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Manipulo-Spatial Processing of Ideographic Characters in Left-handers: Observation in fMRI

Kayako MATSUO^{1,2*}, Chikako KATO^{2,3}, Fukujiro OZAWA⁴, Yasuo TAKEHARA⁴,
Haruo ISODA⁴, Satoshi ISOGAI⁴, Tetsuo MORIYA¹, Harumi SAKAHARA⁴,
Tomohisa OKADA⁵, and Toshiharu NAKAI^{1,2}

¹*Medical Vision Laboratory, Life Electronics Research Center, AIST
1-8-31 Midorigaoka, Ikeda, Osaka 563-8577, Japan*

²*Institute of Biomedical Research and Innovation, Kobe, Japan*

³*Department of Management and Information Sciences, Toyohashi Sozo College, Toyohashi, Japan*

⁴*Department of Radiology, Hamamatsu University School of Medicine, Hamamatsu, Japan*

⁵*Department of Cerebral Research, National Institute for Physiological Sciences, Okazaki, Japan*

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It has been suggested that left-handers have a cerebral ambilaterality for language representation. Specifically, the use of the right hand for writing may have a specific effect on the cerebral organization in left-handers. In an investigation of the relationship between motor and visual language procedures, functional magnetic resonance imaging at three tesla was conducted during stroke counting of kanji (Japanese ideographic characters) in six left-handers who usually write with their right hand. Two types of stimulus presentation, phonography-displayed and kanji-displayed, were employed to examine the different neural pathways used for processing kanji. Each stimulus presentation involved two motor conditions: one allowed finger movements for tracing the characters, while the other disallowed finger movements. The tasks induced activation in the primary motor area, the premotor area, the supplementary motor area, and the anterior cingulate gyrus as well as the parietal and occipital lobes (Brodmann's area 7/39/19). The activated areas in both the movement-allowed and movement-disallowed conditions were almost identical except for the primary motor area. These results clearly contrasted with those of a previous study of right-handers which showed that right-handed volunteers demonstrated decreased activation in the premotor area and the dorsal pathway during the movement-allowed condition. This discrepancy may be attributable to a difference in cerebral organization for language processing. Specifically, in left-handers, the visuospatial procedure for kanji and the motor procedure for tracing the kanji may be ambilaterally distributed in both hemispheres, whereas in right-handers these procedures may be predominantly lateralized in the left hemisphere.

Keywords: *fMRI, left handedness, kanji, counting strokes, language*

Introduction

It has been suggested that left-handed people are less lateralized in their brain function.¹⁻³ The following report on a case of aphasia suggested such an ambilateral brain organization for language function in left-handers. A 69-year-old left-handed Japanese man, who could not speak because of se-

vere Broca aphasia after a right cerebral infarction, communicated by writing kanji (Japanese ideographic characters) but showed jargon agraphia for kana (Japanese syllabic characters).⁴ He wrote with his right hand before and after the infarction. This case demonstrated the dissociation between spoken and written language representations, as well as the dissociation between kanji and kana.⁵⁻⁷ In Japan, left-handers are often strictly trained to use their right hand specifically for writing and using chopsticks.⁸ The authors suggested that the

*Corresponding author, Phone: +81-727-51-8424, Fax: +81-727-51-8387, E-mail: kayako.matsuo@aist.go.jp

training of left-handers to write with their right hand might cause dissociation between the representation for speech in the right hemisphere and the representation for writing ideographic characters in the left hemisphere.⁴

Functional magnetic resonance imaging (fMRI) was conducted to investigate left-handers who write with their right hand during manipulo-spatial language tasks. Counting the strokes of kanji was employed because this task is preferable for examining a possible relationship between the visuospatial recognition process of the ideographic character images and the motor function used for tracing the characters. Conversion from kana to kanji was also considered because this process might also call for motor function.⁷ In our previous fMRI study of right-handers, activation in the higher motor areas such as the premotor area (PMA) and the parieto-occipital areas that may be related to visuospatial processing of characters was augmented when finger movements were disallowed during stroke counting.⁹ These findings suggested that the execution of finger movements could reduce neural activation in the visual processing of character recognition. The purpose of this study was to investigate whether left-handers who write with their right hand demonstrate the same decrease in neural activation of the PMA and parieto-occipital areas as right-handers when finger movements were allowed.

