Are poor readers semantically challenged? An event-related brain potential assessment

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Abstract

This study explores visual event-related potentials components in a group of poor readers (PRs) and control children who carried out figure and word categorization tasks. In both tasks, every child had to categorize between animal and non-animal stimuli in an odd-ball GO–GO paradigm. During the word categorization task, PRs presented longer reaction times, a poorer performance, longer and larger P2 amplitudes, and smaller amplitudes and longer P300 latencies than controls. There were no differences in the N400 component between groups. These results suggest that semantic processing underachievement in PRs may not be a semantic deficit per se, but the late reflection of an early word codification problem, deficient use of attentional resources and lack of target identification during reading.

Keywords: Poor readers, semantic processing, N400, P300, P2; Categorization tasks; Event-related potentials, reading disabled children

1. Introduction

Children who score between 1 and 2 years below their expected reading level have been considered to be poor readers (PRs) (Rayner and Pollatsek, 1989). Children scoring 2 or more years below their expected reading level are referred to as dyslexics. In both cases, children have IQ scores that fall within the normal range. One of the main factors involved in the development of reading skills is to create a transparent interface between orthographic input and phonological structure. Phonological skills that are required to segment words into their constituent phonemes not developing normally, very likely give rise to poor reading. However, it is unlikely that all reading problems are solely due to this factor. Among the prime candidates that have also been proposed are deficits in syntactic processing (Byrne, 1981),
limitations in working memory capacity (Swanson, 1992; Swanson and Sachse, 2001) and impairments in the time course of the processing of the rapid, transient characteristics of auditory and visual input (Tallal et al., 1993).

Our approach to the present study was to obtain behavioral data while simultaneously recording event-related potentials (ERPs) from electrodes placed over different regions of the scalp. ERPs reflect the stimulus-locked cognitive information processing activities in terms of distributed assemblies of neurons firing synchronized across time. Thus, different patterns of brain electrical activity recorded during a task may reflect different cognitive processes and the differences in amplitude and latency of the ERP components across different populations may represent cognitive abilities and/or disabilities.

One ERP component that has traditionally been studied in PRs is the so-called P300 component. The P300 wave is an endogenous positive deflection with an average peak latency at 300 ms or more after stimulus onset and is typically elicited by a rarely and randomly presented target stimulus in a detection task. One prominent interpretation of the P300 is that it represents stimulus evaluation and memory updating (Donchin and Coles, 1988; Polich and Kok, 1995). ERP studies have shown smaller amplitudes and longer latencies of the P300 component in PRs (Diniz et al., 1997; Holcomb et al., 1985; Silva-Pereyra et al., 2001) and dyslexics (Taylor and Keenan, 1990). Some other studies have found that PRs have lower scores than controls during working memory tasks (De Jong, 1998; Isaki and Plante, 1997). Holcomb et al. (1985) found that reading disabled and control subjects could be better differentiated from one another by the amplitude of the P300 when non-target word stimuli were contrasted with non-linguistic symbols: symbols elicited larger P300 than words in reading disabled children, while the two kinds of stimuli elicited equivalent amplitudes in controls. There is also evidence that PRs have longer P300 latencies during a color discrimination task (Silva-Pereyra et al., 2001). Some authors have suggested that the long P300 latency of dyslexic and reading disabled children is due to the fact, that in these children, stimulus evaluation and memory updating processes take more time (Holcomb et al., 1985). Early auditory and visual sensory processing deficits also seem to be an important feature in the profile of reading disabled children. Such deficits apparently lead to compensatory increases in the effort required to integrate words into a context and to a greater reliance on context for word recognition than control subjects (Neville et al., 1993). Several studies have found larger P2 amplitudes to a surprising sound in reading disabled children (Bernal et al., 2000; Iragui et al., 1993). Holcomb et al. (1986) also found larger P2 amplitudes to unexpected stimuli in reading disabled and in children suffering attentional deficit with hyperactivity when compared to controls. The P2 is a component that has been associated with reallocation of attentional resources during task performance (Luck and Hillyard, 1994).

