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Comprehension Skill, Inference Making, and the Role of Knowledge

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Abstract

Behavioral studies of reading comprehension have shown that skilled and less skilled comprehenders can be distinguished in terms of how often, when, and how they make inferences while reading. This paper reviews the evidence for knowledge-based accounts of reading skill. This class of explanations proposes that skilled comprehenders more actively and efficiently use knowledge and strategies to help them comprehend text. Neurological examinations of reading skill differences are reviewed and interpreted in terms of knowledge-based theories. It is argued that individual differences in comprehension skill depend on dynamics associated with knowledge activation during comprehension.

Texts and other forms of written media are frequent means of transmitting information. Thus, the ability to comprehend written material is a critical skill for successfully functioning in modern society. Consequently, one important goal for many reading researchers is to identify the differences between skilled and less skilled readers in terms of cognitive aptitudes and processes engaged during reading. Developing a better understanding of these differences contributes both to theoretical explanations of the reading process and to interventions designed to improve reading ability.

Many researchers are concerned with the initial stages of reading when the reader is essentially acquiring lexical and syntactic decoding skills. Such researchers have found for example that the more successful novice readers have had greater exposure to print (Stanovich, West, Cunningham, Cipielewski, & Siddequi, 1996) and have greater phonological awareness (Hulme & Snowling, 1992). Other research has shown that lower level processes such as lexical quality can distinguish between skilled and less skilled readers (Perfetti, 1985; Perfetti & Hart, in press). According to this view, readers vary in terms of their processing efficiency and lexical knowledge. Comprehension difficulty arises from inefficient lower level processes required for the identification of words. Indeed, one important factor that can affect word identification is the quality of the lexical representation. For example, Pefetti and Hart (in press) found that the quality of the reader's representation affects not only the speed of word retrieval but also the selection of sense (meaning) of ambiguous words. Based on these findings, the authors formulated the Lexical Quality Hypothesis to account for difference in sense selection between skilled and less skilled readers.

According to the Lexical Quality Hypothesis, word quality can vary on three dimensions (constituents): orthographic, phonetic and semantic. The orthographic code specifies the word's spelling, the phonetic code specifies the pronunciation, and the semantic code provides the meaning. If one or more constituents of the word code are deficient, then the quality of the representation decreases. When the representation is of low quality, retrieval may be hampered in terms of the time to retrieve the word (i.e., efficiency) or whether the intended word is retrieved at all (i.e., accuracy).

Moreover, the lexical quality hypothesis asserts that skilled and less skilled readers differ in two ways. First, skilled readers have more resources to repair or embellish impoverished representations. These resources may include more effective decoding, spelling, and grammatical skills. However, the key characteristic that distinguishes skilled from less skilled readers is the number of high quality word representations. High skill readers are more efficient and accurate at retrieving words because the majority of their word representations are complete. This allows for fast and efficient retrieval of orthographic, phonemic, and semantic information. However even skilled readers have low quality representations for some words, such as low frequency words.

While the quality of a word representation and decoding ability have an impact on word identification and low-level comprehension, the focus of this chapter, in contrast, is on readers' higher level comprehension skills. Comprehension refers to the construction of meaning of the words and phrases, such as recognizing the interrelationships within the text, making inferences using prior knowledge, and integrating the text with existing knowledge structures. While decoding and comprehension processes are tightly interwoven, they are nevertheless separate processes. For example, a dyslexic reader can comprehend, but not decode; and a hyperlexic reader can decode but not comprehend. Of course, word decoding difficulties are correlated with and may ultimately result in reading comprehension deficits (e.g., Perfetti, 1985; Schankweiller et al., 1999). However, research also indicates that there are many poor comprehenders who do not have deficits at the level of word decoding or syntactic decomposition (Cain, 1996; Hoover & Gough, 1990; Stothard & Hulm, 1996; Cornoldi et al., 1996). These readers may read fluently and with apparent ease, and yet still perform poorly when answering questions.

