한국산학기술학회논문지
Vol. 11, No. 2, pp. 689-695, 2010

Words for Numbers and Transcoding Processes Reflected by ERPs during Mental Arithmetic

Choong-Myung Kim[1] and Dong Hwee Kim[2*]
[1]Division of Speech, Language and Psychological Therapy, Gwangju University
[2]Dept. of Physical Medicine & Rehabilitation, College of Medicine, Korea University

수 연산과정에서 ERP로 확인된 숫자어휘와 부호변환 과정

김충명[1], 김동휘[2*]
[1]광주대학교 언어심리치료학부, [2]고려대학교 안산병원 재활의학과

Abstract The effect of the code conversion process of Korean script (Hangul), also known as words for numbers, was investigated using event-related potentials (ERPs) during mental arithmetic operations. Study subjects were asked to determine whether the arithmetic results of a given target stimuli were correctly matched. Visual inspection and statistics of mean ERPs showed stimulus type-dependent processing rather than task-dependent processing. Results of addition and multiplication tasks revealed that the overall temporal profiles of the Arabic numerals were similar to the Hangul words for numbers. The only exception to this observation was a delayed positive-slope peak occurring around 300 ms, which was likely related to the encoding process of Hangul words for numbers to Arabic-digits, defined as a 'transcoding-related potential.' Source analysis confirmed that the topography of different waveforms for the two conditions was attributed to a single dipole located in the left temporo-parietal area; this area is known to be involved in Hangul words for number processing. These results suggest that the initial processing for encoding words for numbers was followed by arithmetic operations without direct access of abstract internal number representation.
Korea Academia-Industrial cooperation Society. The Korea Academia-Industrial cooperation Society. The Korea Academia-Industrial cooperation Society. The Korea Academia-Industrial cooperation Society.

요 약 한글 숫자어휘의 부호변환 과정을 알아 봄에 있어, 수연산이 시행되는 동안 주어진 목표자극들 간의 연산결과가 일치하는지에 대한 과제를 ERP 실험방법에 의거 시행하였다. 평균진폭에 대한 실험 결과는 과제-의존적인 처리가 아닌 자극유형-의존적인 처리과정을 보여주었는데, 덧셈 및 곱셈과제에서의 한글 숫자어휘의 시간적인 뇌파개형은 아라비아 숫자에 대한 그것과 유사하게 나타났다. 이 처리과정에서의 유의미한 차이점은 300ms 부근에서 나타난 지연된 양성파형의 성분으로서, 이는 한글 숫자어휘의 아라비아 숫자로의 부호변환 과정으로 해석가능하다. 이 과정에 수반된 뇌영상을 분석한 결과, 두 조건에서 서로 다른 파형을 야기한 영역은 한글문자 처리에 관여하는 좌측 측두-두정영역으로 확인되었다. 이와 같은 결과는 수연산 과정의 개개 자극인 한글 숫자어휘의 내재적 수표상 방식이, 수개념으로의 직접적 접근이 아니라 일정한 부호변환 과정을 통한 도식화된 통로를 거치고 있음을 시사한다 할 수 있다.

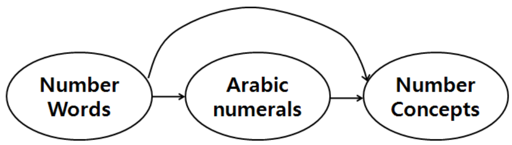
Key Words : Hangul Number-Word, Arabic Numerals, Transcoding Process, Addition, Multiplication, ERPs

1. Introduction

Numbers can be expressed in various forms such as Arabic numerals, number words, Roman numerals, or array dots. Among these different types of expression, the two most common number codes are Arabic numerals

This study was conducted by research funds from Gwangju University in 2009 and most experimental work was carried out at EEG laboratory of Cognitive Neuroscience Lab. at Korea University in Seoul.
*Corresponding author: Dong Hwee Kim (rmkdh@korea.ac.kr)
Received January 15, 2010 Revised February 22, 2010 Accepted February 24, 2010

and verbal words for numbers; these designations are used for the concepts involved in arithmetic operations (for example, the Arabic-digit '5' or the word for the number '오, [o]' which means five in Korean). Single-digit arithmetic operations are usually conducted using an Arabic-digit code that children learn when first introduced to number facts (Zhou & Dong, 2003). In the present study we examined different input codes to determine whether the arithmetic processes differed among the various inputs tested. Specifically, we investigated whether recognition of Hangul words for numbers are processed in the same manner as Arabic-digits. To evaluate this possibility we studied the difference between the two types of numerical inputs by assessing input stimulus identification of the same number concept represented in two different ways. In addition, we studied task-related event-related potentials (ERPs) to determine whether they reflected differences between the two numerical representations. The term 'transcoding' was used to define conversion of Hangul words for numbers to Arabic-digits. However, as to whether transcoding processes have direct access to semantic representation of number concepts or if asemantic transcoding routes for transformation into Arabic numerals exist at all continues to be a matter of debate (Delazer & Bartha, 2001) (Fig. 1).