The design used in the present experiment implies that subjects make semantic category decisions with different probabilities of stimulus in a word (or figure)-list presentation. The decision process could produce a large P3 in addition to a previous N400 (Halgren, 1990; Hill et al., 2002; Nielsen-Bohlman and Knight, 1994; Polich, 1985; Stelmack et al., 1988). The P3 usually overlaps the N400, and is also sensitive to priming, and manipulations of expectancy (Deacon et al., 2000). However, some studies have shown that this overlapping is only partial (Chwilla et al., 1995; Kutas and van Petten, 1994) or not at all affected by the P3 component (Nobre and McCarthy, 1994). The N400 has been associated with semantic processing and it is a negative-going wave between 300 and 600 ms, peaking approximately at 400 ms after stimulus onset, with a posterior, slightly right amplitude predominant asymmetry (Kutas and Hillyard, 1980). The N400 effect has been observed in sentence (Kutas and Hillyard, 1980) and priming paradigms (Bentin et al., 1985). Sentence processing developmental studies (Holcomb et al., 1992; Juottonen et al., 1996) have shown that with age, the N400 effect decreases in amplitude and increases in latency. These results suggest that as children acquire better language skills, they rely less on semantic context for language comprehension.
In contrast to the previous, the N400 elicited during word-list tasks without priming has a more anterior distribution and is the largest at central and frontal locations (especially the midline) (Nobre and McCarthy, 1994). Despite the distributional difference, the anterior N400 is thought to be closely related to the classic N400 and probably reflects similar cognitive processes. In the present study, during word categorization task, a similar anterior N400 is anticipated.

On the other hand, picture-processing paradigms also show an N400 effect that may mirror the pattern found in word-prime studies (Barret and Rugg, 1990; Holcomb and McPherson, 1994). The N400-like effect elicited by pictures is the result of both a frontally distributed N300 and a more widely distributed N450 (Barret and Rugg, 1990). There is no evidence of amplitude change with age on picture processing development, although latency decreases with increasing age (Friedman et al., 1990). Although it has been suggested that the N450 could be related with the processing of semantic relationships between non-verbal stimuli, other studies comparing picture with word semantic processing using ERPs have suggested that the semantic analysis of words and pictures may involve different, at least partially non-overlapping, neural systems (Holcomb and McPherson, 1994).

While there is abundant and convergent evidence showing that PRs tend to be deficient in phonologically based skills (Beitchman and Young, 1997) or working memory capacity (Swanson, 1992; Swanson and Sachse, 2001), there is also evidence of a deficiency in semantically based skills (Champion, 1997; Ben-Dror et al., 1995; Gillon and Dodd, 1994; Stelmack et al., 1988; Vellutino et al., 1985). Some studies have reported differences favoring normal readers in semantic memory as well as semantic learning tasks using visual symbols and paired associates (Vellutino and Scanlon, 1985; Vellutino et al., 1995; Waterman and Lewandowsky, 1993). Stelmack et al. (1988) found larger frontal N400 amplitudes for normal readers with respect to reading disabled children during word recognition. They believe that this effect is consistent with a more extensive semantic evaluation or memory search attributed to that component.

In summary, deficiencies in semantic tasks in PRs may be produced by a less effective processing of stimuli, taking more time for their evaluation, which may be reflected by a smaller and later P300. Although reading disabled children have difficulties with the translation of visual information into a speech code, they also appear to have deficits in the classification and memory processing of the non-verbal visual stimuli (Silva-Pereyra et al., 2001). This deficiency in early processing may also affect semantic processing in PRs (Stelmack et al., 1988). In an attempt to evaluate the access to semantic information independently of stimulus kind, in the present study, categorization tasks of animal/non-animal presented as figures and words were used.

