A Novel Combined Study of Behavioral and ERP to Explore the Effect of Input Mechanisms Formats on Retrieval during Mental Calculation

Cuiyan WANG [1], Yu BAI [1], Min ZHANG [1*], Kunying ZHANG[1], Wangbing SHEN [2]

[1]*School of Education,* Huaibei Normal University, Huaibei, Anhui 235000, China
[2]*School of Public Administration,* Hohai University, Nanjing , Jiangshu 210098, China

***Abstract* — By ERP technique, the paper tested whether retrieval is affected by different input formats during mental calculation and possible mechanisms. Single addition was presented in Arabic figures only (2+4, AA for short), or in Arabic figures and verbal numbers (2+四, AS and AC for short). The results revealed difference of ERP appeared in both 200-300ms and 450-570ms time windows. It supported the hypothesis of retrieval was affected by different input formats, Beyond that, the results suggested that input, encode and retrieval processes of mental calculation were not independent or additive, which was in accordance with encode complex hypothesis. The most significant difference of ERP appeared between AC and AA, but not between AA and AS, which indicted that control process played a role, but not as important as encode when input formats affecting retrieval of mental calculation.**

Key words - Mental calculation, input format, encode, retrieval, ERP

I. INTRODUCTION

Mental calculation is complex cognitive procedure, which includes three processing stages: Convert the stimulus into the appropriate internal codes, retrieve or calculate the answer, and produce the answer, i.e. encode, calculation, and answer production. Whether these three stages are independent and additive or integrated and interactive? In the past three decades, this has always been one important question in cognitive psychology relating to mental arithmetic. There are three theory models attempting to explain this problem: abstract code model, triple code model and encode complex hypothesis. According to abstract code model, different inputs formats would be transformed into the same abstract code, and distinct processing modules communicating via this single modality-independent abstract number code that underlie arithmetic processing, as a result, input formats would not influence computation or retrieval. On the other hand, triple code model assumed that certain arithmetical tasks supported by different functional modules are tied to three distinct number representations, which include analogue magnitude representation, visual-Arabic number form, and auditory-verbal code system. But this model also predicted that once input was transformed into the appropriate code, processing occurred in the same manner regardless of input formats. Only encode complex hypothesis assumed the modular systems that underlie number processing often communicated interactively rather than additively [1].

Related researches have been carried out majorly using two paradigms. One was be called contrast paradigm, by which researchers presented the same arithmetic problem with different surfaces, then recorded response time, error rate or strategy using etc, along with data collections from control task. Noel and Seron (1997) used Roman and Arabic figures to present arithmetic problems to explore whether surfaces influenced the processing of mental calculation. For control group, they designed a number matching task aiming to estimate the time of encode. During this task, two groups of dots were presented first, whereafter Roman or Arabic digit were appeared, the participants need to determine whether the digit or word is equals to the amount of dots presented earlier. The experiment revealed the difference of response time of two input formats in the computation task as well as in the control task. The results showed a time difference of 335ms which makes the RT of verbal arithmetic 2.5 times longer than that of Arabic arithmetic. On the other hand, in control task, the code difference of two input formats was only 140ms. So, there were nearly 200ms that couldn't be explained by encode, therefore

indicating that different input formats not only influenced encode but also the following processing [2]. Campbell et al. have done a series of researches, which proved that stages relating to mental arithmetic are integrated and interactive [3-6]. This paradigm assumed that different input formats require same amount of processing time in different tasks, but that may not be the truth. If so, the difference of RT perhaps reflected the difference of encode, but not the other procedures.

Another paradigm similar to prime paradigm presented the same mental calculation problems by different surface forms as prime stimuli, and the correct or wrong keys as targets. The key point of this paradigm was that the interval between prime stimuli and target was maneuverable, through which may deduce the processing of different formats. Using this paradigm, Jackson and Coney (2005, 2007) replicated the results of the previous studies: surface forms affected not only influence encode stage, but also the following procedures during mental calculation [7, 8]. In additional to behavior research, Electrophysiological method is seldom used to study this kind of problem. Not to mention the influence mechanism, although it is still unclear to us.

