EVENT RELATED POTENTIALS DURING THE VISUAL DISCRIMINATION OF WORDS AND PSEUDOWORDS BY CHILDREN

Lineu C. Fonseca[1], Gloria M.A.S. Tedrus[1], Maria Agnes P. Gilbert[2]

ABSTRACT - Event related potentials (ERPs) in reading were studied in children in a word and pseudoword discriminating task. Seventy-nine children (9 to 11 year old), all with no elements suggesting brain injury and with school performance compatible with their age were studied. The ERP were registered as there were represented, visually, successively and in a random manner, 100 words and 100 pseudowords. For each stimulus the child pressed a key corresponding to the discrimination between word and pseudoword. The register was carried out for the electrodes of the 10-20 system and the mean amplitudes and latency peaks measured and also the amplitude from 200 to 550 milliseconds. The most significant differences between the ERPs occurred in Cz, with greater negativity for the mean of the amplitude between 425 and 550 milliseconds for pseudowords (N400). The N400 was more precocious in 11 year old. The influence of age was thus evident and also the differences in ERPs between words and pseudowords.

KEY WORDS: event-related potential, pseudowords, lexical decision, child, EEG.

Potenciais evocados cognitivos na discriminação visual entre palavras e pseudopalavras em crianças

RESUMO - Foram estudadas 79 crianças (9 a 11 anos) sem elementos sugestivos de comprometimento cerebral e com desempenho escolar compatível com a idade. Os PCL foram registrados enquanto eram apresentados, visualmente, sucessivamente e de modo aleatório, 100 palavras e 100 pseudopalavras. Para cada estímulo a criança acionava uma tecla correspondente à discriminação entre palavra e pseudopalavra. O registro foi realizado para os eletrodos do sistema 10-20 e foram feitas medidas de médias de amplitude e de latências de pico e de amplitude de 200 a 550 milissegundos. Em Cz ocorreram as diferenças mais significativas entre os PCL, com maior negatividade da média de amplitude entre 425 e 550 milissegundos para pseudopalavras (N400). O N400 foi mais precoce nas crianças com 11 anos. Evidenciou-se assim a influência da idade e as diferenças no PCL entre palavras e pseudopalavras.

PALAVRAS-CHAVE: potenciais evocados cognitivos, decisão lexical, EEG, pseudopalavras.

It is possible to register event-related potentials (ERPs) in reading tasks. The ERPs for reading show prolonged latency and consist of a sequence of waves, the most important of which are one with positivity at about 300 ms (P300) and another with negativity between 400 and 450 ms[1,2]. The ERPs have shown peculiarities in tasks involving: semantic and phonological congruence and incongruence[1-5], syntax anomalies[6], word categories in context[7], word frequency and length[8] and specifically in the reading of words and pseudowords[9]. In the event related model for reading/writing, two basic processes can be characterised using the "information processing" approach: reading by way of phonological mediation and visual reading[10-12]. In reading by way of phonological mediation the written word is recognised as if it had been heard whilst in direct visual reading - lexical route - the words are recognised visually and not by hearing. The new word becomes familiar due to repeated exposition. The more familiar the word and its arrangement and structure, the less "activation" is required for it to be recognised. Evidence for the existence of these two basic reading processes can be found in studies showing smaller latencies for reading regular words - *effect of regularity* - and also for the reading of real words as compared to that for invented or pseudowords - *lexical effect.*

Thus studies of reading tasks involving words and pseudowords provide important knowledge on the reading process. In adults, studies on event related potentials in reading tasks involving lexical decisions showed larger negative components for pseudowords than for words[13-16]. This greater negativity for pseudowords was interpreted as being a consequence of the greater amount of lexical search required by the stimuli[13]; there would be a prolonged attempt to try and activate the meaning of the pseudoword whilst uncertainty about its categorisation existed[15]. Research on ERPs in children has shown age-dependent differences and contributed to an understanding of cognitive development[5] and also revealed alterations in groups of children with dyslexia[17,18]. We have no knowledge of studies attempting to directly compare the ERPs in a lexical decision task involving words and pseudowords and also evaluate the influence of age in children.

The objective of the present study was to analyse ERP in children in a task involving the discrimination of words and pseudowords, taking factors such as age and reaction time into consideration.

METHOD

Nine to eleven year old children attending the following criteria were included in this study: no history of neurological or psychiatric problems; normal neuropsychomotor development; normal neurological examination; normal electroencephalogram; absence of cognitive deficit in the Raven test; absence of repetition of school years; result in school performance test (SPT) compatible with age and school grade.

The children were recruited in five fundamental level state schools in different regions of Campinas with respect to the socio-economical level of the public attended. The procedures obeyed the criteria of the Ethics Committee for Research in Human Beings of the Catholic University of Campinas.