[Fig. 1] Two possible pathways for processing number concepts from words for numbers

Psychophysiological measures such as event-related potentials (ERPs) and fMRI scans have been used to study differences in the performance of diverse mental arithmetic problems, i.e., problem size effect or magnitude comparisons (Nunez-Pena MI, et al., 2005; Stanescu, et al, 2000) rather than comparing initial input codes and their associated mental arithmetic processes. To date, the neurobiological basis of transcoding has not been studied. It has been suggested that single-digit arithmetic operations can be divided into three stages of processing, namely, conversion of a number-related stimulus into an appropriate internal code, retrieval or calculation of the result, and lastly reporting the answer (Campbell & Epp, 2005; Michael, 2000). In this study, we evaluated whether the first two stages are processed differently according to the class of input code and arithmetic operation. Different types of input codes during the first stage of processing are thought to be differentially converted into internal codes called number concepts (Michael, 2000). Arabic-numerals can easily be changed directly to conceptual codes in order to calculate results; however, arithmetic written in the form of words for numbers may not be easily changed into a number concept. As shown in Figure 1, this difference might possibly be due to the novelty of the stimulus prior to concept definition.

We investigated whether there was a difference in arithmetic processing between the two operations described above. Differences between procedural strategies and verbal memory have been reported for calculation processes in prior studies (Campbell & Epp, 2005; Dehaene & Cohen, 1997). Therefore, if the transcoding for input code conversion occurs between Hangul words for numbers and number concepts, it is possible that another process that is qualitatively different from direct conversion is involved before the arithmetic operation is performed. The direct conversion of the words for numbers into number concepts, as is the case with Arabic-numerals, should therefore be reflected by the intensities of amplitudes of ERP measurements.

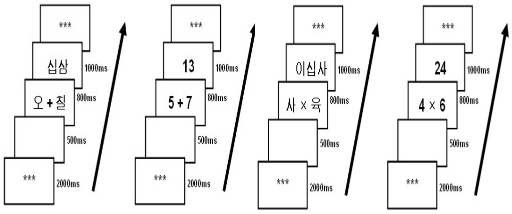
2. Materials and Methods

2.1 Study participants

Fourteen right-handed volunteers (9 male, 5 female) between the ages of 20 and 26 (mean age: 23.2 years) participated in this experiment. None of the subjects had neurological or systemic disease and all were confirmed to be right-handed by the right-hand assessment test. All participants had more than 12 years of education. This study was approved by the ethics committee at our institution and informed consent was obtained from each subject.

2.2 Experimental procedures

Experimental stimuli consisted of addition procedures using Arabic numerals and Hangul words for numbers; single digits were used for all calculations. Arabic digits used for the calculations were presented using a standard form whereby one Arabic digit was placed on each the left and right side of a centered operator (i.e., '5 + 6'). Hangul words for number calculations were presented in the same way as Arabic digits (i.e. '오[o] + 육[juk]', which means 'five + six' in English). To investigate the difference between number code types, we unified the symbols representing the different calculation tasks. The timing scheme of the trial is shown in Figure 2. The warning signal, which was denoted by three asterisks, was displayed for 200 ms. After a delay of 400 ms, the task stimuli were presented for 800 ms. Then, while the answer was displayed for 1000 ms, the subjects were required to determine whether or not the presented solution was correct by pressing a key designated either 'yes' or 'no'. Half of the answers presented to the subjects were correct while the other half were incorrect. ERPs for multiplication were obtained using the same method as for the addition. A total of 72 stimuli for addition and 72 stimuli for multiplication were presented to each subject during the course of two sessions. Hangul words for numbers were displayed using the same method and the same number of stimuli as for the Arabic digits (Fig. 2).



