

**Characteristics of Illiterate and Literate Cognitive Processing: Implications of Brain--
Behavior Co-Constructivism**

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Running head: Cognition modulated by literacy

<A> Abstract

Literacy and education represent essential aspects of contemporary society and subserve important aspects of socialization and cultural transmission. The study of illiterate subjects represents one approach to investigate the interactions between neurobiological and cultural factors in cognitive development, individual learning, and their influence on the functional organization of the brain. In this chapter we review some recent cognitive, neuroanatomic, and functional neuroimaging results indicating that formal education influences important aspects of the human brain. Taken together this provides strong support for the idea that the brain is modulated by literacy and formal education, which in turn change the brains capacity to interact with its environment, including the individual's contemporary culture. In other words, the individual is able to participate in, interact with, and actively contribute to the process of cultural transmission in new ways through acquired cognitive skills.

Characteristics of Illiterate and Literate Cognitive Processing: Implications of Brain--Behavior Co-Constructivism

<A> Introduction

Education plays an essential role in contemporary society. Acquiring reading and writing skills as well as other cognitive skills during formal education can be viewed as a structured process of cultural transmission. Formal education and the educational system represent essential aspects of modern society and are cardinal structures of the intelligent-information environment. These institutionalized structures subserve important aspects of socialization and cultural transmission. The study of illiterate subjects and matched literate controls provides an opportunity to investigate the interaction between neurobiological and cultural factors in cognitive development and learning. Alternative approaches have also been explored with respect to cross-cultural variation, including the implications of transparent and non-transparent orthographies on brain function (Paulesu et al., 2000) and their consequences for the expression of dyslexia (Paulesu et al., 2001).

Reading and writing represent cognitive abilities that depend on human cultural evolution (Vygotsky, 1962). Writing was a relatively late invention in human history, invented some 6,000 years ago. It seems unlikely that specific brain structures have developed for the purpose of mediating reading and writing skills (Ardila, 2004). Instead it is likely that reading and writing are supported by pre-adapted brain structures. A pre-adaptation is a structure that has evolved to serve a specific function but has come to serve as a means for a different end. Several cognitive skills acquired through formal education, including reading, do not represent a species wide adaptation of the kind that natural language is a paradigmatic example of. Varney (2002) emphasizes that reading and writing "evolved through cultural developments that were only acquired as 'typical' human abilities within the last 200 years in Europe and America, and only after World War II in the rest of the world." In fact, reading

and writing skills are still far from universal at the beginning of the 21st century. At present, it is estimated that there are close to one billion illiterate humans in the world (about two thirds are women; UNESCO, 2003), whereas the mean educational level is only about 3--4 years of schooling (Abadzi, 2003).

Natural language is a system of knowledge, a system of representation and processing of these representations, as well as a system for communicative use (Chomsky, 1986). However, aspects of language can also be an object of cognition and meta-linguistic awareness involves explicit processing and intentional control over aspects of phonology, syntax, semantics, discourse, as well as pragmatics. These processes are different from the implicit language processing used in comprehension and production. During the acquisition of reading and writing skills, the child creates the ability to represent aspects of the phonological component of language by an orthographic representation and relate this to a visuo-graphic input-output code. This is commonly achieved by means of a supervised learning process (i.e., teaching). This is in contrast to natural language acquisition, which is largely a spontaneous, non-supervised, and self-organized acquisition process. A similar perspective can be taken on formal education in general.

In addition to the acquisition of language, children gradually create explicit representations and acquire processing mechanisms that allow for reflecting and analyzing different aspects of language function and language use (Karmiloff-Smith, Grant, Sims, Jones, & Cuckle, 1996). Several researchers have investigated the relationship between reading and meta-linguistic awareness (Morais, 1993). Children do not learn language passively but actively construct representations on the basis of linguistically relevant constraints and abstractions of the linguistic input (Karmiloff-Smith et al., 1996). Meta-cognitive and meta-linguistic awareness develops progressively over the early years of life (Karmiloff-Smith, 1992). When children subsequently learn to read, this has repercussions on the phonological representations of spoken language (Morais, 1993; Petersson, Reis, Askelöf,

Castro-Caldas, & Ingvar, 2000). For example, there seems to be an intricate interplay between meta-linguistic awareness and reading, rather than simply a one-way influence. Furthermore, it appears that various types of meta-linguistic skills (including phonological awareness) correlate with literacy skills and levels of formal education (Ravid & Tolchinsky, 2002).

Literacy, reading and writing, as well as printed media represent extensive cultural complexes and, like all cultural expressions, they originate in human cognition and social interaction. Goody's work on literacy emphasizes the role that written communication has played in the emergence, development, and organization of social and cultural institutions in contemporary societies (e.g., Goody, 2000). The emergence of writing transformed human culture, including the ability to preserve speech and knowledge in printed media. This allowed societies with a literate tradition to develop and accumulate knowledge and control over their environment and living conditions in a general sense. In addition, the nature of oral communication has a considerable effect upon both the content and transmission of the cultural repertoire of a society. For example, the content of the cultural traditions and knowledge has to be held in memory when a written record is not an option. Instead, individual memory will mediate the cultural heritage between generations and new experience will be integrated with the old by a process of interpretation. The invention of new communication media have significant impact on the way information is created, stored, retrieved, transmitted, and used, and on cultural evolution as a whole. Furthermore, reading and writing makes possible an increasingly articulate feedback as well as independent self-reflection and promotes the development of meta-cognitive skills; while auditory-verbal language use is oriented towards content, aspects of this knowledge can become explicitly available to the language user in terms of cognitive control and analytic awareness. It has thus been suggested that the acquisition of reading and writing skills, as well as formal education more generally, facilitates this through a process of representational construction and reorganization (Karmiloff-Smith, 1992). Ravid and Tolchinsky (2002) suggested that meta-

linguistic development is related to the acquisition of literacy and school-based knowledge. In other words, the acquisition of written language skills promotes flexible and manipulable representations for meta-linguistic use (Karmiloff-Smith, 1992).