The procedures carried out were the following: anamnesis with the parents or guardians to raise the personal antecedents of neurological, psychological or psychiatric complaints, including data on school performance; conventional neurological examination; eyesight evaluation on the decimal opometric scale; evaluation of lateral dominance - Edinburgh inventory; evaluation of intellectual level using the Raven test for progressively coloured matrices; evaluation of school performance using the SPT, which aims to objectively evaluate fundamental abilities in an overall way, especially in the subtests for writing, reading and arithmetic (Stein)[19]; register of brain electrical activity during a task for discriminating between words and pseudowords - event related potentials for reading.

The register of brain electrical activity was obtained with 12 bits of resolution, 0.5 and 35 Hz filters, in 200 samples per second, using the equipment *Braintech 3.0* (EMSA *Equipamentos Médicos)*. Impedance was maintained below 10 kΩ. The child remained seated during the exam. The electrodes were placed according to the 10-20 international system, using two additional electrodes applied 1cm below (left side) and above (right side) the eyelid cleft, with the objective of evaluating eye movements. The inter-connected auricular electrodes served as the reference.

The ERPs were obtained by randomly presenting 100 words and 100 pseudowords, disyllables paired with respect to the number of letters and composition of the consonants and vowels. High frequency words were used from *Pinheiro* child first readers[12]. The letters of the words and pseudowords were white on a black background, Times New Roman type, regular, 30, with a maximum length of 50mm. The distance from the eyes to the monitor (143 cm) was such that the visual angle was always less than 2 degrees. The presentation time was one second and the interval between stimuli, 4 seconds. During the activity there were short pauses (1 to 3) for resting.

To carry out the procedure, the child was instructed to press a previously determined key (INS or space) with one hand if the stimulus was a word, or another key (space or INS, respectively) with the other hand if it was a pseudoword. The number of cases was balanced for each type of response laterality[20].

The child remained seated in a darkened environment during the test and was submitted to prior training to check for adequate understanding of the instructions. The programme used generated a file containing the type of reaction and time taken for each response. For each child, the percent correct answers and mean time taken for these correct responses for the words and pseudowords, was verified.

Three seconds of brain electrical activity were included in the ERPs average (1.5 seconds before presenting the stimulus, 1 second for presentation and 0.5 seconds after the presentation) for both words and pseudowords in which the response was correct and with insignificant eye movement. The EMSA programme added the result of the average, corrected for the 100 ms prior to the start of stimulus presentation, to the end of the graph. The average data were exported to other programmes (spreadsheets, statistical programmes).

With the objective of comparing the grand average of the event related potentials evoked by the words and pseudowords, the t-test was applied to each development point of the potentials between 300 and 600 ms for each of the electrodes analysed (Cz, Pz, P4, P3, C4, C3, Fp2, Fp1, F4, F3, O2, O1, T6, T5, T4 and T3), after verifying a distribution compatible with normality.

For electrodes in which differences occurred between words and pseudowords for the three age groups (9, 10 and 11 year old), a complementary analysis was carried out, measuring the amplitude and latency of the positive potential between 200 and 300 ms and of the negative potential between 400 and 600 ms (N400 component). The occurrence of greater negativity of the N400 for pseudowords than for words was analysed, and, in these cases, the latency and amplitude of the point showing the greatest difference in potential of this effect were also analysed.

Table 1. Distribution of the children according to age and gender.

Age	Gender		
	Male	Female	Total
9	14	16	30
10	13	10	23
11	15	11	26
Total	42	37	79

The influence of age was studied for these variables. Non-parametric tests were used for these analyses (Mann-Whitney, Wilcoxon and Kruskal-Wallis U-tests). The relation between the reaction times to discriminate words and pseudowords and the above-mentioned latencies was also analysed using Spearmann's correlation coefficient. For all the tests an alpha risk below 0.5, or 5%, was established to reject the null hypothesis.

RESULTS

General aspects – Evidences of well-characterised event related potentials were found in the majority of children, but eye movements led to the exclusion of several to avoid the error factor determined by electrical potentials of ocular origin. Another limiting factor was the fact that only segments corresponding to correct responses on reading could be considered for analysis. Thus of the initial group of 92 children, only 79 were included in the study (Table 1).

The grand average of the ERPs showed a sequence of waves at Cz, C4, C3, Pz, P4, P3, F4, F3, Fp2 and Fp1, with negativity at about 125 ms, positivity between 200 and 300 ms (component P2) and another negativity with a wider range between 400 and 600 ms (component N400).

Table 2 shows the periods, in ms, in which there was significant difference, point to point, between the ERPss for words and pseudowords (greater negativity for pseudowords) for the various ages.

ERPs at Cz – Since there were significant differences between the ERPs for words and pseudowords at Cz for the various age ranges, they were analysed in more detail. Figure 1 shows the grand average for the ERPs at Cz, for the 9 and 11 year old.