[Fig. 2] Schematic representation of the stimulus trials: (A), addition; (B), multiplication

EEG data was recorded from 32 sites on the scalp. We used the extended international 10-20 system mounted on a Quick cap by Brain Vision system (Ver. 4.2) at a sampling rate of 250 Hz. A linked-mastoid reference attached behind both ears was also used, and the electrode impedance was under 5 kΩ. A band-pass filter with cut-off frequencies at 0.5 Hz and 40 Hz was also used. The EOG artifact rejection criterion was set at + 50 uV and − 50 uV. ERPs were collected separately and sampled from between 100 ms before and 600 ms after the onset of the stimulus. The mean amplitude and peak latency were used to evaluate the differences between conditions. Repeated measure two-way ANOVA was performed on the independent variables, stimulus types (consisting of Arabic-digit and Hangul words for numbers), and locations including the anterior, central, and posterior sites.

3. Results

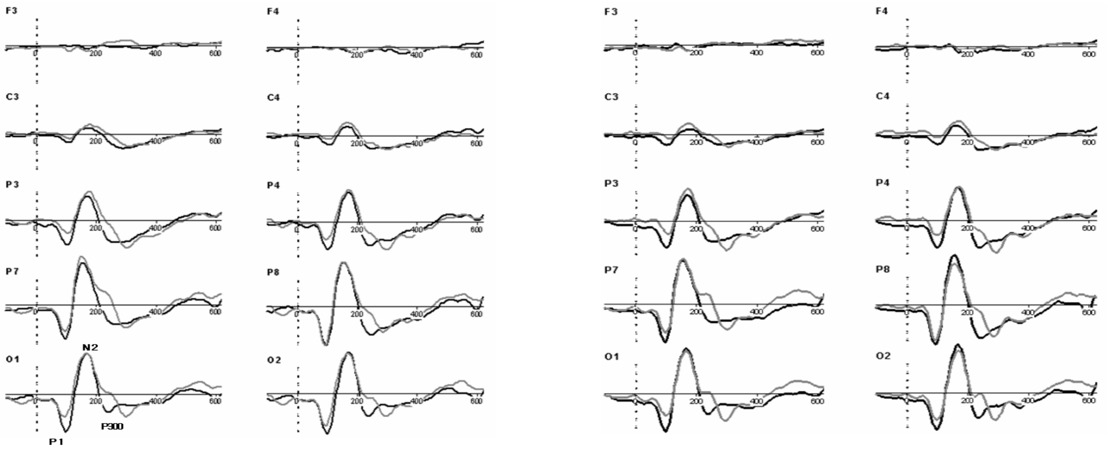
3.1 Analysis of Amplitudes

The mean ERPs elicited by the two types of calculations exhibited similar patterns, consisting of N1-P1 complexes, N2, P300 and CNV components across all channels after the onset of the stimulus presentation (Fig. 3). As shown in Figure 3, the mean amplitude of the first N2 component ranged from 140 ms to 180 ms, where it appeared to be greatest at the parieto-occipital region for both addition and multiplication tasks. However, the two calculation tasks did not exhibit significant main effects for the stimulus type when classified as either Arabic digits or Hangul words for numbers (stimulus type: all $F(1, 24) < 0.28$, $P > .60$). Instead, as shown in Figure 3, the largest N2 amplitudes were elicited from the posterior electrode sites in both tasks (location site: all $F(2, 24) > 38.29$, $P < .001$); no interaction between the two factors was observed.