The present work combined event-related potential technology and behavior research to explore one-digit mental arithmetic. The common view believed one-digit mental arithmetic was so simple that it only entailed retrieval and no computing [9]. So, we mainly examine whether different input formats influence retrieval process and how the influence took place. We hypothesized encode way and control process were probable causes. As to experiment design, we dissociated ERP and behavior procedure in order that sport potential couldn't contaminate the ERP components of mental calculation. In the behavioral procedure, participants should press the response keys as soon as they complete calculation, and another response was needed after the answers appeared. By doing so, we aimed to collect complete behavior results and to acquire pure ERP of mental calculation without being confounded with motor potentials.

In this study, participants need to complete all the three addition tasks. Task 1 was Arabic arithmetical calculation (A+A，AA for short), for example, "2+4", Both task 2 and task 3 were presented by Arabic digit and Verbal numbers, for example, "2+四". Task 2 was to add Arabic and Chinese number (A+C, AC for short). Asides from the input formats, we are also interested in the role control process was playing in encoding stage. Therefore we designed the third task, which was to add Arabic digit and the stroke number of Chinese number(A+S，AS for short). In this task, the meaning of Arabic number can be directly obtained, but it was impossible for Chinese number words, as the number of strokes is not consistent with their number meanings. For instance, 2+四 should be operated as 2+5 as 四 has five strokes. Therefore in contrast to two former tasks, completing the third task, required control resources to prohibit processing of word meaning. It can be postulated that the ERP difference of three tasks would only appear in encode stage if different input formats only affect encode stage. But if they didn't, the differences would arise during both the encode stage and retrieval stage. Furthermore, the difference would not same because of input formats difference between AA and AC, control process between AC and AS, and both input formats and control process difference between AA and AS. The difference caused by both factors would be larger than that of one should if these two factors play an equal role.

II. METHODS

A. Participants

Seventeen right-handed young adults university students out of whom six was male participated in the experiment. Their age was 24.93±1.87years. They had normal or correct to normal vision. They were fully informed and consented to participate in the study. They received a monetary compensation after experiments.

B. Stimuli

Each subject need complete all the three addition tasks. Task 1 was Arabic addition calculation, for example, "2+4", Arabic digits were from 2 to 8, taking "2+4" and "4+2" as the same problem and keeping one

stayed. Both task 2 and task 3 were presented by Arabic digit and Chinese number word, for example, "2+四". In task2, participants should add two different numbers directly, "2+四"should be 6, but in task 3, they should add Arabic digit and the strokes of Chinese number word, so"2+四" should be 7, as "四" has 5 strokes. In last two tasks, Arabic numbers were from2 to 8, Chinese number words were 四、五、六、七、八, which their stroke is 5、4、4、2、2 respectively. The answer was Arabic number, half were correct, the left were wrong. Wrong answers were +1or-1of correct ones at random.Task1 had 54 problems, task 2 and task 3 each had 60 problems.

C. Procedure

The procedure of ERP experiment was slightly different from behavioral experiment (as showed in Fig1). During the behavioral experiment, participants should press the space key as soon as they completed calculation, and another response was needed to decide whether the answer was correct or not after it appeared. During the ERP recording, participants completed the same tasks as in the behavior experiment; the only difference was that they didn't press any response key until the answer appeared. By this dissociated procedure, we aimed to acquire pure ERP of mental calculation without being contaminated by motor potentials, meanwhile, acquired complete behavior results. Trials started with a fixation cross in the middle of the screen, which lasted for 500ms and followed by a 500ms blank screen. Then two single-digital operands connected by compute symbol + were presented for 300ms, and after 900-1100ms blank screen, answers appeared. Participants responded by pressing response keys to indicate whether the presented answers were correct or wrong.