Comparison between words and pseudowords – Table 3 shows the latencies and amplitudes of P2 and N400 and the average amplitudes of the sections from 425-550 ms, 425-485 ms and 490-550 ms. No significant difference was found between word/pseu-

Table 2. Periods (in milliseconds) in which there were significant differences between the grand averages for words and pseudowords, according to the electrode and age.

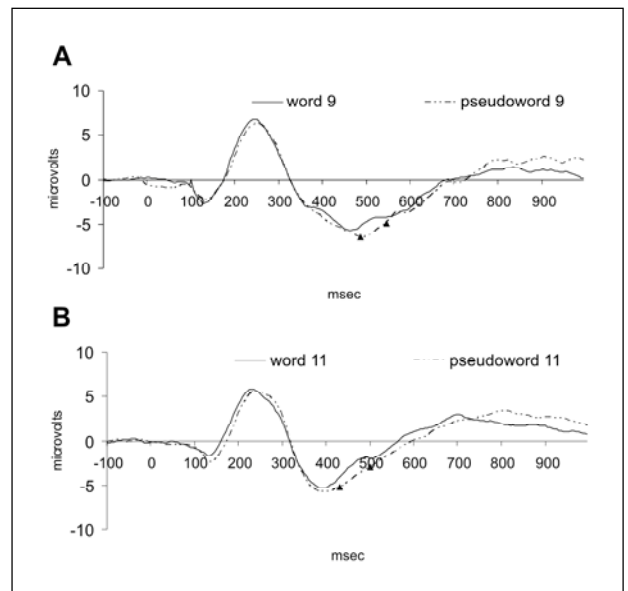| Electrode	Periods with significant differences (ms) and the age		
	9 years	10 years	11 years
Cz	485-535	505-525	425-495; 555-580
Pz	485-535	NS	425-480; 555-590
F4	NS	NS	NS
F3	NS	NS	520-590
C4	495-535	NS	435-470
C3	NS	NS	625-720
P4	500-520	NS	NS
P3	NS	455-485	545-595
O2	NS	455-485	NS
O1	NS	400-490	575-595
T6	NS	400-530	NS
T5	NS	400-514	NS
Fp2	NS	NS	425-495
Fp1	NS	405-575	425-595

NS, not significant.

Fig 1. Grand average ERPs for pseudowords and words at Cz, for the ages (A) 9 and (B) 11 years significant statistical difference.

doword for the latency and amplitude of P2. However the latency and amplitude of N400 were significantly greater for pseudowords.

Table 3. Latencies (in ms) and amplitudes (μV) of P2 and N400 and average ampli - tudes (μV) of the N400 segments for words and pseudowords.

Variable	Words Average & SD	Pseudowords Average & SD	Value for p Wilcoxon
P2 latency	255±41	256±43	0.17
P2 amplitude	102±34	9.6±36	0.06
N400 latency	418 v 57	436±61	0.0008*
N400 amplitude	−7.3±50	−9.2±43	0.0004*
Amplitude 425-550	−3.6±38	−4.7±38	0.0002*

* significant.

Table 4. Averages for the latencies and amplitudes of P2 and N400 and amplitude averages for the N400 segments according to age.

| Variable	Averages for latency (ms) and amplitudes (μV)		
	9 years	10 years	11 years
P2 latency - word	264	257	247
P2 latency - pseudoword	260	261	249
P2 amplitude - word	10.7	10.1	9.7
P2 amplitude – pseudoword	9.4	9.7	9.7
N400 latency – word	430	417	404
N400 latency – pseudoword	451	440	415*
N400 amplitude - word	−8.5	−7.0	−6.1*
N400 amplitude - pseudoword	−9.1	−9.4	−9.1
Amplitude between 425-550ms - word	−4.8	−3.6	−2.3*
Amplitude between 425-550ms - pseudoword	−5.7	−4.6	−3.6*
Greatest difference - latency	467	465	425*
Greatest difference - amplitude	3.9	3.4	4.1

* significant.
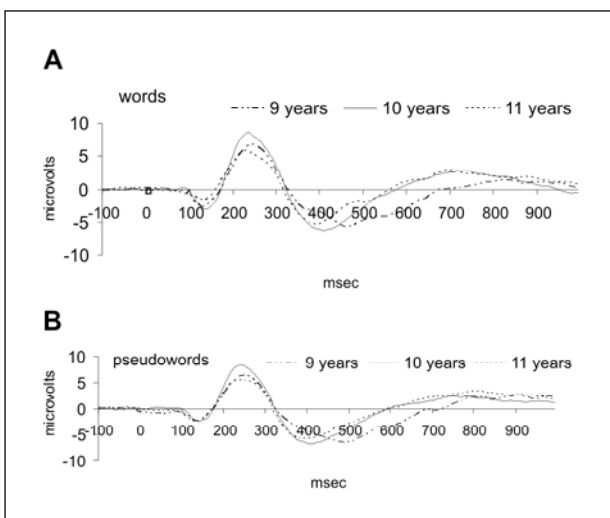
Fig 2. Grand average ERPs for b) pseudowords and a) words from Cz, at the ages of 9, 10 and 11 years old.