Materials and Methods

Subjects: Six native Japanese-speaking volunteers (all males, age 21–40) who gave written informed consent participated in this experiment. Handedness was assessed with the Hatta-Nakatsuka Handedness Inventory for Japanese people.⁸ This inventory contains ten questions about the preference for each hand in daily life. Subjects are judged to be fully right-handed if they score +10 and fully left-handed if they score –10. Subjects are judged to be ambidextrous if they score between –3 and +7. The handedness scores of the volunteers in this study ranged from –8 and –6 (left-handed) to –3, +5, +6 and +7 (ambidextrous). All volunteers reported that they usually write with their right hand.

Stimuli and Procedure: Sixty-eight kanji were selected from the Japanese elementary school education list. The stimuli were projected on a transparent screen in white against a black background. Subjects looked at the visual stimulus reflected in a mirror attached to an MRI head coil. The visual acuity of myopic subjects was adjusted with plastic

Fig. 1. The paradigm schema for the study. The white character in the left column at KM+ and KM– means “morning.” The two characters in the same column at PM+ and PM– represent the pronunciation of the character “morning,” pronounced [a-sa]. KM+: The kanji was projected on a screen for one second and the subjects counted the strokes by moving their index fingers to trace the character. KM–: Same as KM+ but with movements disallowed. PM+: The pronunciation of kanji written in syllabic characters (hiragana script) was projected and the subjects recalled the corresponding kanji and counted its strokes by moving their index fingers. PM–: Same as PM+ but with movements disallowed.

lenses.

Paradigm: The following four tasks were employed in the separate fMRI series.

Kanji-displayed-Movement-allowed task (KM+): A kanji character was presented for one second and the volunteers counted its strokes by moving their right forefingers to trace the character within the following six seconds.

Kanji-displayed-Movement-disallowed task (KM–): The same as KM+ but subjects counted the strokes without finger movements.

Phonography-displayed-Movement-allowed task (PM+): The most common pronunciation of a kanji was projected in Japanese syllabic characters (hiragana script) and volunteers counted the strokes of the recalled kanji corresponding to the pronunciation by moving their right forefingers.

Phonography-displayed-Movement-disallowed task (PM–): The same as PM+ but movements are disallowed.

The paradigm schema is illustrated in Fig. 1. Four task-rest cycles (30 seconds task, 30 seconds rest) were performed after a 30 second rest block for each condition. The volunteers counted the strokes of four ideographic characters in each task

block and watched a fixed point during each rest block.

Data Acquisition: All studies were performed on a three tesla MR scanner (GE 3T Signa ver. 5.4, General Electric, Milwaukee, WI) equipped with a standard birdcage head coil. A gradient-recalled echo multi-shot spiral sequence¹⁰ was used for the functional studies. The parameters were TR 1500 ms, four shots to acquire one image, TE 30 ms, FA 50, FOV 240 mm, in-plane resolution of 3.33 mm (72 × 72 effective matrix size, reconstructed as a 128 × 128 image) and slice thickness 5 mm interleaved. A total of 20 axial slices were obtained. Each time series consisted of 45 frames in total (270 seconds).

Data Analysis: The fMRI images were reconstructed off-line on a Sun workstation and analyzed with a statistical parametric mapping technique, implemented in SPM99 (Wellcome Department of Cognitive Neurology, London College University, <http://www.fil.ion.bpmf.ac.uk/spm>). The first five frames of each time series were discarded to remove the initial signal instability. The data sets were realigned to the first volume with sinc interpolation to remove image drift. The data were then spatially normalized to a standard MNI brain template and smoothed with an 8 mm full-width at half-maximum (FWHM) isotropic Gaussian kernel. The MNI coordinates were later transformed into Talairach's coordinates¹¹ with a non-linear algorithm (<http://www.mrc-cbu.cam.ac.uk/Imaging/mnispac.html>). A fixed-effect model was applied to the smoothed data to statistically infer an effect as a typical characteristic of the employed population.¹² Condition-specific effects as compared with rest blocks for all subjects ($n=6$) were assessed statistically with the height threshold corrected to a p value of 0.05 for multiple comparisons. Comparisons between the movement-allowed and the movement-disallowed conditions (KM+ vs. KM−, PM+ vs. PM−) were also performed (corrected to a p value of 0.05 for multiple comparisons).