2. Materials and methods

2.1. Subjects

Thirty-four children participated in this study. They were selected from a group of third and fourth grade volunteers from two elementary schools.

Children were divided into two groups according to an evaluation carried out by three of the authors, based on interviews with parents and child, the teacher’s opinion and academic achievement (18 controls and 16 PRs). In order to evaluate subject allocation into each group, a battery for the computerized analysis of reading in Spanish was applied to each child. This is the ‘Bateria para los Trastornos de la Lectura’ (BTL, Reading Disabilities Battery, Reigosa et al., 1994).

The mean age for the control group was 10.1 years (1.6 S.D.) and 10.2 years (1.9 S.D.) for PRs. The male:female ratio was 1:1 for normal readers and 2.5:1 for PRs. None of the children had a history of school problems or a neurological disorder. They were all right-handed and had a normal neurological examination, as well as normal IQ scores (WISC-R in Spanish; mean IQE = 106.33 S.D. = 14.68, mean IQV = 105.11 S.D. = 8.81 for controls; mean IQE = 100.81 S.D. = 12.36, mean IQV = 98.81 S.D. = 14 for PRs). Comparison
between groups using the IQ scores showed no significant differences.

2.2. Stimuli

The 260 figures presented were obtained from Snodgrass and Vanderwart’s study (1980) and were digitized and displayed on the center of a computer video. The figures were white line drawings on a black background, with a 3.12×3.12 degrees visual angle. In order to obtain the list of words corresponding to the figures, a pilot study was carried out with another sample of 15 children. After presenting the figures, each child had to say the first word that came to mind. All words produced by each of the 15 children were stored and analyzed for frequency of occurrence and the corresponding percentage. The highest frequency word for each figure was selected. In this way, a list of 201 words produced by figure nomination and the corresponding figures was created.

Two categorization tasks were designed: a figure categorization (F task) and a word categorization task (W task). In the W task, the words employed were obtained from the nomination of the 201 figures to be used in the F task. The words of this list were displayed in 1-cm uppercase letters in the center of a 14-inch computer monitor (white letters on a black screen). At the viewing distance employed, each letter subtended a visual angle of approximately 0.573×0.573 degrees.

2.3. Procedure

2.3.1. F task

All 201 figure trials were randomly presented: 44 figures were animals and 157 were non-animals (household items, utensils, tools, personal objects, fruits and vegetables and vehicles). Participants were instructed to respond by pressing one button of the computer keyboard (letter B) with their index finger if the stimulus presented was an animal and a different button (letter M) with the middle finger if it was not; in a GO–GO task. The use of buttons was counterbalanced across subjects. Children were instructed to respond as rapidly and accurately as possible to each stimulus. Each figure was presented for 2000 ms and the interval (ISI) between figures was 3000 ms.

2.3.2. W task

This task was analogous to the F task in requirements, except that full words instead of figures were displayed. Correct and incorrect responses were automatically marked in the electroencephalogram (EEG) recording.

2.3.3. EEG recording

The EEG was recorded with Ag/AgCl electrodes referenced to linked earlobes from Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T3, T4, T5, T6, Fz, Cz, Pz and Oz of the 10/20 international system. The amplifier bandwidth was set between 0.05 and 30 Hz. All electrode impedances were at or below 5 kΩ and amplified with a gain of 20 000. EEG was sampled every 5 ms and stored on a hard disk for further analysis. EEG segments of 1280 ms with a pre-stimulus time of 100 ms were selected and averaged off-line to obtain the ERPs. The electro-oculogram (EOG) was recorded from a supra-orbital electrode and from an electrode placed at the external canthus of the right eye. Special care was taken to reject segments with eye movements or other artifacts. In addition, trials on which EEG or EOG activity exceeded ±75 μV were rejected. Baseline correction was performed in relation to a pre-stimulus time of 100 ms.