In this chapter we will review some recent cognitive, neuroanatomic, and functional neuroimaging data indicating that formal education and its use influence aspects of the human brain and, taken together, provide strong support for the hypothesis that the functional architecture of the brain is modulated by literacy. In particular we will focus on results from a series of experiments with an illiterate population and their matched literate controls living in the south of Portugal. We conclude that literacy and formal education exert an interesting influence on the development of the human brain and its capacity to interact with its environment.

 The study population of southern Portugal

The fishermen village Olhão of Algarve in southern Portugal, where all of our studies have been conducted, is socio-culturally homogeneous and the majority of the population has lived most of their lives within the community. Mobility within the region has been limited and the main source of income is related to agriculture or fishing. Illiteracy occurs in Portugal due to the fact that forty or fifty years ago it was common for older daughters of a family to be engaged in the daily household activities at home and therefore they did not enter school. Later in life they may have started to work outside the family. In larger families, the younger children were generally sent to school when they reached the age of 6 or 7 while the older daughters typically helped out with the younger siblings at home.

Literate and illiterate subjects live intermixed in this region of Portugal and participate actively in this community. Illiteracy is not perceived as a functional handicap and the same socio-cultural environment influences both literate and illiterate subjects on similar terms. Some of the literate and illiterate subjects in our studies are from the same family, increasing

the homogeneity in background variables. In addition, most of the literate subjects participating in our studies are not highly educated and most often they have had approximately 4 years of schooling. In the present context, it is important to ensure that the subjects investigated are not cognitively impaired and also that the illiterate are matched to the literate subjects in as many relevant respects as is possible, except for the consequences of not having had the opportunity to receive formal education. In our studies we have attempted to match the different literacy groups as far as possible in terms of several relevant variables, including for example age, sex, general health, socio-cultural background, and level of everyday functionality. (For a more detailed characterization of our study population and our selection procedures see Reis, Guerreiro, & Petersson, 2003.) These protocols and procedures ensure with reasonable confidence that the illiterate subjects are cognitively normal, that their lack of formal education results from specific socio-cultural reasons, as already described, and not due to low intelligence, learning disability, or any other pathology potentially affecting the brain. The illiterate subjects and their literate controls included in our studies are comparable along socio-economic dimensions as well.

<A> Recent Cognitive Findings

Behavioral studies have demonstrated that literacy/illiteracy as well as the extent of formal education influence the performance of several behavioral tasks commonly used in neuropsychological assessment (for a recent review see e.g., Petersson, Reis, & Ingvar, 2001). For example, it appears that the acquisition of written language skills modulates aspects of spoken language processing (e.g., Mendonça et al., 2002; Morais, 1993; Silva et al., 2002). Additional data indicate that formal education influences some visuo-spatial skills (e.g., Reis, Petersson, Castro-Caldas, & Ingvar, 2001). However, it is still unclear which cognitive processes and brain mechanisms mediate these effects of literacy. A detailed understanding of which parts of the cognitive system and which processing levels are affected is still lacking.

In this section we will focus on some aspects of object naming, short-term memory, phonological processing and word awareness in spoken sentence context, as well as semantic memory. The basic idea is that literacy influences some aspects of spoken language processing related to phonological processing and verbal short-term working memory as well as visuo-motor skills related to reading and writing.

 Object naming -- color makes a difference to illiterates

Several studies have indicated that the level of formal education and/or literacy influence the performance when subjects name two-dimensional (2D) pictorial representations of objects (e.g., Reis, Guerreiro, & Castro-Caldas, 1994). Naming objects or their 2D pictorial representations are common every day tasks and the performance on simple object-naming tasks is dependent on the systems for visual recognition, lexical retrieval, and the organization of articulatory speech output as well as the interaction between these systems (Levelt, 1989). In our study population, practice in interpreting schematic 2D representations commonly took place simultaneously with the acquisition of written Portuguese and other symbolic representations during school attendance. Moreover, reading and writing depend on advanced visual and visuo-motor skills in coding, decoding, and generating 2D representations. It is thus likely that the interpretation and production of 2D representations of real objects as well as the coding and decoding of 2D material in terms of figurative/symbolic semantic content is more practiced in literate subjects than in illiterate individuals, who generally have received little systematic practice in interpreting conventional visuo-symbolic representations. We thus speculated that there may be differences in 3D and 2D object-naming skills between literate and illiterate individuals. In a simple visual naming experiment in which the participants named common everyday objects, Reis, Petersson et al. (2001) reported differences between literate and illiterate subjects related to 2D object naming but found no difference when subjects named real 3D objects, both with respect to naming performance and in terms of

response times. In addition, the two groups dissociated in terms of their error patterns, with the illiterate group more prone to make visually related errors (recognition failure or visual recognition error, e.g., pen instead of needle), whereas the literate group tended to make semantically related errors (no lexical access or lexical semantic errors, e.g., necklace instead of bracelet).

