Similar brain activation patterns for writing logographic and phonetic symbols in Chinese

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This event-related functional MRI study examined the neural correlates for Chinese writing, by comparing the writing of logographic characters and that of pinyin, a phonetic notation system for Chinese characters. The temporal profile of the activations indicated that the middle frontal gyrus, superior parietal lobule, and posterior inferior temporal gyrus reflected more central processes for writing. Although pinyin writing elicited greater activity overall than character writing, the critical finding is that the two types of symbols recruited essentially the same brain regions. The results were compared with studies in Japanese showing dissociation between logographic kanji and phonetic kana writing and frequency of use was suggested to be an important factor in accounting for result differences across the two writing systems. *NeuroReport* 18:1621–1625 © 2007 Wolters Kluwer Health | Lippincott Williams & Wilkins.

Keywords: Chinese character, functional MRI, kana, kanji, pinyin, writing

Introduction

Classical neuropsychological studies on pure dysgraphia have identified left superior parietal lobule and left middle frontal gyrus as brain regions critical for writing, or the so called 'writing centers' [1]. Modern brain imaging research with healthy participants generally corroborate these observations [2,3], but have also found other brain regions involved in writing, such as motor area [4], angular gyrus [5], and inferior temporal gyrus [6].

Analogous to reading studies [7,8], an important question can be asked for writing from a cross-language perspective, which is, whether the brain mechanisms for writing differ in different writing systems. Taking advantage of a unique feature in Japanese where a logographic kanji and an alphabetical phonetic kana system coexist, some research found a brain structure dissociation where left posterior inferior temporal gyrus (PITG) [9] was responsible for kanji writing but angular gyrus [10] for kana writing. Tokunaga and others [5] suggested that one possible role of the left PITG was to retrieve kanji forms. If so, one would predict that this area should also be involved in writing Chinese characters that are identical to kanji in visual form.

The present study tested this prediction with functional MRI. Following the positron emission tomography study [5], we used a dictation for mental writing task. With functional MRI, we were able to adopt an event-related design to better interpret brain activations on the basis of their temporal profile. Participants would first hear a two-character target word. After a short delay, they would hear a verbal instruction cue, 'write character', upon which they would start the mental writing.

In addition to these character writing trials, there was also a comparison condition with pinyin writing trials. A pinyin writing trial was identical to a character writing trial except that the verbal cue was 'write pinyin' to instruct participants to start writing out the pinyin form of the target word. Pinyin is a system to notate the sound of Chinese characters using the English alphabet. For example, the pinyin form for the Chinese character '房' (meaning house) is fang. The pinyin system is extremely familiar to all educated Chinese who all used it in learning to read. One reasonable assumption is that pinyin writing of a sequence of alphabetical phonetic symbols should be similar to kana writing in Japanese. On the basis of this assumed parallel relationship, we further examined whether a similar brain dissociation pattern was present between character writing and pinyin writing, as that between kanji and kana writing.

Materials and methods

Twelve right-handed, healthy college students (age range: 17–24 years, 6 men) participated in the study. All were native Chinese and none had any psychiatric or neurological disorders. Informed consent was obtained from all participants.

Imaging was performed on a 1.5 T Philips Power 6000 MRI scanner (Philips Company, Amsterdam, The Netherlands). Twenty axial slices covering the whole brain were acquired with a T2*-weighted gradient-echo echo planar imaging pulse sequence (TR=2000 ms, TE=45 ms, flip angle=90°) for the functional scans (matrix=64×64, FOV=230×230 mm, thickness/gap=5/1 mm). A 120-slice high-resolution sagittal structural image was also obtained for coregistration.

It was an event-related design with several events in each trial. Participants first heard a two-character target word presented for 1500 ms. They were told to hold the word in mind and be prepared for mentally writing it after a delay, variable from 4 to 10 s to better separate the BOLD signal for target word presentation and that for other events. At the end of the delay, an auditory instruction, either 'write character' or 'write pinyin', would cue participants to start writing. With no physical movement, they were to imagine writing with their right index finger on a piece of paper. They pressed a button once they finished writing. The time elapsed from the cue onset was taken as their writing time. The next trial started 14 s following the onset of the instruction cue in the present trial. Each participant completed four functional runs, each with 16 trials, half for character and half for pinyin, randomly intermixed. Each run was 356 s long, consisting of 178 three-dimensional volumes.