2.4. Data analysis

2.4.1. Behavioral data

The median of reaction times (RTs) for correct responses from each subject was calculated and the data used to perform a three-way ANOVA. The variables included were: group (PRs and controls), task (F and W) and category (animal and non-animal). A second three-way ANOVA was performed using percentage of error. Tukey honest significant difference post hoc tests were done.

2.4.2. ERP data

ERPs from correct responses by task (F, W) and by category (animal, non-animal) were obtained.
Fig. 1. The top figure shows RT mean values from the group × task and group × category interactions. PRs showed longer RT during the W task, even this difference was larger to non-animals category. The bottom figure shows proportion of error interaction effect (task × category × group). Differences were observed between PRs and controls on the animal category in the word categorization task. Significant differences are marked with an asterisk (P < 0.05).

Approximately an equal number of EEG segments (≈ 25 segments) were taken to average by experimental condition across subjects.

According to their appearance in the grand average waveforms, the P2 peak was defined as the most positive voltage within the interval of 200–300 ms, the N400 peak was defined as the most negative voltage within the interval of 400–600 ms and the P300 as the most positive value within the interval of 600–900 ms.

2.4.3. Amplitude

Separate five-way ANOVAs were carried out for each component using the following variables: group × task × category × hemisphere (left and right) × anterior–posterior (Frontal F3–F4, frontotemporal F7–F8, Central C3–C4, Parietal P3–P4, anterior temporal T3–T4, posterior temporal T5–T6 and Occipital O1–O2). The Huynh–Feldt epsilon was applied to the degrees of freedom of those analyses with more than one degree of freedom in the numerator. Tukey honest significant difference post hoc tests were done. Because the latency of the P2 varies across the head, the data were analyzed using ten electrode positions (Fp1–Fp2, F3–F4, C3–C4, T3–T4 and F7–F8).

2.4.4. Latency

Separate three-way ANOVAs for each component were done using latency measurements at Cz. The variables were group (PRs and controls) × task (figures and words) × category (animals vs. non-animals). Tukey honest significant difference post hoc tests were done.

3. Results

3.1. Behavioral results

3.1.1. Reaction times

There were significant group × task (F(1, 32) = 8.3 P = 0.007) and group × category (F(1, 32) = 10.05 P = 0.003) interactions. The first interaction revealed significantly longer RTs for PRs in the
W task \((P=0.0003)\) (see left-top of Fig. 1). The second one shows longer RTs for PRs than controls to animals \((P=0.001)\) and to non-animals \((P=0.0002)\) (right-top of Fig. 1).

3.1.2. **Percentage of error**

Regarding percentage of errors, there was a significant group×task interaction \((F(1, 32)=8.94, P=0.005)\), indicating a higher percentage of error in PRs during the W task \((P=0.0003)\). There was also a significant group×task×category interaction \((F(1, 32)=7.35, P=0.001)\). PRs may have therefore been less efficient than controls in categorizing when the stimulus was an animal during the W task \((P=0.0002)\) (Fig. 1).

3.1.3. **ERP results**

For both groups and tasks, three components were visible. The first major positive peak, most pronounced over anterior sites, began approximately at 175 ms during post-stimulus onset and reached its maximum amplitude at 240 ms. The next component was a negative wave of approximately 400 ms. This negativity was larger to the non-animal than to the animal category. This negativity was more visible in the F task over anterior sites, and in both groups; during the W task, it showed two peaks with 100 ms of difference (Fig. 2). The third major component was a positive waveform which was more prominent at posterior regions of approximately 600 and 90 ms. This peak was larger to infrequent stimuli (animal) than to frequent stimuli (non-animals).

