COGNITIVE DEVELOPMENT OF SEMANTIC PROCESS AND MENTAL ARITHMETIC IN CHILDHOOD: AN EVENT-RELATED POTENTIAL

Xuan Dong[1], Suhong Wang[1], Yilin Yang[2], Yanling Ren[1], Ping Meng[3], Yuxia Yang[3]*

[1]*Department of Neuroscience,* [2]*Department of Neurosurgery,* [3]*Department of Pedology*
The First People's Hospital of Changzhou, Jiangsu Province, China
Email address: dx6868@hotmail.com

ABSTRACT

The objective of this work is to investigate the cognitive development of semantic process and arithmetic calculation in childhood using event-related potential tools. Sixty children of three age groups (8-, 9- and 11-year-old groups) participated in the experiment. Each group included 10 girls and 10 boys. Stimuli were presented in two separate lists: semantic priming list and mental arithmetic list. Participants were instructed to decide whether the target word was a real Chinese character or not in semantic priming task and decide whether the production of the arithmetic operation (addition, subtraction, multiplication) was correct or false in mental arithmetic task. The main new observation was that the cognitive process reflected by major ERP components changes with the age growing up. In the lexical decision task, the amplitude of N400 elicited by semantic non-related target was significantly larger than that of a related target in all the children groups. The latency and amplitude of N400 component in 8-year-old group were larger than that of 11-year-old group. A similar RP component was elicited by either a Chinese single-character word or pseudo-word as reported by other authors. In mental arithmetic task, similar results were observed that the latencies of P2, N2, P3 in 8-year-group were longer than those of the 11-year-old group. These was no significant differences in amplitude across the three operation and age groups. These results suggest that semantic priming effects and mental arithmetic are developmental processes even in the early childhood. These two cognitive processes may be used to evaluate the development of language and arithmetic abilities.

Keywords: Mental arithmetic, Semantic, Event-related potential (ERP), Cognitive development, Children

1 INTRODUCTION

Language and arithmetic have been extensively investigated within various disciplines. Linguistics, cognitive psychology and neuropsychology have all sought to establish reliable distinctions between semantic, syntactic, and phonological levels in the knowledge of language. Mental arithmetic can be understood as a complex of higher order brain functions, including identifying numerals, performing mathematical calculations, and memorizing the results. The electrophysiological recording of event-related potentials (ERPs) of the brain is one of the few online methods that is both usable with children and relatively well suited to the investigation of real-time language processing in the brain. Scalp-recorded ERPs reflect the stimulus-locked

information-processing activities and provide tentative information about localization and lateralization of brain activity.

Recognition potential (RP) is an electrical response of the brain that is highly sensitive to the semantic content of stimuli and, according to brain electrical source analysis algorithms, reflects activity generated within basal extrastriate areas (Hinojosa et al., 2000; Rudell & Hua, 1997; Martín-Loeches et al. 2001). RP was originally described by Rudell (1990), who presented English and Chinese words to subjects who could not speak Chinese. He found a positivity with a peak latency in the 200- to 250-ms interval in occipital regions in response to English words but not to Chinese ones. Martín-Loeches et al. (1999) found that orthographically correct stimuli devoid of meaning also yielded a RP but of significantly lower amplitude. In their experiment, even the letter-strings showed some degree of RP, although apparently lower than that for orthographically correct stimuli. One aim of the present study was to determine whether RP exists in accessing Chinese words. In the Chinese language, words can be formed with one, two, three, or more characters. In this study, we adopted a single character word to test the brain process for a specific task. The orthographic system of Chinese can be described at a number of different levels: strokes, radicals, characters, and words (Ding et al. 2004). Here, we used pseudowords as the orthographically correct stimuli devoid of meaning in Martín-Loeches' study. The pseudowords were constituted by joining radicals of Chinese characters together that do not exist in Chinese vocabulary. We wanted to test whether the pseudoword would elicit a corresponding RP.

Semantic priming is a phenomenon in which a target word (e.g., "milk") is recognized more rapidly when it is preceded by a semantically related word (e.g., "cow") than when it is preceded by an unrelated word (e.g., "fork"). This lexical decision task requires subjects to indicate, as rapidly as possible, whether a letter string stimulus presented in each trial is or is not a word. In the lexical decision paradigm used to evaluate the context effect or semantic priming effect, a trial consists of presentation of a single word. A number of studies have investigated the cognitive basis of this phenomenon and demonstrated that semantic priming consists of several cognitive processes. A late event-related potential (ERP) negativity with a peak latency near 400ms (N400) was introduced in a seminal article in which reported that the semantically incongruent terminal words of visually presented sentences, as compared to semantically congruent terminal words (Kutas & Hillyard, 1980). Previous studies indicated that the amplitude of the N400 elicited by a sentence-terminal word was an inverse function of the close probability of that word in context: The more related and predictable the word, the less the amplitude of the N400 (Holcomb & Neville, 1991). Moreover, N400 could be elicited in the context of words presented in pairs and by words presented in lists (Holcomb & Neville, 1990; Nobre & McCarthy, 1994). In lexical decision tasks, the endogenous component has greater amplitude for unrelated targets than for related ones. This effect is the so-called N400 semantic priming effect. The N400 is small for related target words because the lexical detector for the target benefits from the spread of activation associated with the processing of the prime (Holcomb, 1993; Silva-Pereyra et al., 1999). However, these were some of the few studies to investigate the N400 semantic priming effect in Chinese language.