How do these readers, who can decode words and syntax without difficulties but struggle to comprehend the deeper meaning of the text, differ from those who more successfully comprehend text? Behavioral studies of individual differences in comprehension have shown that good and poor readers differ in terms of inference processes such as solving anaphoric reference, selecting the meaning of homographs, processing garden-path sentences, making appropriate inferences on line, integrating text structures, and so on (e.g., Long & Golding, 1993; Long, Oppy & Seely, 1994; Oakhill, 1983, 1984; Singer, Andrusiak, Reisdorf, & Black, 1992; Singer & Ritchot, 1996;

Whitney, Ritchie & Clark, 1991; Yuill & Oakhill, 1988). Skilled readers are more likely to generate inferences that repair conceptual gaps between clauses, sentences, and paragraphs (e.g., Long, Oppy, & Seely, 1994; Magliano & Millis, in press; Magliano, Wiemer-Hastings, Millis, Muñoz, & McNamara, 2002; Oakhill, 1984; Oakhill & Yuill, 1996). In contrast, less-skilled readers tend to ignore gaps and fail to make the inferences necessary to fill in the gaps (e.g., Garnham, Oakhill, & Johnson-Laird, 1982; Oakhill, Yuill, & Donaldson, 1990; Yuill, Oakhill, & Parkin, 1989). In sum, one of the clearest distinctions between skilled and less-skilled comprehenders is their ability to make inferences while reading.

Less-skilled readers perform poorly on tasks that require inferential reasoning. They are less likely to generate topic related inferences on line or to integrate incoming information with preceding discourse (Long, Oppy, & Seely, 1994). In particular, skilled readers are more likely to process the separate relations between sentences and paragraphs; that is, they are more likely to make bridging inferences. For example, skilled readers perform better on questions that address both text-based and implicit inferences, even when the text is made available during questioning (Oakhill, 1984). However, less-skilled readers' performance on non-inference questions is the same as skilled readers when the text is present. Oakhill (1982) also found that skilled readers made more recognition errors with foils that were congruent with the story theme but not explicitly mentioned in the text. Skilled readers are more likely to construct an integrated representation of related sentences that are organized around the main purpose or theme of the text. Thus, skilled readers' inferencing ability allows them to relate ideas in text to one another and to their existing knowledge.

Whereas the differences found between good and poor readers in a variety of linguistic tasks are generally robust and replicable, the theoretical explanations are more questionable. The most popular explanatory theory of these differences is that comprehension skills are determined by differences in working memory capacity, generally measured by various versions of the reading span task (e.g., Daneman & Carpenter, 1980; Just & Carpenter, 1992). This account holds that skilled readers are better able to make inferences while reading because they have greater working memory capacity and are able to hold in working memory more information from the text or discourse. A second explanation proposes that poor readers have difficulty suppressing "noisy" information, such as contextually irrelevant meanings of homographs. One such theory proposes that less skilled readers lack a suppression mechanism and thus perform frequent structure "shifts" whereas good readers continue mapping information into an ongoing structure (e.g., Gernsbacher, 1990). As such, the successful comprehender is better able to suppress or inhibit irrelevant information, leaving more resources for relevant information (e.g., Rosen & Engle, 1998). Recently, a third class of explanations have emerged which emphasize skilled comprehenders more active and efficient use of knowledge and strategies (e.g., Bereiter & Bird, 1985; Ericsson & Kintsch, 1995; McNamara, 1997; McNamara & McDaniel, in press; McNamara & Scott, 2001; Schmalhofer, 1998; MacDonald & Christiansen, 2002; Paris & Jacobs, 1984; Pressley & Afflerbach, 1995; Snow, Burns, & Griffin, 1998; see also, Zwaan & Kaup, this volume). Accordingly, skilled readers activate and use knowledge more than less skilled readers, either because they know and use more metacognitive reading strategies (e.g., McNamara & Scott, 2001) or because they have more prior knowledge about the text topic (e.g., McNamara & McDaniel, in press). Below, we review evidence supporting the knowledge-based explanation of reading skill.