3.2. **P2**

3.2.1. **Amplitude**

The P2 was distributed over the scalp with a most pronounced amplitude over frontal areas (main effect of electrode site \(F(2.6, 82.4)=47.7, P<0.0001\)), and the left hemisphere (hemisphere main effect \((1, 32)=10.7, P=0.003\)). It was larger in amplitude for the W than for the F task (main effect of task \((F(1, 32)=80.18, P<0.00001)\)). The distribution of the P2 during the F with respect to the W task was different (task×electrode site interaction \(F(2.7, 85.73)=8.53, P<0.0001)\). During the F task, the P2 could be seen on fronto-polar (Fp1–Fp2), frontal (F3, F4, F7, F8) and central (C3, C4, T3, T4) sites. On the other hand, during the W task, the distribution was frontal (Fp1, Fp2, F3, F4), central (C3, C4, F7, F8) and temporal (T3, T4).

There was a significant group×task interaction \((F(1, 32)=8.22, P=0.007)\), that is, PRs showed larger P2 than controls during the W task \((P=0.03)\). PRs also showed larger P2 amplitudes than controls \((P=0.003)\) on the left hemisphere for animals (group×category×hemisphere interaction \(F(1, 32)=5.7, P=0.023\)).

Finally, there was a significant group×hemisphere×electrode site interaction \((F(2.7, 86.3)=2.86, P=0.047)\; (Fig. 3), indicating that PRs had larger P2 amplitudes on Fp1 \((P<0.0001)\), F3 \((P=0.0002)\) and F7 \((P<0.0001)\), whilst the control group showed larger amplitudes than PRs on T4 \((P=0.02)\).

3.2.2. **Latency**

Significantly longer P2 latencies during the W than during the F task (main effect of task \(F(1, 32)=5.62, P=0.024\)) and for animals than non-animal (main effect of category \(F(1, 32)=11.96, P=0.0016\)) were observed in both groups.

PRs showed longer P2 latencies than Controls \((P=0.0013)\) during the W task (group×task interaction \(F(1, 32)=15.1, P=0.0005;\) Fig. 3). PRs also showed longer latencies than controls \((P=0.0007)\) for the non-animal category (group×category interaction \(F(1, 32)=6.9, P=0.01)\). Finally, there was a significant group×task×category interaction \((F(1, 32)=11.6, P=0.002)\): Controls had longer latencies than PRs \((P=0.001)\) for animals during the F task. On the other hand, PRs showed longer P240 latencies than controls for animals \((P=0.0002)\) and non-animals \((P=0.0009)\) during the W task.

3.3. **N400**

3.3.1. **Amplitude**

There were no significant main effects of group or interactions by group. However, there was a significant main effect of task \((F(1, 32)=20.8, P<0.001)\) which means larger N400 amplitudes for the F than the W task. This difference was
Fig. 2. This figure shows: (a) grand average ERPs to figures (animal and non-animal) for PRs and controls; (b) ERPs to words (animal and non-animal) for both groups. Larger P2 amplitudes and smaller P300 amplitude for PRs during the word categorization task were observed. Two cursors on both N400 peaks are shown at Cz from 350 to 560 ms.
3.4. P300

3.4.1. Amplitude

There was a significant group×task×category ×hemisphere interaction (F(1, 32) = 5.99, P = 0.02). The P300 effect (larger amplitudes for animals than non-animals) was observed for controls on the left hemisphere during the F task (P = 0.0002) and the W tasks (P = 0.0006). Controls also showed this P300 effect on the right hemisphere during both tasks (F, P = 0.04 and W, P = 0.02). In contrast, PRs showed a P300 effect on the left hemisphere only during the F task (P = 0.0002; Fig. 4). The topographical distribution of this effect was different regarding task and group (group×task×category×electrode site F(2.26, 72.45) = 2.98, P = 0.05). In the control group, the P300 effect was significant on parietal (P < 0.0001), posterior temporal (P = 0.0001) and occipital (P < 0.0001) areas during the F task. Controls also showed a significant P300 effect on central electrodes (P = 0.0005), parietal (P < 0.0001), posterior temporal (P = 0.0001) and occipital (P < 0.0001) areas during the W task. In contrast, PRs showed a significant P300 effect during F task on central (P = 0.014), parietal (P < 0.0001), posterior temporal (P < 0.0001) and occipital (P < 0.0001), but there was P300 effect during W task.