Interest in researching cognitive arithmetic has increased exponentially in recent years. Some studies demonstrate that mental arithmetic is reflected in the time course of event-related potential (ERP) waveforms, with the early ERP components (within 300ms after visual stimulus presentation) reflecting mental processes for identification of stimuli (Czigler & Csibra, 1990) and the late slow potentials associated with accessing of memory systems (Pratt et al., 1989; Iguchi & Hashimoto, 2000). According to the traditional view, a number of visual features, such as orientation, color, and size, are thought to be processed preattentively, i.e., without the

aid of attention. Niegeggen et al. (2002) reported that the attention modulation of visual motion was reflected in the amplitude of a sensory, motion-evoked component (N200) and in a late positive complex (P300). Yagoubi et al. (2003) suggested that the early portion of the ERPs reflected physical identification of the numeral and that a late positive slow wave was functionally related to exact mental arithmetical calculations. In our previous study, we observed that mental calculation elicited a negativity peaking at about 170ms-280ms (N2) and a positivity peaking at about 200-470ms (pSW) in raw ERPs (Dong et al., 2006). These components are probably identical to those found earlier in raw ERPs (N200, P300).

Previous studies in the literature on cognitive aging suggested that performance and process speed-in perception, memory, and executive functions decline from early to late adulthood. Several neurobiological changes accompany these cognitive deficits. Psychologists have long established the exact link between the behavioral and neurobiological levels. Interest in relationships between brain and behavioral development has grown substantially in recent years. In that regard, there are few studies to investigate the cognitive development in children using the ERPs method. In this study, we tested the ERP waveform elicited by a lexical decision task and a mental arithmetic task in three age groups of children. The primary purpose of this study was to investigate the development of language and arithmetic in childhood. Specially, we looked at whether or not the semantic priming effect is evident in children. How might the arithmetic be processed?

2   EXPERIMENT

2.1 Participants

The sample included three age groups: 8-, 9-, and 11-year-old children. Each group included 10 girls and 10 boys. All the participants were right-handed, native monolingual Chinese speakers, with normal or correct-to-normal vision. IQ was obtained from all subjects before explanation of the experiment by using the WISC-R (Wechsler Intelligence Scale for Children-Revised, Wechsler, 1974) test. Each participant had a normal intelligence and was reported to be at or above grade level in reading by parents or teachers. Data from 9 participants were discarded because of excessively high sensor impedances, excessive eye blinking, excessive movement, computer malfunction, or misinstruction. The final sample used for analysis included 17 8-year-old children (average 8.8), 18 9-year-old children (average 9.6), and 16 11-year-old children (average 11.5). Subjects sat on a comfortable chair in a dim room with electrical and auditory shielding. They were fully informed and consented to participate in the study. As the subjects were minors, consent was obtained from their guardians. Participants were given a gift after the test.

2.2 Stimuli, design, and procedure

Stimuli were presented in two lists: a word list and an arithmetic problem list. The two lists were separated by a 10-minute break. The word stimuli were formed from 180 pairs of semantically related words (e.g., wind-rain, black-white), non-related words (e.g. table-grass, soft-red), and pseudowords (60 pairs respectively). All the words were Chinese characters from a textbook suitable for pupils of grade 1. The primes were always Chinese characters, and the targets were either Chinese characters or pseudowords. The pseudowords were made by joining radicals of Chinese characters together. They looked like Chinese characters but did not really exist. The semantic links of related and non-related pairs were confirmed by two linguists. All the stimuli were manipulated and modulated by E-Prime software.

The following sequence of events occurred in each trial in the word list: (1) a fixation point (a plus sign) was presented in the center of the screen for 250ms; (2) a dark screen was presented for 500 ms; (3) a prime character was presented in the center of the screen for 250 ms; (4) a dark screen was presented for 500 ms; (5) a target character was presented in the center of screen for 2000 ms; (6) a 3 s interval was included before the next trial. The subjects were instructed to read the first character (prime) silently and press one key if they knew the second character (target) or another key if they did not knew it. The second characters disappeared as soon as the subjects responded.

The arithmetic problem list included three types of operation: addition, subtraction, and multiplication. Each type included 50 problems. All the stimuli for addition and subtraction were Arabic digits between 1 and 19. The stimuli in multiplication operations were all one-digit. This sequence of events occurred in each trial of the arithmetic problem list: (1) a fixation point (an asterisk sign) was presented in the center of the screen for 250ms; (2) a dark screen was presented for 500 ms; (3) an operation was presented for 1500 ms; (4) a dark screen was presented for 500 ms; (5) an answer to the calculation was presented in the center of screen for 1000 ms; (6) a 2s interval was included before the next trial. The subjects' task was to mentally calculate when the operation was present and indicate by a button pressed with the left or right index finger if the answer that appeared was equal to the result of the operation. Response hands were counterbalanced. The correct result was presented in 50% of the cases. When the presented answer was incorrect, it could deviate by ±2 from the correct result.