Though the results with 2D line drawings and real objects were clear in the study of Reis, Petersson et al. (2001), the results with colored photos did not clearly dissociate between the literacy groups in terms of 2D vs. 3D naming skills. We therefore speculated that the semantic significance of object color might play a role, in particular for the illiterate subjects because they are prone to be driven by semantic rather than formal aspects of stimuli or information, a theme we will return to in subsequent sections.

In a recent follow-up study, using a similar experimental set-up as Reis, Petersson et al. (2001), we presented common everyday objects as black and white (i.e., grey scaled) as well as colored drawings and photos in an immediate 2D object naming task. Consistent with the results outlined above the literate group performed significantly better than the illiterate group on black and white items (i.e., both line drawings and photos). In contrast, there was no significant difference between literacy groups on the colored items (Figure 1). Interestingly, the illiterate participants performed significantly better on colored line drawings compared to black and white photos. Preliminary investigations also indicate that the color effect is related to the semantic value of the color in the sense that the effect seems more pronounced for objects with no or little consistency in the color--object relation compared to objects with a consistent relation to its color (e.g., lemons are yellow).

<Figure 1 about here>

In summary, the absence of group differences when real 3D objects are named, and in particular the absence of response time (RT) differences on correctly named real objects indicate that the RT differences on drawings and photos are not simply related to slower visual or language processing in general. Instead, the longer processing time in the illiterate group appears to be related to the processing of 2D visual information or the interaction between lexical retrieval and the processing of 2D visual information. The latter possibility would suggest that the interface between the two systems is configured differently in the two literacy groups, leading to differences in the effectiveness of the necessary information transfer. The result of the error analysis is consistent with this interpretation, since the illiterate subjects made relatively more visually related than language related errors whereas the pattern was the opposite for the literate group. In fact, the qualitative distribution of errors was not significantly different for real object naming between groups. Taken together this interpretation is consistent with a recent suggestion that orthographic knowledge is an integral component of the general visual processing system (Patterson & Lambon Ralph, 1999), indicating that the acquisition of alphabetic orthographic knowledge may affect specific components of visual processing. Interestingly, a positive correlation between reading abilities and the capacity to name line drawings has also been reported (Goldblum & Matute de Duran, 2000). Recent findings also indicate that color can play an important role for the illiterate group when naming 2D pictorial representations of common everyday objects. This seems to be true when the semantic value of the color of an object is prominent (Reis et al., 2004).

 Phonological processing, short-term working memory, and literacy

As a general background to the following subsections, we note that repetition of pseudowords and digit span tasks are considered as measures of verbal working memory capacities. These measures have been shown to be correlated with reading achievements in children (Baddeley,

Gathercole, & Papagno, 1998; Gathercole & Baddeley, 1995). Additional research also points toward a role of verbal working memory and the efficiency of phonological processing in relation to reading skills (Brady, 1991). Verbal short-term working memory is a system subserving the representation and on-line processing of verbal information. In the Baddeley and Hitch model, one role of the phonological loop, a subsystem for short-term storage of phonologically represented information, is to store unfamiliar sound patterns while more permanent learning changes can be formed. This suggests that the phonological loop may serve as a language learning device and it may play an integral part in the systems for spoken and written language acquisition (Baddeley et al., 1998).

Several researchers have investigated the relationship between reading and meta-linguistic awareness, including so-called phonological awareness (e.g., Morais, 1993). With respect to phonological awareness this research has indicated that illiterate subjects have some difficulty in dealing with tasks requiring explicit phonological processing. For example, the results of Morais et al. (1979) showed that illiterate subjects found it more difficult to add and remove phonemes at the beginning of words as well as pseudowords. One may ask to what extent these tasks are equally natural (i.e., of similar ecological relevance) to literate and illiterate individuals, thus complicating the interpretation of these findings. This issue has recently been emphasized by Reis and colleagues (Reis & Petersson, 2003; Silva, Petersson, Faísca, Ingvar, & Reis, 2004).

Generally speaking, it is still unclear what type of relation exists between phonological processing, verbal working memory, and the acquisition of orthographic knowledge. Moreover, it appears that the phonological processing difficulties in illiterate subjects are not limited to phonological awareness per se but involve other aspects of sub-lexical phonological processing as well as skills related to verbal working memory (e.g., phonological recoding in working memory). There is some evidence indicating that these effects may be specific to alphabetic orthographies and it is unclear whether or not these

generalize to non-alphabetic orthographies. In the following subsections, we will review some recent results on short-term memory span, pseudoword processing, and word awareness in sentence context.

<C> Short-term memory -- Digit and spatial span

Several studies have indicated that there is a difference in digit span between literate and illiterate subjects (e.g., Ardila, Rosselli, & Rosas, 1989; Reis, Guerreiro, Garcia, & Castro-Caldas, 1995). In a recent study, Reis et al. (2003) showed that the difference in digit span is not a simple effect of literacy as such but that digit-span performance appears to be dependent on the extent of formal education. In particular, illiterate participants had a mean digit span of $4.1 (\pm 0.9)$, performing significantly more poorly than literate participants. However, also literate subjects with 4 years of education (5.2 ± 1.4) performed significantly lower than literate subjects with 9 years of education (7.0 ± 1.8). Thus it appears that not only literacy but education more generally contributes to the observed difference (overall effect $p < .001$).