Sixty high-frequency two-character words were used. All participants were interviewed after test to confirm they knew how to write out character and pinyin forms for them. Pilot study was also conducted to control writing complexity so that the average writing time was comparable for the two types of symbols.

Preprocessing and data analysis were conducted following a standard procedure as in our earlier research with random effect analysis [11,12]. After removing linear trends, the echo planar images were motion-corrected, normalized to Talairach space [13], and smoothed (FWHM=6 mm). The imaging data from two participants were discarded due to serious head motion. A general linear model was used to fit the BOLD signal from each voxel with a stimulus function which specified the type and onset times of the three types of trial events, that is target word presentation, character writing cue, or pinyin writing cue. The analysis produced three F statistics (and three associated P values), one for each event type, indicating the extent to which this voxel was engaged in responding to that particular trial event. Using a threshold of $P<10^{-5}$ combined with a cluster size greater than 270 mm^3 (10 voxels) threshold, functional activation maps were generated, one for each of the three trial events.

For each voxel, the mean BOLD signal in response to each of the three types of events was calculated. Such signal was also called a voxel's impulse response functions (IRFs), showing the temporal dynamics of its response to a trial event. The length of these functions was set by convention to be 14 s (seven time points or TRs). The IRF for a specific brain region of interest (ROI) was obtained by averaging the IRFs from all voxels in that ROI.

Contrast between the two cueing events (character vs. pinyin writing) was conducted with a paired t-test (d.f.=9) across all participants by comparing participants' mean IRF signal intensity for the character writing event and that for

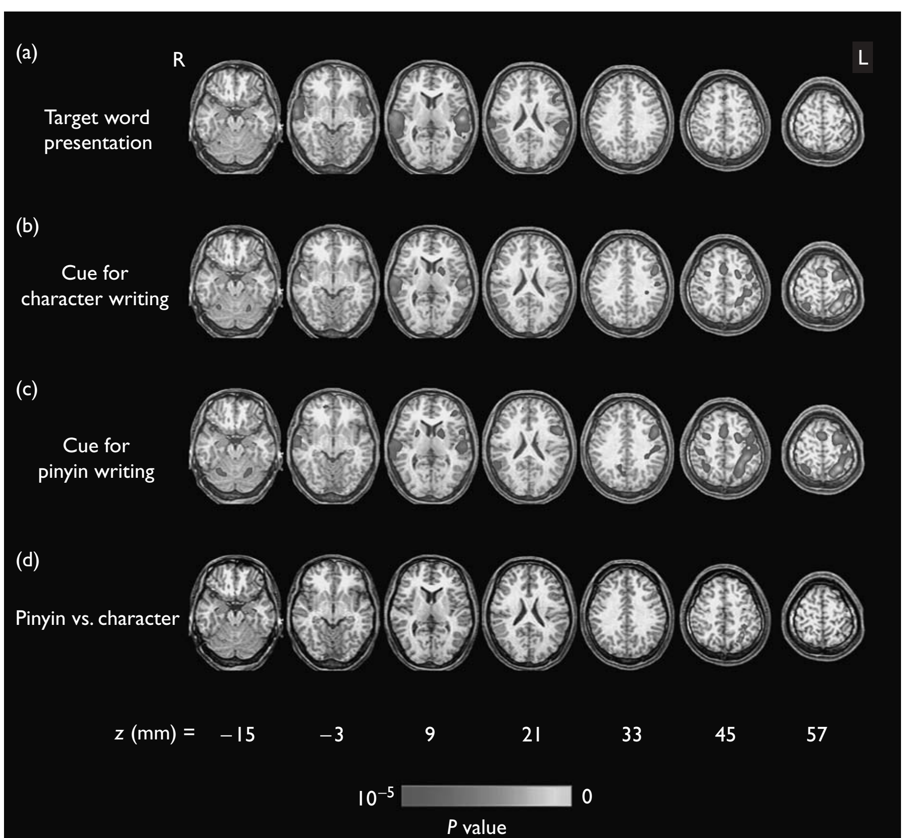

Fig. 1 Axial brain activation maps ($P<10^{-5}$, minimum 10 contiguous voxels) associated with presentation of (a) the target word, (b) the cue for character writing, and (c) the cue for pinyin writing. (d) Axial brain activation map ($P<0.05$, minimum 10 contiguous voxels) from the direct contrast between two trials events, the cue for character writing and the cue for pinyin writing.

the pinyin writing event. Using a $P<0.05$ threshold combined with a cluster size greater than $270\,mm^3$ (10 voxels) threshold, the activation map thus constructed showed brain regions with significantly greater activity for one cueing event relative to the other.

