitude with regard to language objects and their manipulation. For instance, literacy helps in realizing that words have no intrinsic relation to the things they stand for but are just arbitrary symbols. This is difficult to understand for young children (e.g., Berthoud-Papandropoulou, 1978) as well as for illiterate adults (Kolinsky, Cary, & Morais, 1987), who assert, for instance, that a cat has a longer name than a butterfly.

Among metalinguistic abilities, *phonological awareness* (or *metaphonological* ability) refers specifically to the understanding that spoken words can be broken down to smaller parts. This is a multilevel skill, depending on the unit that is considered. With phonemes, only alphabetic literacy plays a critical role in the development of explicit representations, or *phonemic awareness*. Indeed, it is only in alphabetic writing systems that the individual printed characters represent phonemes (see Kessler & Treiman, this volume). Neither preliterate children (e.g., Liberman, Shankweiler, Fisher, & Carter, 1974) nor adults who have never learned an alphabet (either fully illiterates, e.g., Morais, Cary, Alegria, & Bertelson, 1979, Morais, Bertelson, Cary, & Alegria, 1986; or literates in a nonalphabetic system, e.g., Read, Zhang, Nie, & Ding, 1986) are able to tell that there are three "sounds" in the word *cab*, and all are very poor at phoneme deletion (e.g., /kæb/→/æb/; in all studies, around 20% average correct responses in illiterates or nonalphabetic readers, vs. more than 70% in late alphabetic literates), reversal (e.g., /kæb/→/bæk/), and detection (e.g., of /k/ in /kæb/). Awareness of higher-level units such as syllables or rhymes does not depend so critically on reading, as differences are smaller than with phonemes, but is improved by it. For example, in Morais et al.

(1986), late literates scored better than illiterates in syllable deletion (85% vs. 55% correct, respectively) and rhyme detection (92% vs. 67%, respectively). Notably, the representations involved in metaphonological tasks differ from perceptual representations: the same illiterate people who perform poorly on phonemic awareness tasks can discriminate almost perfectly between pairs like /ta–sa/ or /pa–ba/ (Adrián, Alegria, & Morais, 1995; Scliar-Cabral, Morais, Nepomuceno, & Kolinsky, 1997).

Orthographic Knowledge Influences Metaphonological Performance in Literates

Not surprisingly, as metaphonological representations are closely linked to reading acquisition (e.g., Adams, 1990; Ehri et al., 2001), orthographic knowledge influences performance in purely auditory metaphonological tasks. Various orthographic effects in speech processing rely on the fact that in many alphabetic writing systems, the relationships between letters and phonemes are often not one-to-one, for reasons discussed by Kessler and Treiman (this volume). In addition to inconsistency in spelling-to-sound mapping (e.g., in English ‹OUGH› can be pronounced as in *cough, through, tough*), a phenomenon that affects reading performance, there is also inconsistency in sound-to-spelling mapping, namely multiple ways to spell a specific pronunciation, as for instance the rhyme of *toast* and *ghost* (e.g., Stone, Vanhoy, & Van Orden, 1997). The latter phenomenon mainly affects auditory processing (Ziegler, Petrova, & Ferrand, 2008).

In metaphonological tasks, inconsistencies in sound-to-spelling mapping lead to several effects, including *orthographic congruency effects*, with better performance, faster responses, or both when orthography and phonology lead to the same response than when they lead to opposite, competing responses. For instance, Seidenberg and Tanenhaus (1979) reported that literate adults take less time to decide that two spoken words rhyme when their spellings are similar (e.g., *toast–roast*) than when they are dissimilar (e.g., *toast–ghost*), and conversely for negative decisions (e.g., faster decisions for *leaf–ref* than *leaf–deaf*). In addition, orthographic inconsistency of phonemes leads to *orthographic consistency effects*. Indeed, in phoneme detection (a task that involves a strong metalinguistic component, as illustrated by the illiterate adults' difficulties, Morais et al., 1986), literate adult listeners more rapidly detect orthographically consistent phonemes, for which there is only one spelling in the language, than orthographically inconsistent phonemes (Frauenfelder, Seguí, & Dijkstra, 1990), which are spelled in different ways in different words (e.g., /k/ in French words, as it is realized orthographically in French by the letters ‹c›, ‹k›, ‹cq› or ‹qu›). Metaphonological performance is also influenced by the complexity of the relationship between the phonemes and the letters representing them: phoneme deletion and phoneme reversal performances are better when there is a one-to-one relationship between the phonemes and their spelling (e.g., deleting /d/ from *dentist*) than when there is a complex correspondence, as when deleting /n/ from *knuckle* or /k/ from *queen* (Castles, Holmes, Neath, & Kinoshita, 2003). Even letter names affect metaphonological judgments: in phoneme counting, syllables that are letter names (e.g., /ɑr/) are judged to contain fewer "sounds" than syllables that are not letter names (Treiman & Cassar, 1997).

Explicit phonological judgments about the structure of syllables are also shaped by orthographic representations: when aurally blending two consonant-vowel-consonant (CVC) monosyllabic words into a new CVC word (cf. Treiman, 1983), Portuguese adults prefer C/VC blends when the word spellings end with a consonant, as in *bar–mel*, /bar mɛl/, but prefer CV/C blends when the word spellings end with a mute ‹e›, as in *cure–pele*, /kur pɛl/ (Ventura, Kolinsky, Brito-Mendes, & Morais, 2001). Furthermore, a study of natives of Thai, a language in which tones are lexically contrastive and orthographically marked (but not orthographically consistent), showed that the influence of spelling knowledge extends beyond sublexical units. Indeed, literate Thai listeners show an orthographic congruency effect at the suprasegmental level, with better performance when the tone and the tone marker lead to the same response than when they lead to competing responses (Pattamadilok, Kolinsky, Luksaneeyanawin, & Morais, 2008).

Thus when becoming literate, listeners change the way in which they perform metaphonological tasks and use spelling knowledge in purely aural situations. An important question is whether they use this knowledge either in addition to or instead of their phonological skills. This issue has been hotly debated, as the latter possibility may cause researchers to revisit the role of phonological awareness in reading acquisition. Indeed, according to some researchers, phonological awareness does not represent a distinct set of spoken-language skills that is directly related to reading acquisition. Instead, the association between the ability to manipulate the sounds of spoken language and literacy acquisition may reflect the fact that once individuals acquire reading and spelling skills they change the way in which they perform phonological awareness tasks, using their orthographic skills to arrive at a solution. So on this account, the association between phonological awareness and literacy acquisition arises because both are, to a greater or lesser extent, indices of orthographic skill (e.g., Castles et al., 2003; Castles & Coltheart, 2004; but see Hulme, Caravolas, Malkova, & Brigstocke, 2005, for experimental arguments refuting the idea that phoneme manipulation ability can only develop as a consequence of orthographic—i.e., letter-sound correspondence—knowledge). This question is connected to the issue of the automaticity of the activation of orthography by speech: does spelling knowledge become inseparable from phonological knowledge, or is it chiefly used strategically when useful?

Some studies reported that orthographic representations are activated even when disadvantageous to performance. For example, in the phoneme deletion task used by Castles et al. (2003), adults did not improve their performance on complex items (e.g., when deleting /n/ in *knuckle*) when these items were presented in pure rather than mixed blocks. Yet in pure blocks participants could have adopted a strategy that maximizes performance by not spelling the items, given the deleterious consequences in that case. But several orthographic effects occur only when the stimuli direct participants' attention to spelling, which could potentially invoke strategic effects. This is the case, for instance, with the orthographic consistency effect in phoneme detection (cf. Frauenfelder et al., 1990), which only occurs when spelling is rendered salient by the presence of many irregularly spelled words like *kneel, cough*, and *pyjamas* (Cutler, Treiman, & van Ooijen, 2010). Similarly, the orthographic congruency effect in rhyme judgment is eliminated when nonrhyming words with similar spelling (e.g., *leaf–deaf*) are not presented or when many filler items are added (Damian & Bowers, 2010). In addition, metaphonological studies using event-related brain potentials (ERPs) showed that orthographic congruency effects emerge relatively late in the time course of processing, much later than phonological effects (in rhyme judgment: Pattamadilok, Perre, & Ziegler, 2011; Yoncheva, Maurer, Zevin, & McCandliss, 2013; in initial phoneme same-different judgment: Lafontaine, Chetail, Colin, Kolinsky, & Pattamadilok, 2012).

Nevertheless reading acquisition reorganizes a large brain network that includes phonological areas. As a matter of fact, a functional magnetic resonance imaging (fMRI) study (Brennan, Cao, Pedroarena-Leal, McNorgan, & Booth, 2013) showed that in aural rhyme judgment, brain activation is greater in adults than in eight- to 12-year-old children reading an alphabet (but not in readers of Chinese; see Kessler & Treiman, this volume for further discussion of its writing system), especially for words with conflicting orthography such as *pint–mint*. This occurs not only in inferior frontal areas (typically involved in phonological awareness tasks, e.g., Burton, Small, & Blumstein, 2000; Zatorre, Meyer, Gjedde, & Evans, 1996) but also in left hemisphere phonological areas (superior temporal gyrus). As discussed in the next two subsections, the impact of spelling knowledge on speech processing is, in fact, much more profound than originally suspected.