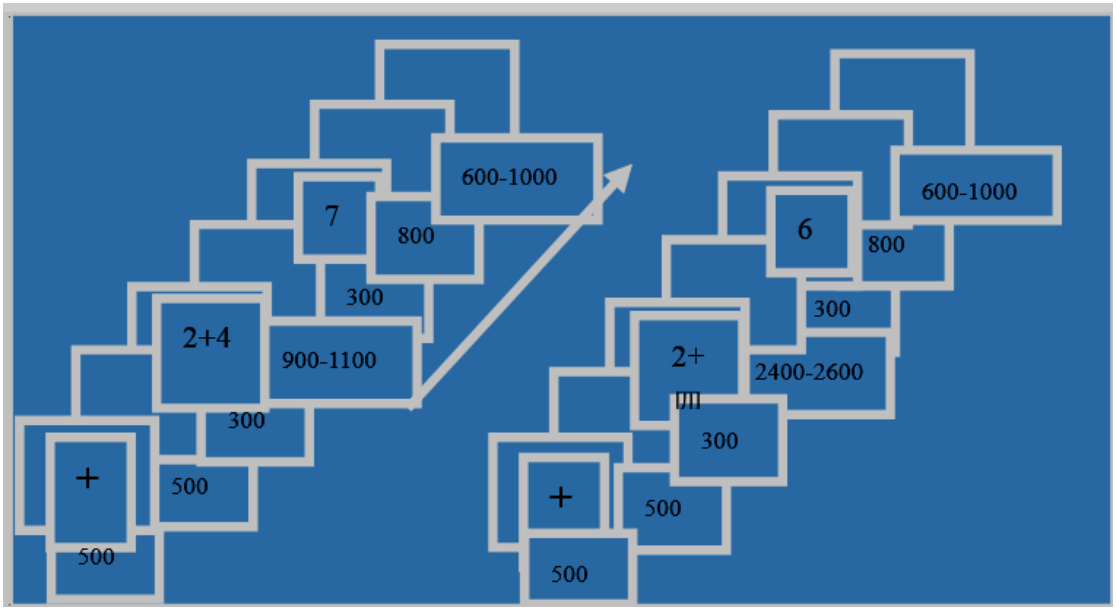

Fig 1. Procedure of ERP experiment (left) and behavioral experiment (right)

D. ECG Recording And Analysis

Scalp voltages were recorded by a NeuroSCAN system, using a 64 channel Quick-cap with Ag/Agcl electrodes (Neurosoft, Inc., Stering, USA). Linked-ears served as reference. Two channels were placed at the outer canthi of both eyes to record the horizontal electrooculogram (HEOG), and another two channels above and below the left eye for vertical electrooculogram (VEOG). The sampling rate was 500HZ. The impedance of all electrodes was kept below 5KΩ. Trials were edited automatically, and all trials contaminated with ocular or movement artifacts were discarded. DC correction was applied. The trigger threshold for ocular artifacts was set to 10%. The minimum number of the average artifacts was 400ms. The EEG data that had

been edited were segmented into epochs from 200ms prestimulus until 1200ms poststimulus. The 200ms prestimulus served as baseline. EEG was detrended and baseline-corrected. Epoch exceeding the range of -70 to 70 μv at any channel except HEOG and VEOG were rejected as artifacts. The averaged waveform was filter with a lowpass of 30HZ (zero-phase, 24db/octave). Electrodes were selected according to the maxima of the typical ERP-components at posterior area of brain such as frontal, central and parietal. We selected typical electrodes from both right and left hemisphere such as FC1, FC2, if lateralization was obvious. If not, we selected electrodes at central axle from up to down such as FZ, FCZ, CZ.