Knowledge-based Account of Reading skill

The knowledge-based account of reading comprehension skill asserts that better readers more actively and efficiently use prior knowledge to comprehend text (Bereiter & Bird, 1985; Ericsson & Kintsch, 1995; McNamara, 1997; McNamara & McDaniel, in press; McNamara, & Scott, 2001; MacDonald & Christiansen, 2002; Paris & Jacobs, 1984; Pressley & Afflerbach, 1995; Snow, Burns & Griffin, 1998). This knowledge use may either arise because they have more prior knowledge about the text topic (e.g., McNamara & McDaniel, in press) or because they know and use more metacognitive reading strategies (e.g., McNamara & Scott, 2001). However, the underlying assumption of these theories is that it is greater activation and use of knowledge that drives reading skill, rather than working memory capacity or suppression mechanisms.

There is ample evidence that readers who have more knowledge about the topic of a text better understand the written material (e.g., Chiesi, Spilich, & Voss, 1979; Bransford & Johnson, 1972; Haenggi & Perfetti, 1994). Readers with greater prior knowledge are also better able to comprehend texts that require numerous inferences (McNamara, Kintsch, Songer, & Kintsch, 1996; McNamara & Kintsch, 1996; O'Reilly & McNamara, 2002). This latter research demonstrated that the comprehension differences between high- and low-knowledge readers were most exaggerated for texts with more conceptual gaps (low-coherence texts). Moreover, high-knowledge readers show a reversed-cohesion effect. They benefit from reading low-coherence texts, assumedly because they induce the reader to generate more inferences while reading. Other studies have similarly demonstrated advantages for text-induced active processing (e.g., Einstein, McDaniel, Owen, & Cote, 1990; Mannes & Kintsch, 1987; McDaniel, Einstein, Dunay, & Cobb, 1986; O'Brien & Myers, 1985; Rauenbusch & Bereiter, 1991). Essentially, comprehension is enhanced when readers are induced by the text to generate inferences and these inferences are successful.

McNamara (2001) provided further evidence that the reversed-cohesion effect found for the high-knowledge readers was the result of active processing induced by the low-cohesion text. In this study, adult participants read both high and low version of a text about cell mitosis. Comprehension was enhanced only for participants who read the low-cohesion version, followed by the high-cohesion version. This result showed that the low-cohesion text induced gap-filling inferences while the participant was reading the text, and it was this on-line active processing that enhanced comprehension. When the reader was exposed to the high-cohesion version first, and thus was not induced to generate the inferences, these benefits did not appear. These results further demonstrated that the amount of material read is not a factor that can explain the reversed cohesion effect. That is, the readers were all exposed to the same information, and thus the same amount of information – only the order of presentation differed.

According to the Construction-Integration model of text comprehension (Kintsch, 1988; 1998), text-based and knowledge-based inferences result in more links between concepts, and thus a more cohesive mental structure. Thus, activation of prior knowledge helps the reader form a more coherent mental representation of the text. Readers with more knowledge of the text domain (e.g., science or history) show better comprehension when they use their prior knowledge to comprehend and learn, particularly on measures that assess deeper levels of understanding (e.g., bridging-inference and problem solving questions, rating and sorting tasks).

Along the same lines, Ericsson and Kintsch (1995) proposed that skilled performance (such as reading skill) is due to the use of *long-term working memory* (LTWM*)*, which is a more efficient WM with faster access to LTM than normal WM. Typical WM retrievals from LTM require 1 to 2 seconds, whereas LTWM retrievals require approximately 400 milliseconds (e.g., McNamara & Kintsch, 1996b). More efficient LTM access results from using cues in STM to activate retrieval structures. LTWM bypasses STM processing limitations because experience within a particular domain leads to enriched knowledge structures and information retrieval strategies.

