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FROM LANGUAGE TO READING AND READING DISABILITY:

Cognitive Functions and their Neural Basis

Abstract. Reading comprehension is seen as an end product of a number of subprocesses involving the mediation from visual input to phonological representation, in particular, and processes of language comprehension in general which in turn are modulated by aspects of working memory and attention. The neural basis of each of these functionally different subprocesses constituting normal reading is presented. Empirical findings and theories of reading disability are discussed with respect to a possible impairment of one or more of these subprocesses.

1. INTRODUCTION

For millions of years, humans have spoken and understood language. Their ability to read and write, however, has been established only in more recent times. From a psycholinguistic perspective, reading must be considered as a secondary process which apart from the visual identification of the word form relies in its consecutive processes on the primary language system (e.g., Perfetti, 1998; Perfetti, Bell & Delaney, 1998; Perfetti & Sandak, 2000). The language system provides the phonological, morphological, semantic and syntactic information over which comprehension processes operate. The processes and components that are specific to reading as compared to auditory language comprehension are (i) the identification of visual features relevant to define letters, (ii) the identification of a visual word form, (iii) and transcoding from orthography to phonology. Thus, there are a number of functionally distinct subprocesses which must be intact to guarantee normal reading. Any research on impaired reading must keep the complexity of the process in mind. The present book discusses the relevant processes and subprocesses involved in reading with respect to their functional relevance and partly with respect to their neural basis allowing the reader to locate past and present empirical findings and theories.

In the following, we will first outline the basic functions of normal reading and their neural basis. We will see that the process of normal reading involves the fundamental processes known to constitute the comprehension of spoken sentences plus those basic processes that allow the mediation from visual input to the phonological representation on which higher order linguistic processes are built. Moreover, it will be shown that cognitive processes outside the language domain, namely working memory and attention affect reading processes. After laying these

grounds we will try to specify at which of these different processing level and in which domains, normal reading might derail.

2. BASIC FUNCTIONS OF LANGUAGE COMPREHENSION

The initial level that becomes active within the language system proper is the *phonological processing level*. At this level the phonological information is assembled and a phonological representation is built up. This phonological representation allows access to the lexicon and to identify a particular lexical entry that matches the phonological representation (Marslen-Wilson & Warren, 1994; Pisoni & Luce, 1987). At the *lexical level*, semantic and morphological information, as well as syntactic information (i.e., word class, argument structure), become available. This information is the basis for the relevant processes at the *sentence level*. At this level the syntactic structure is built up and thematic relations between the different elements in the sentences are assigned to achieve a sentence representation (Frazier, 1987; Just & Carpenter, 1992, see also Swinney & Love, this volume; Saddy, this volume). The further integration of such a sentence representation into the world knowledge may be viewed as the process of understanding in its most general use of the term. Integration of a sentence representation into prior discourse is achieved at the *discourse or text level* (Kintsch, 1988; Noordman & Vonk, 1999).

Each of these processes has been identified to correlate with particular brain areas within a network supporting language comprehension. In brief, these brain areas can be specified as follows. *Phonological processes* have been located at an integrated network consisting of the posterior part of the superior temporal gyrus/sulcus and the inferior frontal gyrus (Brodmann Area (BA) 44), (Démonet et al., 1992; Zatorre, Evans, Meyer, & Gjedde, 1992; Price et al, 1992). *Lexical-semantic processes* have been reported to correlate with activation in the middle temporal gyrus and the inferior frontal gyrus (BA 45/47), (Fiez, 1997; Kapur et al., 1994; Thompson-Schill, D'Esposito, Aquirre, & Farah, 1997). *Syntactic processes* were shown to involve the anterior part of the superior temporal gyrus and the inferior frontal gyrus (inferior part of BA 44 and the adjacent frontal operculum), (Caplan, Alpert, & Waters, 1998; Friederici, Meyer, & von Cramon, 2000; Just, Carpenter, Keller, Eddy, & Thulborn, 1996; Stromswold, Caplan, Alpert, & Rauch, 1996). *Discourse level processes*, furthermore, involve brain areas in the frontal median wall (Ferstl & von Cramon, 2001).