Results

Behavioral results

The mean writing time for the 12 participants was 8.05 ± 2.23 s for pinyin writing and 8.83 ± 2.19 s for character writing. Writing Chinese took significantly longer than writing pinyin ($P<0.05$).

Imaging results

The brain regions activated in response to the three types of trial events are shown in Fig. 1. For the target word presentation event, the regions include bilateral superior temporal gyri, left posterior middle frontal gyrus, left inferior prefrontal gyrus, left precentral and postcentral gyrus, and regions surrounding the anterior cingulate sulcus (Fig. 1a). The activated regions for the character cueing event overlapped with that for the pinyin cueing event, including bilateral superior temporal gyri, bilateral superior parietal lobule, bilateral premotor area, bilateral cerebellum, bilateral basal ganglia, and supplementary motor area (Fig. 1b and c).

Table 1 Summary information for regions of activation associated with different trial events, including target word presentation, cuing for character writing, and cuing for Pinyin writing, and for activations from the direct contrast between cuing for character writing and cuing for pinyin writing

Anatomic structure	L/R	Peak activation coordinates			F or *t* value for peak activation
Target word presentation					
Prefrontal gyrus	L	−44	41	9	12.1
Middle frontal gyrus	L	−41	17	27	16.2
Precentral gyrus	L	−32	−20	63	15.6
SMA	—	−2	20	42	15.3
Inferior parietal lobule	L	−53	−26	48	12.2
Superior temporal gyrus	L	−53	−17	9	45.9
	R	59	−11	3	51.3
Cueing for character writing					
Middle frontal gyrus BA 6	L	−20	−2	54	30.4
	R	29	−2	45	17.7
Middle frontal gyrus BA 9	L	−47	8	36	22.5
	R	59	11	33	19.0
Postcentral gyrus	R	41	−26	45	12.2
SMA	—	2	2	54	35.5
Superior parietal lobule	L	−26	−53	57	35.5
	R	29	−53	54	18.4
Superior temporal gyrus	L	−53	−17	9	26.4
	R	59	−11	3	36.1
Basal ganglion	L	−17	5	9	15.2
	R	23	2	9	11.5
Cerebellum	L	−23	−59	−19	14.3
Cueing for pinyin writing					
Middle frontal gyrus BA 6	L	−23	−2	54	38.2
	R	29	2	48	18.5
Middle frontal gyrus BA 10	L	−41	41	12	18.5
Inferior frontal gyrus BA 45	R	56	11	18	20.1
Postcentral gyrus	R	41	−26	48	17.1
SMA	—	5	5	51	37.0
Superior parietal lobule	L	−26	−53	54	43.8
	R	32	−53	51	27.9
Inferior temporal gyrus	L	−50	−59	−1	17.0
Superior temporal gyrus	L	−53	−17	6	21.9
	R	59	−11	3	36.7
Supermarginal gyrus	R	53	−50	21	14.9
Precuneus	R	14	−50	30	14.8
Basal ganglion	L	−17	5	9	15.7
	R	23	8	9	12.0
Cerebellum	L	−23	−59	−19	16.4
	R	26	−56	−16	19.0
Pinyin > character					
Middle frontal gyrus BA 9	L	−38	8	27	8.4
Inferior frontal gyrus BA 10/46	L	−35	35	15	4.0
Precentral gyrus	L	−44	−11	54	3.8
Superior parietal lobule	L	−29	−53	45	5.5
Inferior temporal gyrus	L	−44	−59	−1	4.1
Cerebellum	R	17	−62	−16	4.0
Character > pinyin					
None					

Note: Coordinates shown are for peak activation in the Talairach space. Voxel size is 3 × 3 × 3 mm.
SMA, supplementary motor area.