2.3 EEG/ERP methods

Scalp voltages were collected with a Stellate^{TM} System 32-channel digital video EEG (Stellate System Inc., CA) connected to a 32-channel Digital Amplifier (LA MONT MEDICAL Inc., Montreal, CA) from 32 scalp electrodes (impedances $<$5 KΩ, bandpass filtered from 0.1 to 35 Hz, digitized at 1000 Hz). The electrodes (LOC, ROC, T3, T4, T5, T6, FPz, FP1, FP2, Fz, F3, F4, F7, F8, CZ, C3, C4, PZ, P3, P4, OZ, PZ, P3, P4, OZ, O1, O2, M1, M2, REF) were aligned according to the 10-20 system (Figure 1, Jasper, 1958). ERPs were baseline corrected with respect to a 100-msec pre-stimulus recording interval and digitally low-pass filtered at 35Hz. Trigger signals corresponding to stimulus type (i.e. related, non-related, addition, subtraction, et al.) were recorded simultaneously with the EEG. to produce ERP waveforms. EEG records corresponding to all the stimuli were averaged from 200ms before stimulation onset to 1500ms for each condition. Trials were discarded from analyses if they contained eye movements (vertical EOG channel differences greater than 100μV) or more than five bad channels (a gradient of more than 75 degrees, defined as the amplitude difference between two neighboring samples or reaching amplitudes over 100μV). ERPs from individual channels, which were consistently bad for a given subject, were replaced using a spherical interpolation algorithm (Srinivasan, 1996).

ERPs were averaged for three different conditions in the semantic list and three conditions in the arithmetic list: related [yes]; non-related [yes]; pseudoword [no]; addition; subtraction; and multiplication. The number of misplayed responses was too small to be averaged. An average-reference transformation was used to minimize the effects of reference-site activity and accurately estimate the scalp topography of the measured electrical fields (e.g. Bertrand, Perin, & Pernier, 1985; Dien, 1998; Curran, Tucker, Kutas, & Posner, 1993). To facilitate comparison with results from other laboratories, we present the mastoid-referenced ERP plots here. Because children's ERPs were likely to be contaminated by blinks and movement, a minimum criterion for participant inclusion was established. Nine schoolchildren did not meet this criterion and were not included in further

analysis.

2.4 Statistical analysis

The data of latency and amplitude in ERPs between conditions were subjected to analysis of variance (ANOVA) by SPSS 11.0 software.

3 RESULTS

When computing the average ERP of both related and unrelated conditions, less than 20% of trials were rejected for artifacts or incorrect responses. The grand-average ERPs waveform for the semantic list (related, non-related, pseudowords) in three age groups (8-, 9- and 11-year-olds) was plotted in Fig. 2. One of the first visible components in all ERPs was an anterior negativity peaking around 100 ms (N1). Following the N1, a positivity peaking around 200 ms was elicited (P2). After the P2, there was a negative-going wave that peaked at about 300 to 400 ms (N400) with a broad scalp distribution.

Across tasks, the latencies of P2 and N400 did not show significant differences in any age group (see Tables 1 and 2). The latency of P2 elicited by related pairs in the 11-year-old group was smaller than that in the 8-year-old group. The latency of P2 elicited by non-related pairs in the 9-year-old group was smaller than that in the 8-year-old group. The latencies of N400 elicited by non-related and pseudowords in the 9-year-old group were smaller than that of the 8-year-old group. The mean amplitude of the N400 was larger for unrelated and pseudowords than for related word pairs in the three age groups (see Tables 3 and 4). The amplitudes of N400 for three conditions in the 8-year-old group were significant larger than that of the 11-year-old groups.

Figure 3 presents the grand average waveforms for the three age groups for the arithmetic lists. Three major components were determined according to the ERP features observed in the data set that are shown for electrodes Fz, Cz, and Pz: P2 (180-220 ms postprobe); N2 (300 -400 ms); and P3 (400 -800 ms). The statistical analysis revealed that the latencies of major components in the 11-year-old group were significant smaller than that in the 8-year-old groups (see Tables 5, 6, 7). The amplitudes did not shown differences across the conditions and age groups.

Topographic analysis by the BESA algorithm assumed that all the conditions in the semantic priming task presented the same activated brain region (see Figure 4). The voltage map of the N400 component elicited by non-related targets in different age groups suggested that the central region was activated. With all the ages grouped, the region showed a tendency to convergence. Similar results were observed in arithmetic tasks (see Figure 5). The voltage map of the N2 component elicited by the multiplication operation in different age groups showed that the frontal-central region was activated when the subject was presented an arithmetic problem. The younger children exhibited more dispersed activated brain regions.