III. RESULTS

A. Behavioral Results

Two female participants were excluded from the data analysis because of EEG artifacts or high error rate. There was one set of reaction time data and two sets of error rate data, as the former was recorded only in behavior experiment, and the later were recorded both in behavioral and ERP experiment. As for reaction time, AS was much larger than AA, and AC was in the middle (as showed in table1). One-way ANOVA showed that main effect was significant, $F(2, 14)=30.11$, $p < 0.01$, further analysis showed that the differences between AA and AS, AA and AC, AS and AC are all significant. Error rate analysis obtained the similar results in both procedures, $F(2, 14)=6.52$, $p < 0.01$; $F(2, 14)=3.36$, $p < 0.05$. In both procedures,

The correct rate of AS was significantly lower than that of AA or AC, but the difference between AA and AC was not statistically significant.

TABLE I THE MEAN REACTION TIME AND CORRECT RATES OF TASKS IN THE EXPERIMENT 1

Group	Reaction time （M±SD）	Correct rate (%,ERP)	Correct rate (%,behavior)
AC	580.03 (178.88)	95.27（4.55）	95.45（3.94）
AS	617.88 (179.12)	88.78（6.96）	90.83（6.99）
AA	539.20 (167.59)	94.73（3.89）	94.29（3.36）

B. ERP results

1) 200-300ms: One-way analysis of variance (ANOVA) on mean amplitude of FC1 and FC2 showed that the task condition effect was significant, $F(2, 14)=12.44$, $p < 0.01$.There were differences between AZ and AA , AB and AA, AZ and AB. The mean amplitude of FC1 was larger than that of FC2.

2) 300-350ms: P300 appeared in this time window in task AC and task AS, which were both presented by mixed input format. However, there was no statistical difference on P300 between two tasks. P300 of AA was not as obvious as the former two tasks.

3) 350-450ms: In this time window, the mean amplitude of FC3 was much larger than that of FC4, $F(1, 14)=16.63$, $p < 0.01$, but task condition showed no significant difference.

4) 450-750ms: There appeared a late positive complex in this time window. Dominated electrodes mainly distributed in posterior frontal and parietal lobe. Effect of task condition was significant, $F(2, 14)=7.24$, $p < 0.01$. Further statistical analysis revealed that AC was significantly different from AA and AS. The difference between AA and AS was not significant.

5) 570-670ms: In this time window, the mean amplitude of AS was the maximum, and the minimum amplitude went to AC, and AA was in the middle. Effect of the task condition was significant, $F(2, 14)=8.45$, $p < 0.01$. Further statistical analysis showed that each task condition was different from the other and the mean amplitude of C1 was larger than C2