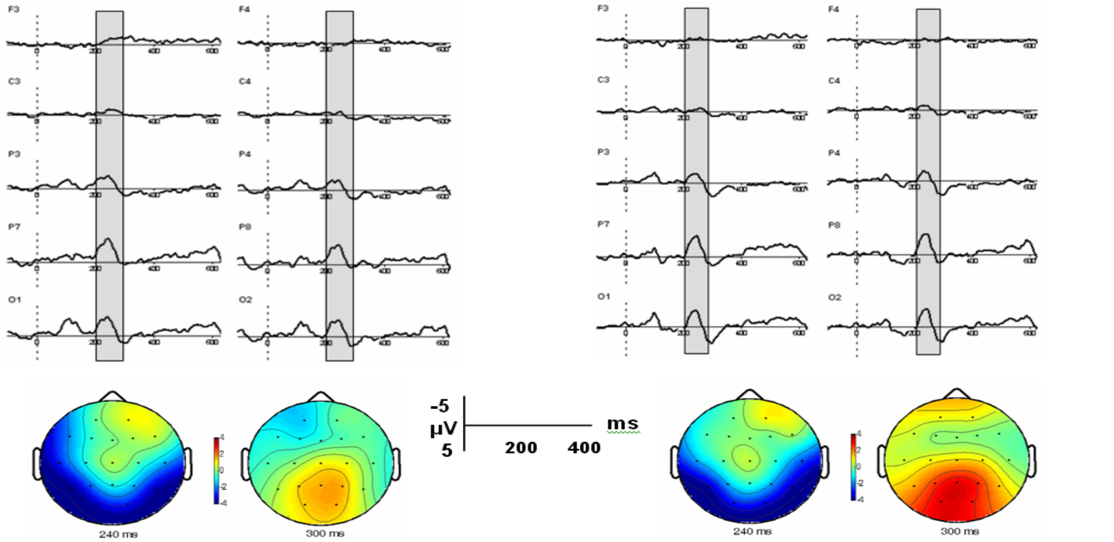
Next, in the P300 component, Hangul words for numbers and Arabic digits did not show a main effect for the stimulus type based on the mean amplitude ($F(1, 24) = 0.18$, $P > 0.67$) during the addition task; however, the effects of the electrode location were greatest for the posterior sites ($F(2, 24) = 38.08$, $P < .001$). By contrast, a more positive P300 for multiplication tasks was found for Hangul words for numbers compared to Arabic digits for stimulus type and electrode sites (stimulus type: F(1,

24) = 2.66, P = .11; location site: F (2, 24) = 47.52, P <.001, respectively). The two tasks exhibited no interaction effects for stimulus type and location sites (all F(2, 24) < 0.37, P > .69).

A topographic map of the ERPs for the transcoding-related processes was computed by subtracting the data obtained for Arabic digits from the data on Hangul words for numbers on both the addition and multiplication tasks. As shown in Figure 4, for a given time period, more negative peaks with posterior bilateral temporo-parietal activation did not appear to be a function of calculation type. Further analysis was performed using BESA software (Brain Electrical Source Analysis; Version 5.1) to determine the locations of the transcoding-related neural sources underlying the differences between the input codes; a single-dipole model based on the mean difference of waveforms was used. PCA (principal component analysis) was applied to the 216-240 ms window, and the first spatial component of the PCA accounted for 94.0% and 97.8% of the



[Fig. 3] Mean waveforms across two types of calculations. Left panel: addition task, right panel: multiplication task, solid line: Arabic digit, gray line: Hangul words for numbers



[Fig. 4] Average differences in waveforms computed by subtracting the data from the Arabic digits from the Hangul words for numbers on the addition and multiplication tasks (left and right side in the upper panel, respectively). Topographic maps for transcoding-related potentials with posterior centro-parietal activation bilaterally and calculation-related potential with posterior parietal activation with Hangul words for numbers at specific points in the different waves for the two types of calculations (left and right side in the lower panel, respectively) variance in the topography of the interval for each arithmetic operation involving

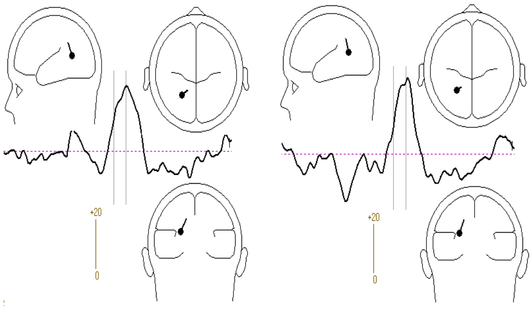
the addition and multiplication tasks, respectively. Each dipole was set approximately at the left medial temporal gyrus (Talairach coordinates:-24, -54, 14 and -25, -53, 13) in the vicinity of the angular gyrus, with residual variances (RVs) of 7.5% and 4.2%, as shown in Figure 5. Another map showing the positive peaks over the posterior parietal sites demonstrated greater responses with the multiplication tasks compared to the addition tasks, suggesting that the strength of activation was likely a function of the calculation type (Fig. 4).

3.2 Analysis of Latencies

The data from the latencies of the N2 component based on the results of the 21 electrode sites withbilaterally increased activity in the posterior regions were analyzed by one-way ANOVA to determine whether a condition's effect was associated with the stimulus type. The N2 latencies of the addition and multiplication tasks did not show an effect associated with the stimulus type (all $F(1, 40) < 1.62$, $P > .21$). Thus, the N2 component measure did not distinguish numerical expressions. Conversely, the peak latencies of the P300 components showed significant delayed responses between the two stimulus types for both addition and multiplication tasks (all $F(1, 40) > 154.25$, $P < .001$). The presence of these delayed latencies suggests that the two calculation task types, Hangul words for numbers and Arabic digits, are associated with an intermediate process related to encoding of Hangul words for numbers to Arabic digits. Data from the other pairs assessed during the addition and multiplication tasks associated with the Arabic stimulus showed no effect on latencies during the time range of interest (all $F(1, 40) < .98$, $P > .33$).

