Hemispheric metacontrol of a mental addition task in right- and left-handers

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利き手の差異が心的加算課題におけるメタコントロール半球に与える影響

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要約

本研究の目的はHellige（1987）が提案したメタコントロールパラダイムを利用して、利き手とメタコントロール半球の関係を検討することであった。メタコントロールの概念は、Levy and Trevarthen（1976）が分離脳患者の結果から提案したもので、課題に優位な半球とは別に、課題遂行をコントロールする半球の存在を提案したものである。Hellige（1987）が、この概念を健常者に適用できるようにパラダイムを開発したのがメタコントロールのパラダイムである。 このパラダイムでは一側半球に情報を投入する条件に加えて、同じ情報を左右両半球に同時に投入する条件を必要とする。 一側視野の成績パターンと左右同時に呈示された条件での成績パターンを比較し、 メタコントロール半球を推測するのである。我々は、右手利き群と左利き手群に対して心的加算課題を実施した。この課題は、1組の漢数字や算用数字が瞬間呈示され被験者に足し算を求めるものであった。Helligeのパラダイムを適用するためには、（1）左右両半球に同時に同じ情報が投入されること、（2）左右視野条件と実験条件の交互作用が見られること、が必要となる。そこで数字対は左視野、右視野、あるいは中央視野に呈示され、また数字対の組み合わせとして、漢数字対（三－七）、算用数字対（2 － 9）、漢数字・算用数字対（四－ 6）の3条件が用意された。その結果、左右視野と刺激対条件の間に交互作用が見られ、算用数字対条件においてのみ、利き手群間にラテラリティパターンの差異が認められた。 つまり、右手利き群では左半球優位性が、左手利き群では右半球優位性がみられた。利き手群別にメタコントロール半球の分析を行った結果、各群ともメタコントロール半球の存在が示唆された。右手利き群においては中央視野成績パターンと右視野成績パターンが同様であり、左視野成績パターンとは異なるものであった。 このことは、右手利き群では左半球が課題をコントロールしていることを示唆している。 これに対して左手利き群においては、 中央視野成績のパターンと同じパターンを示したのが左視野条件の成績であったことから、右半球が課題をコントロールしていることが推察された。 これらの結果は、課題をコントロールする半球は、課題に対して優位な半球となることを示唆している。

Key words

hemispheric metacontrol, mental addition task, laterality

1. Introduction

Many studies have suggested that handedness relate to many psychological as well as pathological factors such as the cognitive ability (e.g., Hardyck, Petrinovich, & Goldman, 1976; Lewis & Harris, 1990; Leask & Crow, 2001; Levy, 1969; Nagae, 1985; Teasdale, Owen, 2001), the personality (e.g., Ellis & Ames, 1989; Hicks & Pellegrini, 1978; Lippa, 2003; Orme, 1970), the school achievement (e.g., Benbow, 1986; Kimura & D'Amico, 1989; Noroozian, Lotfi, Gassemzadeh, Emami, & Mehrabi, 2002), the athletic ability (e.g., Holtzen, 2000; Porac & Coren, 1981) and so on so forth.

In this study, we examined interhemispheric interaction in right and left-handers. As we believe, one of main concerns of human handedness is their cerebral lateralization. We know the physiological fact that each hemisphere dominates the contralateral hemispace and therefore information processing mechanisms from the outer space might not the same in the left and the right-handers. Further, more than 90 percents of human being are right-handers and their speech center is localized in the left hemisphere whereas this pattern in the left-handers is not the same to the right-handers (Rasmussen & Milner, 1977). These addressed the examination to the question whether the brain function in the left-handers and right-handers is different. That is, the decade of laterality and handedness study has begun and a pile of studies has conducted in 1970's and in 1980's. Most of those studies have demonstrated the different pattern of cerebral specialization between the left and the right-handers in various facets of cognitive function (see review, Bradshaw & Nettleton, 1983; Hatta, 1996; Hellige, 1993; Springer & Deutsch, 1997).

In the mean time, the study of interhemispheric interaction has been prevailing as a new direction in so-called laterality studies. This topic is based on the idea that two hemispheres would be a unity and constitute one system (Banich, 1994, 1995, 2003; Hellige, 1993). Although not a few researchers engaging the laterality studies have noticed that the "collaboration" and "interaction" between the hemispheres should be also investigated, much effort has been devoted to investigating the functional "specialization" and "asymmetry" between the hemispheres.