Although all these areas show their activation predominantly in the left hemisphere, right homologue areas are reported to be simultaneously active, in particular, at the sentential level when the input is presented auditorily. Recent studies have shown that the increased right hemisphere activation is partly due to prosodic information present in spoken sentences (Meyer, Alter, & Friederici, in press). Furthermore, a comparison between auditory and visual studies at the sentence level reveals that the left inferior frontal gyrus is always active when the input is visual, but also, albeit less consistently when it is auditory (Michael, Keller, Carpenter, & Just, 2001). This seems to suggest that during sentence reading phonological processes (located in the superior part of BA 44) become active.

3. BASIC FUNCTIONS OF READING

In most general terms reading can be characterized as language comprehension, including all aspects introduced above, plus visual decoding (Everatt et al., 1999). However, reading cannot be defined as simply the sum, but rather as an interaction of these components (e.g., Perfetti & Sandak, 2000). Furthermore, the visual processes involved in reading are not identical to those of visual object recognition. Instead, they are highly specialized to a fast and accurate desymbolization of visual icons (Deacon, 2000). In this respect, reading can be characterized as a highly automated desymbolization process. Different levels of the visual domain are involved in this desymbolization process.

At the *visual feature level*, different features relevant for the identification of a letter such as lines, angles and contours have to be processed to allow the activation of letters (Massaro, 1998). At the *visual word form level*, the identification of visual word forms takes place (Seymour & Evans, 1993). Dual Route Models of word reading assume a direct route from the visual word form to the word's meaning for high frequency words and a second route for low frequency words (Coltheart & Rastle, 1994; Ellis, 1984; Joubert & Lecours, 2000; Samuels, LaBerge, & Bremer, 1978; see also Jimenez-Gonzalez, this volume). This latter route to the lexicon proceeds via a *grapheme-to-phoneme conversion rule system* in which individual letters are mapped onto phonological units before these are assembled into a phonological word form. All models agree that the latter system certainly has to be activated during pseudoword reading. However, the different models are less univocal as to whether low frequency words are the only real words processed by means of grapheme-to-phoneme conversion rules (Coltheart & Rastle, 1994) or whether the identification of a word always involves the immediate co-activation of graphemic and phonological constituents (Booth, Perfetti & MacWhinney, 1999).

The brain areas which were identified to be involved in word reading are the following. Brain areas in the occipital lobe specified to detect line orientation and contours are involved in the processing of the *visual features* of letters. Within the occipito-temporal brain areas the fusiform gyrus is activated when reading between words and pronounceable non-words is compared (Fiebach, Schlesewsky, & Friederici, in press; Herbster, Mintun, Nebes, & Becker, 1997). The middle part of the fusiform gyrus has been taken to be the locus of the *visual word form area*, in which a perceptually invariant higher-order orthographic unit (i.e., a visual word form) is computed from the visual input (Cohen et al., 2000). Note that this brain area in the fusiform gyrus, although relevant for reading, is not reading-specific as it is also activated during visual face recognition (Haxby, Hoffman, & Gobbini, 2000), and more generally when experts process highly familiar objects of the category of their expertise (Gauthier, Skudlarski, Gore, & Anderson, 2000). Fiebach et al. (in press) proposed that this notion of a category-specific recognition component could be extended to written words - a category for which any normal literate adult is an expert.

The left inferior frontal gyrus and the anterior insula have been associated with phonological processing, phonological retrieval and phonemic analysis (for review see Fiez & Petersen, 1998). Activation of this area was not only observed during

pronunciation tasks, but also during lexical decision (Fiebach et al., in press). Increased activation of the superior part of the left pars opercularis (BA 44) was observed for low frequency words and for pseudo-words compared to real words suggesting that lexical access was mediated by phonological information for the former word types. Thus, it appears that this area can be viewed to subserve *grapheme-to-phoneme conversion*. Note, however, that this area is involved in phonological processes both during production and perception. The left middle temporal gyrus known to be involved in auditory language processing has been observed as part of the neural network of word reading. The combined data from different studies suggest that activation in this area can be associated with the activation of *phonological word forms* (Hagoort, Brown, & Osterhout, 1999; Price et al., 1994) which are part of the word's lexical entry.