Orthographic Knowledge Influences Spoken Word Recognition

There are reliable orthographic effects in aural word recognition tasks. Ziegler and Ferrand (1998) first reported an orthographic consistency effect in auditory lexical decision ("is a spoken item a word or not?"): responses to words such as *deep*, which include rimes that can be spelled differently in other words (e.g., *heap*), are slower and less accurate than responses to words with rimes that are spelled only one way. This effect has been replicated in several languages (e.g., French: Pattamadilok, Morais, Ventura, & Kolinsky, 2007; Portuguese: Ventura, Morais, Pattamadilok, & Kolinsky, 2004; English: Ziegler et al., 2008) and tasks (semantic and gender decision: Pattamadilok, Perre, Dufau, & Ziegler, 2009; Peereman, Dufour, & Burt, 2009).

Contrary to the influence of spelling in metaphonological judgments, the orthographic effects in recognition tasks take place rapidly in the course of processing, unfolding on-line with the word recognition process. This conclusion is supported, among other things, by ERP data. In semantic judgment (Pattamadilok et al., 2009) and lexical decision tasks (Perre, Pattamadilok, Montant, & Ziegler, 2009; Perre & Ziegler, 2008), the ERP orthographic consistency effect is time-locked to the orthographic inconsistency (e.g., earlier with the word French *rhume*, in which the initial /ry/ has multiple spellings, than with the word *noce*, in which the final /ɔs/ is inconsistent), and it starts before the onset of the frequency effect. Thus, orthography is activated early enough to modulate the core processes of lexical access.

Yet exactly how orthographic knowledge modulates speech processing is under debate. According to the *online account* (e.g., Ziegler & Ferrand, 1998), hearing a spoken word activates its corresponding orthographic code via cross-modal linkages; that is, through bidirectional connections between the spoken language (phonological) and visual (orthographic) systems. More precisely, in the *bimodal interactive activation model* (Grainger & Ferrand, 1996), there are bidirectional connections at both the lexical and sublexical (e.g., rhyme) levels. Words with consistent spellings thus benefit from self-consistent feedback from orthographic to phonological representations. For words with inconsistent spellings, in contrast, there is conflict at the sublexical level between several possible spellings and hence reduced feedback from orthographic to phonological representations. Alternatively, according to the *offline account*, orthographic effects take place within the phonological system itself. They reflect learning effects that happen during the course of learning to read and permanently alter the nature of the phonological representations (e.g., Muneaux & Ziegler, 2004; Taft, 2006; 2011).

The offline account is related to the *lexical restructuring* hypothesis (e.g., Garlock, Walley, & Metsala, 2001; Metsala, 1997), according to which phonological representations undergo important changes throughout language development: with children's oral vocabulary growth, the representations of lexical items become more detailed (more phonemic) with increasing pressure to discriminate between more and more similar-sounding words (*phonological neighbors*). For instance, recognizing the spoken word *dad* will require a more detailed representation for a child who also has acquired the words *bad, pad, mad, did*, and so on than for a child who has not. Lexical restructuring depends not only on vocabulary size but also on the words' characteristics: high-frequency words are generally acquired earlier and hence undergo restructuring earlier than low-frequency words. Among the latter, only those with many phonological neighbors need to be finely represented, leading to an interaction between word frequency and number of phonological neighbors in word recognition tasks. For instance, Metsala (1997) used a gating task, in which listeners are presented with increasingly longer segments of a spoken word while attempting to identify it. She found that 7- to 11-year-old children and adults performed better (i.e., needed less input for recognition) for high-frequency words from sparse, as opposed to dense, neighborhoods, whereas they did better for low-frequency words from dense neighborhood. The idea that children process words in a more holistic manner and that representations become more segmental with lexical growth was supported by the fact that the smallest developmental difference was found for high-frequency words from dense neighborhoods and the greatest developmental difference for low frequency words from sparse neighborhoods, which are supposedly more holistically represented and the latest to undergo segmental restructuring. Although reading acquisition was not explicitly mentioned in the lexical restructuring hypothesis, it has been suggested that learning about letter-sound correspondences, and hence about phonemes, may make lexical representations more detailed in readers of an alphabetic script (e.g., Goswami, 2000). Yet contrary to this idea, illiterate adults present a phonologically restructured auditory lexicon similar to the one of literates, displaying the same interaction between word frequency and number of phonological neighbors (Ventura, Kolinsky, Fernandes, Querido, & Morais, 2007). Thus, phonological restructuring of the lexicon occurs in the absence of literacy. Ventura et al.'s finding argues against the idea that developmental lexical restructuring is mostly influenced by orthographic representations, but it does not refute the more general assumption that orthography impacts the phonological system.

Until recently, data supporting the offline account were scarce and disputable, as they were collected in situations that either involve phonemic awareness (e.g., the neighbor generation task used by Muneaux & Ziegler, 2004; see discussion in Ventura et al., 2007) or that use written strings (Taft, 2006), which may generate phonological codes different from those of speech. But more recent studies have shown that the orthographic consistency effect in lexical decision takes place within the phonological system itself: the cortical generator of the ERP effect sits within the vicinity of the left auditory cortex (Perre et al., 2009), and transcranial magnetic stimulation applied to an area involved in phonological processing (left supramarginal gyrus) cancels the effect (Pattamadilok, Knierim, Duncan, & Devlin, 2010).

In addition, fMRI studies suggest that both the online and offline mechanisms exist, with their relative involvement depending on the task. A study comparing illiterate to late and early literate adults disclosed both effects (Dehaene, Pegado et al., 2010). On the one hand, actively processing speech in lexical decision, but not passively listening to spoken sentences, activates the visual word form area (VWFA, Cohen et al., 2000), the area of the left ventral occipitotemporal cortex (in the fusiform gyrus) involved in written word processing. This activation is orthographic rather than semantic, as it occurs in early and late literates but not illiterates. In literates, the recruitment of the VWFA has also been observed in other demanding tasks requiring selective attention to and analysis of the phonology of complex speech stimuli (e.g., when making rhyme judgment on words overlaid with tones, Yoncheva, Zevin, Maurer, & McCandliss, 2010). On the other hand, in both passive listening to spoken sentences and auditory lexical decision, there is a huge increase in fMRI activation of the planum temporale in literates compared to illiterates (see similar results in literate vs. preliterate age-matched children in Monzalvo & Dehaene-Lambertz, 2013). The planum temporale, like the surrounding superior temporal cortex, probably houses relatively abstract phonemic representations, as it encodes acoustic changes that are crucial for the categorical perception of speech (e.g., Chang et al., 2010; Mesgarani, Cheung, Johnson, & Chang, 2014) and also responds during silent lip reading (Calvert et al., 1997). The increase in planum temporale activation found in literate compared to illiterate adults may therefore indicate that reading acquisition enhances this kind of abstract phonological coding.

However, literacy is probably not like a "virus" that "infects all speech processing," as proposed by Frith (1998, p. 1011). Indeed, several perceptual phenomena are immune to the influence of literacy. In addition to being able to make fine phonetic discriminations (Adrián et al., 1995; Scliar-Cabral et al., 1997), like literates, illiterate adults experience slip-of-the-ear errors involving consonantal phonemes, revealing similar implicit representations of the perceptual constituents of speech (Morais & Kolinsky, 1994; see also Morais, Castro, Scliar-Cabral, Kolinsky, & Content, 1987, for errors involving phonetic features). Yet a study investigating categorical perception of speech sounds pointed to potential fine-grained differences between illiterate and literate adults (Serniclaes, Ventura, Morais, & Kolinsky, 2005). Categorical perception of speech means that only differences between identified phonemic categories (e.g., between phonemes identified as /b/ or as /d/) can be distinguished, not the within-category variants (e.g., between two physically different sounds, both identified as /b/, Liberman, Harris, Hoffman, & Griffith, 1957). Categorical perception per se is thus estimated through the relation between performance in identification (obtained e.g., through labeling) and discrimination (e.g., same-different judgment) tasks. This relation is the same in illiterate and literate adults. Yet, literates show a steeper identification slope than illiterates. Although in Serniclaes et al.'s study this effect could be attributed to a lexical bias (one of the continuum end points was a word), similar results were reported for adults and six- to eight-year-old children (Hoonhorst et al., 2011). There was no effect of age on the relation between identification and discrimination performances, but the boundary precision increased with age and was correlated with reading level. Thus although the data do not confirm the strong hypothesis according to which perceptual categorization of speech sounds depends on reading acquisition (Burnham, 2003), they suggest that literacy helps in finely tuning phonemic boundaries and hence in increasing the precision of phoneme identification.

Reading Acquisition Influences Short-Term Memory Codes and Performance

A common view is that oral memory has been traded off against literacy (e.g., Cole, Gay, Glick, & Sharp, 1971). This view was first articulated by Plato who, in *Phaedrus*, expressed concern about the "inhuman" nature of writing, stating that written words have a destructive effect on human memory (cf. Ong, 1982). Yet poor verbal short-term memory (STM) is usually observed in illiterate adults, who display low word and digit spans (e.g., Kosmidis, Zafiri, & Politimou, 2011; Morais et al, 1986). The origin of this effect is unclear. Although it may be partly ascribed to formal education rather than literacy, as late literates also display lower word spans than early literates (Morais et al., 1986), there seems to be an additional slight benefit specifically due to literacy. For example, late literate adults who never attended school themselves but learned to read at home with their children have better forward digit-span scores than illiterates (Kosmidis et al., 2011), whereas no effect of literacy is observed with nonverbal materials (in forward spatial span, Kosmidis et al., 2011).

As discussed by Ardila et al. (2010), illiterate participants' poor recall may reflect inefficient encoding and retrieval strategies or poor organization of the material to be learned, as recall requires considerable self-initiated activity and executive skills.