4   DISCUSSION

The aim of the present study was to determine whether the semantic priming effect and mental arithmetic show a development pattern similar to that shown in other psychological studies. The study found that the semantic priming effect and mental arithmetic exist even in childhood. The main new observation was that the cognitive process reflected by major ERP components changes with increasing age. The latencies of P2, N400 in the semantic priming effect, and P2, N2, P3 in the arithmetic operations were longer for 8-year-old children than 11-year-old children.

Recognition potential is an electrical response in the brain that appears when a subject views recognizable images of words. As RP presents both short latency and good signal quality, it appears to be a promising tool in the study of language perception in the visual system. The RP reaches its positive peak at about 200-250 ms (Rudell, 1992). In this study, we found a postivity (P2) with peak latency around 200 ms in response to Chinese characters. The latency of P2 in the 11-year-old group is marginally smaller than in the 8-year-old group. Several task manipulations increase RP latency, such as degrading image quality or increasing word difficulty. On the other hand, presenting a prime stimulus decreases RP latency (Rudell, 1991; Rudell & Hua, 1996). Martín-Loeches et al. (1999) found that RP amplitude increased progressively and significantly as the level of linguistic analysis increased, showing the highest amplitudes in the case of words. This finding may raise the assertion that RP is sensitive to semantic processing. The postponement of P2 in the 8-year-old group revealed that younger children may had fewer reading skills and perceive words at a slower speed.

The present study demonstrated that the amplitude of N400 was attenuated by semantic*s*, which is consistent with observations by other investigators (Anderson & Holcomb, 1995; Hill et al., 2002; Matsumoto, 2005). A great number of experiments have been performed concerning priming effects on N400. Both its latency and its amplitude diminish with semantic and phonological priming, this reduction being more remarkable in the first case (Nobre, Allison, & McCarthy, 1994; Radeau et al., 1998). Here the latency of N400 elicited by Chinese characters is less than that of other languages, e.g. English and German (Coch et al., 2002; Weisbrod et al., 1999). A possible interpretation for these results could be that because Chinese characters are hieroglyphic, they are easier to identify and categorize. Non-related targets and pseudowords elicited similar N400s; in fact, non-related targets were statistically indistinguishable from pseudowords during all the groups. The lack of differences among ERPs elicited by pseudowords and non-related targets suggests that children may have processed pseudowords as not-yet-learned real words, i.e. children tend to treat pseudowords as possible words that are simply outside their vocabulary (Henderson & Chard, 1980). Some previous studies have reported that the N400 varies with age. Its latency diminishes as age increases, probably because of facilitation of lexical access and semantic integration processes.

Our results showed a significant arithmetic N2 effect in the middle electrodes. Classical N2 is a negativity evoked 180 to 325 ms following the presentation of a specific visual or auditory stimulus. Previous studies suggest the N2 component results from a deviation in form or context of a prevailing stimulus (Hoffman, 1990). Several distinct N200 potentials have been characterized: one set reflecting involuntary processing and another evoked through active processing. The latency and amplitude of N2 were sensitive to age and conditions. In one oddball detection study involving the effects of color deviation on N2b elicitation in subjects from age 7 to age 24, increasing age was found to correspond directly to decreases in N2b latency and alternation. This suggests the optimization of visual and cognitive discrimination processes result from physical maturation. In our

previous study, the amplitude of N2 in school-aged groups was significantly higher than in the undergraduate student group (Dong, et al., 2006). This may indicate that more attention resources were devoted to arithmetic tasks.

In this study, the latency of P3 in the 11-year-old group was significantly smaller than that in the 8-year-old group. This component is similar to P300, PSW (positive slow wave) or LPC (later positive component, a positivity following the N400) reported by other psychologists (Pauli et al., 1998; Szűcs & Csépe 2005). Pauli et al. (1998) suggested that the shift in positivity from the amplitude of the slow cortical potential (SCP) before problem presentation to the amplitude of the positive slow wave after problem presentation was smaller in positivity-required compared to negativity-required trials, mainly because of the manipulation of SCP starting points by biofeedback. Clear support exists for age-related modulation of the P300 deflection. In visual tasks, latencies increase with age although the precise correlative nature of age and latency time is not certain. The well-characterized component P3b is similar to the P3 in our experiment. One possible interpretation of P300 is that it reflects broad recognition and memory-updating processes, with P3b proposed to reflect match/mismatch with a consciously-maintained working memory trace, while P3a reflects a passive comparator (Patel & Azzam, 2005).

5   REFERENCES

Anderson, J.E. & Holcomb, P.J. (1995) Auditory and visual semantic priming using different stimulus onset asynchronies: an event-related potential study. *Psychophysiology 32*, 177-190.

Bertrand, O., Perin, F. & Pernier, J. (1985) A theoretical justification of the average reference in topographic evoked potential studies. *Electroencephalography and Clinical Neurophysiology 62*, 462-464.

Coch, D., Maron, L., Wolf, M., & Holcomb, P.J. (2002) Word and picture processing in children: An event-related potential study. *Developmental Neuropsychology 22*, 373-406.