Price (2001) recently pointed out that the combined results from a number of brain imaging studies indicate that there are no brain areas that are specific to reading. Rather it appears that learning to read involves "establishing associate connections between object processing areas in the visual cortex and speech processing areas in temporal and frontal cortices" (Price, 2001). This result is compatible with the notion that from an evolutionary point of view, reading is a secondary system which is not associated with areas specific to reading, but which rather recruits brain areas primarily subserving other functions.

4. ASPECTS OF MEMORY AND ATTENTION DURING READING

Besides these fundamental processes of reading and language comprehension, cognitive processes outside these domains appear to be necessary to guarantee normal reading, namely working memory capacity and attention.

Working memory has been identified as a main factor determining reading comprehension (Just & Carpenter, 1992; MacDonald, Just, & Carpenter, 1992; but see Waters & Caplan, 1996). This view is based on a large number of behavioral studies showing that sentence comprehension performance decreases when the individual working memory capacity is low, as assessed by the Reading Span Test or when concurrent working memory capacity is high (e.g., Carpenter, Miyake, & Just, 1994). Event-related brain potential studies support the view that syntactic comprehension is constrained by individual working memory constraints (Friederici, Steinhauer, Mecklinger, & Meyer, 1998) and by concurrent working memory load (Vos, Gunter, Schriefers, & Friederici, 2001).

The underlying factor for the performance difference in high and low span readers, however, is defined differently in these studies. While Carpenter and Just (1992) claim that low span readers' difficulty to process syntactically ambiguous sentences is due to an inability to keep the two possible underlying syntactic structures active, others hold that their problem lies in the inability to commit themselves early to the preferred structure and in order to keep the working memory load low (Friederici et al., 1998).

Whatever the valid interpretation of the underlying processes is, the observation is that the correlation between the individual working memory capacity and of reading comprehension ability is high. A correlation between working memory and

reading has also been demonstrated for the level of lexical processing. It was found that the resolution of lexical ambiguity is influenced by working memory (Gernsbacher & Faust, 1991; Miyake, Just, & Carpenter, 1994). As mentioned before, two different explanations have been put forward. The first states that low span readers are not able to keep both reading of and ambiguous word active (Miyake et al., 1994), while the other claims that low span readers are unable to actively suppress the irrelevant reading.

This correlation between lexical aspects of comprehension and working memory has not been evaluated using electrophysiological measures so far. However, working memory for single words has been investigated in recent brain imaging studies and so has the relation between working memory and syntactic processing. Aspects of lexical-semantic working memory were shown to be correlated with activation in left temporal regions and in the left inferior frontal gyrus (BA 45/47), (Paulesu, Frith, & Frackowiak, 1993; Gabrieli, Brewer, & Poldrack, 1998; Wiggs, Weisberg, & Martin, 1999).

Aspects of syntactic working memory also activate parts of the left inferior frontal gyrus, namely BA 44/45 (Fiebach et al., in press). While this region was shown to be active when syntactic complex sentences requiring working memory resources are processed in English (Just et al., 1996; Stromswold et al., 1996). Fiebach et al. (in press) using German were able to show that this brain area selectively reacts to working memory constraints rather than to syntactic complexity per se. Note, however, that these two factors are compounded in natural sentences. Thus, the combined data indicate that working memory as tested by the Reading Span Test (Daneman & Carpenter, 1980) influences comprehension performance during reading (see also Osaka & Osaka, this volume). Moreover, they indicate that adjacent, but separable brain areas in the inferior frontal and temporal cortex support lexical and syntactic aspects of working memory.

What seems noteworthy is that working memory capacity interacts with so-called higher levels of processing during reading, namely lexical and syntactic processing, and not with lower level processes such as visual perception and phoneme-to-grapheme conversion. Attention on the other hand appears to be more likely to interact with lower as well as higher level reading processes (McCarthy & Nobre, 1993; Otten, Rugg, & Doyle, 1993; Smid, Jakob, & Heinze, 1999).

Taken together, reading is a complex process that involves lower level perceptual processes and central language processes which interact with aspects of attention and working memory. These processes were discussed to differ not only functionally, but also at the level of neuronal systems. It is not unlikely that reading disability may have its origin in each of these different systems. Therefore, it is not surprising that a number of different theories and models of reading disability have been proposed.

Basic Functions of Language, Reading and Reading
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