In a recent follow-up study we compared literate and illiterate participants directly on the digit span and spatial span sub-tasks of the Wechsler Memory Scale (III revision). Consistent with the results just described there was a significant difference between literacy groups on the digit span ($p = .004$) while there was no significant difference on the spatial span task ($p = .3$). These results indicate that the illiterate subjects have a lower verbal span for compared to literate subjects, while this is not the case for spatial span. These results represents a first hint that verbal short-term memory might be influenced by literacy and formal education, and this is possibly related to more effective verbal working memory representations in literate individuals (e.g. chunking, cf. e.g., Olesen, Westerberg, & Klingberg, 2004).

<C> Word and pseudoword processing

Pseudoword repetition is a commonly used task to investigate verbal working memory capacity. Reis and Castro-Caldas (1997) concluded that illiterate performed similarly to literate subjects on word repetition, whereas there was a significant difference on pseudoword repetition. We have suggested that this is related to an inability to handle certain aspects of sub-lexical phonological structure (Petersson et al., 2000) and indicates that the phonological representations or the processing of these representations are differently developed in literate and illiterate individuals (Petersson et al., 2000; Petersson et al., 2001). Alternatively, the system for orthographic representations may support phonological processing as an auxiliary interactive processing network (Petersson et al., 2001).

Because several aspects of auditory-verbal language may differ between literate and illiterate subjects, it is of interest to isolate the different sources contributing to these differences in phonological processing. In particular, it is important to study the differences in phonological processing relatively independent of lexicality effects (e.g., vocabulary size and frequency effects) as well as articulatory mechanisms. In order to do so we used an immediate auditory-verbal serial recognition paradigm (Gathercole, Pickering, Hall, & Peacker, 2001) in a recent follow-up study (Petersson et al. 2004). In general, immediate serial recognition is independent of speech output. In addition, serial recognition of pseudowords is (relatively) independent of lexicality effects. In this experiment we compared illiterate and literate subjects on immediate recognition of lists of 3 CVCV-syllable items (C = consonant, V = vowel). The lists varied in lexicality (words/pseudowords) and phonological similarity (dissimilar/similar). The participants were asked to judge whether two lists (presented one after the other) contained items presented in the same or different order. Group comparisons showed significant differences, the literate group performing better than the illiterate, in all conditions (pseudoword/dissimilar, $p < .001$; pseudoword/similar, $p = .03$; word/similar $p = .003$), except for phonologically different words ($p = .2$). Of the four different conditions, the phonologically different word condition is of course the easiest to handle from a phonological

point of view. Words are more familiar than pseudowords and the phonological contrast is greater in the different compared to the similar condition. These results are thus consistent with the differences in pseudoword repetition (literate > illiterate) and digit span performance and further supports the idea that there are differences in verbal working-memory capacity between literacy groups. In addition, the results on immediate serial recognition indicate that these differences are (relatively) independent of lexicality effects, articulatory organization (e.g., output phonology), or other speech output mechanisms.

 Awareness of phonological form and the intrusion of lexical semantics in illiterates

A characteristic of problem-solving capabilities in illiterate individuals is their tendency to prefer semantic-pragmatic strategies, if such are possible, over more formally oriented strategies. In other words, when an illiterate individual is confronted with a problem that can be solved by using strategies based on formal/abstract or semantic/pragmatic aspects of the problem, the illiterate individual is generally more likely to base the strategy on the latter type of information. For example, Kolinsky, Cary, and Morais (1987) investigated the notion of phonological word length in literate and illiterate subjects. Even when explicitly asked to attend to the abstract phonological properties of words, the illiterate group still found it difficult to ignore their semantic content; thus, the illiterate group found it difficult to inhibit the intrusion of semantic information when attempting to solve the task based on a form criterion. This suggests that explicit awareness of words as a phonological form may depend on orthographic knowledge or more generally on formal education.

In a recent experiment of ours (Silva et al., 2002), literate and illiterate participants listened to words and pseudowords during a phonological ("sound") length decision task, in which the participants were asked to decide which item in a pair was the longest in phonological terms. In the word condition, we manipulated the relationship between word length and size of the denoted object, yielding three sub-conditions: (1) *Congruent* -- the

longer word denoted the larger object; (2) *Incongruent* -- the longer word denoted the smaller object; (3) *Neutral* -- only phonological length of the words varied, denoting objects of similar size. Pseudoword pairs were constructed based on the real-words pairs by changing the consonants and maintaining the vowels as well as word length. All subjects practiced each condition until they fully understood the task.

<Figure 2 here>

Two effects were of interest in the results. First, the literate subjects showed no effect of semantic interference whereas this was clearly the case in the illiterate group (Figure 2). Secondly, while the literates performed at similar levels on words and pseudowords, the illiterate group performed significantly better on pseudowords compared to words. In fact, the mean performance in the pseudoword condition was slightly better than in the neutral word condition. These results indicate that the illiterate subjects show a greater difficulty in inhibiting the influence of semantic interference, the intrusion of lexical semantics in the decision process.