However, a study of hemispheric "metacontrol", where Levy and Trevarthen (1976) originally proposed a theoretical concept, addressed questions how two hemispheres interact.

Metacontrol, which Hellige (1987) used to hypothesize about the mechanisms of neural control, is also a changeable theoretical concept, but a fascinating concept. Metacontrol is a very high-level theoretical concept of neural mechanism whereby one hemisphere asserts control over the other hemisphere in a given task. In an experiment where both functional and physical types of processing were possible (Levy & Trevarthen, 1976), split-brain subjects processed right visual-field stimuli functionally, while they processed left visual-field stimuli physically. The results, using split-brain patients as subjects, showed that the responses were coincident with the researcher's prediction on most but not all the trials.

Using neurologically normal subjects but not split-brain subjects, Hellige (1987) examined the metacontrol by a newly developed paradigm, using three presentation conditions: a left (LVF), right (RVF), and redundant both visual-field (BVF) conditions. Hellige hypothesized that, if some interactions of unilateral visual-fields (LVF and RVF) and any independent variables are significant, and if the pattern of performance in unilateral hemispheric functioning, i.e., LVF or RVF, is similar to that in bihemispheric functioning (BVF), the unilateral hemisphere asserts control over the other. For example, when the pattern of performance in BVF is similar to that in LVF and is not similar to that in RVF, a right hemispheric metacontrol is suggested.

Hellige and Michimata (1989a) asked subjects to judge whether a pair of uppercase letters, which were tachistoscopically presented to a LVF, RVF, or BVF, were physically identical. Their results showed the interaction between the unilateral visual-fields and similarity (same / different) was significant, suggesting that while a RVF advantage showed up in the same judgment, a LVF advantage was obtained in the different judgment. Therefore, they applied their data to the paradigm of hemispheric metacontrol. The results showed an interaction between left/both visual-field conditions and same/different judgments, but no interaction between right/both visual-field conditions and same/different judgments. On this basis, they suggested a left hemispheric metacontrol. Using this paradigm, Hellige and his colleagues conducted several experiments. For example, Hellige, Taylor, and Eng (1989) asked right-handed subjects to identify consonant-vowel-consonant (CVC) nonsense syllables presented in a LVF, RVF and BVF. While an interaction between types of error by right/both visual-field conditions was shown, no interaction between error types by left/both visual-field conditions was indicated. From the analyses of error patterns, they suggested right hemispheric metacontrol in this task. Eng and Hellige (1994) also supported this finding. Hellige, Jonsson, and Michimata (1988) investigated hemispheric metacontrol using stimuli of faces, and suggested a left hemispheric metacontrol in the face-matching task.

Yoshizaki (1995) examined hemispheric metacontrol in a random shape-matching task *before* and *after* phases of paired-association learning. From analyses of interaction between types of response (same/different judgments) and visual-fields (right/both visual-field conditions; left/both visual-field conditions), he suggested that the left hemisphere exerted metacontrol in the random shape-matching task after the association between random shapes and phonetic labels was over-learned.

As seen from the above review, this paradigm is very post hoc for the analysis. When we obtain a significant interaction between the unilateral visual-fields and the independent variables, we can apply this paradigm to the obtained data. It is likely that several variables interact with the unilateral visual fields, so that treating which interaction is chosen depends on researchers.

Although such a shortcoming in the paradigm of hemispheric metacontrol still exists, further empirical findings should be accumulated.

All the mentioned studies dealt with only right-handed subjects, therefore the mechanism of hemispheric metacontrol in non right-handers is totally unclear. The influence of handedness upon hemisphere specialization is also well known (e.g., Coren, 1990; Hardyck & Petrinovich, 1977; Hatta, 1996; Hellige, 1993; Springer & Deutsch, 1997). Investigating the effects of handedness on hemispheric metacontrol may lead to confirm the validity for the model of hemispheric metacontrol. The aim of the present experiment was to examine possible effects of handedness on hemispheric metacontrol.

We gave the right- and familial left-handers a mental addition task, which required the subjects to recognize two digits presented tachistoscopically, and to orally report the sum of the two numbers. Compared to the previous studies described above our review, this mental addition task involved a deeper level of processing. In the central presentation condition (CVF), two digits were arranged one above the other in the center of the screen. The CVF corresponded to the redundant both visual-field conditions (BVF) because identical information was projected to both hemispheres. In the unilateral presentation condition, two digits were displayed one above the other in a left (LVF) and right visual-field (RVF).