3.4.2. Latency

Latency differences between animals and non-animals were bigger in both groups only during the F task (task×category F(1, 32) = 7.26, P = 0.01). PRs showed significantly longer P300 latencies (P = 0.03) during the W task (group×task interaction F(1, 32) = 4.83, P = 0.035; Fig. 4).

4. Discussion

In the present study, animal/non-animal figures' and words' categorization tasks elicited three ERP components in PRs and control subjects: P2, N400 and P300. An anterior P2 was seen on fronto-polar and frontal leads and more pronounced over the left hemisphere mainly during the W task. Following the P2 component, a frontally negative waveform of approximately 445 ms and a posterior negativity of approximately 520 ms were clear during the F task. A dual-negative-going, anteriorly maximal, but widely distributed negative peak between 350 and 560 ms in the W task was evident. At posterior sites a positive-going com-
ponent peaking approximately at 750 ms (P300) was present and largest for the animal condition which has the lowest presentation probability. This peak was practically absent in PRs during the word categorization task.

In order to compare both groups exclusively at the semantic level, it is of great importance to assume that the tasks are equivalent in cognitive terms. It could be argued, for example, that in order to categorize figures, subjects rely on shape similarity and other physical attributes, which could facilitate a successful performance (Snodgrass and McCullough, 1986). In such a case, one should obtain shorter RTs and/or earlier latencies of semantic related late ERP components during the F task in both groups. If anything, the results of the present study showed only earlier P2 latencies in the F task than in the W task in both groups. We argue that this difference could reflect a lower complexity in stimulus’ evaluation (Taylor and Khan, 2000) to access the semantic system, but not semantic differences per se. In this way, we believe the comparison between tasks is valid.

PRs presented longer RTs and a higher percentage of errors with respect to the control group during the word categorization task. Phonological processes such as accessing a word by first decoding the written symbols into sound representations and phonological coding to maintain information in working memory have been implicated in reading failure (Beitchman and Young, 1997; Wagner and Torgesen, 1987). Deficiencies at the phonological level interfere at least with the activation of word meaning or slow down the semantic information access (Zecker and Zinner, 1987). It has also been suggested that PRs could primarily activate the meanings of words using the phonological route, which could make the whole process
longer P2 latencies which may mirror the use for reading difficulties. Our PRs also showed ing age. Khan et al. efficient strategies to evaluate stimuli with increas-
children become faster or that they have more age. This developmental trend could mean that the latency of the P2 component decreases with  
Holcomb et al., 1992) and L>R anterior P2 asymmetries have been found in children at risk for reading difficulties (Khan et al., 1999). Although there is a controversy about distributional ERP component differences between poor and normal readers, the lateralization of semantic processing with increased age has also been previously reported (Holcomb et al., 1992). Our results clearly showed L>R P2 asymmetries in the PRs group and, in agreement with Khan et al. (1999) we claim that this group employs less mature strategies in the word processing; even the allocation of more attentional resources could be the expression of an inappropriate strategy.

The maturation of the prefrontal cortex is extremely important during cognitive development (Stauder et al., 1993) and therefore, reading. Segalowitz et al. (1992) argue that PRs may have difficulty with attentional requirements for visual processing and metacognitive strategies associated with reading, which place a demand on the frontal system. According to Taylor and Smith (1995), the latency of the P2 component decreases with age. This developmental trend could mean that children become faster or that they have more efficient strategies to evaluate stimuli with increasing age. Khan et al. (1999) observed longer anterior P2 latencies on a group of children at risk for reading difficulties. Our PRs also showed longer P2 latencies which may mirror the use of an immature stimulus evaluation strategy and a deficit to reallocate attentional resources.