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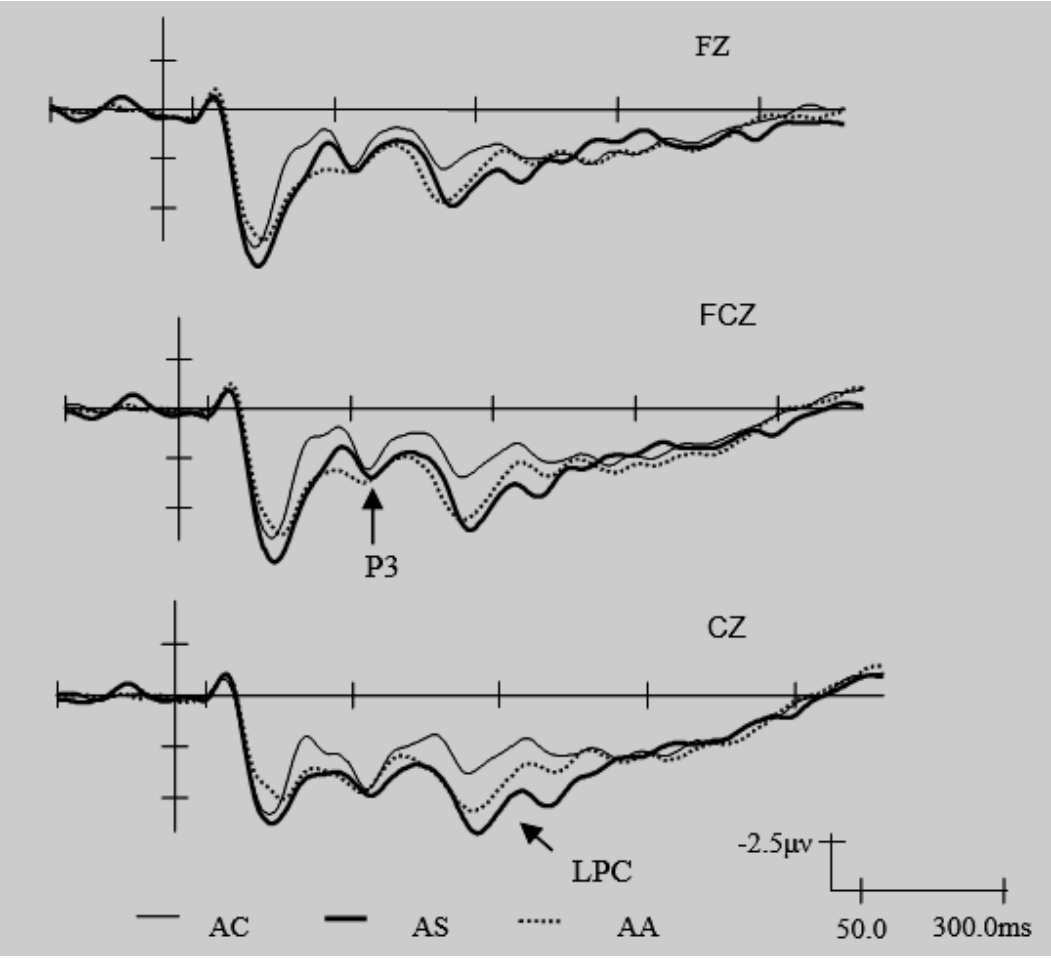

Fig2. ERP wave of three tasks

IV. DISCUSSION

Task AA was presented in simple Arabic digits which were familiar with all subjects. On the contrary, the other two tasks were presented in rarely-used form of mixed input formats i.e. Arabic digits and Verbal numbers. Though task AC was not as difficult as task AS, subjects had to process two different input formats respectively. Completing task AS, however, participants demanded certain level of control process to prohibit the meaning of number words, and at the same time to discern their strokes. The analysis of behavioral data also supported that AS was the most difficult task. The reaction time of AA, AC and AS gradually increased, and the error rate showed the same tendency. According to the previous studies and the ERP data obtained in this study [9,10], the whole wave of mental calculation could be divided into two parts by p300. Before P300, it mainly pertained to encoding, i.e. converting input formats into internal representation and preparing for the following processing. During this time, especially 200-300ms time window, the difference appeared in encode stage would affect the following stages, especially in 450-540ms and 570-670ms time window, which was retrieval stage of mental calculation, according to previous studies [10-14]. From 670ms to the end, the difference was not discernible any longer. In this time window, subjects has completed the calculation and withheld the answer till the proposed keys appeared. It was clear that both encode and retrieval stage revealed differences, which indicated that retrieval was indeed affected by different input formats, and

also proved inputting, encoding and retrieving that mental calculation involved were not independent or additive.

During encoding stage, it was easy to explain the difference between AC and AA. Task AA had only one input format, for example, 2+4, and one encode only. However, task AC was presented by mixed input formats, for example, 2+四, and each input format must be encoded respectively. Therefore encode way contributed to the difference between AC and AA, and did the difference between AS and AA. Task AC and task AS shared the same input format, so their difference originated from control process.

