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LITERACY INFLUENCES COGNITIVE ABILITIES FAR BEYOND THE MASTERY OF WRITTEN LANGUAGE

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Abstract
Recent experimental evidence from cognitive psychology and cognitive neuroscience shows that reading acquisition has non-trivial consequences for cognitive processes other than reading per se. In the present chapter I present evidence from three areas of cognition: phonological processing, prediction in language processing, and visual search. These findings suggest that literacy on cognition influences are far-reaching. This implies that a good understanding of the dramatic impact of literacy acquisition on the human mind is an important prerequisite for successful education policy development and guidance of educational support.

Keywords: cognition, literacy, phonology, reading, visual search

1. Introduction

About 16% of the world's adult population today lack ''the ability to read and write with understanding a simple statement related to one's daily life'' (UNESCO Institute for Statistics, 2013). What consequence has illiteracy on human cognition? Scholars have speculated about the impact of reading and writing on human cognition and society at large almost as soon as writing systems were invented (see Huettig & Mishra 2014, for a recent review). Plato regarded writing an inhuman and alien technology with a strong potential for detrimental effects on memory and weakening the mind more generally (Ong 1982). Goody and Watt (1968) pointed out that writing preserves what is said and thereby, they argued, facilitates critical debate and thinking. Similarly, Havelock (1963) proposed that it was literacy which led to modern society because it encouraged explicit definitions of terms and logical analysis. McLuhan (1962) pointed out that the invention of the printing press led to a shift from oral to silent reading. This resulted in a more fundamental separation of spoken and written language. Finally, Ong (1982) made the case that writing

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transforms spoken language into an object of thought and reflection (see also Vygotsky 1978, for a similar view). It is difficult to evaluate these claims without considering evidence from controlled experimental studies. Over the last thirty years cognitive psychologists and neuroscientists have experimentally investigated the effects of literacy acquisition on the human mind. In the present chapter I present evidence from three areas of cognition (phonological processing, prediction, and visual search) which suggest that literacy has significant cognitive consequences that go far beyond the processing of written words and sentences. This evidence suggests that the ability to read shapes general cognitive processing in non-trivial ways.

2. Effects of literacy on phonological processing

Many studies have found important differences in illiterates' phonological awareness. Morais, Cary, Alegria, and Bertelson (1979) first demonstrated that phonemic awareness (i.e. the knowledge that all words can be decomposed into smaller segments and the ability to manipulate these segments) is not acquired spontaneously but requires specific training. Thirty illiterates and thirty late literates (who had taken part in adult literacy programs after the age of 15) from Portugal were asked to add or delete one phoneme (e.g., /p/) of a word. Mean correct responses on non-word trials were 19% for illiterates but 72% for late literates. Many subsequent studies have replicated these results. It is typically observed that illiterates perform better on tasks that require manipulation of units of larger phonological grain size such as syllable detection (Morais, Content, Cary, Mehler, & Segui 1989) and rhyme awareness (Morais et al. 1986; Adrian, Alegria, & Morais 1995) than units of smaller phonological grain size such as phonemes. It is important to note that it is not the ability to read and write per se but the knowledge of an alphabetic script which results in phonemic awareness. Read, Zhang, Nie, and Ding (1986) in this regard found that phonemic awareness of Mandarin Chinese readers who had no alphabetic knowledge was similar to illiterates. In contrast, phonemic awareness of Mandarin Chinese readers who had alphabetic knowledge (the Chinese pinyin) was similar to those of late-literates.

The question whether performance in phonological awareness tasks is an important ability is a valid one since phonological awareness is not necessary for understanding and producing speech. Reis and Castro-Caldas (1997) conducted experiments in which participants were required to repeat words and pseudowords (i.e. non-existing 'words'). Pseudoword repetition is a task which requires both explicit and implicit phonological processing and is therefore better suited to assess phonological abilities. They found that illiterates performed much worse than literates in repeating pseudowords. Illiterates however performed as well as literates when they had to repeat real (i.e. existing) words. These results suggest that the absence of reading acquisition leads to impoverished processing at the level of sublexical phonological structure (cf. Petersson et al. 2000).