Curran, T., Tucker, D.M., Kutas, M., & Posner, M.I. (1993) Topography of the N400: Brain electrical activity reflecting semantic expectation. *Electroencephalography & Clinical Neurophysiology 88*, 188-209.

Czigler, I. & Csibra, G. (1990) Event-related potentials in a visual discrimination task: negative waves related to detection and attention. *Psychophysiology 27*, 669-676.

Dien, J. (1998) Issues in the application of the average reference: Review, critiques, and recommendations. *Behavior Research Methods, Instruments, & Computers 30*, 34-43.

Ding, G., Peng, D., & Taft, M. (2004) The nature of the mental representation of radicals in Chinese: A priming study. *Journal of Experimental Psychology: Learning, Memory and Cognition 30*, 530-539.

Dong, X., Wang, S., Yang, Y., Meng, P., Xu, F., Yang W., & Sheng, W. (2007) Age difference in numeral recognition and calculation: an event-related potential study. *Child Neuropsychology 13*, 1-17.

Henderson, L. & Chard, J. (1980) The reader's implicit knowledge of orthographic structure. In Frith, U. (Ed.),

Cognitive process in spelling (pp. 85-116). New York: Academic.

Hill, H., Strube, M., Rosech-Ely, D., & Weisbrod, M. (2002) Automatic vs. controlled processes in semantic priming-Differentiation by event-related potentials. *International Journal of Psychophysiology 44*, 197-218.

Hinojosa, J.A., Martín-loeches, M., Gómez-Jarabo, G., & Rubia, F.J. (2000) Common basal extrastriate areas for the semantic processing of word and pictures. *Clinical Neurophysiology 111*, 552–60.

Hoffman, J.E. (1990) Event-related potentials and automatic and controlled processes. In: Rohrbaugh, J.W., Parasuraman, R., & Johnson, R. Jr. (Eds.). *Event Related Brain Potentials* (pp. 145-147). New York: Oxford University Press.

Holcomb, P.J., & Neville, H.J. (1990) Auditory and visual semantic priming in lexical decision: A comparison using event-related brain potentials. *Language and Cognitive Processes 5*, 281-312.

Holcomb, P.J., & Neville, H.J. (1991) Natural speech processing: An analysis using event-related brain potentials. *Psychobiology* 19, 286-300.

Holcomb, P.J. (1993) Semantic priming and stimulus degradation: implications for the role of the N400 in language processing. *Psychophysiology 30*, 47-61.

Iguchi, Y., & Hashimoto, I. (2000) Sequential information processing during a mental arithmetic is reflected in the time course of event-related brain potentials. *Clinical Neurophysiology 111*: 204–213.

Jasper, H.A. (1958) The ten-twenty system of the international federation. *Electroencephalography and Clinical Neurophysiology 10*, 371-375.

Kutas, M., & Hillyard, S.A. (1980) Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science 207*, 203-204.

Martín-Loeches, M., Hinojosa, J. A., Gómez-Jarabo, G., & Rubia, F. J. (1999) The recognition potential: An ERP index of lexical access. *Brain and Language 70*, 364–384.

Martín-Loeches, M., Hinojosa, J.A., Gómez-Jarabo, G., & Rubia, F.J. (2001) An early electrophysiological sign of semantic processing in basal extrastriate areas. *Psychophysiology 38*, 114–24.

Matsumoto, A., Iidaka, T., Haneda, K., Okada, T., & Sadato, N. (2005) Linking semantic priming effect in functional MRI and event-related potentials. *NeuroImage 24*, 624-634.

Niegeggen, M., Sahraie, A., Hesselmann, G., Milders, M., & Blakemore, C. (2002) Is experimental motion blindness due to sensory suppression? An ERP approach. *Cognitive Brain Research13*, 241–247.

Nobre, A. C., Allison, T., & McCarthy, G. (1994) Word recognition in the human inferior temporal lobe. *Nature 372*, 260–263.

Nobre, A.C., & McCarthy, G. (1994) Language related ERPs: Scalp distributions and modulation by word-type and semantic priming. *Journal of Cognitive Neuroscience 6*, 233-255.

Patel, S.H, & Azzam, P.N. (2005) Characterization of N200 and P300: Selected studies of the Event-related potential. *International Journal of Medical Sciences 2*, 147-154.

Pauli, P., Schleichert, H., Bourne, L.E. Jr., & Birbaumer, N. (1998) Effects of cortical polarization on mental arithmetic. *Cognitive Brain Research 7*, 49-56.

Pratt, H., Michalewski, H. J., Barrett, G., & Starr, A. (1989) Brain potentials in a memory-scanning task. I. Modality and task effects on potentials to the probes. *Electroencephalography and Clinical Neurophysiology 72*, 407–421.

Radeau, M., Besson, M., Fonteneau, E., & Castro, S. L. (1998) Semantic, repetition and rime priming between spoken words: Behavioral and electrophysiological evidence. *Biological Psychology 48*, 183–204.

Rudell, A. P. (1990) The recognition potential: A visual response evoked by recognizable images. *Neurosciences Abstracts 16*, 106.