McNamara and Scott (2001) proposed that LTWM retrieval structures and strategies may be particularly important to WM task performance because of the need to switch attention repeatedly between processing and storage tasks. LTWM allows an individual to more efficiently re-access the words from LTM that were no longer available in STM. Hence, a person using strategies would appear to have greater WM capacity. Other researchers have similarly proposed that WM constraints are not caused by limits in the amount of WM activation, but instead by how efficiently that capacity or activation is used (e.g., Case, Kurland, & Goldberg, 1982; Cowan, 1988; Daneman & Carpenter, 1980; Engle & Marshall, 1983; Shiffrin & Schneider, 1977). McNamara and Scott demonstrated that participants who reported using more effective memory strategies such as imagery when completing STM tasks, also performed better on the WM span task. Moreover, participants who received training to use a chaining strategy (i.e., creating sentences to link the words) during STM tasks, showed substantial improvement on WM tasks. These results collectively show that participants can and do use strategies during WM tasks, and these strategies improve WM performance.

McNamara and Scott (2001) reasoned that if WM task performance depended even least partially on strategy use, that factor may contribute to correlations between reading skill and WM capacity. Accordingly, high capacity individuals and skilled readers are more strategic across a variety of tasks. In this sense, skilled readers make more inferences because they are strategic, they know how to make the inferences, and they know when the inferences are necessary. This explanation is further supported by research showing that skilled readers have more metacognitive knowledge (Baker, 1982; Wong, 1985) and more likely to use reading strategies (e.g., Baker, 1994; Garner, 1987; Long & Golding, 1993; Long et al., 1994; Oakhill, 1982, 1983).

As mentioned earlier, another critical difference between skilled and less skilled readers is their ability to resolve anaphors, especially when referent is distant (Oakhill & Yuill 1986; Yuill & Oakhill, 1988). Comprehension of anaphors is more critical in text than discourse comprehension because there is little shared context in the former. In contrast, there is a wealth of contextual information available to the speakers in face to face conversations. Anaphor resolution is problematic for younger and less-skilled readers, particularly with one type of anaphor, personal pronouns. This difficulty persists even when there is a gender cue and when the clause containing the referent is available to the reader (Oakhill & Yuill, 1986). Moreover, skilled and less skilled readers seem to have a different method of resolving anaphoric relations. Less-skilled readers seem to search the preceding sentence for an appropriate syntactic form, whereas the high-skilled readers tend to resolve anaphors by relying on their model of the story and integrated this into existing knowledge (Yuill & Oakhill, 1988; see also, Noordman, Vonk, and Frank, this volume).

Results showing that the advantage of skilled reader's performance on inference questions persist even when the text is made available to the readers (Oakhill, 1983, 1984) shed doubt on a working memory or capacity account. The reader's memory resources should be at least partially relieved if the text is made available when the reader answers the inference questions. In contrast, these results indicate that inferencing ability requires the knowledge that relating different parts of the text is necessary for successful comprehension.

One of the strongest sources of evidence in favor of knowledge-based accounts is that interventions that target more active or strategic use of knowledge improve reading skill and comprehension (e.g., Bereiter & Bird; 1985; Chi, de Leeuw, Chiu, & LaVancher, 1994; Cornoldi & Oakhill, 1996; Dewitz, Carr, & Patberg, 1987; Hansen & Pearson; 1983; Kucan & Beck, 1997; McNamara, 2003; McNamara & Scott, 1999; Palincsar & Brown, 1984; Paris, Cross, & Lipson, 1984; Yuill & Oakhill, 1988). Such studies demonstrate that simply knowing how and when to make inferences dramatically improves reading comprehension. This large body of research shows that when readers learn strategies to more effectively use their knowledge while reading, their reading comprehension improves.