We (Huettig, Singh, & Mishra 2011) have recently used an online method (visual world eye-tracking) to study the effect of literacy on moment-by-moment phonological processing. Such methods are important because phonological processing happens over very short periods of time and phonological effects are transitory and dynamic in nature. Moreover, it is essential to use experimental techniques that allow the researcher to measure ongoing processing while participants' task activities are not interrupted. In our study, participants listened to simple spoken sentences such as '*Today he saw a crocodile*'. At the same time they were looking at a visual scene of four objects while their eye movements were measured for later analyses. It is important to realize that fixations and saccades are relatively discrete events. Data from a single trial by a participant thus cannot provide information about the continuous processing of the speech signal. However, by averaging across trials and participants it can be computed how likely listeners are on average at a given moment in time to look at each of the areas of interest in the visual scene. Inferences about the time course of the underlying cognitive processes based on these eye gaze data can be drawn (see Huettig, Rommers, & Meyer 2011, for further discussion and a recent review of the method). By measuring looks to phonological and semantic competitor objects in the visual scene it can be examined how individuals differing in literacy use phonological and semantic information. In our first experiment in India, 42 high literates of Devanagari script with fifteen mean years of formal schooling (range: 13-17 years) and 32 low literates of Devanagari script with two mean years of formal schooling (range: 0-9) listened to the sentences containing a critical word (e.g., 'magar', crocodile) while looking at the visual scene. The visual scene contained a phonological competitor of the critical word (e.g., *matar* 'peas', the Hindi words *matar* and *magar* are phonological similar), a semantic competitor (e.g., *kachuwa*, 'turtle', both turtles and crocodiles are reptiles) and two completely unrelated distractor objects. In our second experiment the semantic competitors were replaced with another unrelated distractor object. We observed that both low and high literates looked to the semantic competitors in Experiment 1. High literates, in both experiments, shifted their eyes towards phonological competitors as soon as phonological information became available. Moreover, high literates moved their eye gaze away as soon as the acoustic information mismatched. Low-literates on the other hand only used phonological information when semantic matches between spoken word and visual referent were not possible (i.e. in Experiment 2 when no semantic competitor was present in the visual scene). Furthermore, in contrast to high literates this phonological word-object mapping in low literates was not closely time-locked to the concurrent speech input. Overall these findings suggest that low literates do not exploit phonological matches between spoken words and visual referents for language-mediated visual orienting in such an efficient manner as high literates.

Computational modeling is a means by which mechanisms that drive effects of literacy can be isolated. We (Smith, Monaghan, and Huettig 2014) recently used modeling to test the hypothesis that increases in the granularity of phonological processing elicit the literacy-related changes (cf. Ziegler & Goswami 2005). To this end we constructed three connectionist models with phonological representations of varying grain sizes (fine, medium, coarse). The representational structure in the fine grained model involved distinct componential sequences of phonemes (target and competitor shared their initial two phonemes). In the moderate grained model in contrast two components similar to 'onset' and 'rime' representations were encoded for each word. Finally, the coarse grained model contained only a single component (similar to a word-level representation). The fine grained model showed 'eye gaze' to phonological competitors closely time-locked to the unfolding speech signal. In other words it performed very similar to the fixation behavior of high literates. The coarse grained model in contrast performed very similar to low literates. There was no time locking between speech signal and looks to phonological competitors. These connectionist simulations therefore provide further support that literacy results in changes in the grain size of phonological mappings. In short, literacy acquisition has substantial consequences on phonological processing: after learning to read our speech processing will never be the same

3. Prediction of up-coming words during speech processing

A second influence of written language on spoken language that I would like to mention here concerns the prediction of up-coming words in spoken language processing. There is plenty of evidence from other domains of psychology that individuals' ability to anticipate upcoming events is modulated by their level of expertise at the task at hand. Studies in the field of sports psychology have found that athletes' prediction abilities are strongly related to their proficiency levels. Elite basketball players anticipate the success of free shots at baskets earlier and more accurately than people with comparable visual experience (i.e., coaches and sports journalists, Aglioti, Cesari, Romani, & Urgesi, 2008). Professional volleyball players are better than amateur players in predicting the landing location of volleyball serves (Starkes, Edwards, Dissanayake, & Dunn 1995), etc. This connection of high levels of ability and prediction is typically explained by the fine-tuning of specific anticipatory mechanisms that enable athletes to predict others' actions prior to their realization (Aglioti et al. 2008).