Rudell, A. P. (1992) Rapid stream stimulation and the recognition potential. *Electroencephalography and Clinical Neurophysiology 83*, 77-82.

Rudell, A. P., & Hua, J. (1996) The recognition potential and word priming. *International Journal of Neuroscience 87*, 225–240.

Rudell, A.P., & Hua, J. (1997) The recognition potential, word difficulty, and individual reading ability: on using event-related potentials to study perception. *Journal of Experimental Psychology: Human Perception and Performance 23*, 1170–95.

Silva-Pereya, J., Harmony, T., Villanueva, G., Fernández, T., Rodríguez, M., Galán, L., Díaz-Comas, L., Bernal, J., Fernández-Bouzas, A., Marosi, E., & Reyes, A. (1999) N400 and lexical decisions: automatic or controlled processing? *Clinical Neurophysiology 110*, 813-824.

Srinivas, K. (1996) Size and reflection effects in priming: A test of transfer-appropriate processing. *Memory & Cognition 24*, 441-452.

Szűcs, D., & Csépe, V. (2005) The effect of numerical distance and stimulus probability on ERP components elicited by numerical incongruencies in mental addition. *Cognitive Brain Research 22*, 289-300.

Wechsler, D. (1974) *Manual for the Wechsler intelligence scale for children – revised*. New York: Psychological Corporation.

Weisbrod, M., Kiefer, M., Winkler, S., Maier, S., Hill, H., Roesch-Ely, D., & Spitzer, M. (1999) Electrophysiological corraltes of direct versus indirect semantic priming in normal volunteers. *Cognitive Brain Research 8*, 289-298.

Yagoubi, R.El., Lemaire, P., & Besson, M. (2003) Different brain mechanisms mediate two strategies in arithmetic: evidence from Event-Related brain Potentials. *Neuropsychologia 41*, 855-862.