The latter view is supported by the fact that illiterates are quite good on word recognition tests (telling which ones among different spoken words were previously presented, Ardila, Ostrosky-Solis, & Mendoza, 2000). Actually, illiterates' poor STM performance could reflect the fact that they were usually tested on ordered recall. Whether literacy specifically enhances memory for order, as opposed to memory for items, remains to be investigated. However, the reverse association has been reported: in kindergarteners, order (but not item) STM capacity predicts independent variance in nonword decoding abilities at the end of first grade (Martinez Perez, Majerus, & Poncelet, 2012). As regards encoding, literacy may improve it in two ways. First, it may improve phonological storage by affording more finely tuned phonological representations. Illiterate adults spontaneously use phonological codes in STM: like literates (e.g., Baddeley, 1966; Conrad & Hull, 1964), they display a *phonological similarity effect* in ordered recall of lists of words, with poorer performance for rhyming lists than for nonrhyming ones (Morais et al., 1986). Yet illiterate adults seem to differ from literates at a finer grain size (phonemic boundaries, cf. Serniclaes et al., 2005), and this may lead to inaccurate identification of phonemes, at least in the absence of lexical support. Consistent with this idea is the fact that, in immediate repetition, illiterate adults perform poorly on pseudowords and do not activate the same brain regions as literates, but are quite good on words, with no group difference in neural activation (e.g., Castro-Caldas, Petersson, Reis, Stone-Elander, & Ingvar, 1998). Also consistent with the notion that literacy improves phonological storage are data showing that reading at six years predicts growth in nonword repetition between six and seven years (Nation & Hulme, 2011). Moreover, in literates, spelling knowledge helps maintaining the representation of spoken strings in STM. This has been demonstrated in serial recall, in which orthographic representations modulate the phonological similarity effect (Pattamadilok, Lafontaine, Morais, & Kolinsky, 2010). Compared to words that share neither the phonological nor the orthographic rime, literates' performance is less affected when words rhyme but have different spellings (as in the French *laine, gêne, traîne*, etc., all ending with /ɛn/) than when they both rhyme and have the same spelling (as in the French *classe, brasse, chasse*). Thus, inter-item orthographic dissimilarity reduces the detrimental effect of phonological similarity.

Reading Acquisition Induces Anatomical Changes

In addition to establishing a functional link between phonological and orthographic representations, literacy also leads to structural changes in brain connectivity. As a matter of fact, several studies have identified structural brain differences in late and early literate adults compared to illiterates. These differences, as suggested by functional connectivity analyses, seem to reflect both increased inter-hemispheric functional connectivity (manifested by thickening of the splenium or the isthmus of the corpus callosum, Carreiras et al., 2009; Castro-Caldas et al., 1999; Petersson, Silva, Castro-Caldas, Ingvar, & Reis, 2007) and strengthened intra-hemispheric functional coupling (at the level of the left arcuate fasciculus, Thiebaut de Schotten, Cohen, Amemiya, Braga, & Dehaene, 2014) between the visual and phonological processing areas. Together with the studies that showed increases in grey matter density in several brain regions involved in reading (Carreiras et al., 2009; Castro-Caldas et al., 1999; Petersson et al., 2007), these data strongly support the idea that literacy changes basic brain anatomy.

The Influence of Reading Acquisition on Spoken Language: A Brief Summary

Literacy influences many spoken language processes—not only metaphonological skills, but also word recognition and verbal memory processes and perhaps even some perceptual processes. Some of these effects seem to reflect online influence of orthographic or metaphonological representations, whereas others suggest offline restructuring of lexical representations. If both online and offline mechanisms are involved, there might be multiple types of phonological representation in the lexicon, including orthographically (or metaphonologically) restructured ones (see discussions in e.g., Ranbom & Connine, 2011; Taft, 2011). In any case, these changes are also reflected at the structural level, in terms of both white- and grey-matter density. In fact, these enhanced connections reveal a bidirectional (sound-to-sight and sight-to-sound) pathway: in literate but not illiterate people, the language network of left temporal and inferior frontal regions activates almost identically to written and spoken language (Dehaene, Pegado et al., 2010). Thus the acquisition of reading gives us access, from vision, to the spoken language system, and conversely spoken-language processing is modified by literacy.

The deep influence of literacy on spoken language is remarkable, as reading lags speech acquisition by several years and depends on explicit teaching. Frith (1998, p. 1012) wondered whether "learning to read has an equally transforming effect on processes underlying visual perception and thinking." In the following sections it is shown that the impact of literacy definitely goes beyond auditory skills and the language domain.

The Effects of Reading Acquisition on Visual Processing

The main effect of reading acquisition is that it allows the emergence of brain structures tuned to the processing of written strings (e.g., Cohen et al., 2000), thereby creating an interface through which linguistic inputs can be interpreted through vision, as already mentioned. Reading acquisition also qualitatively alters visual processes. Letter strings benefit from flexible position coding, leading to more difficulties in differentiating sequences with transposed letters such as NTDF–NDTF than sequences with replaced letters such as NSBF–NDTF (for a review, see e.g., Duñabeitia, Dimitropoulou, Grainger, Hernández, & Carreiras, 2012), an effect that is not observed in illiterate adults (Duñabeitia, Orihuela, & Carreiras, 2014). In addition, letter-string processing involves a specialized system that reduces the spatial extent of *crowding* for letters in words, limiting the integration of inappropriate features from neighboring stimuli (e.g., Grainger et al., 2010). Consistently, there is less integration with a surrounding geometrical shape for letters than nonletters (Van Leeuwen & Lachmann, 2004). Indeed, facilitation is smaller for letters than nonletters when the target stimulus is surrounded by a shape with a similar global contour than when it is surrounded by a shape with a different global contour (see Figure 25.1). This effect is also observed in illiterate adults with some knowledge of letters (Fernandes, Vale, Martins, Morais, & Kolinsky, 2014). Notably, the next subsections illustrate that literacy also alters nonlinguistic visual processes.

Script Directionality Influences Visual Scanning and Spatial Associations

Script direction influences visual scanning not only of text (e.g., Pollatsek, Bolozky, & Rayner, 1981) but also of nonlinguistic stimuli (for a review, see e.g., Chokron, Kazandjian, & De Agostini, 2009; see also Bramão et al., 2007, for a comparison of literate and illiterate adults). The directional habits associated with text and numbers also contribute to the spatial representation of numbers: people who read words and numbers from left to right associate small numbers with the left space and large numbers with the right space (the *SNARC effect*, Dehaene, Bossini, & Giraux, 1993), whereas people reading from right to left show the reversed effect (Shaki, Fischer, & Petrusic, 2009). The direction of the writing system even affects the axis used to represent time in terms of space, for example by modulating how people place sets of cards (e.g., egg, chick, chicken) in temporal order (Bergen & Chan Lau, 2012), as well as the visual representations of action events, with literates, but not illiterates, showing a script-dependent spatial bias (e.g., Dobel, Enriquez-Geppert, Zwitserlood, & Bölte, 2014).

Reading Acquisition Induces Neural Competition in the Left Fusiform Gyrus

As the VWFA is involved in written word processing in literates (e.g., Cohen et al., 2000), it is worth asking what role this brain area plays prior to reading acquisition. In illiterate adults the VWFA is not inactive, but strongly responsive to nonlinguistic pictures, particularly to faces. With increasing literacy, cortical responses to faces become restricted to a somewhat smaller area in the left fusiform gyrus

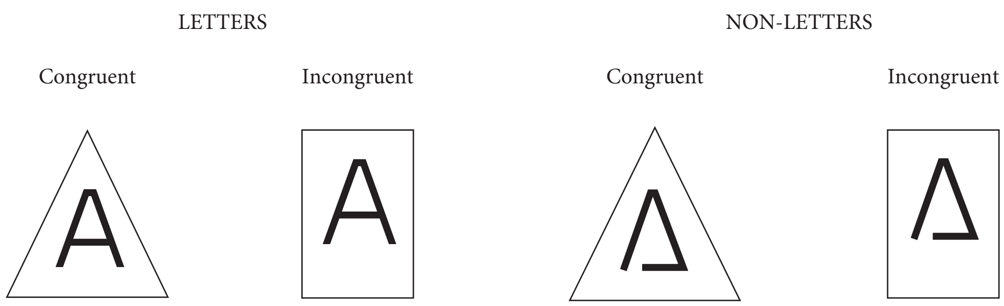

Fig. 25.1 Examples of material used by Fernandes, Vale, Martins, Morais and Kolinsky (2014; after Van Leeuwen & Lachmann, 2004): letters and nonletter shapes in congruent and incongruent surroundings.

and increase in the right fusiform gyrus (Dehaene, Pegado et al., 2010). Thus reading acquisition induces neural competition between written words and other object categories, in particular faces, leading to stronger right-hemispheric lateralization for faces in literate compared to illiterate adults. A similar shift of face responses toward the right hemisphere is observed in developmental studies using fMRI (Monzalvo, Fluss, Billard, Dehaene, & Dehaene-Lambertz, 2012), ERP recordings (Li et al., 2013) and behavioral hemifield lateralization (Dundas, Plaut, & Behrmann, 2013), suggesting that word lateralization, which emerges earlier in development, may drive later face lateralization.