Whereas there is a large body of evidence that comprehension skill is critically tied to readers' ability to activate and use knowledge, there is another body of literature indicating that inhibiting or suppressing irrelevant knowledge is linked to comprehension ability (e.g., Gernsbacher, 1990; Rosen & Engle). However, McNamara (1997) proposed that suppression could be explained in terms of greater elaboration of sentences. Within the framework of the Construction-Integration model of comprehension (Kintsch, 1988), she demonstrated that the results reported by Gernsbacher and colleagues (e.g., Gernsbacher et al., 1991) could be explained more parsimoniously in terms of enhancement of relevant information via elaborative inferences, rather than inhibition of irrelevant information. According to the Construction-Integration model, incoming information and associated knowledge are represented as an associative network of nodes (concepts, ideas, or propositions) and links (relations or actions). Concepts that are compatible with the overall context generally have more links whereas irrelevant concepts tend to have fewer links. Because the model relies on connectionist principles of constraint satisfaction, concepts with more links increase in activation, whereas concepts with fewer links gradually lose activation.

McNamara (1997) proposed that if more knowledge associated with the context provided in the sentence were activated during comprehension, then more links to the relevant meaning of the ambiguous word would be created and the irrelevant meaning would quickly lose activation. In support of that hypothesis, she demonstrated within a computational simulation that the number of activated associations to the relevant meaning predicted the rate of activation loss for the irrelevant meaning. In this knowledge-based model, skilled comprehenders were assumed to more actively process the information provided in the sentence, which in turn activated more relevant knowledge. These links essentially fed activation to the relevant meaning of the ambiguous word and led to a rapid deactivation of the irrelevant meaning. To simulate less-skilled comprehenders, less associated knowledge was activated. The relevant meaning was rapidly activated to threshold leading to an accurate understanding of the sentence, but the irrelevant meaning retained enough below-threshold activation to interfere with processing when it was presented in the decision task.

McNamara (1997) showed that the differences between skilled and less-skilled comprehenders in her simulation emerged primarily from interference from the irrelevant meaning (for less-skilled comprehenders), and not because of differences in facilitation. That is, the increase in associations to the appropriate meaning (for skilled comprehenders) had minimal effects on the time for the correct response to reach threshold. However, the increased associations in the skilled comprehender simulation essentially took over the network such that the irrelevant meanings essentially died out. In contrast, in the less-skilled comprehender simulation, the lack of competition for resources between relevant links and irrelevant links resulted in residual activation for the irrelevant meaning of the ambiguous word. Accordingly, less-skilled comprehenders do not use resources effectively, whereas skilled comprehenders' maximal use of resources drives out irrelevant information.

In is important to note that suppression can be simulated using the Construction-Integration model with either inhibition mechanisms or enhancement processes (cf. Kintsch, 1998). McNamara (1997), however, showed that enhancement (i.e., elaborative inferences) provides a more parsimonious explanation because a decline in activation simply falls out of the model for information with fewer links. In addition, the Construction-Integration model has been used similarly to account for declining activation associated with other kinds of comprehension processes, such as predictive inferences (McDaniel, Schmalhofer, & Keefe, 2001; Schmalhofer, McDaniel, & Keefe, 2002).

More recently, McNamara and McDaniel (in press) have provided empirical evidence for McNamara's (1997) model by showing that greater domain or general knowledge produced effects similar to those obtained for skilled comprehenders. Specifically, participants with greater general knowledge showed a reduction of the ambiguity effect after a delay whereas the interference persisted for those with less general knowledge. In addition, participants with more knowledge of baseball showed an ambiguity effect with baseball sentences at the immediate test and the absence of an effect after a delay. In contrast, participants with less knowledge of baseball maintained a reliable ambiguity effects after a delay. These results support the theoretical framework that individual differences in ambiguity resolution can depend on dynamics associated with knowledge activation during comprehension.

Neurological Research

Neuropsychological studies can shed some light to the issue of individual differences in comprehension. In the next section, we review some of these studies. As far as we know, PET or fMRI have not been applied yet in this field, probably because the number of participants in such studies is usually very small. Nevertheless, there are several well designed studies using event related potential (ERP) that show how poor and good readers differ in their brain activity while they perform comprehension tasks.