The observed ERP wave during encoding stage ceased to appear in retrieving stage. Task AA and task AS both showed difference in 570-670ms time window, but not in 450-540ms time window. Unlike expectations, AS and AA didn't showed the most significant difference. Task of AS was to add Arabic number and strokes of Verbal numbers. Prior to the experiment, participants had been very familiar with strokes of each Chinese numerical word. As a result, when a problem appeared, for example "3+四", in order to reduce the interference by the meaning of "四", subjects deliberately ignore it (a type of control process) and directly retrieved the stroke from long term memory. We regarded it as task-specific encoding procedure, the mental process of which was similar to that of AA, but not AC, which reduced the ERP difference between AA and AS, but the much larger RT difference was not affected because of extra control process needed to complete AS. Perhaps that was why the wave difference between AA and AS was not so large, and it can also explain why the results of AS was so different from AC, given they had the same input formats. In conclusion, the most significant difference of ERP appeared between AC and AA, but not between AA and AS despite their mild difference, which indicted the role control process might play, existing yet not as important as encode when input formats affecting retrieve of mental calculation.

V. CONCLUSIONS

(1) The study indicated that retrieval was indeed affected by different input formats, and in addition proved input, encode and retrieval processes of mental calculation were not independent or additive.

(2) Control process accounted for an obvious yet not so significant part in input formats interacting with retrieval during mental calculation.

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REFERENCES

[1] J. I. D. Campbell, Handbook of mathematical cognition, NK: New York, 2004, pp. 347–360

[2] M. P.Noel, and X. Seron, On the existence of intermediate representations in numerical processing, Journal of Experimental Psychology: Learning, Memory, and cognition, vol 23, pp. 697–720, Sep. 1997.

[3] J. I. D. Campbell, and N. M. Alberts, Operation-Specific Effects of Numerical Surface Form on Arithmetic Strategy, Journal of Experimental Psychology: Learning, Memory, and Cognition, vol35, pp. 999–1011, Apr. 2009.

[4] J. I. D. Campbell, and J. Fugelsang, Strategy choice for arithmetic verification: effects of numerical surface form, Cognition, vol80, pp. 21–30. 2001.

[5] J. I. D. Campbell, and A.W. S. Metcalfe, Arithmetic rules and numeral format, European journal of cognitive psychology, vol19, pp. 335–355. Mar. 2007.

[6] J. I. D. Campbell, H. R Parker, and N. L. Doetzel, Interactive effects of numerical surface form and operand parity in cognitive arithmetic, Journal of Experiment Psychology: Learning, Memory, and Cognition, vol30, pp. 51–64, Dec. 2004.

[7] N. D. Jackson, and J. R. Coney, Simple arithmetic processing: the question of automaticity. Acta Psychologica, vo119, pp. 41–66. Nov. 2005.

[8] N. D. Jackson, and J. R. Coney, Simple arithmetic processing: surface form effects in a priming task. Acta psychological, vol125, pp. 1–19, May. 2007.

[9] G. J. Groen, and J. M. A. Parkman, Chronometric analysis of simple addition, Psychological Review, vol79, pp. 329 – 343. Apr. 1972.

[10] K. Jost, U. Beinhoff, E. Hennighausen, and et al., Facts, rules, and strategies in single-digit multiplication: evidence from event-related

brain potentials. Cognitive Brain Research, vol20, pp. 183–193. Aug. 2004.

[11] I. Yoshinobu, and H. Isao, Sequential information processing during a mental arithmetic is reflected in the time course of event-related brain potentials, Clinical Neurophysiology, vol111, pp. 204–213, Feb. 2000.

[12] J. Y. Liang, J. Yin, T. Chen, and et al., Number representation is influenced by numerical processing level: An ERP study, Experimental Brain Research, vol218, pp. 27-39.Jan. 2012.

[13] M. I. N´u˜nez-Pe˜na, M. L. Honrubia-Serrano, and C. Escera, Problem size effect in additions and subtractions: an event-related potential study. Neuroscience Letters, vol373, pp. 21–25, Jan. 2005.

[14] M. I. N´u˜nez-Pe˜na, and C. Escera, An event-related brain potential study of the arithmetic split effect. International Journal of Psychophysiology, vol64, pp. 165–173, Apr. 2007.

[15] P.Pauli, W. Lutzenberger, H. Rau, et al., Brain potentials during mental arithmetic: effects of extensive practice and problem difficulty, Cognition Brain Research, vol2, pp. 21–29, Mar. 1994.