Current studies aim at identifying the behavioral consequences of this process of neural competition between written strings and faces. Indeed, the stronger right-hemispheric lateralization for face processing with literacy raises the possibility that reading acquisition turns face processing more holistic in literates, as holistic (configurational) face processing is mainly implemented in the right fusiform gyrus (e.g., Rossion et al., 2000). Yet recent data on the *composite face effect* do not support this idea. The composite face effect reflects holistic face processing, as it shows that the parts of a face cannot be perceived independently from the whole face. Indeed, composite faces in which the two halves belong to two different face identities lead to a visual illusion (Young, Hellawell, & Hay, 1987). For instance, in a same-different matching task on pairs of composite faces, identical bottom face halves are perceived as being different when their top halves belong to different faces, an illusion that disappears when the bottom halves are spatially offset. Although literates may be expected to present a stronger composite face effect than illiterates, the opposite was observed: literates were better at deciding whether the bottom halves of faces are the same or different without being distracted by the top part of the images (Ventura et al., 2013). This suggests that literacy improved an analytic strategy of attending to pictures. As a similar effect was observed with houses, it probably does not reflect the change in the lateralization of face processing but a general impact of literacy, which may bring more flexibility in reducing the influence of holistic processing when this is detrimental to the task.

Reading Acquisition in the Latin Script Pushes to "Unlearn" Mirror Invariance

Most natural categories are invariant for left-right inversion, and hence lateral reversals convey little or no information about the identity of natural objects. Accordingly, there exists an intermediate stage of recognition in the ventral visual cortex where responses to pictures of objects are invariant to left-right mirror symmetry (e.g., Dehaene, Nakamura et al., 2010; Pegado, Nakamura, Cohen, & Dehaene, 2011). Yet mastering a script that includes mirror-image characters (e.g., in the Latin script, ‹p q› and ‹b d›) requires taking mirror-image contrasts into account. It pushes readers of these scripts to "unlearn" mirror invariance. At the brain level, this is reflected by the fact that the VWFA, which is the site of the visual system with the strongest mirror invariance for familiar objects, does not perform mirror-image generalization for words (Dehaene, Nakamura et al., 2010) or letters (Pegado et al., 2011). Behaviorally, this process of unlearning mirror invariance generalizes to nonlinguistic materials. Compared to readers of scripts that include mirror-image characters, both fully illiterate adults (e.g., Kolinsky et al., 2011) and readers of scripts that do not include mirror-image characters (Danziger & Pederson, 1998) are quite poor at discriminating mirror images of geometric shapes (e.g., ↙ and ↘) or of pictures of familiar objects (Fernandes & Kolinsky, 2013). Thus, reading in a script that includes lateral mirror images boosts the ability to discriminate these contrasts even with nonlinguistic materials.

Remarkably, the ability to discriminate mirror images interferes with other visual processes. For example, using an orientation-independent, identity-based same-different comparison task in which participants had to respond "same" to both physically identical and mirror-image stimuli, Pegado et al. (2014) showed that both early and late literate adults (reading the Latin script) performed worse when written stimuli and pictures of familiar objects were mirrored rather than strictly identical, whereas illiterates showed no cost for these mirrored pairs. Thus, interference from irrelevant mirror-image variations on identity processing is a side effect of literacy for readers of scripts including such contrasts.

These influences of literacy occur at a relatively high processing level. Indeed, illiterate adults do register mirror-image contrasts at an earlier processing level: they display the same level of illusory conjunctions (false detections of a target in very briefly presented displays; see Figure 25.2) as early literates in a situation in which, to perceive the target, the lateral mirror orientation of diagonal lines has to be registered preattentively [Kolinsky, Morais, &

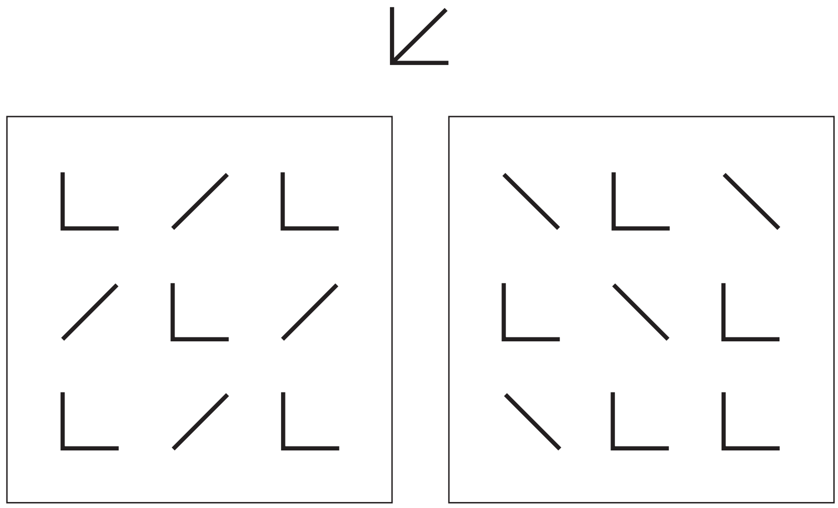

Fig. 25.2 Examples of target-absent trials used by Kolinsky, Morais, and Verhaeghe (1994) to elicit illusory conjunctions (i.e., false detections) of the target, presented on the top. On the left: experimental trial, in which the orientation of diagonal lines match the orientation of the diagonal line of the target. On the right: control trial, in which orientation of diagonal lines is opposite.

Verhaeghe, 1994]). Nonetheless, other data demonstrate that literacy also alters some early vision processes, as discussed in the next subsection.

Reading Acquisition Alters Early Visual Processing

In the fMRI study by Dehaene, Pegado et al. (2010), reading acquisition was shown to increase occipital responsiveness to all visual (linguistic and nonlinguistic) categories in a situation in which participants only had to perform an incidental task (detecting an occasional target star).[2] Even activation in the primary visual area V1, which is the first point of entry of visual signals into the cortex, was augmented by literacy: relative to illiterates, trained readers showed enhanced fMRI responses in V1 to written sentences and checkerboards. The latter effect was selective for horizontal over vertical checkerboards; as the spatial arrangement of the image is maintained in V1 (stimuli adjacent in the visual field are represented in adjacent positions in the visual cortex), intensive training with horizontally presented words had clearly led to a refinement of the corresponding region of the visual field.

More generally, the Latin alphabet provides an ideal stimulus for perceptual learning through extensive practice on a restricted set of visually simple shape primitives. Discriminating these shapes puts a challenge on visual resolution, which may explain the importance of visual areas sensitive to oriented bars (V1) and local contours (secondary visual cortex, V2). In agreement with this idea, areas V1/V2 of expert alphabetic readers show increased fMRI activation specific to words relative to matched scrambled controls (Szwed et al., 2011; Szwed, Qiao, Jobert, Dehaene, & Cohen, 2014). Interestingly, this effect is not observed in Chinese readers (Szwed et al., 2014), probably because Chinese characters are much more numerous and visually complex than Latin letters. Discriminating between thousands of characters that each comprises a hierarchical arrangement of many strokes seems rather to put emphasis on a relatively higher level of visual processing, as Chinese expert readers show enhanced activations in intermediate visual areas (V3/V4, sensitive to more complex patterns than V1/V2) that are absent in alphabetic readers.

These early effects may benefit several visual tasks outside of reading. For instance, in readers of the Latin script visual integration is enhanced, as shown by early and late literates' superior capacity (compared to illiterates) in connecting local elements into an overall shape (Szwed, Ventura, Querido, Cohen, & Dehaene, 2012). The early visual changes induced by the acquisition of the Latin alphabet might also form the foundations of the more analytical strategy of attending to pictures observed in (alphabetic) literates compared to illiterates (Ventura et al., 2013). As discussed by Zhang, McBride-Chang, and Perfetti (this volume), better fine visual discrimination skills, including of nonlinguistic stimuli, have also been reported in readers of modern Standard Chinese, which has been visually simplified in the 1950s and is used in mainland

China, compared to readers of the traditional, visually more complex, Chinese script, still used for example in Hong Kong and Taiwan. This is a counterintuitive result, as one might have expected the more visually complex script to engender better fine visual discrimination. It remains to be investigated whether the greater emphasis on intermediate visual areas put by the more complex scripts (Szwed et al., 2014) induces other behavioral changes.

The Influence of Reading Acquisition on Visual Processing: A Brief Summary

In sum, reading acquisition gives individuals qualitatively new processing modes tuned to the processing of written strings; modifies scanning habits and spatial associations with numbers, time, and action events; and reorganizes the visual ventral pathway through a process of neuronal competition with other visual categories, principally with faces. It also alters early visual processes, enhances fine visual discrimination, and pushes readers of scripts that include mirror images to "unlearn" mirror invariance. The following section illustrates that in addition, literacy affects some aspects of higher-level functions.

The Effects of Reading Acquisition on Higher-Level Functions

Semantic Knowledge and Organization

Both learning to read in the classroom and activities linked to literacy (reading books, magazines, etc.) certainly increase the richness and precision of semantic knowledge. This is observed, for instance, in semantic fluency tasks in which participants are asked to generate as many words as they can that belong to a specified taxonomic category (e.g., animals). As a matter of fact, illiterate adults provide far fewer responses than early literates (e.g., Ratcliff et al., 1998), and a similar difference is observed between age-matched illiterate and literate children (Matute et al., 2012). However, this finding does not imply that literacy changes the way entities are represented in conceptual memory, including their taxonomic organization, or the mechanisms of access to stored knowledge. In semantic fluency tasks, when participants have to generate a list of words corresponding to a given taxonomic category such as animals, they tend to produce clusters of words belonging to the same subcategory (e.g., pets, insects, birds), which reflects both organization and retrieval by subcategory (e.g., Gruenewald & Lockhead, 1980). Even illiterates display such a pattern (e.g., Kosmidis, Tsapkini, Folia, Vlahou, & Kiosseoglou, 2004). Thus, contrary to the richness and precision of knowledge, taxonomic clustering and retrieval by semantic subcategory does not strongly depend on literacy. This outcome is consistent with the idea that, although unschooled illiterate people show a preference for thematic relations in categorization tasks (grouping for instance *leg* with *trousers* rather than with *arm,* e.g., Luria, 1976), they do use taxonomic organization of the items when the categories are explicitly indicated to them or simply suggested by having them sort the items into piles (e.g., Scribner & Cole, 1981).