The study of language with ERP

ERP consists of forming averages from the EEG of many individual trials, time-locked to the trigger event (e.g., a word). The assumption behind this approach is that transient activity that is not directly associated with the triggering event is random and will average out over the course of many repetitions. By contrast, an ERP signal will emerge for the specific activity associated with the time-locked events.

The ERP data are becoming a standard dependent measure in psycholinguistic experiments, having some clear advantages over more traditional behavioral measures (see also, Perfetti & Schmalhofer, this volume). Some of these advantages include high temporal resolution; a continuous picture of brain (and cognitive) activity; and it is less intrusive than others techniques. Most of the ERP components associated to language processes are fast, transient responses triggered by individual words (e.g., N280, N400, P300, LAN, P600, etc). There is also a more slow activity in very low frequency bands of the ERP (less than 1 Hz) that is much less used in language research, although it is quite appropriate for analyzing processes that occur in longer linguistic units such as whole clauses or sentences. For the present purpose of exploring individual differences in comprehension we will focus on some of the fast components generated by individual words (mainly the N400), but also on slow potentials generated by whole sentences.

Individual differences in fast-response components of ERP

In the investigations we are going to review, participants perform a comprehension task while their EEG is recorded, and ERPs for good and poor readers are calculated separately. Typically, the comprehension task involves reading sentences, presented automatically word-by-word. Sentence reading tasks are sufficient to explore cohesion and coherence processes at the local level. This provides the means to study the processing of inferences, cohesion marks, anaphor resolution, and inter-clausal integration processes.

The overarching idea behind the studies described here is that good readers' ERPs responses are generally much more sensitive to manipulations in the reading tasks, showing a more extensive brain activity to more difficult versions of sentences. By contrast, poor readers' responses remain relatively insensitive to manipulations of the reading task.

Among the transitory components of ERP, N400 and P600 have been especially informative to reveal language processes at the sentence level. N400 is a negative-going wave between 200 and 600 ms, peaking around 400 ms, with a somewhat posterior, slightly right-hemisphere amplitude maximum. The N400 is obtained both with isolated words, and with words embedded in linguistic contexts. It is sensitive to lexical parameters such as word frequency, or word concreteness, but is also sensitive to the sentence and the discourse context in which the words appear. In particular, N400 amplitude increases when a word is semantically anomalous within a sentence (e.g., Kutas and Hillyard 1980). P600 is a positive-going wave starting 500 ms after stimulus onset, reaching the maximum amplitude at about 600 ms, which is usually observed at posterior sites. It is sensitive to morpho-syntactic violation in sentences, and corresponds to sentence re-processing, of both syntactic and semantic natures (Friederici, 2002).

One research question is whether individual differences in the comprehension of sentences arise at the lexical associative level or at a more thematic level (cf. Long et al, 1994). Van Petten, et al (1997) asked individuals with high, medium, and low working memory capacity (as measured by Daneman & Carpenter's span test) to read sentences that included two critical associated words or non-associate words, and the context was manipulated as to produce congruent and anomalous sentences. Examples of the four resulting experimental conditions are the following:

Congruent-associated

When the **moon** is full it is hard to see many **stars** or the Milky Way.

Congruent-unassociated

When the **insurance** investigators found that he'd been drinking they **refused** to pay the claim.

Anomalous-associated

When the **moon** is rusted it is available to buy many **stars** or the Santa Ana.

Anomalous-unassociated

When the **insurance** supplies explained that he'd been complaining they **refused** to speak the keys.

Thus, the lexical association factors and the sentence congruence factors were dissociated experimentally. The results suggested that all subjects were sensitive to the lexical association of words. Thus, when anomalous-associated and anomalous-unassociated sentences were contrasted, all readers showed the same increase in N400 for the non-associated critical word. However, when congruent-unassociated and anomalous-unassociated sentences were compared, only the high and medium working memory capacity groups showed a larger N400 for the anomalous-unassociated sentences. Interestingly, the contextual effect for high and medium span groups continued in the next temporal window of 500 to 700ms after the word onset, suggesting that these readers tried to solve the semantic incongruence for almost one second.