6   FIGURES
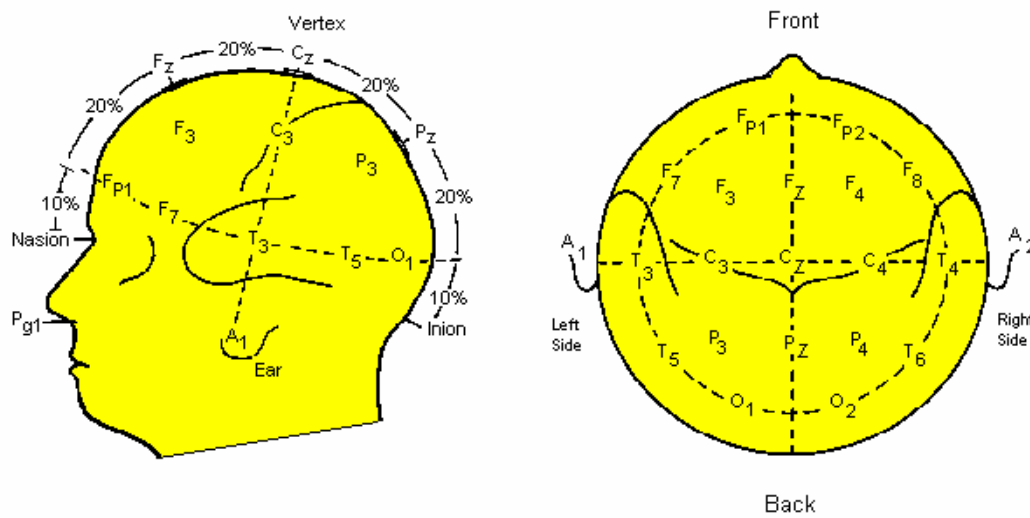
Figure 1. The internationally standardized 10-20 system of electrode placement.
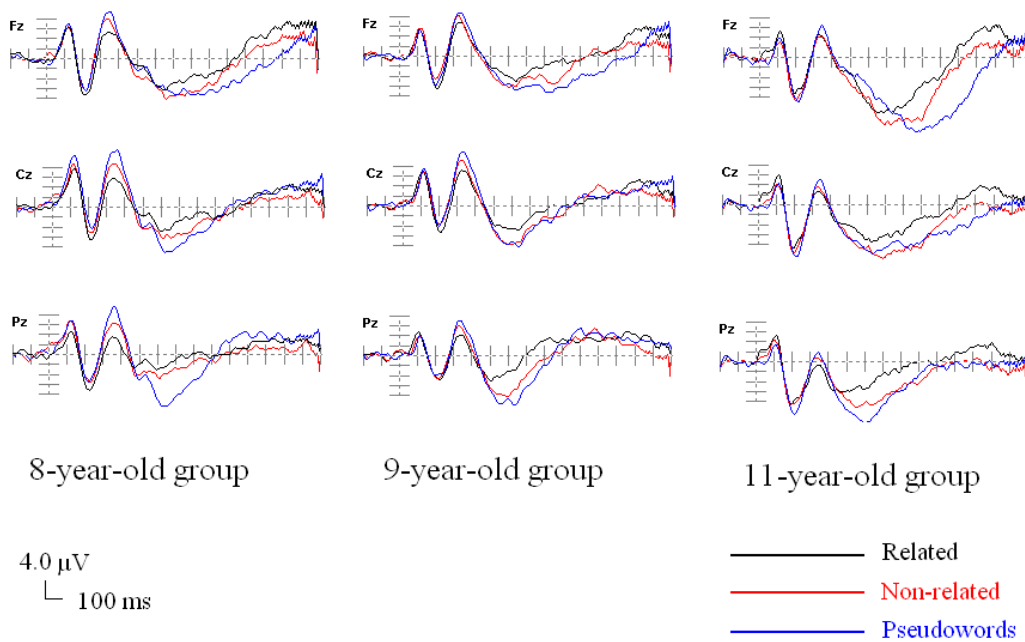
Figure 2. The ERPs waveform of lexical decision task in three age groups.
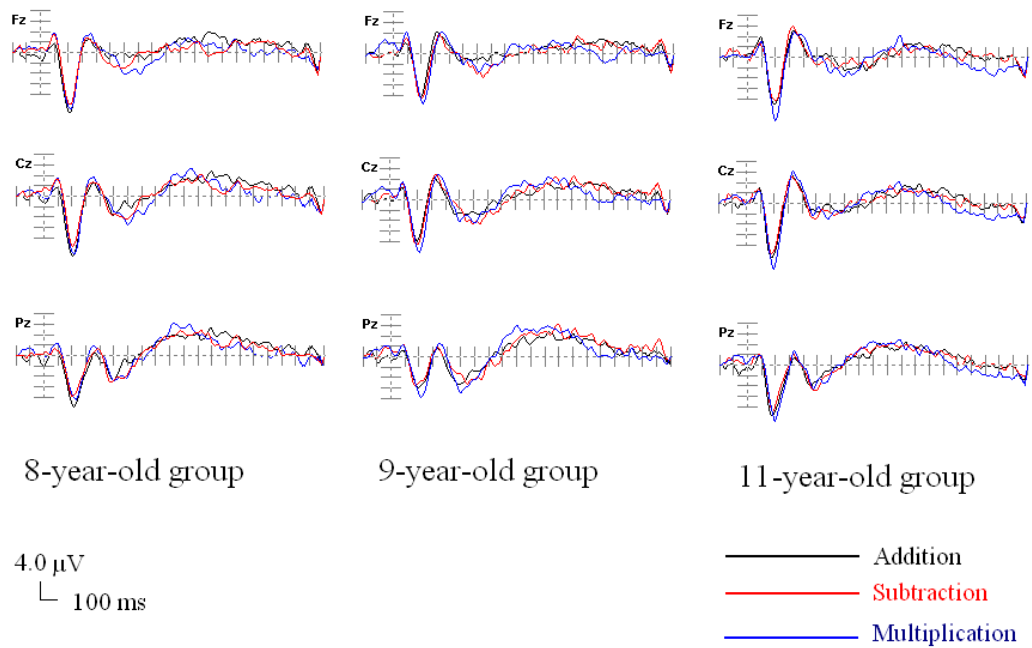
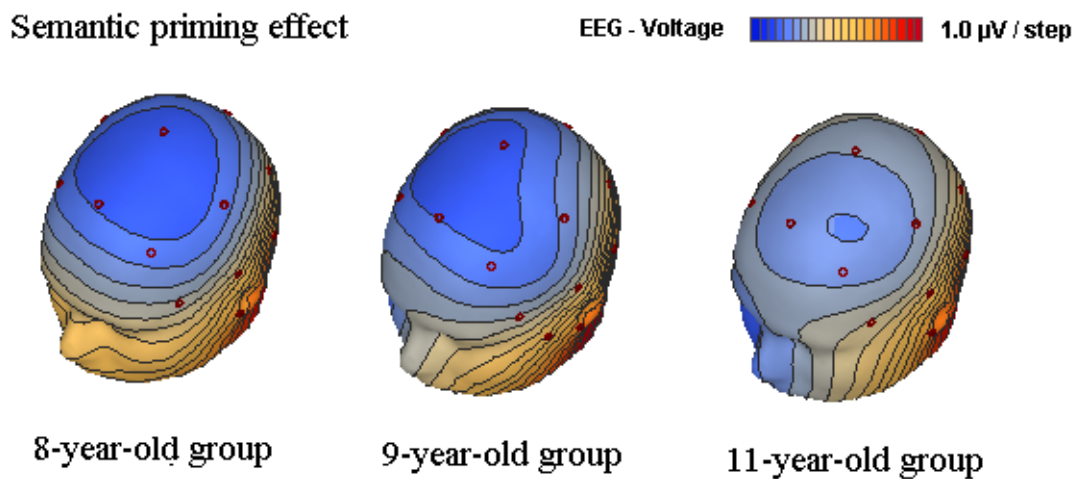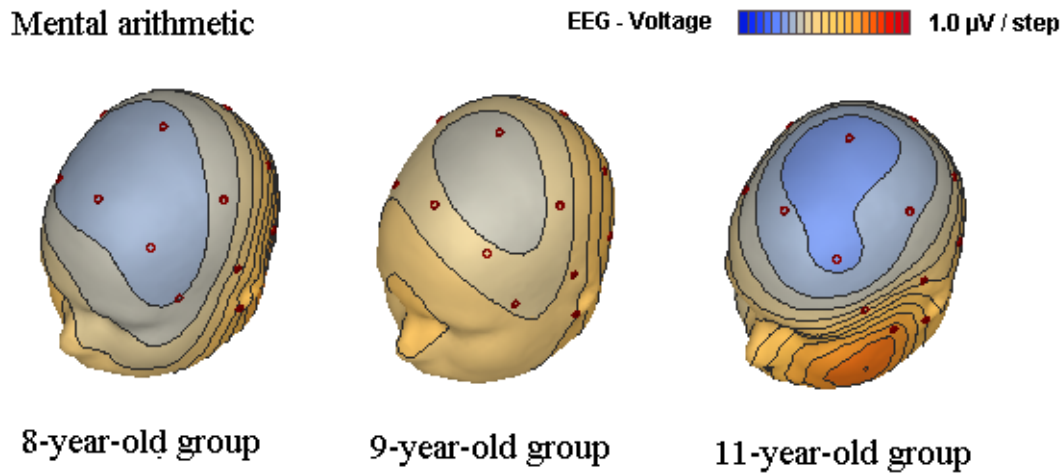**Figure 3.** The ERPs waveform of mental arithmetic in three age groups.