Working Memory and Executive Functions

The use of external symbolic storage systems (books, computers, etc.) induces the need to manage multiple memory stores (both internal and external) and multiple knowledge codes (phonemic, orthographic, metalinguistic), which may modify executive functions, in particular working memory (e.g., Donald, 1993). Examining this idea is difficult, as the so-called executive functions form a set of related but clearly distinct functions (e.g., Miyake et al., 2000) and there are virtually no data as regards the effects of literacy on shifting between multiple tasks or criteria, deliberate inhibiting of dominant responses, and planning and organizing output sequences (but see preliminary results reviewed by Morais & Kolinsky, 2002, suggesting an effect of formal education rather than of literacy per se).

There is, however, some evidence for an effect of literacy on so-called working memory (WM) tasks, namely on tasks that, by adding a processing demand to the requirement to remember a list of items, involve manipulation of information in addition to simple storage. Appropriately revising the items held in memory to keep track of which information is old and no longer relevant, and replacing it by newer, more relevant information is an ability closely related to the executive functions of selecting, updating and monitoring representations (e.g., Miyake et al., 2000; for a review, see e.g., Bledowski, Kaiser, & Rahm, 2010). According to the results reported by Kosmidis et al. (2011), literacy strengthens working memory, but this skill may be further reinforced through formal education, presumably as individuals develop learning strategies. Indeed, in backward digit span (in which participants have to recall the list of items in reverse order), late literates perform similarly to illiterates, both less well than early literates. Yet a specific effect of literacy is observed on listening span (in which participants have to listen to a series of sentences, retaining the final word of each sentence for recall at the end of the series), with poorer performance in illiterates than late literates and no significant difference between late and early literates. Nevertheless, as for short-term memory, literacy effects on WM tasks may be restricted to or stronger with verbal than nonverbal materials. The reported effects of literacy on spatial WM tasks are in fact confounded with the effects of formal education, with early literates better on spatial span backward than "functionally illiterates" who attended school for only a very short time (Kosmidis et al., 2011).

Reasoning Capacities, IQ, and Cognitive Style: Effects of Formal Education or of Literacy?

Given their context-independency and permanence, written materials and hence literacy are often considered as fostering formal thought and abstraction (e.g., Donald, 1993; Harris, 2009; Ong, 1982). Consistently, both Goody (1968) and Luria (1976) considered literacy to be a precondition for deductive reasoning, as applied in syllogisms (namely, the capacity to deduce, e.g., that Socrates is mortal from the premises "All men are mortal; Socrates is a man"), and Luria reported that illiterate adults perform poorly on reasoning tasks. In fact, illiterate adults' reasoning ability is generally masked by an "empirical bias" (Scribner, 1977): when presented with unfamiliar premises, they use their own experience to supplement, distort, or even reject them (e.g., Cole et al., 1971; Luria, 1976; Scribner & Cole, 1981). For example, when given the problem: *In the far North, where there is snow, all bears are white. Novaya Zemlya is in the far North. What color are the bears there?*, an illiterate participant answered: *I don't know. I've seen a black bear. I've never seen any others…Each locality has its own animals* (Luria, 1976, pp. 108-109). Yet unschooled people are quite good with syllogisms based on familiar information (Scribner & Cole, 1981) and, with unfamiliar information, illiterate adults reason accurately and appropriately justify their conclusions in terms of the supplied premises when explicitly prompted to think of these as pertaining for example to a distant planet, which allows them setting empirical considerations aside (Dias, Roazzi, & Harris, 2005). Nevertheless, the illiterate participants of Dias et al. (2005) performed less well overall than the early literates. Observations made by Scribner and Cole (1981) on the Vai people of West Africa suggest that formal education in Western-type schools (long-term tuition delivered by trained teachers and including various activities beyond literacy: mathematics, history, etc.) is responsible for this effect: performance with logic problems demonstrated strong effects of this type of schooling, but neither Vai (syllabic) literacy, acquired at home through individual tuition, nor Arabic (consonantal alphabetic) literacy, acquired in Koranic schools (where tuition was restricted to reading and writing out known passages of the Koran or frequently used prayers), was found to improve performance.

A clear case of formal education influence concerns the performance displayed in tests that are designed to measure intelligence. Although IQ scores usually correlate with literacy, there is either no difference—or only a tiny one—between illiterates and late literates, both displaying far poorer scores than early literates (Verhaeghe & Kolinsky, 2006; see also the longitudinal study by Landgraf et al., 2011 on almost unschooled adults involved in a literacy course). Formal education, but not literacy, also seems responsible for differences in so-called cognitive styles. The influence of prior beliefs in reasoning and consequent cross-cultural variations led to the idea that people from different cultures use different cognitive processes when they reason. For example, Nisbett (2003) described Eastern reasoning as holistic and dialectical and Western reasoning as analytical and logical. Similarly, Easterners are supposed to engage in context-dependent holistic visual processes by attending to the relationship between the object and the context in which the object is located, whereas Westerners are said to engage in context-independent analytic processes by focusing on a salient object independently from the context in which it is embedded (e.g., Nisbett & Miyamoto, 2005). Ventura et al. (2008) showed that Western schooling, as part of or in addition to culture, is a crucial factor in this effect, but that literacy per se is irrelevant: only Portuguese early literates presented a context-independent analytic processing style, whereas all other groups (Portuguese illiterates and late literates, as well as Thai illiterates and early and late literates) presented a context-dependent holistic style.

Conclusions

Much behavioral and brain-imaging evidence has now accumulated to support Frith's (1998) assertions that literacy is changing the brain, including its basic anatomy. As regards speech, apart from a few unaffected domains (phonetic discrimination; categorical perception; phonological restructuring of lexical representations; implicit phonemic codes), reading does change the way spoken language is processed. Literates do not process speech as illiterates do, and they are more deeply influenced by spelling knowledge than was initially thought. The same conclusion holds true for visual perception: reading acquisition allows the emergence of processes and brain structures tuned to written strings, alters the way other visual categories are processed, and induces neural competition effects. In addition, literacy modifies the anatomy of the brain, including the connections between the visual (orthographic) and phonological processing areas.

Evidence for the influence of literacy on higher-level functions is far less clear. Despite interesting discussions about the extent to which new cultural tools such as reading retool our mind (e.g., Ansari, 2012; Donald, 1993; Wilson, 2010), data on the influence of literacy on executive functions and reasoning are inconclusive. Much work has still to be done to understand what may be considered the new "agenda of cognitive science," namely "to understand the shared principles by which individual brains develop into diverse adult minds" (Wilson, 2010, p. 186).

Future Directions

Beyond the previously noted lack of evidence on high-level functions, the mechanisms by which reading changes brain function and structure often remain opaque. On the one hand, we need detailed models of the ways in which cultural tools affect brain function (see proposals on neural reuse in e.g., Anderson, 2010; Dehaene & Cohen, 2007). On the other hand, more data are necessary to identify the behavioral correlates of the observed brain changes (e.g., of the neural competition between written word and face processing, Dehaene, Pegado et al., 2010) and to identify the exact brain correlates of reported behavioral effects.

Important questions also arise concerning the effects of literacy across the life span. Can adults learn to read as efficiently as children? Or is it the case, as advocated by Abadzi (2012), that adults have more difficulties than children in acquiring a new script, displaying "neoliterate dyslexia?" A related question is whether there are sensitive periods for reading-dependent effects on brain and cognition, including for neural competition. Answers to these questions have important implications for the timing and content of educational interventions, but they depend on detailed examination of the populations' characteristics. For example, the fact that neural competition between words and faces is observed only in early but not in late literates (Dehaene, Pegado et al., 2010) may reflect either the rudimentary reading level of the latter or limited plasticity in adulthood. Likewise, we do not yet know whether late literates' rudimentary reading reflects adults' limitations, differences in number of learning years, or differences in motivation linked to personal goals.

More generally, as we begin to understand which processes and brain networks are changed by literacy, we may start thinking about how to optimize reading acquisition, particularly for children who struggle in this process despite having normal access to reading education as well as adequate intelligence and intact sensory abilities, namely developmental dyslexics. Longitudinal studies on either age-matched children (e.g., Monzalvo & Dehaene-Lambertz, 2013) or unschooled adults involved in literacy classes (e.g., Landgraf et al., 2011) as well as training studies (e.g., Brem et al., 2010) monitoring both participants' behavioral progress and brain activation changes, offer promising avenues. Indeed, studying the impact of literacy should lead to better understanding of the pathogenesis (or "proximal causes"; see Pennington & Peterson, this volume) of developmental dyslexia. For example, dyslexics present reduced neural integration of letters and phonemes in the planum temporale as well as reduced activation in the same brain area with purely aural presentation of phonemes (Blau et al., 2010; Monzalvo et al., 2012). This has been interpreted as a proximal cause of reading failure (Blau et al., 2010). Yet as a similar reduced activation in response to speech is observed in illiterate adults (Dehaene, Pegado et al., 2010) and preliterate children (Monzalvo & Dehaene-Lambertz, 2013) compared to literates, reading level might be the real cause. In the future, we should thus integrate better what we learn from studies on missing literacy with what we know on failed literacy, both in terms of pathogenesis and new remediation programs. In this respect, comparative approaches that go beyond the exclusive examination of what have been called WEIRD (Western, Educated, Industrialized, Rich, and Democratic) members of humanity (Henrich, Heine, & Norenzayan, 2010) to include the study of illiterate and late literate adults become more and more urgent, as it is increasingly hard to find representative samples of these populations.