These results concur with behavioral studies and fit quite well with the knowledge-based account of individual differences. Poor readers efficiently activate basic word-based associations, which help them to build the sentence meaning. However, poor readers fail to activate deeper background knowledge necessary for understanding sentence level thematic relations (see e.g., Cantor & Engle, 1993) when lexical associations are not available in the text. In contrast, more skillful readers activate a rich network of background knowledge, even when they try to understand anomalous-unassociated sentences.

More specific comprehension skills have been explored in a jokes comprehension task by Coulson and Kutas (2001). They recorded participants' EEG while reading sentences that ended either as jokes involving a frame-shifting, or with equally surprising non-joke endings. For instance, "She read so much about the bad effects of smoking she decided she'd have to give up reading/the habit". The ERPs were averaged for the critical final word, and the participants were split into good and poor joke comprehenders, depending on their responses to control questions about the meaning of the jokes. The pattern of ERP was considerably more complex for good joke comprehenders, who elicited a left-lateralized sustained negativity for all jokes (N400) combined with a frontal and posterior positivity (P600). By contrast, poor joke comprehenders showed only a right frontal negativity to jokes that continued beyond the N400 temporal window. The N400 obtained by all participants indicates that all of them are sensitive to the contextually unexpected critical word. But the later positivity, only observed in good joke comprehenders, suggests that they engaged in an additional frame-shifting process. Namely, they initially activated a schema or frame based expectation, but when they read the critical joke word they successfully shifted to another frame. Poor readers, instead, are unable to manage schematic information efficiently enough to produce a frame-shift.

Other studies analyzed ERP in good and poor readers when they read relative sentences (King & Kutas, 1995; Mueller, King, & Kutas 1997; Vos & Friederici, 2003). Relative sentences provide a controlled way to study different factors in sentence processing because they differ in complexity despite a close similarity in structure. Some studies on relative clause comprehension developed in German demonstrated that good comprehenders produce a much clear ERP pattern than poor comprehenders. For instance, Vos and Friederici (2003) used subject-first (e.g, He found out that it was the actress who distracted the producers) and object-first relative sentences (He found out that it was the actress who the producers distracted). They found that skilled readers showed a larger late positivity (P600) for disambiguating words in the object-first than in the subject-first relative clauses. In contrast, poor readers' ERP were not sensitive to the relative clause manipulation. Vos and Friederici (2003) proposed that skilled readers' P600 reflected their syntactic re-analysis of the disambiguating information, after they had followed a garden-path. By contrast poor readers would not garden-path because their lack of working memory resources. However, P600, even when triggered by a syntactic garden path, occurs too late as to exclusively reflect a syntactic process. Actually, P600 is also sensitive to semantic factors, and could reflect an interaction between both syntactic and semantic processes (Friederici, 2002). Moreover, P600 increases for target words that are incoherent with a previous text, even though the target words are embedded in syntactically appropriate sentences (e.g., Bartholow, Fabiani, Gratton, & Bettencourt, 2001; Díaz, León, & de Vega, 2003). Consequently, individual differences in the P600 component could reflect in part that skilled readers more efficiently mobilize background knowledge to integrate syntactic and semantic information in the object-first clauses.

Finally, individual differences in inference generation have also been explored by St. George, Mannes, and Hoffman (1997). They gave high-span and low-span participants different types of paragraphs that were intended to produce either bridging inferences (necessary to establish the local coherence of discourse), or elaborative inferences (invited by the context, but not required for local coherence). In addition there were two control conditions: word-based priming paragraphs and non-inference paragraphs. Examples of the materials are the following:

Bridging

Pam set the dinning room table

She forgot about the turkey in the oven

The guests were disappointed with the ruined meal.

It was too bad the turkey burned.

Elaborative

Pam set the dinning room table

She forgot about the turkey in the oven

Pan was disappointed when the argumentative guests ruined the meal.

It was too bad the turkey burned.

Word-based priming

Pam set the dinning room table

She put the turkey in the oven

Pan was disappointed when the argumentative guests ruined the meal.