 Awareness of words in sentence context

Little is known about how adult illiterate subjects perceive words in sentence context. Awareness of words as independent lexical units has been investigated in children, both before and after acquiring reading skills (e.g., Barton, 1985; Hamilton & Barton, 1983; Karmiloff-Smith et al., 1996), and also in illiterate adults (Cary & Verhaeghe, 1991). The results show that explicit knowledge of words as independent lexical units is to some degree dependent on literacy. Cary & Verhaegh (1991) suggested that the difficulty for illiterate subjects is to efficiently identify closed-class words because of their relative lack of semantic content. However, given the prominent syntactic role of closed-class words in sentence

processing, including sentence comprehension, and the fact that illiterate and literate individuals acquire spoken language on similar terms, we were interested in whether the effects related to closed-class words could be given a phonological explanation. In two recent studies we revisited these issues (Mendonça et al., 2002). In the first study, we investigated the awareness of words in sentence context with the aim of clarifying the role of literacy in the recognition of words as independent lexical units and the possible relation to the known phonological processing characteristics of illiterate subjects. We presented short sentences that varied in their constituent structure in random order to the participants. All articles, prepositions, pronouns, and adverbs were included in the closed-class category. We divided this class into phonologically stressed and non-stressed words, where the latter are characterized by the absence of a stressed vowel. Each sentence was orally presented and subjects were instructed to listen to the sentence, to immediately repeat it, and to identify its constituent words by enumerating them. All spontaneous corrections were considered and after the experimental session subjects were asked to correct three of the incorrect segmentations. The behavioral data were scored according to the following aspects: (A) Global quantitative: (1) total of correct sentence segmentations (maximum score: 18), (2) spontaneous corrections, and (3) corrections made when probed; (B) Segmentation errors: (1) blending (a so-called "clitization" phenomena) words at the boundaries of sentence's main constituents and (2) blending words within phrases; (C) Omissions of stressed and non-stressed closed-class words.

<Table 1 here>

It is clear from Table 1a, that the literate group performed significantly better than the illiterate on the sentence segmentation task. The results also show that illiterate subjects did not spontaneously correct themselves, not even when probed. For all error types investigated,

group comparison showed significant differences. Therefore, and in order to further understand the behavioral pattern of illiterate group, the subsequent error analysis focused on this group only. In order to compare the incidence of the different error types, percentage of errors was computed based on the total number of possible occurrences for each type. The illiterate group showed a specific pattern of merging or "clitization" of words (Table 1b and Figure 3b). There are very few mergers between the major syntactic constituents (1.4% error rate), meaning that illiterates are sensitive to the major syntactic structure of the sentence. This was also the case for syntactic boundaries within verb phrases (VP; 4.3%). Increasing rates of mergers were observed within phrase internal constituents related to noun phrases (NP) and prepositional phrases (PP), but this seemed to depend on the particular syntactic context or alternatively on the linear sentence position. The words of NPs in subject position were more frequently merged (60%) compared to NPs within VPs or PPs in complement position (47% and 37%, respectively). Within the PPs composed of a preposition or contraction and a noun, the illiterates committed the highest rate of mergers; in differently composed PPs mergers were less frequent.

The closed-class word analysis revealed that illiterate subjects were unable to correctly segment 50% of the instances. Comparing the stressed and the non-stressed closed-class words showed that the merging tendency was significantly more prominent for the non-stressed closed-class words (Figure 3a).

<Figure 3>

In a recent follow-up study using a similar experimental design (Mendonça et al., 2003), these effects were replicated. In brief, while there was no significant difference in sentence repetition ($p = .7$), the literate sentence segmentation performance was significantly better than the illiterate ($p < .001$) and the mergers related to closed-class words was observed

significantly more often with non-stressed as compared to stressed closed-class words in the illiterate group ($p < .001$). More detailed preliminary analysis indicates that the merging effect is dependent on the type of closed-class, that is, the stressed versus non-stressed effect was most common for determiners and least common for prepositions. Overall then, the present results corroborate previous suggestions that recognition of words as independent phonological units in sentence context depends on literacy. Cary and Verhaegh (1991) suggested that the difficulty observed in illiterate subjects is related to a difficulty in efficient identification of closed-class words due to their relative lack of semantic content. However, the present results show that this can not serve as a unitary explanation since the segmentation failures did not distribute evenly over closed-class words (not even within sub-types) but occurred more often with phonologically non-stressed than phonologically stressed closed-class words. The illiterate subjects are thus more sensitive to phonologically stressed closed-class words which they are able to segment quite efficiently. We suggest that illiterate segmentation performance is closely related to sentence internal prosody and phonological stress. Thus, the difficulty seems to be a phonological phenomenon rather than related to lexical semantics. In addition, the "clitization" phenomenon seems not to be related to phrase structure per se, since the illiterate group respected phrasal boundaries; blending mainly occurred within phrases and rarely across phrasal boundaries or boundaries between major sentence constituents. Another contributing factor to segmentation difficulties may be verbal working-memory capacity, since the performance of the illiterate group increased from the start to the end of sentences. In other words, also the linear sentence position may play a role. In summary, illiterate word segmentation of sentences appears to depend on factors related to phonology, syntactic structure, and linear position, and it does not seem to be related to lexical semantic factors.