As mentioned before, a significant interaction between unilateral visual-fields and the independent variables has to be obtained in order to apply the paradigm of hemispheric metacontrol to the data. Therefore we set up the three conditions as in stimulus-type presentations; two digits in Arabic numerals (Arabic condition), two in Kanji numerals (Kanji condition) and one in Arabic and the other in Kanji (Mixed condition). The Mixed condition seemed to require a much deeper level of processing compared to the Kanji and the Arabic conditions. A number of the previous research has clarified the effect of levels of processing on hemispheric asymmetry (e.g., Bryden & Allard, 1976; Cohen, 1983; Hatta, 1983; Moscovitch, 1979, 1986). In addition, a number of research have reported that a right hemisphere more involved in recognizing Kanji characters (e.g., Endo, Shimizu, & Nakamura, 1981; Hatta, 1977, 1978 ; Hatta, Katoh, & Aitani, 1983; Sasanuma, Itoh, Mori, & Kobayashi, 1977), compared to that for recognizing other scripts (e.g., alphabets, Arabic numerals and Kanas). From these findings, an interaction between the unilateral visual-fields and the stimulus-types would be significant.

2. Experiment

2.1 Method

2.1.1 Subjects

Twenty-two (10 women and 12 men: age 18 - 22) right-handed and fourteen (11 female and 3 male: age 18-22) left-handed university students who all were native speakers of Japanese participated. H. N. Handedness Inventory (Hatta & Nakatsuka, 1975) assessed their handedness, and their vision was either normal or corrected by contact lenses or glasses. All of the 14 left-handed subjects had at least one left-handed first-degree relative.

2.1.2 Stimulus

The numerals ranging from 1 to 9 were presented in Arabic and Kanji. An asterisk was used as a masking stimulus. Two numerals were presented in each trial, centrally to a CVF, unilaterally to a LVF, or unilaterally to a RVF. Ten pairs of digits were prepared. The magnitude of difference between the two digits in all pairs was more than two. Each numeral obtained a visual angle of .85° x .57°.

There were three conditions for the pairing of stimulus types. In the Arabic and Kanji conditions, two digits were presented in Arabic or Kanji numerals respectively. In the Mixed condition, one was presented in Arabic numerals and the other in Kanji numerals. Samples are shown in Figure 1.

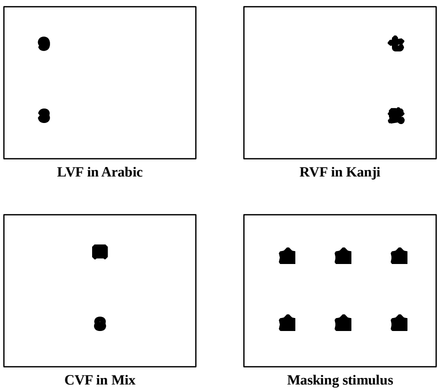

Figure 1: Samples of stimulus materials in the present experiment

2.1.3 Apparatus

The stimuli were presented with a tachistoscopic visual presentation system (IS-701: Iwatsu-Isell co.) controlled by a personal computer.

2.1.4 Procedure

Subjects were tested individually and were instructed to gaze at the central fixation point in the center of the monitor screen during the task. Their eyes were located 100 cm from a monitor screen. Following a 1.5-sec. central fixation, two numerals were presented for 120 msec in the left, right, or central visual-fields. Then the masking stimuli were presented for 80 msec. The inter trial interval was 3.5 sec. In a LVF and RVF, the stimuli were located within 3.81° and 4.37° to the left and the right of the central fixation point, and within 1.50° and 2.35° above and 1.50ß and 2.35° below the level of the fixation point. In the central visual-field condition the stimuli were located centrally within 1.50° and 2.35° above and 1.50° and 2.35° below the level of the fixation point. The subjects were required to add the two numbers and to respond orally. They were also informed that the numbers were not equal. There were 60 trials in the Arabic stimuli (20 for the left visual-field condition, 20 for the right visual-field condition, and 20 for the central visual-field condition), 60 in the Kanji stimuli, and 60 in the Mixed stimuli. Following 18 practice trials, 180 trials were carried out. The presentation order of the three visual-field conditions and the three stimulus-type conditions (Arabic, Kanji, and Mixed stimuli) was randomized.