Results

Activation maps are summarized in Fig. 2. The movement-allowed conditions (KM+ and PM+) induced activation centered at the left primary motor area (M1). The other activated areas were almost identical among the four conditions: the bilateral dorsal and lateral premotor areas (PMA, Brodmann area [BA] 6); the bilateral middle frontal gyri (MFG, BA 46/9/10); the bilateral supplementary motor areas (SMA, BA 6); the bilateral

anterior cingulate gyri; the left anterior parts of the intraparietal sulcus (IPS, BA 7/40); the bilateral posterior part of IPS (BA 7/39/19); and the bilateral inferior frontal gyri (BA 44/47). Coordinates of the activation peaks are summarized in Table.

Comparisons of KM+ versus KM− (KM+ > KM−) as well as PM+ versus PM− (PM+ > PM−) yielded a differential activation centered at M1 (Fig. 2 e and f). On the other hand, KM− versus KM+ (KM− > KM+) and PM− versus PM+ (PM− > PM+) demonstrated no differences.

Discussion

To our knowledge, this investigation is the first to examine brain activation during manipulo-spatial language tasks in left-handed people who write with their right hand. The results suggested definite distinctions between left-handers and right-handers. In contrast to the results for right-handers,⁹ the four conditions demonstrated very similar activation patterns, except for the M1 activation during the movement-allowed conditions (KM+ and PM+, Fig. 2 a and c). Also, the difference in stimuli presentation (phonography or kanji) had no effect in our left-handed volunteers. These results were of interest because, when finger movements were disallowed during stroke counting, right-handers obviously showed increased activation in PMA in the phonography-displayed condition and in the parieto-occipital areas in the kanji-displayed condition.

Although counting of strokes is a language task, it is also a visuospatial task as well as a motor task when accompanied with finger movements. The performance of stroke-counting requires a visuospatial procedure for creating an image of the ideographic character and a motor control procedure for tracing the character. For right-handers, both of these procedures may be performed predominantly in the left hemisphere because that hemisphere is dominant for language functions in most of them, as shown by a functional transcranial Doppler ultrasonography study.¹³ The right hemisphere, however, is also involved in some language tasks specifically for the visuospatial procedure. For example, mirror reading of words comprising Japanese syllabic characters employed the right superior parietal lobule.¹⁴ The counting of strokes may also involve the right hemisphere because it requires control of the manual movements required to trace a spatial configuration of characters, and the right hemisphere is superior in manipulo-spatial processing, as shown by a split-

Fig. 2. Activation maps of six subjects generated by fixed-effect models (for multiple comparisons, the p value is corrected to 0.05). Arrows indicate activation of primary motor area (M1) in the left hemisphere during the movement-allowed conditions. KM + : Kanji-displayed-Movement-allowed task. KM - : Kanji-displayed-Movement-disallowed task. PM + : Phonography-displayed-Movement-allowed task. PM - : Phonography-displayed-Movement-disallowed task.

brain case study.¹⁵

On the other hand, strong left-handers demonstrated an incidence of right-hemisphere language dominance (27%) nearly seven times that of strong

right-handers (4%).¹³ Left-handers often demonstrate a cerebral ambilaterality for language processing.¹⁻³ The ambilaterality in left-handers was also suggested in visuospatial processing by the