4. Discussion and Conclusion

Digits in the Arabic system have a defined magnitude; for example, the symbol '5' written in Arabic denotes its corresponding number concept. Further, in auditory verbal coding, numbers expressed by spoken word can be easily transformed into Arabic-numerals, such as '5', in order to identify the corresponding abstract number concept when heard or calculated. However, when words for numbers are presented visually rather than verbally, it is not yet known whether there is a specific process involved in number-word recognition and calculation. Neuropsychological models for transcoding or number processing have not focused on calculation of written number-words (McCloskey, et al., 1991; Dehaene, 1992), because this is not a problem for patients with language disorders and is not a function that interferes with normal activities of daily living. Further, prior studies have only focused on abnormalities in number processing and/or arithmetic concepts in adult subjects with brain trauma (Campbell & Clark, 1988; Dehaene, 1992), and thus processes involved in transcoding of arithmetical operations have had limited attention. The goal of this study was to improve our understanding of the transcoding process by evaluating responses to specific tasks using Hangul words for numbers and Arabic numerals and measuring responses to such stimuli with ERPs.



[Fig. 5] Source activity waveforms (0-450 ms) and corresponding models for dipole source analysis of the wave differences (Hangul number-word vs. Arabic digit). The selected intervals for dipole fitting were 216-240 ms for both addition (left panel) and multiplication (right panel) tasks. The dipole was located approximately in the left temporo-parietal cortex (Talairach coordinates: -24, -54, 14)

Three major components were observed during the time window evaluated in this study, namely, P1, N2, and P300. The first of these components, P1, appeared to be bilaterally distributed in the parieto-occipital sites and was not influenced by calculation type. Secondly, negative deflection, or N2, exhibited neither an amplitude or latency effect for the stimulus types, with the exception of the posterior location, where there was an effect for both calculation types. Together, these findings suggest that Hangul words for numbers were processed primarily over the posterior sites. Lastly, the P300 component had the most sensitive time range for targets and revealed significant differences between the different stimulus types.

Both visual inspection and statistical analysis revealed that the ERP waveforms, related to both types of calculation, produced stimulus type-dependent differences between the two conditions as opposed to task-dependent differences. Specifically, with respect to stimulus type, both the addition and multiplication tasks were associated with similar overall temporal profiles, with the exception of the presence of N2 occurring at approximately 240 ms and a delayed positive-trending peak at P300 after 50 ms. As shown in Figure 3, for the different calculation task types, the ERP-patterns elicited by each stimulus type consisting of Arabic digits and Hangul words for numbers appeared to almost overlap across the full time range with little difference in the amplitudes of the N2 and P300 components.

During the tasks related to Arabic digit calculations, positive peaks that appeared earlier by approximately 50 ms were more pronounced than those found with Hangul word for number calculations. For Hangul-related calculations, processing of input related to the stimulus appeared to take longer (Fig. 3). The results for addition tasks were similar to those for the multiplication tasks. Specifically, the P300 latency of Hangul-related stimuli was significantly delayed compared to Arabic-digit stimuli, suggesting that any other cognition of an input code-related process such as Nd240 (from Hangul number-word to Arabic digit) could be considered to be transcoding, as evidenced by the latency effect (Fig. 4).

As reported in previous studies, brain regions associated with number processing have been identified by various psychophysiological measures such as ERPs or fMRI. These studies have located the associated activation of the horizontal segment of the intraparietal sulcus bilaterally, fusiform gyri bilaterally, and the angular gyri (Cohen, et al., 2000; Dehaene, 1992; Dehaene, et al., 2004; Simon, et al., 2002; Zhou, et al., 2006). Of particular relevance to the present study, topographic distribution of ERPs to transcoding-related processes has also been located at the temporo-parietal areas bilaterally for arithmetic operations. Furthermore, the finding in this study of the transcoding potential of Hangul words for numbers by BESA supports the idea that activation is indeed associated with both number processing-related areas and Hangul word processing-related areas(Lee, 2004). Together, these results imply that Hangul words for numbers and the corresponding conversion into Arabic-digits are processed simultaneously during the transcoding process(Fig. 5).