 Semantic fluency -- An example of the importance of ecological relevance

Literacy and formal education is also associated with the acquisition of a broader knowledge-base of general information as well as to process this information in a more systematic abstract and elaborate manner. Hence, literacy and formal education catalyze the development of several cognitive skills in addition to reading and writing skills. Task selection can thus be of importance when investigating populations of different cultural backgrounds. In particular, when the objective is to interpret differences in performance between populations in cognitive terms, it is sometimes important that the task is of comparable ecological relevance to the populations involved. This goes beyond matching populations for background variables related to socio-economic status, etc. (cf. e.g., Coppens, Parente, & Lecours, 1998; Reis & Petersson, 2003). This is illustrated by the results from a recent study of semantic fluency by Silva et al. (2004).

Verbal fluency tasks (i.e., production tasks in which subjects generate as many words as possible during a limited time according to some given criteria) are commonly used in neuropsychological assessment because they are easy to administer, sensitive to brain damage and cognitive deterioration, and have been applied to groups of different cultural background. Clear and consistent differences between literacy groups have been reported when a phonological fluency criterion is used (for a recent review see Silva et al., 2004). In contrast, several studies comparing literate and illiterate subjects have yielded different results when using semantic criteria. At present, the reasons for this are unclear but might be related to the specific semantic criteria and/or the particular study populations investigated. Reis et al. (2003) suggested that the non-convergence of results could be related to the ecological or cultural relevance of the chosen semantic criterion. In order to investigate this issue in greater detail, Reis et al. (2001; 2003) decided to use a semantic criterion of equal natural relevance to female literate and illiterate subjects and asked the participants to name things one can buy at the supermarket. The relevance of this criterion springs from the fact that almost all of these individuals do the major part of their regular shopping at supermarkets and at

comparable levels over time. As expected, Reis, Guerreiro et al. (2001; 2003) found no significant difference between illiterates, subjects with 4 years of education, and subjects with more than 4 years of education.

Silva et al. (2004) attempted to relate the concept of ecological relevance to the level of shared cultural background, except for differences in literacy or formal education. More specifically, Silva et al. (2004) compared the performance of the same illiterate and literate subjects on two time-constrained semantic fluency tasks, the first using the semantic category of food items, which can be bought at the supermarket (supermarket fluency task), and the second, animal names (animal fluency task). Note that the equal performance on the supermarket task excludes a simple explanation for the performance differences on the animal fluency task (literate > illiterate) in terms of general factors such as cognitive speed or fluency. Instead, the interaction between literacy and semantic criterion might be explained in terms of similarities and differences in shared cultural background, that is, greater for supermarket items and lesser for animals.

<Figure 4 here>

This possibly reflects a type of frequency of exposure effect, making lexical access less readily available in illiterate subjects in the animal fluency task. In other words, this difference may be a consequence of education or secondary effect of literacy. For example, reading skills should facilitate access to information through printed media, thus providing an opportunity to broaden different semantic categories that transcend the shared socio-cultural background of the two literacy groups. However, it appears that it is not just that the two semantic categories used in this study are associated with differences in socio-cultural background specifically related to literacy/education; they also differ in the level of reference to a concrete knowledge and to specific situations. The observed differences between the

literacy groups may not only relate to the semantic category used but potentially also to the extension (the semantic field; the potential number of available elements) of the semantic category. On this view, written language provides the opportunity to broaden different semantic categories, and by using written language, we can access information that we cannot access through our direct experience. Thus, an important determinant for verbal fluency performance might relate to the type of experience we have with the elements of a semantic category.

We further investigated the effects of formal schooling on the semantic organization of the responses from the animal fluency task (Faísca, Reis, & Petersson, in preparation) using a non-metric multidimensional scaling approach. This approach assumes that the item sequence in a fluency task reflects the semantic organization of a given semantic domain. The most frequent responses in both groups were selected for further analysis and the serial position was used to build a distance matrix. The matrix for each group was analyzed using multidimensional scaling to represent the results in a 2D semantic space. As can be seen from Figure 4, the semantic organization for the common responses is similar in the two literacy groups. Both groups allocated the different exemplars according to the same sub-categories (farm birds, farm animals, and wild animals).

In summary, the semantic fluency study illustrates two things. Firstly, significant literacy effects may or may not be observed depending on the choice of semantic criterion, and this emphasizes the importance of developing instruments that are free of educational and cultural biases. Secondly, the multidimensional scaling results on the animal category suggest that on the high frequency responses there is no difference between groups in terms of semantic organization, indicating that differences between groups emerged after the first items of a category had been generated. Thus it seems that the initial production reflects the shared cultural background while group differences only emerge in the later phase of the animal fluency production.

<A> Functional and Neuroanatomical Differences Between Literacy Groups

In a positron emission tomography (PET) study of literate and illiterate subjects, we compared the two literacy groups on immediate verbal repetition. The subjects were instructed to repeat words or pseudowords, and though there were performance differences between groups, these did not correlate with the pattern of brain activations in either group (Petersson et al., 2000). Within-group comparisons indicated that there was a more prominent left-sided inferior parietal (Brodmann's area (BA) 40) activation in words versus pseudowords in the literate group, while in the reverse comparison, pseudowords versus words, the literate group displayed a significant activation in the anterior insular cortex (BA 14/15) bilaterally and in the right inferior frontal/frontal opercular cortices (BA 44/45/47/49), left perigenual anterior cingulate cortex (BA 24/32), left basal ganglia, midline anterior thalamus/hypothalamus and midline cerebellum. In the illiterate group, significant activation was only observed in the right middle frontal/frontopolar region (BA 10). These results were generally reflected in the between-group comparisons, including a greater activation of the left inferior parietal region (BA 40) in the literate compared to the illiterate group related to the word versus pseudoword comparison. Taken together with the behavioral findings outlined above, these results indicate that the functional architecture of auditory-spoken language processing is influenced by literacy, suggesting that a relation between the acquisition of reading and writing skills and aspects of phonological processing also exists in terms of the functional brain organization.