We (Mishra, Singh, Pandey, & Huettig 2012) explored whether predictive language processing is influenced by language experience. Specifically we investigated whether high proficiency in reading is related to anticipatory language-mediated eye-movements. This possibility arises because many psycholinguistic experiments have shown that one reason why language processing tends to be so effortless, accurate, and efficient is that mature (e.g., DeLong, Urbach, & Kutas 2005; Federmeier & Kutas 1999; Van Berkum, Brown, Kooijman, Zwitserlood, & Hagoort 2005; Wicha, Moreno, & Kutas 2004; Huettig, 2015, for recent review) and developing (e.g., Borovsky, Elman, & Fernald 2012; Nation, Marshall, & Altmann 2003; Mani & Huettig 2012) language users anticipate upcoming words during language processing. We presented Indian low and high literates (i.e. groups with similar characteristics as in the eye-tracking study described above) with simple every day spoken sentences containing a critical word (e.g., "door"). Participants listened to these sentences while they looked at a visual display of four objects (the target object, i.e. the door, and three unrelated distractor objects). We constructed the spoken Hindi sentences in such a way that syntactic markers and semantic information in the sentence could be used to predict the upcoming target. Eye movements to the visual target objects and distractor objects were measured. We observed that the high literacy group started to move their eye gaze to the target object well before target word onset. The participants in the low literacy group in contrast did not anticipate the targets and looked at the target objects only more than a second later (that is only when the target object was mentioned in the speech).

These initial results suggested that literacy modulates predictive spoken language processing. Reading proficiency therefore appeared to influence prediction even in basic every day spoken language processing but further evidence seemed required. It is difficult to exclude the social reasons behind one group being illiterate from having an influence on their performance. Literate and illiterate adults tend to differ in many aspects such as socioeconomic status, general education, parental education, childhood nutrition, access to medical care and many other factors. We therefore attempted to find converging evidence for the connection between literacy and prediction by testing children as they learn to read. Moreover, by observing correlations between children's developing reading skills and their performance in language-based tasks allows investigation of the individual differences in processing. This may provide more information as to individual-specific reasons why reading acquisition interacts with prediction. We (Mani & Huettig 2014) therefore investigated the role of word and pseudoword reading skills on listener's prediction of upcoming spoken language input in children at the cusp of literacy acquisition. 8-year-old German children were presented with a visual display containing two familiar objects (for example a cake and a bird). The children heard sentences as ''Der Junge isst den großen Kuchen'' (The boy eats the big cake) as they looked at the visual display. We tracked their eye movements across the visual display and examined the correlation between children's performance in the anticipation eye-tracking task and their reading abilities. The children, like in previous studies (e.g. Mani & Huettig 2012), were successfully able to predict upcoming spoken language input. More importantly, there was a robust positive correlation between children's word reading (but not their pseudo-word reading and meta-phonological awareness or their spoken word recognition) skills and their prediction skills. Those children who performed better in the word reading task were more able to predict upcoming linguistic input and fixated thematically appropriate objects soon after the onset of the semantically constraining verb (i.e. after hearing the verb 'eat'). These results (from children growing up in the same area with similar exposure to literacy) provide further support for the notion of a relationship between children's literacy skills, specifically their real-word reading skills, and their ability to predict upcoming spoken language input.