The average amplitudes of the sections from 425-550 ms, 425-485 ms and from 490-550 ms were more negative for pseudowords.

N400 (greater negativity for pseudowords than for words) occurred in 70 (88.6%) of the 79 children; in 83.3% of the 9 year old, 90.9% of the 10 year old and 85.1% of the 11 year old. On average, the latency of the largest difference in amplitude of the N400 effect occurred at 435 ms (±64).

Age and ERPs – The grand averages of the ERPs at 9, 10 and 11 years of age, for words and pseudowords, are shown in Figure 2.

Table 4 shows the relation between age and the latencies and amplitudes of the various potentials, as also the averages of the amplitudes of the N400 segments.

There was no overall significant difference on comparing the various age ranges. However, on comparing the 11 year old with the others, there was a statistically significant difference (Mann-Whitney U-test; p<0.05) for the N400 latencies of pseudowords and for the N400 latency with the greatest difference, which were both shorter in 11 year old.

The average amplitudes in the section from 425-550 ms were significantly smaller for the 11 year old than for the other children (p<0.001).

Relation between reaction time to discriminate words from pseudowords and the ERPs – For the whole group of children, the reaction time to discriminate words was 1325.2 ms (±417) and 1769.2 ms (±653.8) for pseudowords.

There was a statistically significant correlation (Spearman's correlation coefficient) between the reaction time for words and pseudowords and the respective latencies of N400 (p<0.01) and the greatest difference of N400 (p<0.05).

DISCUSSION

In tasks directly related to reading, differentiation of ERPs has also been observed for activities involving: semantic and phonological congruence and incongruence[2,3,4,21], phrases (semantic ambiguity)[1] and syntactic anomalies[6]. Some studies on ERPs refer to the reading of phrases, studying the potentials evoked by the various components of the phrase and in particular by the last word, which could be semantically or visually incongruent or otherwise in relation to the previous words[1,2]. For example, after the last word Kutas and Hillyard[1] noted a potential of higher amplitude, negative for semantic incongruence and positive for visual incongruence.

The study of the discrimination between words and pseudowords can contribute to an understanding of the various aspects of the reading process. In 1972, Shelburne[9] compared potentials evoked by the reading of words with those of pseudowords. Three letter series (consonant, vowel, consonant) were presented, in which the final consonant determined whether it was a word or not (e.g. C-A-T or C-A-F). The potential observed after the 3rd letter, that is, that connected to decision taking, was different from that after the 1st and 2nd letters, but there was no significant difference between the potentials after the 3rd letters of words and pseudowords. In later research, the words and pseudowords were presented individually in a complete way and in this case differences in the potentials were verified, with greater negativity for the pseudowords between 300 and 500 ms for semantic tasks[13-16].

In the present study whole words and pseudowords were also presented individually, and greater negativity was observed for the pseudowords later on (between 400 and 500 ms) than shown in the studies with adults[13-16], showing that the process is still slower in children.

Differences in the potentials at the same location and the same period of time were also reported when evaluating children from the 1st to the 6th school grades using tasks connected to semantic congruence/incongruence[5], which allows for the suggestion that "the effect of incongruence" could be a possible factor involved in the differences found between words and pseudowords in the present study. These differences could also reflect an attempt and failure to find semantic lexical information in the long-term memory, associated with the pseudowords[7].

It is known that in phonological and orthographic tasks not involving semantic aspects, the greater negativity of N400 did not occur for pseudowords[16].

The greater latency time of N400 for pseudowords could be explained by the greater complexity of the information processing task up to the point of deciding to treat it as a pseudoword. In studies using positron emission tomography, Petersen et al.[22] showed greater extension of the visual extra-striated area activated on reading pseudowords than on reading words. Different regions are activated depending on the type of reading task[23].

In the present study it was also possible to verify the effect of maturation on the ERPs studied within the 9 to 11 year old age range, in a way analogous to that observed with other event related potentials connected to cognitive events[5,24-26].

A reduction in amplitude of the potentials between 420 and 550 was also observed for this age range, in agreement with that observed for the potentials connected to the incongruence effect[5] and in semantic paradigms[27].

Some research has shown that a study of event related potentials in reading could contribute to knowledge about reading difficulties in children or in those with the attention deficit disorder[17,18,28,29].

In conclusion, the present study showed that a study of ERPs in the discrimination of words and pseudowords could provide a significant contribution to the understanding of reading.

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