A complementary approach to the results outlined in the previous paragraph takes a network perspective on cognitive brain function. In general, information is thought to be represented as distributed activity in the brain, while information processing subserving cognitive functions is thought to emerge from the interactions between different functionally specialized regions. When trying to understand cognitive processing as instantiated in the brain, it is therefore natural to take a network perspective on information processing (Ingvar

& Petersson, 1999). Structural equation modeling (SEM) provides one approach to characterize network interactions and to test network hypotheses explicitly. Petersson et al. (2000) employed a SEM analysis of the PET data outlined above in order to characterize the functional organization of immediate verbal repetition in literate and illiterate subjects. This approach aimed at characterizing the functional organization in terms of effective connections between regions in a functional-anatomical model. Our objective was to construct a simple network that could explain a sufficient part of the observed covariance in both groups during both word and pseudoword repetition. At the same time we required that the network model should be both theoretically and empirically plausible based on the literature on the functional organization of language.

In terms of network interactions, the results showed no significant difference in the literate group when comparing the word and pseudoword condition. Neither was there any significant difference between the literate and illiterate group in the word repetition condition. In contrast, there were significant differences between word and pseudoword repetition in the illiterate group and between the illiterate and literate group in the pseudoword condition. The differences between groups were mainly related to the phonological loop, in particular, the interaction between Broca's region and the inferior parietal region.

The absence of significant difference between word and pseudoword repetition in the literate group relates to the fact that the network interactions were similar during word and pseudoword repetition. This indicates that the literate subjects automatically recruit the same processing network during immediate verbal repetition for both word and pseudoword repetition. In contrast, this was not the case for the illiterate group, consistent with the suggestion that phonological processing is differently organized in illiterate individuals due to a different developmental background related to the acquisition of reading and writing skills. Based on this, in conjunction with the behavioral results outlined above, we suggest that these differences in the phonological loop interactions might represent a primary difference

between the two literacy groups. This is in line with the suggestion that the parallel interactive processing characteristics of the language system differ between literate and illiterate subjects (Pettersson et al., 2000).

<C> The corpus callosum and hemispheric differences between literacy groups

One may wonder whether there are neuroanatomic correlates corresponding to the literacy status. It is well-known that the corpus callosum, the large fiber bundle that interconnects the two brain hemispheres, develops during childhood and into young adulthood. In particular, there is an active myelination process of the neuronal axons running through this structure in order to establish efficient communication between the brain's two hemispheres (Giedd et al., 1996). Recent evidence suggest that the posterior mid-body part of the corpus callosum undergoes extensive myelination during the years of reading acquisition, that is, from 6 to 10 years of age (Thompson et al., 2000). The fibers that cross over in this region of the corpus callosum interconnect the left and right parieto-temporal regions (for a general review see e.g., Zaidel & Iacoboni, 2003). The parieto-temporal regions of the brain, in particular in the left hemisphere is related to language processing, verbal working memory, and reading, and it has been suggested that the corpus callosum plays an important role in the inter-hemispheric exchange of orthographic and phonological information during reading.

<Figure 5>

A recent study of the morphology of the corpus callosum in literate and illiterate subjects suggested that the posterior mid-body region (Figure 5a) is thinner in the illiterate compared to the literate subjects (Castro-Caldas et al., 1999). Pettersson, Reis, Askelöf, Castro-Caldas, and Ingvar (1998) hypothesized that this may be related to a difference in the inter-hemispheric interactions between literacy groups with respect to the parieto-temporal cortices.

Behavioral and lesion data have suggested, though not unambiguously so, that certain aspects of language processing in illiterate individuals recruit bilateral brain regions to a greater extent than literate subjects (for a recent review see e.g., Coppens et al., 1998). For example, an early study suggested that the risk of aphasia as a consequence of left hemisphere lesions was lower in illiterate than literate subjects (Cameron, Currier, & Haerer, 1971). More recently, Lecours et al. (1988) suggested that illiterate subjects are more likely to use processing networks that include right-hemisphere regions when performing certain language tasks. In a recent study (Pettersson, Reis, Castro-Caldas, & Ingvar, in preparation), we attempted to characterize the hemispheric left--right differences in two independent datasets acquired with PET from two different samples of illiterate subjects and their matched literate controls. In the first dataset, in which the subjects repeated words and pseudowords, we explored the possibility of a left--right difference between literacy groups, predicting a greater left--right difference in the literate compared to the illiterate subjects in the inferior parietal region. In order to test this prediction we investigated regions of interest in the angular-supramarginal region (BA 39/40). In a random effect analysis, the left--right difference was greater in the literate group compared to the illiterate for word and pseudoword repetition (Figure 5c). In the second sample, in which subjects listen to and encoded word-pairs, we attempted to replicate this finding. Again, the literate group showed greater left--right difference in the angular-supramarginal region (BA39/40) compared to the illiterate subjects, thus replicating the finding from the first study (Figure 5b and d).