3. Results

3.1 The analysis of handedness by stimulus-types by visual-fields.

The mean correct numbers of responses in the Arabic, Kanji, and Mixed stimuli for the right-handed and left-handed groups are shown in Figure 2, and in Figure 3, respectively.

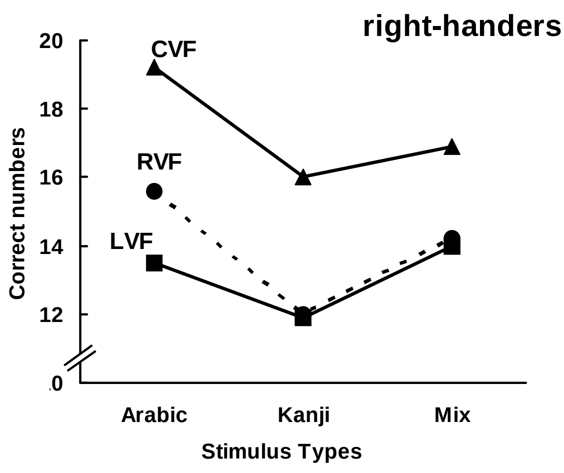

Figure 2: Mean numbers of correct responses to Arabic, Kanji, Mixed stimuli in each visual-field by right-handers

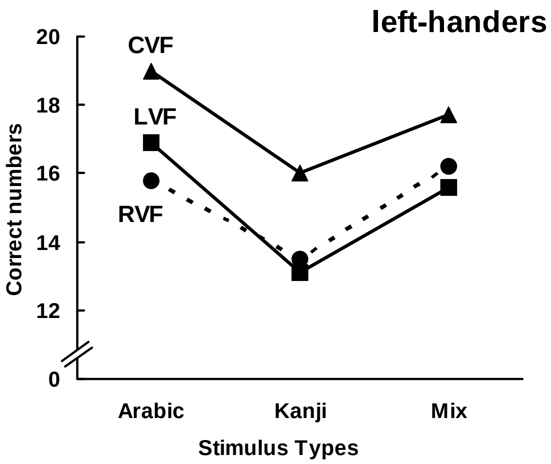

Figure 3: Mean numbers of correct responses to Arabic, Kanji, Mixed stimuli in each visual-field by left-handers

The analysis of variance (2 groups X 3 stimulus types X 3 visual-fields) showed that both main effects of stimulus types and visual-fields were significant ($F_{2, 68}$=30.94, p<.005; $F_{2, 68}$=78.45, p<.005). Interactions between stimulus types and visual-field conditions, and between groups and visual-fields were significant ($F_{4, 136}$=2.88, p<.05; $F_{2, 68}$=3.58, p<.05). The second-order interaction was also significant ($F_{4, 156}$=4.58, p<.01). Therefore further analyses were carried out for each group.

In the right-handed group, a simple interaction was found ($F_{4, 136}$=18.67, p<.005). *Post hoc HSD* tests (p <.05) indicated that (1) for the Arabic stimuli, the performance in a RVF was better than that in a LVF, and the performance in a CVF was better than that in a LVF and RVF, and (2) for the Kanji and Mixed stimuli, no difference between performance in a LVF and RVF was found, and the performance in a CVF was better than those in a LVF and RVF. In terms of perceptual asymmetry, these findings suggested that the lateral difference depended on the stimulus-type; while a RVF advantage was obtained in the Arabic condition, there was no difference between the unilateral visual-fields in the conditions including Kanji stimuli.

In the left-handed group, a simple interaction was also significant ($F_{4, 136}$=3.06, p<.05). *Post hoc HSD* tests (p<.05) indicated that (1) for the Arabic, Kanji, and Mixed stimuli there was no difference between the performance in a LVF and a RVF, (2) for the Arabic and Mixed stimuli, the performance in a CVF was better than those in a LVF and a RVF, and (3) for the Mixed stimuli, the performance in a CVF was better than that in a LVF, but not in a RVF. These results indicated that no difference between the unilateral visual-fields was obtained irrespective of the stimulus-types.

3.2 The analysis of hemispheric metacontrol (see Figure 2 & 3)

The main purpose of the present study was to manifest hemispheric metacontrol of a higher cognitive task, i.e. mental addition. Following Hellige's paradigm (1987), whereby interaction between unilateral visual-fields and some manipulated variables existed, the performance pattern in a CVF was compared with that in a LVF and RVF. If there is an interaction between left/central visual-field conditions and the stimulus-types, and if an interaction between right/central visual-field conditions and the stimulus-types does not exist, i.e., the performance pattern in a CVF is similar to that in a RVF, it is inferred that the left hemisphere exerts metacontrol over the task.