Acknowledgments

Preparation of this chapter was supported by the Fonds de la Recherche Scientifique-FNRS under grant FRFC 2.4515.12 and by an Interuniversity Attraction Poles (IAP) grant 7/33, Belspo. The author is Research Director of the Fonds de la Recherche Scientifique–FNRS, Belgium.

Notes

1 As most of the data reviewed in this chapter concern alphabetic writing systems, the terms *literate* and *literacy* are used here to refer to alphabetic literacy, unless otherwise specified. Also, unless otherwise specified, the term *illiterate* refers to adults who never learned to read and write any script.

2 The ventral visual pathway that is involved in the recognition of objects, including written strings, is organized as a hierarchy of areas. From posterior (occipital) to more anterior regions, the size of the neurons' receptive fields strongly increases, in parallel with increasing sensitivity to complex patterns (from line segments to feature combinations and whole objects) and decreasing sensitivity to physical changes (e.g., in size, location, or viewpoint).

References

Abadzi, H. (2012). Can adults become fluent readers in newly learned scripts? *Education Research International*, *2012*, 1–8.

Adams, M. J. (1990). *Beginning to read: Thinking and learning about print*. Cambridge, MA: MIT Press.

Adrián, J. A., Alegria, J., & Morais, J. (1995). Metaphonological abilities of Spanish illiterate adults. *International Journal of Psychology*, *30*, 329–353.

Anderson, M. L. (2010). Neural reuse: A fundamental organizational principle of the brain. *Behavioral and Brain Sciences*, *33*, 245–313.

Ansari, D. (2012). Culture and education: new frontiers in brain plasticity. *Trends in Cognitive Sciences*, *16*, 93–95.

Ardila, A., Bertolucci, P. H., Braga, L. W., Castro-Caldas, A., Judd, T., Kosmidis, M., . . . Rosselli, M. (2010). Illiteracy: The neuropsychology of cognition without reading. *Archives of Clinical Neuropsychology*, *25*, 689–712.

Ardila, A., Ostrosky-Solis, F., & Mendoza, V. U. (2000). Learning to read is much more than learning to read: A neuropsychologically-based learning to read method. *Journal of the International Neuropsychological Society*, *6*, 789–801.

Baddeley, A. D. (1966). Short-term memory for sequences as a function of acoustic, semantic and formal similarity. *Quarterly Journal of Experimental Psychology*, *18*, 362–365.

Bergen, B. K., & Chan Lau, T. T. (2012). Writing direction affects how people map space onto time. *Frontiers in Psychology*, *3*:109.

Bertelson, P. (1972). Listening from left to right versus right to left. *Perception*, *1*, 161–165.

Bertelson, P., & Tisseyre, F. (1972). Lateral asymmetry in the perceived sequence of speech and nonspeech stimuli. *Perception & Psychophysics*, *11*, 356–362.

Berthoud-Papandropoulou, I. (1978). An experimental study of children's ideas about language. In A. Sinclair, R. J. Jarvella, & W. J. M. Levelt (Eds.), *The child's conception of language* (pp. 55–65). Berlin: Springer.

Blau, V., Reithler, J., van Atteveldt, N., Seitz, J., Gerretsen, P., Goebel, R., & Blomert, L. (2010). Deviant processing of letters and speech sounds as proximate cause of reading failure: A functional magnetic resonance imaging study of dyslexic children. *Brain*, *133*, 868–879.

Bledowski, C., Kaiser, J., & Rahm, B. (2010). Basic operations in working memory: Contributions from functional imaging studies. *Behavioural Brain Research*, *214*, 172–179.

Bramão, I., Mendonça, A., Faísca, L., Ingvar, M., Petersson, K. M., & Reis, A. (2007). The impact of reading and writing skills on a visuo-motor integration task: A comparison between illiterate and literate subjects. *Journal of the International Neuropsychological Society*, *13*, 359–364.

Brem, S., Bach, S., Kucian, K., Guttorm, T. K., Martin, E., Lyytinen, H., . . . Richardson, U. (2010). Brain sensitivity to print emerges when children learn letter-speech sound correspondences. *Proceedings of the National Academy of Sciences USA*, *107*, 7939–7944.

Brennan, C., Cao, F., Pedroarena-Leal, N., McNorgan, C., & Booth, J. R. (2013). Reading acquisition reorganizes the phonological awareness network only in alphabetic writing systems. *Human Brain Mapping*, *34*, 3354–3368.

Burnham, D. K. (2003). Language specific speech perception and the onset of reading. *Reading and Writing: An Interdisciplinary Journal*, *16*, 573–609.

Burton, M. W., Small, S. L., & Blumstein, S. E. (2000). The role of segmentation in phonological processing: An fMRI investigation. *Journal of Cognitive Neuroscience 12*, 679–690.

Calvert, G. A., Bullmore, E. T., Brammer, M. J., Campbell, R., Williams, S. C. R., McGuire, P. K., . . . David, A. S. (1997). Activation of auditory cortex during silent lipreading. *Science*, *276*, 593–596.

Carreiras, M., Seghier, M., Baquero, S., Estévez, A., Lozano, A., Devlin, J. T., & Price, C. J. (2009). An anatomical signature for literacy. *Nature*, *461*, 983–986.

Castles, A., & Coltheart, M. (2004). Is there a causal link from phonological awareness to success in learning to read? *Cognition*, *91*, 77–111.

Castles, A., Holmes, V. M., Neath, J., & Kinoshita, S. (2003). How does orthographic knowledge influence performance on phonological awareness tasks? *Quarterly Journal of Experimental Psychology*, *56A*, 445–467.

Castro-Caldas A., Cavaleiro Miranda, P., Carmo, I., Reis, A., Leote, F., Ribeiro, C., & Ducla-Soares, E. (1999). Influence of learning to read and write on the morphology of the corpus callosum. *European Journal of Neurology*, *6*, 23–28.

Castro-Caldas, A., Petersson, K. M., Reis, A., Stone-Elander, S., & Ingvar, M. (1998). The illiterate brain: learning to read and write during childhood influences the functional organization of the adult brain. *Brain*, *121*, 1053–1063.

Chang, E. F., Rieger, J. W., Johnson, K., Berger, M. S., Barbaro, N. M., & Knight, R. T. (2010). Categorical speech representation in human superior temporal gyrus. *Nature Neuroscience*, *13*, 1428–1432.

Chokron, S., Kazandjian, S., & De Agostini, M. (2009). Effect of reading direction on visuospatial organization: a critical review. In A. Gari, & K. Mylonas (Eds.), *Quod erat demonstrandum: from Herodotus' ethnographic journeys to cross-cultural research* (pp. 104–114). Athens: Pedio Books.

Cohen, L., Dehaene, S., Naccache, L., Lehéricy, S., Dehaene-Lambertz, G., Hénaff, M. A., & Michel, F. (2000). The visual word form area: spatial and temporal characterization of an initial stage of reading in normal subjects and posterior split-brain patients. *Brain*, *123*, 291–307.

Cole, M., Gay, J., Glick, J. A., & Sharp, D. W. (1971). *The cultural context of learning and thinking: An exploration in experimental anthropology*. New York, NY: Basic Books.

Conrad, R., & Hull, A. J. (1964). Information, acoustic confusion and memory span. *British Journal of Psychology*, *55*, 429–432.

Cutler, A., Treiman, R., & Van Ooijen, B. (2010). Strategic deployment of orthographic knowledge in phoneme detection. *Language and Speech*, *53*, 307–320.

Damian, M. F., & Bowers, J. S. (2010). Orthographic effects in rhyme monitoring tasks: are they automatic? *European Journal of Cognitive Psychology*, *22*, 106–116.

Danziger, E., & Pederson, E. (1998). Through the looking-glass: literacy, writing systems and mirror-image discrimination. *Written Language and Literacy*, *1*, 153–164.

Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General*, *122*, 371–396.

Dehaene, S., & Cohen, L. (2007). Cultural recycling of cortical maps. *Neuron*, *56*, 384–98.

Dehaene, S., Nakamura, K., Jobert, A., Kuroki, C., Ogawa, S., & Cohen, L. (2010). Why do children make mirror errors in reading? Neural correlates of mirror invariance in the visual word form area. *Neuroimage*, *49*, 1837–1848.

Dehaene, S., Pegado, F., Braga, L. W., Ventura, P., Nunes, G., Jobert, A., . . . Cohen, L. (2010). How learning to read changes the cortical networks for vision and language. *Science*, *330*, 1359–1364.

Denny, J. P. (1991). Rational thought in oral culture and literate decontextualization. In D. R. Olson, & N. Torrance (Eds.), *Literacy and orality* (pp. 66–89). New York, NY: Cambridge University Press.

Dias, M., Roazzi, A., & Harris, P. L. (2005). Reasoning from unfamiliar premises: a study with unschooled adults. *Psychological Science*, *16*, 550–554.