It has recently been indicated that infants are left lateralized in the superior temporal gyrus when listening to speech or speech-like sounds (Dehaene-Lambertz, G., Dehaene, S., & Hertz-Pannier, L.; 2002) and in order to test the specificity of our results with respect to the inferior parietal cortex, we also investigated the superior temporal region (BA 22/41/42). The results showed that both literacy groups were similarly left lateralized in this region (Figure

5e) indicating that the functional lateralization of early speech related brain regions does not depend on literacy.

It is well accepted that both cerebral hemispheres play a role in language processing. However, the results outlined here lend support to the suggestion that there is a relatively greater involvement of the right hemisphere in illiterate compared to literate subjects in the language tasks investigated. These results provide evidence that literacy, a cultural factor, influences the hemispheric balance in inferior parietal language related regions. One may speculate that acquiring reading and writing skills at the appropriate age shapes not only the local morphology of the corpus callosum but also the degree of functional specialization as well as the pattern of interaction between the interconnected inferior parietal regions. Thus there might be a causal connection between reading and writing acquisition, the development of the corpus callosum, and the hemispheric differences reported here.

<A> Conclusion

Formal education and the educational system can be viewed as an institutionalized process of structured cultural transmission. The study of illiterate subjects and their literate controls represents one approach to investigate the interactions between neurobiological and cultural factors in cognitive development. The results reviewed here indicate that formal education influence important aspects of cognition as well as structural and functional properties of the brain. Taken together, the evidence provides strong support for the hypothesis that certain functional properties of the brain are modulated by literacy and formal education. In other words, literacy and formal education influence the development of the human brain and its capacity to interact with the environment. This includes the culture of the individual who, through acquired cognitive skills, actively can participate in, interact with, and contribute to, the process of cultural transmission.

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<A> Figure Legends

Figure 1. The 2D stimuli included black and white (B&W) as well as colored line drawings and photos of common everyday objects. The literate subjects performed significantly better than the illiterate group on black and white items (B&W line drawings: $p = .009$; B&W photos: $p < .001$). In contrast, there was no significant difference between literacy groups on the colored items (colored photos: $p = .21$). Interestingly, the illiterate participants performed significantly better ($p = .02$) on colored line drawings compared to black and white photos.

Figure 2. The literate group performed significantly better than the illiterate group on both words ($p < .001$) and pseudowords ($p = .001$). The results between the different word conditions (i.e., congruent, neutral, vs. incongruent) showed a significant effect in the illiterate group ($p < .001$). There was no significant difference between word (collapsed over conditions) and pseudoword performance in the literate group ($p = .3$). In contrast, the illiterate group showed significantly better performance on pseudowords compared to words ($p = .01$).

Figure 3.(a) The proportion of errors related to closed-class words. The closed-class words were either phonologically stressed or non-stressed. The illiterate subjects committed significantly more segmentation errors related to the non-stressed ($64 \pm 24\%$) compared to the stressed closed-class words ($17 \pm 14\%$; Wilcoxon $p < .001$). (b) The proportion of segmentation errors related to the phrase structure of the sentence.

Figure 4. (a) Hierarchical cluster analysis (Ward's method) of the semantic fluency responses. (b) Multi-dimensional scaling including the seventeen most frequent responses. Observe that the results are rotationally invariant so the results indicate that the aspects of semantic memory reflected in the data are similarly organized in both literacy groups.

Figure 5. (a) Differences between literacy groups in the local thickness of the corpus callosum indicate (circle) that this is thinner in illiterate compare to the literate subjects ($p < .01$). (b) Hemispheric differences (left--right) in activations levels between literacy groups in the inferior parietal region (Brodmann's area 39/40). (c) In experiment 1 the participants listen to and repeated words and pseudowords. The diagrams show the level of left- and right activation levels (regional cerebral blood flow, arbitrary units) as a function of literacy group (illiterate: dashed). Differences averaged over conditions $p = .009$ (words: $p = .017$; pseudowords: $p = .006$). (d) In experiment 2 the participants were listening to and encoded word-pairs. Again we observed left-right activation differences (nearest supra-threshold cluster test, $p = .029$, corrected) between literacy groups in the inferior parietal region (Brodmann's area 39/40). (e) To test the specificity of these left--right results with respect to the inferior parietal cortex, we also investigated the superior temporal region (BA 22/41/42) in the second experiment. The results showed that both literacy groups were similarly left lateralized in this region indicating that the functional lateralization of early speech related brain regions does not depend on literacy.

Table 1. (a) Means and standard deviations for sentence segmentation scores (maximum = 18; between-group Mann-Whitney U Test). (b) Mean and standard deviations of proportions of segmentation errors committed internal to the phrase type by the illiterate group.

Table 1a)

Behavioral Measure	Illiterate	Literate	<i>p</i> -value
Correct sentence segmentation	3 ± 2.9	17 ± 2.0	< .001
Spontaneous corrections	0.1 ± 0.2	1 ± 1.3	.001
Percentage of questions corrected	19 ± 33	80 ± 45	.01

Table 1b)

Blending internal constituents of phrases	Percentage
Determiner + noun	51 ± 22
Preposition + determiner + noun	18 ± 19
Preposition + determiner	14 ± 13
Preposition + noun	77 ± 28
Contraction + noun	62 ± 28