It was too bad the turkey burned.

No inference

Pam set the dinning room table

She put the turkey in the oven

The guests were outside playing badminton

It was too bad the turkey burned.

A reduction in the amplitude of N400 for the final sentence words in bridging or elaborative paragraphs (in comparison to the control conditions) could be considered as evidence that an inference was generated. All participants showed a N400 reduction in the final sentence of bridging paragraphs. However, poor readers also showed the same amount of N400 reduction for word-based priming paragraphs, which means that their bridging inferences could be based on lexical associations rather than broader general knowledge background (see similar results in the aforementioned study by van Petten et al., 1997). The ERP pattern considerably differs in skilled readers. They showed a significant N400 reduction for bridging and elaborative paragraphs, but not for word-based priming, suggesting that they mobilize broader nets of pre-stored knowledge (not just lexical associations) to support both necessary and optional inferences.

Individual differences in sentence-level slow potentials

The most striking picture of individual differences in comprehension emerges when ERP slow potentials are explored. Slow potentials are obtained in sentence reading when the ordinary more transient potentials produced by words are low-pass filtered. The resulting signals are positively or negatively drifting potentials along the whole sentence, with a very distinctive distribution throughout the scalp. Slow potentials are particularly appropriate to explore more global language processes beyond lexical factors, as they offer a picture of unfolding sentence processing and are presumably sensitive to the mobilization of knowledge and integrative processes.

In an exploratory experiment, Kutas and King (1996) recorded slow potentials for six-word clauses (e.g., The secretary answered the phone because...), without any specific manipulation of variables, and the data from poor and good readers (categorized according to their recall of the sentences in the experiment) were analyzed separately. The results showed a more left-hemisphere lateralized frontal positivity for the good than the poor comprehenders. By contrast, poor comprehenders showed a larger and more left-hemisphere positivity at occipital electrode sites. These results strongly suggest that poor comprehenders devote more cognitive resources to the encoding of words visual features (more occipital activity), having less resources available for sentence integration processes (less frontal activity). By contrast, good readers devote much more resources to the whole sentence integrative processes as evidenced by more frontal activity (see also, Münte, Schiltz, & Kutas, 1998).

Conclusions

Event related potentials have proven to provide a useful tool to explore individual differences in comprehension skills. Despite the apparent complexity of the ERP data, good and poor readers produced clearly different electrophysiological patterns in most experiments. Good readers produced responses more sensitive to manipulations in the reading task, showing a more extensive and discriminative brain activity to the most difficult, or less normative, versions of the sentences, such as syntactic garden-path, non normative role assignment, joke comprehension, or elaborative inferences. In most cases the good readers' ERP pattern could be interpreted as a more extensive knowledge-based processing of less normative sentences. By contrast, poor readers' responses remain relatively insensitive to sentence level manipulations in the reading task, because they tend to rely on a more superficial processing of discourse. They devote more cognitive resources to the visual encoding of sentences, and to the lexical-associative processes, and they do not manage efficiently deeper background knowledge, such as schematic or situation model information.

These neurological results concur with behavioral studies showing that poor comprehenders fail to generate sentence-based and knowledge-based inferences (even when the text is present), but do not have difficulties processing at the word or syntactic levels. Moreover, teaching readers to generate inferences successfully improves comprehension.

As has happened regarding so many cognitive phenomena, we imagine that, in the end, the most viable account of skilled comprehension will be a 'Multifactor' account. We can easily imagine that working memory capacity, suppression, and metacognitive processes work together in a complex, interdependent fashion. However, the knowledge-based account is useful in the sense that it provides a direction of remediation for students and educators. Knowing that a less skilled readers' working memory capacity may be low, or that they may lack the ability to suppress irrelevant information hardly provides hope for their bridging the comprehension gap. In contrast, the focus on metacognitive reading strategies has led to a host of reading skill remediation techniques. And, these techniques have successfully improved both text comprehension and academic performance.

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