In another recent study we looked at this link between reading abilities and anticipation in adults with dyslexia. We reasoned that if reading ability mediates predictive language processing then we should find evidence for this in adults with dyslexia. There are no previous studies that have explored anticipatory spoken language processing in individuals with dyslexia. Nation and colleagues (2003) showed skilled and less skilled comprehenders (children of 10 or 11 years of age) a visual scene. At the same time the children heard spoken sentences such as "Jane watched her mother choose the cake" (all objects in the scene were choosable) or "Jane watched her mother eat the cake" (the cake was the only edible object in the display). The less skilled comprehenders were matched to the skilled comprehenders for nonword reading scores but scored below average on a reading comprehension test. Nation et al. found that skilled and less skilled comprehenders did not differ in the speed of their language-mediated anticipatory eye movements to the target objects. Two studies looked at general non-linguistic anticipation skills in children with dyslexia. Stoodley and Stein (2006) observed that children with dyslexia and poor readers showed a general motor slowing related to a general deficit in processing speed.

Moreover, Wolff (2002) observed that individuals with dyslexia (10 to 16 years of age) took three or four times as long as normal readers to anticipate the signal of an isochronic pacing metronome during a motor sequencing task. The individuals with dyslexia also took significantly longer than normal readers to switch back to anticipation mode after an abrupt change in the metronome rate. We (Huettig & Brouwer, 2015) tested Dutch adults with dyslexia and a control group of adults with no history of reading disorders in two eye-tracking experiments. In Experiment 1 we assessed whether adults with dyslexia show the typical language-mediated eye gaze patterns observed in previous research with adults with no reading impairments. The eye gaze of both adults with and without dyslexia closely replicated earlier research. Both groups used spoken language to direct attention to relevant objects in the environment in a closely time-locked manner. In Experiment 2 our participants received instructions (e.g., "Kijk naar de$_{COM}$ afgebeelde piano$_{COM}$", look at the displayed piano) while at the same time viewing four objects. The Dutch articles ("het" or "de") were gender-marked such that the article agreed in gender only with the target. Our participants could therefore use gender information from the articles to predict the target object. We observed that the adults with dyslexia anticipated the target objects but much later than the controls. As for our study with the 8-year-old German children (Mani & Huettig 2014) participants' word reading scores correlated positively with their anticipatory eye movements.

In sum, we observed that high but not low literates anticipate up-coming target objects. Word reading scores significantly correlated with anticipatory looks in eight year-olds. Adults with dyslexia show significantly delayed anticipatory eye movements. What might be the reason for this consistent influence of literacy on anticipation? A full explanation is likely to be complex. One possibility is that reading leads to stronger associations also when spoken language input is processed. This explanation fits with the notion of literacy as a proxy for experience. Borovsky, Elman, and Fernald (2012) for example observed that children aged 3 to 10 with relatively high vocabulary knowledge are faster to anticipate target words than children with lower vocabulary knowledge. It is also conceivable that production-related mechanisms of prediction play a role. Written language experience in children has been observed to increase the spoken production of relative clause sentences (Montag & MacDonald 2014). Another possibility I want to raise here is that the process of learning orthographic representations during reading acquisition sharpens pre-existing lexical representations. Orthographic exposure provides listeners with orthographic representations which may result in lexical representations becoming richer and sharper and available more quickly during online speech processing (Mani & Huettig 2014).

4. Spatial biases and visual search

In the last two sections I presented evidence for the influence of learning to read and write on spoken language processing. With the final example I chose for this chapter I want to demonstrate how the effects of literacy extend beyond language processing to (seemingly) unrelated areas of cognition such as visual search. Literacy has been found to have substantial effects on the way we sample the visual world such as when we are looking for something among distracting objects.

It is important to know first that in the broader human population there is a general left hemifield (that is right hemisphere) bias in tasks requiring fine discrimination of visual stimuli (Jewell & McCourt 2000; Kimura 1966; Landau & Fries 2012; Nicholls & Roberts 2002). Importantly however several studies with illiterate and literate participants have shown that there is an additional directional bias due to the direction of the writing system individuals are exposed to (for example, left-to-right or right-to-left writing). Urdu is a language written in right-to-left direction using the Persian script. Padakannaya et al. (2002) observed that illiterate Urdu speaking adults did not show any right-left bias. They administered two tasks, naming linearly arranged pictures and recall of linearly arranged pictures after brief exposure. Literate Urdu speaking adults however did show such a right-to-left scanning bias. Padakannaya and colleagues concluded that directional scanning habits are a consequence of reading habits.