Dobel, C., Enriquez-Geppert, S., Zwitserlood, P., & Bölte, J. (2014). Literacy shapes thought: the case of event representation in different cultures. *Frontiers in Psychology*, *5:*290.

Donald, M. W. (1993). Précis of *Origins of the modern mind: Three stages in the evolution of culture and cognition*. *Behavioral and Brain Sciences*, *16*, 737–791.

Duñabeitia, J. A., Dimitropoulou, M., Grainger, J., Hernández, J. A., & Carreiras, M. (2012). Differential sensitivity of letters, numbers, and symbols to character transposition. *Journal of Cognitive Neuroscience*, *24*, 1610–1624.

Duñabeitia, J. A., Orihuela, K., & Carreiras, M. (2014). Orthographic coding in illiterates and literates. *Psychological Science*, *25*, 1275–1280.

Dundas, E. M., Plaut, D. C., & Behrmann, M. (2013). The joint development of hemispheric lateralization for words and faces. *Journal of Experimental Psychology: General*, *142*, 348–358.

Ehri, L. C., Nunes, S. R., Willows, D. M., Schuster, B. V., Yaghoub-Zadeh, Z., & Shanahan, T. (2001). Phonemic awareness instruction helps children learn to read: Evidence from the National Reading Panel's meta-analysis. *Reading Research Quarterly*, *36*, 250–287.

Fernandes, T., & Kolinsky, R. (2013). From hand to eye: The role of literacy, familiarity, graspability, and vision-for-action on enantiomorphy. *Acta Psychologica*, *142*, 51–61.

Fernandes, T., Vale, A. P., Martins, B., Morais, J., & Kolinsky, R. (2014). The deficit of letter processing in developmental dyslexia: Combining evidence from dyslexics, typical readers, and illiterate adults. *Developmental Science*, *17*, 125–141.

Fodor, J., & Bever, T. G. (1965). The psychological reality of linguistic segments. *Journal of Verbal Learning and Verbal Behavior*, *4*, 414–420.

Frauenfelder, U. H., Seguí, J., & Dijkstra, T. (1990). Lexical effects in phonemic processing: Facilitatory or inhibitory? *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 77–91.

Frith, U. (1998). Editorial: Literally changing the brain. *Brain*, *121*, 1011–1012.

Garlock, V. M., Walley, A. C., & Metsala, J. L. (2001). Age-of-acquisition, word frequency, neighborhood density effects on spoken word recognition by children and adults. *Journal of Memory and Language*, *45*, 468–492.

Goody, J. (1968). *Literacy in traditional societies*. Cambridge, England: Cambridge University Press.

Goswami, U. (2000). Phonological representations, reading development and dyslexia: Towards a cross-linguistic theoretical framework. *Dyslexia*, *6*, 133–151.

Grainger, J., & Ferrand, L. (1996). Masked orthographic and phonological priming in visual word recognition and naming: Cross-task comparisons. *Journal of Memory and Language*, *35*, 623–647.

Grainger, J., Tidgat, I., & Isselé, J. (2010). Crowding affects letters and symbols differently. *Journal of Experimental Psychology: Human Perception and Performance*, *36*, 673–688.

Gruenewald, P. J., & Lockhead, G. R. (1980). The free recall of category example. *Journal of Experimental Psychology: Human Learning and Memory*, *6*, *225–240*.

Harris, R. (2009). *Rationality and the literate mind*. New York, NY: Routledge.

Henrich, J., Heine, S. J., & Norenzayan, A. (2010). The weirdest people in the world? *Behavioral and Brain Sciences*, *33*, 61–135.

Hoonhorst, I., Medina, V., Colin, C., Markessis, E., Radeau, M., Deltenre, P., & Serniclaes, W. (2011). Categorical perception of voicing, colors and facial expressions: A developmental study. *Speech Communication*, *53*, 417–430.

Hulme, C., Caravolas, M., Malkova, G., & Brigstocke, S. (2005). Phoneme isolation ability is not simply a consequence of letter-sound knowledge. *Cognition*, *97*, B1–B11.

Kolinsky, R., Cary, L., & Morais, J. (1987). Awareness of words as phonological entities: the role of literacy. *Applied Psycholinguistics*, *8*, 223–232.

Kolinsky, R., Morais, J., & Verhaeghe, A. (1994). Visual separability: a study on unschooled adults. *Perception*, *23*, 471–486.

Kolinsky, R., Verhaeghe, A., Fernandes, T., Mengarda, E. J., Grimm-Cabral, L., & Morais, J. (2011). Enantiomorphy through the looking-glass: Literacy effects on mirror-image discrimination. *Journal of Experimental Psychology: General*, *140*, 210–238.

Kosmidis, M. H., Tsapkini, K., Folia, V., Vlahou, C. H., & Kiosseoglou, G. (2004). Semantic and phonological processing in illiteracy. *Journal of the International Neuropsychological Society*, *10*, 818–827.

Kosmidis, M. H., Zafiri, M., & Politimou, N. (2011). Literacy versus formal schooling: influence on working memory. *Archives of Clinical Neuropsychology*, *26*, 575–582.

Lafontaine, H., Chetail, F., Colin, C., Kolinsky, R., & Pattamadilok, C. (2012). Role and activation time course of the phonological and orthographic information during phoneme judgment. *Neuropsychologia*, *50*, 2897–2906.

Landgraf, S., Beyer, R., Pannekamp, A., Schaadt, G., Koch, D. Foth, M., & Meer, E. (2011). Dissociating improvement of attention and intelligence during written language acquisition in adults. *International Journal of Intelligence Science*, *1*, 17–24.

Li, S., Lee, K., Zhao, J., Yan, Z., He, S., & Weng, X. (2013). Neural competition as a developmental process: Early hemispheric specialization for word processing delays specialization for face processing. *Neuropsychologia*, *51*, 950–959.

Liberman, A. M., Harris, K. S. Hoffman, H. S., & Griffith, B. C. (1957). The discrimination of speech sounds within and across phoneme boundaries. *Journal of Experimental Psychology*, *54*, 358–368.

Liberman, I. Y., Shankweiler, D., Fischer, F. W., & Carter, B. (1974). Explicit syllable and phoneme segmentation in the young child. *Journal of Experimental Child Psychology*, *18*, 201–212.

Luria, A. R. (1976). *Cognitive development. Its cultural and social foundations*. Cambridge, MA: Harvard University Press.

Martinez Perez, T., Majerus, S., & Poncelet, M. (2012). The contribution of short-term memory for serial order to early reading acquisition: Evidence from a longitudinal study. *Journal of Experimental Child Psychology*, *111*, 708–723.

Matute, E., Montiel, T., Pinto, N., Rosselli, M., Ardila, A., & Zarabozo, D. (2012). Comparing cognitive performance in illiterate and literate children. *International Review of Education*, *58*, 109–127.

Mesgarani, N., Cheung, C., Johnson, K., & Chang, E. F. (2014). Phonetic feature encoding in human superior temporal gyrus. *Science*, *343*, 1006–1010.

Metsala, J. L. (1997). An examination of word frequency and neighborhood density in the development of spoken-word recognition. *Memory & Cognition*, *25*, 47–56.

Miyake, A., Friedman, N. P., Emerson, N. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*, 49–100.

Monzalvo, K., & Dehaene-Lambertz, G. (2013). How reading acquisition changes children's spoken language network. *Brain and Language*, *127*, 356–365.

Monzalvo, K., Fluss, J., Billard, C. Dehaene, S., & Dehaene-Lambertz, G. (2012). Cortical networks for vision and language in dyslexic and normal children of variable socio-economic status. *NeuroImage*, *61*, 258–274.

Morais, J., Bertelson, P., Cary, L., & Alegria, J. (1986). Literacy training and speech segmentation. *Cognition*, *24*, 45–64.

Morais, J., Cary, L., Alegria, J., & Bertelson, P. (1979). Does awareness of speech as a sequence of phones arise spontaneously? *Cognition*, *7*, 323–331.

Morais, J., Castro, S.-L., Scliar-Cabral, L., Kolinsky, R., & Content, A. (1987). The effects of literacy on the recognition of dichotic words. *Quarterly Journal of Experimental Psychology*, *39 A*, 451–465.

Morais, J., & Kolinsky, R. (1994). Perception and awareness in phonological processing the case of the phoneme. *Cognition*, *50*, 287–297.

Morais, J., & Kolinsky, R. (2002). Literacy effects on language and cognition. In L. Bäckman, & C. von Hofsten (Eds.) *Psychology at the turn of the millenium, Vol. 1: Cognitive, biological, and health perspectives* (pp. 507–530). Hove, UK: Psychology Press.

Muneaux, M., & Ziegler, J. C. (2004). Locus of orthographic effects in spoken word recognition: Novel insights from the neighbour generation task. *Language and Cognitive Processes*, *19*, 641–660.

Nation, K., & Hulme, C. (2011). Learning to read changes children's phonological skills: Evidence from a latent variable longitudinal study of reading and nonword repetition. *Developmental Science*, *14*, 649–659.

Nisbett, R. E. (2003). *The geography of thought: How Asians and Westerners think differently . . . and why*. New York: Free Press.

Nisbett, R. E., & Miyamoto, Y. (2005). The influence of culture: Holistic versus analytic perception. *Trends in Cognitive Sciences*, *9*, 467–473.

Olson, D. (1991). Literacy as metalinguistic activity. In D. R. Olson, & N. Torrance (Eds.), *Literacy and orality* (pp. 251–270). Cambridge, England: Cambridge University Press.

Ong, W. J. (1982). *Orality and literacy: The technologizing of the word*. New York, NY: Methuen.