At first, an overall analysis of variance for stimulus-types (the Arabic, Kanji, and Mixed stimuli) and unilateral visual-fields (LVF / RVF) was performed with the right-handed group. A significant interaction was found ($F_{2, 42}$=9.40, p<.01). This was followed by a comparison of patterns of responses in the central visual-field condition to those in the left and right visual-field conditions, respectively. Analyses of variance for stimulus-types and visual-fields (left/central visual-fields or right/central visual-fields) showed that while the interaction for stimulus types and left/central visual-fields was significant ($F_{2, 42}$=5.24, p<.01), no interaction for stimulus types and right/central visual-fields was found ($F_{2, 42}$=3.09). These results suggest that the pattern of responses to stimuli in the central visual-field condition is similar to that in the right visual-field condition and that the left hemisphere exerts control over the mental addition task.

As did for the right-handed group, we examined hemispheric metacontrol for the left-handed group. An analysis of variance for stimulus types and unilateral visual-fields showed no significant interaction ($F_{2, 26}$=3.01, p= .067). Although this interaction did not reach a significant level, it was demonstrated by the analysis based on the reversed association logic that the processing mechanism for Kanji was dissociated from that for Arabic, so that the performance pattern in a CVF was compared to that in a LVF and RVF, respectively, to compare the pattern of hemispheric metacontrol in the left-handed group with that in the right-handed group. Analyses of variance for stimulus types and visual-fields (left/central visual-fields or right/central visual-fields) showed that while the interaction for stimulus types and left/central visual-fields was not significant ($F_{2, 26}$=1.56), an interaction of stimulus types and right/central visual-fields was found ($F_{2, 26}$=3.49, p<.05). These results seem to suggest that the performance pattern in the central visual-field condition was similar to that in the left visual-field condition and that the right hemisphere exerted control over the mental addition task.

4. Discussion

4.1 The lateral difference between the left and right-handers

The right-handed group showed a RVF for the Arabic stimuli but not for the Kanji and Mixed stimuli. This finding corresponds to the research which employed Kanji as the stimuli (e.g., Hatta, 1977, 1978; Sasanuma, Itoh, Mori, & Kobayashi, 1977). Hatta (1977) measured a visual-field difference for Kanji recognition in right-handers and found a left visual-field advantage. On the other hand, the left-handed group showed no differences in responses for the left and right visual-field conditions for Arabic, Kanji and

Mixed stimuli. This inconsistent pattern for laterality between the right- and left-handers was also congruent with the previous findings (Hardyck & Petrinovich, 1977; Hellige, 1993). This different laterality pattern between the two groups might be explained by the comparison of the right-handers and familial left-handers who have first-degree left-handed relatives. For example, Schmuller and Goodman (1979) examined differences in responses for a LVF and a RVF for word recognition among right-handers, familial left-handers and nonfamilial left-handers. They showed that the laterality pattern for word recognition in the right-handers was similar to that in the non familial left-handers but not to that in familial left-handers.

This different pattern of laterality for the mental addition task might be caused by a different processing mechanism for the Kanji and the Arabic stimuli. To clarify the processing dissociation, a reversed association logic proposed by Dunn and Kirsner (1988) was applied. Applying this logic necessitates an independent variable of at least three levels. As the present study used three presentation conditions, a reversed association logic can be applied to the present study to examine processing dissociation of the mental addition task between Kanji and Arabic conditions. Following Dunn and Kirsner (1988), the number of the correct responses to Kanji condition was plotted as a function of that to Arabic condition in right- and left-handers (Figure 4, and 5, respectively). If a single processing mechanism was used for both the Kanji and Arabic stimuli, the data must be plotted monotonically. As seen in Figure 4 and 5, the present data patterns deviates from a monotonic pattern. That is, a reversed association seems to exist in both right- and left-handers, although the different laterality pattern was not obtained in the left-handed group.