Table. Activation peaks of clusters (corrected to a p value of 0.05 for multiple comparisons)

location	Talairach's coordinates (x, y, z)			
	KM +	KM –	PM +	PM –
lt M1 (BA 4)	– 40, – 22, 64	—	– 40, – 22, 64	—
lt dorsal PMA (BA 6)	—	– 42, – 1, 52	—	—
lt lateral PMA (BA 6)	—	– 57, 6, 35	—	– 57, 4, 37
rt lateral PMA (BA 6)	—	—	55, 2, 35	55, 6, 33
lt MFG (BA 46/9/10)	– 38, 57, 19	– 40, 55, 19	– 36, 59, 17	– 40, 50, 25
rt MFG (BA 46/9/10)	42, 50, 25	40, 50, 27	46, 50, 20	40, 50, 27
lt SMA (BA 6)	—	– 4, 5, 51	—	– 4, 6, 51
rt ant. IPS (BA 7/40)	38, – 48, 41	—	44, – 35, 35	—
lt post. IPS (BA 7/39/19)	—	– 32, – 67, 49	—	– 32, – 67, 53
rt post. IPS (BA 7/39/19)	24, – 75, 48	26, – 73, 48	36, – 68, 46	20, – 73, 53
lt IFG (BA 44/47)	– 40, 16, 5	– 46, 15, – 6	– 34, 27, 0	– 55, 23, – 6
rt IFG (BA 44/47)	44, 14, 1	44, 16, – 1	44, 12, – 2	50, 17, – 9

Notes. KM + : Kanji-displayed-Movement-allowed task. KM – : Kanji-displayed-Movement-disallowed task. PM + : Phonography-displayed-Movement-allowed task. PM – : Phonography-displayed-Movement-disallowed task. lt: left. rt: right. BA: Brodmann area. M1: primary motor area. PMA: premotor area. MFG: middle frontal gyrus. SMA: supplementary motor area. ant.: anterior. post.: posterior. IPS: intraparietal sulcus. IFG: inferior frontal gyrus

dorsal route.² A mirror-writing study with Chinese characters suggested that normal writing of characters engaged the left hemisphere in both left-handers and right-handers, whereas mirror writing engaged the right hemisphere in right-handers and both hemispheres in left-handers.¹⁶ This may be evidence of the ambilaterality of left-handers for visuospatial processing of characters in mirror writing. The subjects of this study might also demonstrate ambilaterality for stroke-counting tasks because, in the movement-allowed conditions (KM + and PM +), they showed activation in the bilateral parieto-occipital areas (Fig. 2 a and c), whereas the right-handers showed little activation in the right but extensive activation in the left parieto-occipital areas.⁹

For left-handers, the execution of movements seemed to affect only M1, and the movements had no explicit relationship to any other areas (Fig. 2). However, for right-handers,⁹ the same movement-allowed conditions decreased the activation in PMA and the parieto-occipital areas, which suggests that the finger movements compensated for the neural demands in tracking the segment of each stroke included in a character. For example, the Japanese often spontaneously use finger movements to count strokes when they are looking up kanji in a dictionary. These observations may indicate that the motor procedure interacts with the visuospatial procedure for ideographic characters in the brain. Thus, the lack of the movements' explicit effects on the parieto-occipital areas in this

study may indicate a lower interactive communication between the motor procedure and the visuospatial procedures in left-handers.

Although a definitive conclusion cannot be derived from only this and previous studies, the following hypothesis can be drawn. For right-handers, both a motor control procedure and a visuospatial procedure may be performed predominantly in the same left hemisphere. Thus, the interactive communication between these two procedures may be more likely to take place if they are performed in the same hemisphere. The right parieto-occipital areas may also be recruited to work on additional visuospatial procedures. In contrast, left-handers employed the bilateral hemispheres regardless of whether movements were allowed or disallowed (Fig. 2). This suggests that left-handers differ from right-handers in the relationship between their motor and visuospatial language procedures as well as in their hemispheric lateralization.

Conclusion

The results of our study suggest that processing of the written language by left-handers who write with their right hand was different from that of right-handers specifically with regard to the relationship between the motor and visuospatial language procedures of the brain. This difference may be a consequence of the ambilaterality of left-handed people when performing a manipulo-spatial aspect of language processing. The separa-

tion and relationship among multiple language procedures should be further investigated through comparisons of left-handers and right-handers.

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