In contrast to the previous ERP component results, there were no clear significant differences between groups regarding the N400 component. Both groups showed an anterior negativity of approximately 445 ms and a posterior negativity of approximately 520 ms during the figure categorization task. These two negativities were previously reported during picture priming (Barret and Rugg, 1990) and picture list studies (Coch et al., 2002). Both groups also showed a more pronounced anterior N400 during figure categorizations than word categorizations. These amplitude topographical distribution differences could show that different cognitive components may be involved in the figure and word semantic processing (Holcomb and McPherson, 1994). The point we wish to emphasize here is that PRs showed no differences in their performance and N400 component with respect to the controls during the figure categorization task where they can easily access the semantic information provided by these stimuli.

Both groups showed a negative dual-peak during the word categorization task. Prior studies have shown that stimuli presented in list form tend to elicit such anteriorly distributed negativities (Nobre and McCarthy, 1994). Approximately, the first peak was observed at 350 ms and the second at 560 ms, they were mainly distributed on C3, Cz and C4. This finding has also been previously reported by other groups (Coch et al., 2002; Dykman et al., 2000). Dykman et al. (2000) compared the performance of a failure to thrive group (FTT)¹ with controls during a lexical decision task. Dykman et al. (2000) as well as Coch et al. (2002) observed the dual-peak negative waveform. According to their explanation, the later peak may mirror a postlexical confidence. The two peaks of the N400 in both groups may have shown the postlexical revision necessary to match or mismatch the target.

¹ FTT was a group of children with abnormally low weight for age and gender and some studies have shown that the FTT have poorer language development and less developed reading skills.
A P300 amplitude effect was expected during both F and W tasks given the different presentation probabilities of animals and non-animals. PRs displayed larger P300 amplitudes for animals compared to non-animals during the F task, as expected, but not during the W task. The non-significant P300 effect during the W task in PRs can be interpreted as a less efficient categorization processing of two types of stimuli. Previous studies on dyslexic, reading disabled and/or subjects with attention deficit disorders have also reported an attenuation of the P300 effect (Diniz et al., 1997) and attributed it to less efficient processing systems. A prolonged P300 peak latency in the W task was also found in PRs as previous studies have shown (Silva-Pereyra et al., 2001). Latency of the P300 seems to reflect stimulus classification speed (Magliero et al., 1984) and it has also been commonly interpreted as reflecting the time needed for stimulus evaluation and memory updating (Polich and Kok, 1995). According to the so-called ‘memory updating model’ (Donchin and Coles, 1988), infrequent events elicit large P300 because the immediate memory for the preceding target stimulus has decayed and is refurbished by the neural events which occur upon the presentation of a new target stimulus. In contrast, frequent stimulus events, maintaining stronger representations, do not require as much updating and therefore yield smaller P300 waves. Our results support the notion that PRs take more time than controls to update their context model during the W task, because their processing system is not fast enough to read the odd trial and accommodate the new information in the previous memory model. The word categorization task we used needs both word recognition and semantic processes to allow a decision on whether an item belongs to one or other semantic category. The developing ability to read quickly, accurately and effortlessly is critical to skilful reading comprehension (Adams, 1990), because it frees cognitive resources to allow for the integration of a word and their context, which leads to understanding the meaning of a text (Stanovich, 1980).

Taking together our behavioral and ERP results, PRs may appear as underachievers in semantic tasks but not because of a semantic processing deficit itself (Waterman and Lewandowski, 1994). Our study suggests that PRs have deficiencies very early in the processing of words. Every word presented is a problem for these children because it takes much time and effort to be read, although when finally read, they can decide the semantic category to which the word belongs. PRs may use a less efficient and demanding strategy to process words. This strategy consumes extra attentional resources and seems to be slow, with the subject storing and accommodating new difficult information into a memory model before the next trial arrives. We suggest that the most invasive deficit that PRs face when reading takes place very early, probably at the first encounter with the processing of graphemes. In this way a chain reaction of general slowness is triggered. Thus, previous behavioral studies may have mistakenly concluded that the deficit is at semantic level. Our results challenge this interpretation.

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References