Pattamadilok, C., Knierim, I. N., Duncan, K. J., & Devlin, J. T. (2010). How does learning to read affect speech perception? *Journal of Neuroscience*, *30*, 8435–8444.

Pattamadilok, C., Kolinsky, R., Luksaneeyanawin, S., & Morais, J. (2008). Orthographic congruency effects in the suprasegmental domain: Evidence from Thai. *Quarterly Journal of Experimental Psychology*, *61*, 1515–1537.

Pattamadilok, C., Lafontaine, H., Morais, J., & Kolinsky, R. (2010). Auditory word serial recall benefits from orthographic dissimilarity. *Language and Speech*, *53*, 321–341.

Pattamadilok, C., Morais, J., Ventura, P., & Kolinsky, R. (2007). The locus of the orthographic consistency effect in auditory word recognition: further evidence from French. *Language and Cognitive Processes*, *22*, 700–726.

Pattamadilok, C., Perre, L., Dufau, S., & Ziegler, J. C. (2009). On-line orthographic influences on spoken language in a semantic task. *Journal of Cognitive Neuroscience*, *21*, 169–179.

Pattamadilok, C., Perre, L., & Ziegler, J. C. (2011). Beyond rhyme or reason: ERPs reveal task-specific activation of orthography on spoken language. *Brain and Language*, *116*, 116–124.

Peereman, R., Dufour, S., & Burt, J. S. (2009). Orthographic influences in spoken word recognition: The consistency effect in semantic and gender categorization tasks. *Psychonomic Bulletin & Review*, *16*, 363–368.

Pegado, F., Nakamura, K., Braga, L., Ventura, P., Nunes, G., Jobert, A., . . . Dehaene, S. (2014). Literacy breaks mirror invariance for visual stimuli: A behavioral study with adult illiterates. *Journal of Experimental Psychology: General*, *143*, 887–894.

Pegado, F., Nakamura, K., Cohen, L., & Dehaene, S. (2011). Breaking the symmetry: mirror discrimination for single letters but not for pictures in the Visual Word Form Area. *NeuroImage*, *55*, 742–749.

Perre, L., Pattamadilok, C., Montant, M., & Ziegler, J. C. (2009). Orthographic effects in spoken language: On-line activation or phonological restructuring? *Brain Research*, *1275*, 73–80.

Perre, L., & Ziegler, J. C. (2008). On-line activation of orthography in spoken word recognition. *Brain Research*, *1188*, 132–138.

Petersson, K. M., Silva, C., Castro-Caldas, A., Ingvar, M., & Reis, A. (2007). Literacy: A cultural influence on functional left-right differences in the inferior parietal cortex. *European Journal of Neuroscience*, *26*, 791–799.

Pollatsek, A., Bolozky, S., Well, A. D., & Rayner, K. (1981). Asymmetries in the perceptual span for Israeli readers. *Brain and Language*, *14*, 174–180.

Ranbom, L. J., & Connine, C. M. (2011). Silent letters are activated in spoken word recognition. *Language and Cognitive Processes*, *26*, 236–261.

Ratcliff, G., Ganguli, M., Chandra, V., Sharma, S., Belle, S., Seaberg, E., & Pandav, R. (1998). Effects of literacy and education on measures of word fluency. *Brain and Language*, *61*, 115–122.

Read, C., Zhang, Y., Nie, H., & Ding, B. (1986). The ability to manipulate speech sounds depends on knowing alphabetic reading. *Cognition*, *24*, 31–44.

Rossion, B., Dricot, L., Devolder, A., Bodart, J. M., Crommelinck, M., De Gelder, B., & Zoontjes, R. (2000). Hemispheric asymmetries for whole-based and part-based face processing in the human fusiform gyrus. *Journal of Cognitive Neuroscience*, *12*, 793–802.

Scliar-Cabral, L., Morais, J., Nepomuceno, L., & Kolinsky, R. (1997). The awareness of phonemes: So close—so far away. *International Journal of Psycholinguistics*, *13*, 211–240.

Scribner, S. (1977). Modes of thinking and ways of speaking: Culture and logic reconsidered. In P. N. Johnson-Laird & P. C. Wason (Eds.), *Thinking: Readings in cognitive science* (pp. 483–500). New York, NY: Cambridge University Press.

Scribner, S., & Cole, M. (1981). *The psychology of literacy*. Cambridge, MA: Harvard University Press.

Seidenberg, M. S., & Tanenhaus, M. K. (1979). Orthographic effects on rhyme monitoring. *Journal of Experimental Psychology: Human Learning and Memory*, *5*, 546–554.

Serniclaes, W., Ventura, P., Morais, J., & Kolinsky, R. (2005). Categorical perception of speech sounds in illiterate adults. *Cognition*, *98*, B35–B44.

Shaki, S., Fischer, M. H., & Petrusic, W. M. (2009). Reading habits for both words and numbers contribute to the SNARC effect. *Psychonomic Bulletin & Review*, *16*, 328–331.

Stone, G. O., Vanhoy, M., & Van Orden, G. C. (1997). Perception is a two-way street: Feedforward and feedback phonology in visual word recognition. *Journal of Memory & Language*, *36*, 337–359.

Szwed, M., Dehaene, S., Kleinschmidt, A., Eger, E., Valabregue, R., Amadon, A., & Cohen, L. (2011). Specialization for written words over objects in the visual cortex. *Neuroimage*, *56*, 330–344.

Szwed, M., Qiao, E., Jobert, A., Dehaene, S., & Cohen, L. (2014). Effects of literacy in early visual and occipitotemporal areas of Chinese and French readers. *Journal of Cognitive Neuroscience*, *26*, 459–475.

Szwed, M., Ventura, P., Querido, L., Cohen, L., & Dehaene, S. (2012). Reading acquisition enhances an early visual process of contour integration. *Developmental Science*, *15*, 139–149.

Taft, M. (2006). Orthographically influenced abstract phonological representation: evidence from non-rhotic speakers. *Journal of Psycholinguistic Research*, *35*, 67–78.

Taft, M. (2011). Orthographic influences when processing spoken pseudowords: Theoretical implications. *Frontiers in Psychology 2*: *140*.

Thiebaut de Schotten, M., Cohen, L., Amemiya, E., Braga, L. W., & Dehaene, S. (2014). Learning to read improves the structure of the arcuate fasciculus. *Cerebral Cortex*, *24*, 989–995.

Treiman, R. (1983). The structure of spoken syllables: Evidence from novel word games. *Cognition*, *15*, 49–74.

Treiman, R., & Cassar, M. (1997). Can children and adults focus on sound as opposed to spelling in a phoneme counting task? *Developmental Psychology*, *33*, 771–780.

Van Leeuwen, C., & Lachmann, T. (2004). Negative and positive congruence effects in letters and shapes. *Perception & Psychophysics*, *66*, 908–925.

Ventura, P., Fernandes, T., Cohen, L., Morais, J., Kolinsky, R., & Dehaene, S. (2013). Literacy acquisition reduces the automatic holistic processing of faces and houses. *Neuroscience Letters*, *554*, 105–109.

Ventura, P., Kolinsky, R., Brito-Mendes, C., & Morais, J. (2001). Mental representations of the syllable internal structure are influenced by orthography. *Language and Cognitive Processes*, *16*, 393–418.

Ventura, P., Kolinsky, R., Fernandes, S., Querido, L., & Morais, J. (2007). Lexical restructuring in the absence of literacy. *Cognition*, *105*, 334–361.

Ventura, P., Morais, J., Pattamadilok, C., & Kolinsky, R. (2004). The locus of the orthographic consistency effect in auditory word recognition. *Language and Cognitive Processes*, *19*, 57–95.

Ventura, P., Pattamadilok, C., Fernandes, T., Kolinsky, R., Klein, O., & Morais, J. (2008). Schooling in Western culture promotes context-free processing. *Journal of Experimental Child Psychology*, *100*, 79–88

Verhaeghe, A., & Kolinsky, R. (2006). *O que os iletrados nos ensinam sobre os testes de inteligência* [*What illiterate people teach us about intelligence tests*]. Lisbon, Portugal: Fundação Calouste Gulbenkian- Fundação para a Ciência e a Tecnologia.

Wilson, M. (2010). The re-tooled mind: How culture re-engineers cognition. *Social Cognitive and Affective Neuroscience*, *5*, 180–187.

Yoncheva, Y. N., Maurer, U., Zevin, J. D., & McCandliss, B. D (2013). Effects of rhyme and spelling patterns on auditory word ERPs depend on selective attention to phonology. *Brain and Language*, *124*, 238–243.

Yoncheva, Y. N., Zevin, J. D., Maurer, U., & McCandliss, B. D. (2010). Auditory selective attention to speech modulates activity in the visual word form area. *Cerebral Cortex*, *20*, 622–632.

Young, A. W., Hellawell, D., & Hay, D. C. (1987). Configurational information in face perception. *Perception*, *16*, 747–759.

Zatorre, R., Meyer, E., Gjedde, A., & Evans, A. (1996). PET studies of phonetic processing of speech: Review, replication and reanalysis. *Cerebral Cortex*, *6*, 21–30.

Ziegler, J. C., & Ferrand, L. (1998). Orthography shapes the perception of speech: The consistency effect in auditory recognition. *Psychonomic Bulletin & Review*, *5*, 683–689.

Ziegler, J. C., Petrova, A., & Ferrand, L. (2008). Feedback consistency effects in visual and auditory word recognition: Where do we stand after more than a decade? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*, 643–661.