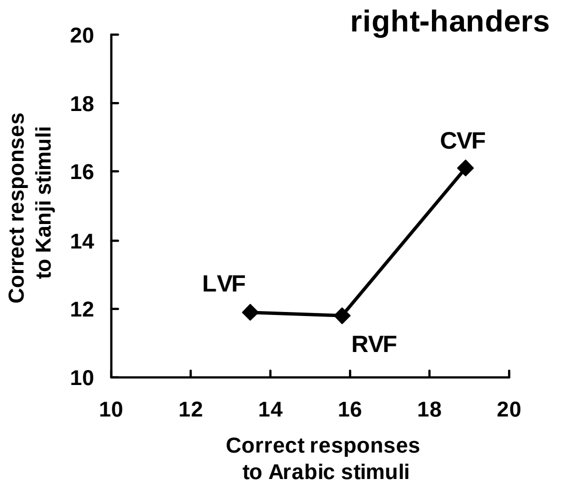

Figure 4: Numbers of correct responses to the Kanji stimuli plotted as a function of those to the Arabic stimuli by right-handers (n=22)

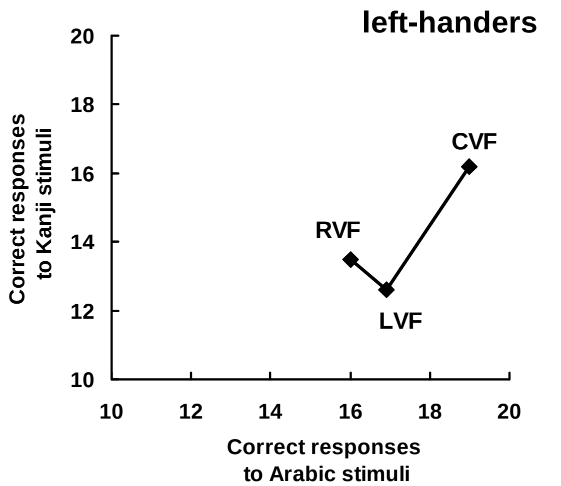

Figure 5: Numbers of correct responses for the Kanji stimuli plotted as a function of those for the Arabic stimuli by left-handers (n=14)

4.2 Hemispheric metacontrol in the mental addition task

Even in the higher cognitive task, mental addition, a hemispheric metacontrol seemed to appear for the right handers; the left hemisphere seemed to exert metacontrol in that task. As described before, a hemispheric metacontrol has been shown in the shallow level processing. For example, Hellige, et al. (1988) investigated a hemispheric metacontrol using nonverbal materials as stimuli. They asked right handed subjects to compare a drawing of a face presented in the center of a screen with a second face briefly presented in a LVF, RVF, and BVF. They focused upon reaction times of correct responses in 'different' trials as a function of a location of feature difference (hair, eyes, mouth, jaw), and examined interactions between locations of features (hair, eyes, mouth, jaw) and visual-fields (right/both visual-fields: left/both visual-fields). The results indicated that the performance pattern in a BVF was identical to that in a RVF, but not that in a LVF. This suggests a left hemisphere metacontrol in the face-matching task. Furthermore, Hellige and Michimata (1989b) required right-handed subjects to judge a spatial relation to a category, such as "above" or "below" and to judge a metric distance, such as "near" or "far." Their results showed a RVF advantage for categorical processing, and a LVF advantage for distance processing. The performance pattern in a BVF was also similar to that in a RVF. These results suggested a left hemispheric metacontrol for processing spatial information. Hellige and his colleagues indicated a hemispheric metacontrol largely over the recognition task, e.g., matching, identifying. The present results show, on the contrary, that in a higher cognitive task a mechanism for hemispheric metacontrol functions.

4.3 The difference in hemispheric metacontrol between the handedness groups

The main finding of our experiment is to show the possibility that which hemisphere controls over the mental addition task may depend on handedness. While in right-handers the left hemisphere seemed to exert control over the mental addition task, in familial left-handers the right hemisphere seemed to exert control. This finding suggested that the dominant hemisphere for the mental addition could exert control over a mental addition task. That is, while in right-handers a RVF advantage was clearly shown for the Arabic stimuli (LVF 13.5 vs. RVF 15.8), there was a slight, although not statistically significant, LVF advantage for the Arabic stimuli (16.9 vs. 16.0).

The laterality study based on the idea where two hemispheres would be a unity and constitute one functional system has just started. Further research concerning a hemispheric metacontrol should be needed, because hemispheric metacontrol would be one of dimensions where the individual difference in terms of handedness is well described.

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（Received October 9, 2003; revision accepted November 22, 2003）