Vaid et al. (2002) asked their participants to draw a quick sketch of simple objects (for example, a pencil, a fish, a house). They found that script directionality and handedness affected preference for drawings in literates. Right and left-handed Urdu literates however showed a right-to-left stroke bias. Illiterates however, as predicted, showed no overall bias (right-handed illiterates showed a left-to-right stroke bias and left-handed illiterates showed a right-to-left stroke bias). The authors concluded that hand movement-related directional biases and directional scanning biases arise at least partly from reading and writing experiences (cf. Dobel, Diesendruck, & Bőlte 2007; Eviatar 1995, 1997, 2000; Maas & Russo 2003).

Brucki and Nitrini (2008) conducted a study with illiterate and low literate river bank dwellers of the Amazon region of Brazil. Participants were shown random arrays of geometric visual stimuli and were asked to mark every open circle with a single slanted line as fast as they could. The authors found that illiterates were much more likely than the low literates to conduct a random search for the target circles. Bramao and colleagues (2007) asked illiterate and literate participants in Portugal to touch visual targets as quickly as possible on a computer screen (for example a red square among yellow squares). The illiterates performed less accurate and slower compared to the literates in target detection. Importantly, literates were faster in detecting the target objects on the left side of the screen (in line with left-to-right script direction). Illiterates however did not show any directional bias.

The above studies suggest that there are literacy-related differences in selective attention. These studies however leave some questions open. Are the differences observed just due to less experience with abstract geometric stimuli? Do these effects reflect attentional processes? Or, do they reflect processes at stages after target selection has taken place (for example decision or response selection processes)? We (Olivers, Huettig, Singh, & Mishra 2014) tested low to high literacy observers in India in two experiments. Each experiment contained an easy and a more difficult visual search task. In the easy task participants were asked to find a red chicken among green chickens (a color 'pop-out' search). In the difficult task participants were asked to find a skinny chicken among fat chickens (a shape search). The task involved looking for different types of chicken to avoid that low literates had an immediate disadvantage. We observed that low literates were slower in both experiments. More detailed analyses of reaction times and eye movement analyses showed that the slowing was to some extent due to differences in parallel sensory processing. The main differences between the groups however occurred post-selection. First, low literates were slower to generate the manual response after target fixation. Second, both groups differed in the distribution of search performance across the visual display. High literates performed particularly well in central and right parts of the visual field. This suggests that learning to read results in an extension of the functional visual field from the fovea to parafoveal areas. It has long been known that reading exploits nonfoveal visual information. Readers obtain partial information parafoveally about the next word when they fixate the preceding word. Our results suggest that this spatially-specific training of the covert attentional system leads to attentional benefits (that is better search performance) even in non-language tasks. Third, high literates showed a more general bias towards the top and the left compatible with left-to-right reading direction of the Hindi-speaking participants. This suggests that learning to read also leads to asymmetries in scan patterns.

To conclude, in the present chapter I have presented three examples of how literacy has important cognitive consequences which go beyond the processing of orthographic stimuli. First, literacy increases phonological awareness and leads to phonological restructuring and changes in the grain size of phonological mappings. Second, there is strong evidence from studies with illiterates, children, and adults with dyslexia that literacy skills enhance the ability to predict upcoming spoken language input. Third, learning to read changes the spatial distribution of visual search even for non-linguistic searches and extends the function field of view into parafoveal areas. Literacy is an important skill in literate societies. The results I have presented here suggest that the influences on cognition are far-reaching. It is important that policy makers are aware of these far-reaching effects of literacy on the mind, otherwise there is a real danger that educational policies and pedagogical support will not be efficacious or even be misdirected.

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