Figure 4. The voltage map of N400 component elicited by non-related targets in different age groups.

Mental arithmetic

EEG - Voltage   1.0 µV / step

8-year-old group   9-year-old group   11-year-old group

Figure 5. The voltage map of N2 component elicited by multiplication operation in different age groups.

7 TABLES

Table 1. The latencies (ms) of P2 component at Cz electrode elicited by semantic related, non-related, pseudowords targets in three age groups.

	8-year-old	9-year-old	11-year-old
Related	216.8±17.5	208.8±19.8	200.0±23.2*
Non-related	214.6±15.5	196.9±25.5*	202.2±24.5
Pseudowords	210.0±16.8	197.8±19.4	203.1±15.7

*Compared to 8-year-old group, P<0.05

Table 2. The latencies of N400 component at Cz electrode elicited by semantic related, non-related, pseudowords targets in three age groups.

	8-year-old	9-year-old	11-year-old
Related	345.9±32.0	333.1±30.3	330.6±26.8
Non-related	350.6±21.5	327.9±16.0**	335.9±34.5
Pseudowords	345.4±24.7	327.9±15.3*	336.8±29.8

*Compared to 8-year-old group, P<0.05

**Compared to 8-year-old group, P<0.01

Table 3. The amplitudes (µV) of P2 component at Cz electrode elicited by semantic related, non-related, pseudowords targets in three age groups.

	8-year-old	9-year-old	11-year-old
Related	8.0±5.8	6.2±4.9	10.3±7.4
Non-related	3.5±6.6	5.1±7.8	8.1±6.0

Pseudowords	3.9±6.3	3.6±5.9	8.6±8.4*

*Compared to 8- and 9-year-old group, P<0.05

Table 4. The amplitudes (µV) of N400 component at Cz electrode elicited by semantic related, non-related, pseudowords targets in three age groups.

	8-year-old	9-year-old	11-year-old
Related	-6.8±5.5	-9.4±6.9	-3.4±7.3*
Non-related	-12.1±4.6	-10.4±6.3	-8.7±5.2
Pseudowords	-11.7±8.8	-13.6±5.9	-7.8±8.8*

*Compared to 8-year-old group, P<0.05

Table 5. The latencies (ms) of P2 component at Cz electrode elicited by addition, subtraction, multiplication targets in three age groups.

	8-year-old	9-year-old	11-year-old
Addition	215.4±30.2	189.6±27.1*	190.2±18.7*
Subtraction	206.8±16.7	193.9±23.6	192.1±18.5**
Multiplication	216.5±21.1	210.8±30.2	199.9±19.1**

*Compared to 8-year-old group, P<0.01

**Compared to 8-year-old group, P<0.05

Table 6. The latencies (ms) of N2 component at Cz electrode elicited by addition, subtraction, multiplication targets in three age groups.

	8-year-old	9-year-old	11-year-old
Addition	352.2±30.1	333. 9±34.7	346.9±26.5
Subtraction	369.9±36.1	347.1±42.5	341.8±23.3*
Multiplication	366.5±47.1	370.3±78.6	350.3±38.4

*Compared to 8-year-old group, P<0.05

Table 7. The latencies (ms) of P3 component at Cz electrode elicited by addition, subtraction, multiplication targets in three age groups.

	8-year-old	9-year-old	11-year-old
Addition	746.0±115.9	630.8±119.3*	589.7±121.0*
Subtraction	692.0±120.1	641.2±94.6	570.1±79.7**
Multiplication	679.1±71.6	654.7±113.2	593.1±70.4**

*Compared to 8-year-old group, P<0.01

** Compared to 8- and 9-year-old group, P<0.05