The results of this study demonstrated that cognitive processes involved in the calculations using Korean words for numbers were similar to those used for Arabic digit calculations. However, these similarities do not extend to conversion of words for numbers to Arabic digits, which is thought to involve transcoding processes for calculations using the Korean words for numbers. The ERP data associated with the transcoding processes demonstrated maximal amplitude at the left temporo-parietal areas consistent with the areas associated with both number processing and Hangul word processing.

References

[1] Campbell J.I.D, Clark JM: An encoding complex view of cognitive number processing: comment on McCloskey, Sokol, and Goodman (1986). Journal of Experimental Psychology: General 117: 204 - 214, 1988.

[2] Campbell J I D, Epp LJ, Architectures for arithmetic. In: Campbell JID, editor. Handbook of mathematical cognition New York: Psychology Press, p 347-360, 2005.

[3] Cohen L, Dehaene S, Chochon F, Lehericy S, Naccache L, Language and calculation within the parietal lobe: a combined cognitive, anatomical and fMRI study. Neuropsychologia 38: 1426 -1440, 2000.

[4] Dehaene S, Varieties of numerical abilities. Cognition 44: 1-42, 1992.

[5] Dehaene S, Cohen L, Cerebral pathways for

calculation: Double dissociation between rote verbal and quantitative knowledge of arithmetic. Cortex 33: 219–250, 1997.
[6] Dehaene S, Molko N, Cohen L, Wilson AJ, Arithmetic and the brain. Current Opinion in Neurobiology 14: 218-224, 2004.
[7] Delazer M, Bartha L, Transcoding and calculation in aphasia. Aphasiology, 15: 649-679, 2001.
[8] Lee KM, Functional MRI comparison between reading ideographic and phonographic scripts of one language. Brain Language 91: 245-251, 2004.
[9] McCloskey M, Harley W, Sokol SM, Models of arithmetic fact retrieval: an evaluation in light of findings from normal and brain-damaged subjects. J Experimental Psychology: Learning, Memory, and Cognition 17: 377-397, 1991.
[10] Michael von A, Developmental cognitive neuropsychology of number processing and calculation: varieties of developmental dyscalculia. European Child & Adolescent Psychiatry, 9: 41-57, 2000.
[11] Nunez-Pena MI, Honrubia-Serrano ML, Escera C, Problem size effect in additions and subtractions: an event-related potential study. Neurosci Lett 373: 21-25, 2005.
[12] Simon O, Mangin JF, Cohen L, Le Bihan D, Dehaene S, Topographical layout of hand, eye, calculation, and language-related areas in the human parietal lobe. Neuron 33: 475-487, 2002.
[13] Stanescu-Cosson R, Pinel P, van De Moortele PF, Le Bihan D, Cohen L, Dehaene S, Understanding dissociations in dyscalculia: a brain imaging study of the impact of number size on the cerebral networks for exact and approximate calculation. Brain 123: 2240-2255, 2000.
[14] Zhou X, Chen C, Dong Q, Zhang H, Zhou R, Zhao H, Chen C, Qiao S, Jiang T, Guo Y, Event-related potentials of single-digit addition, subtraction, and multiplication. Neuropsychologia, 44, 2500-2507, 2006.
[15] Zhou X, Dong Q, The representation of addition and multiplication. Acta Psycholgica Sinica, 35; 345-351, 2003.

Choong-Myung Kim [Regular member]

- Aug. 1993 : Seoul National Univ., MA
- Feb. 2003 : Seoul National Univ., PhD
- Nov. 1999 ~ Feb. 2003 : Clinical researcher, SNUH
- May. 2004 ~ Feb. 2008 : KU. Research professor
- Mar. 2008 ~ current : Gwangju Univ. Professor

<Research Interests>
Language disorders, Cognitive neuroscience

Dong Hwee Kim [Regular member]

- Aug. 1991 : KU. College of medicine., MD
- Feb. 2001 : KU. College of medicine., PhD
- Sep. 2004 ~ Aug. 2007 : KU. Dept. of Rehabilitaion, Prof.
- Sep. 2007 ~ Aug. 2008 : Mayo Clinic Research Fellow
- Sep. 2007 ~ current : KU. Dept. of Rehabilitaion, Prof.

<Research Interests>
Language/Cognitive Impairment, stroke, Pain