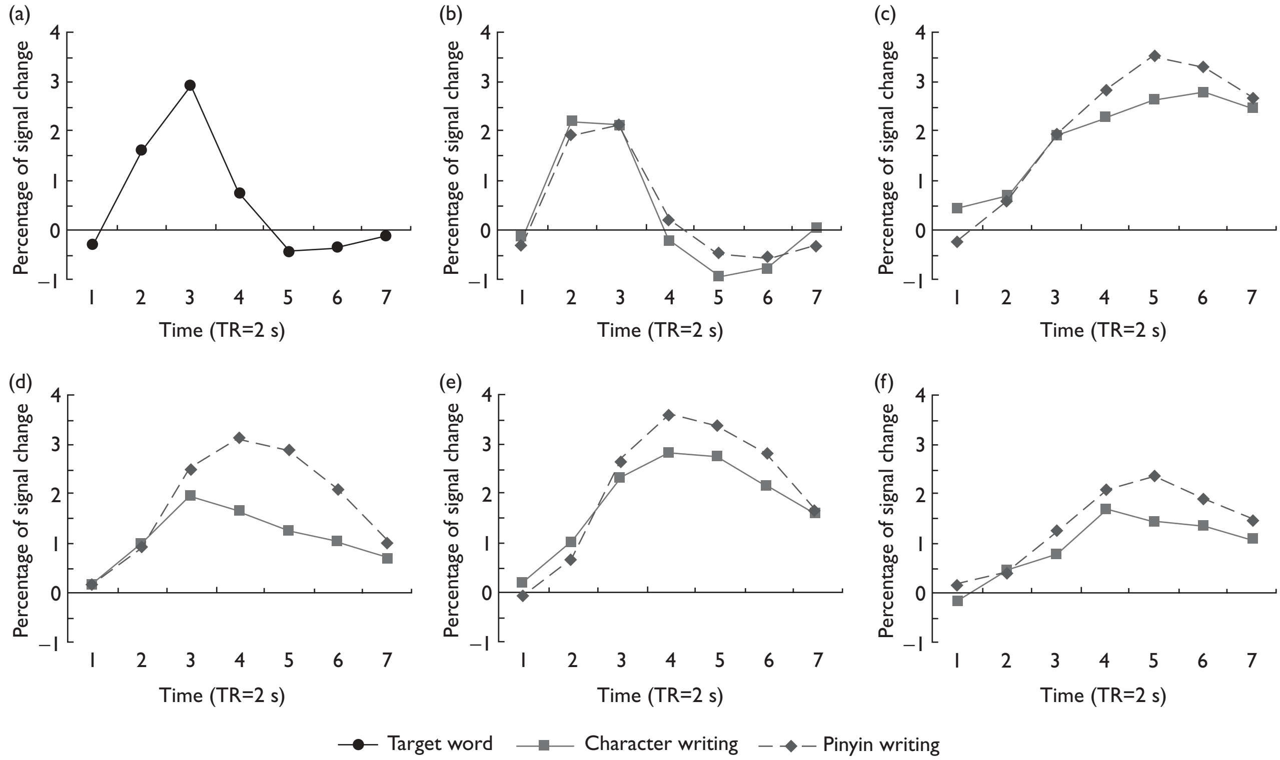

Fig. 2 The impulse response function (IRF) time course for some ROIs (regions-of-interest). (a) Left primary auditory area when listening to target words, (b) left primary auditory area, (c) left precentral gyrus, (d) left middle frontal gyrus, (e) left superior parietal lobule, and (f) left posterior inferior temporal cortex [(b–f): in Chinese character and pinyin writing].

Figure 1d shows results from the direct contrast between the character cueing and pinyin writing events. Six regions showing greater activity for pinyin writing than for character writing, including left middle frontal gyrus (BA 9), left superior parietal lobule, left posterior inferior temporal cortex, left prefrontal gyrus (BA 10/46), left precentral gyrus, and right cerebellum existed. No brain region was significantly more activated for character writing than for pinyin writing. Detailed information about these activations is listed in Table 1.

Related to the main interest of this study, IRFs were extracted (Fig. 2) from six ROIs to expose the temporal dynamics of the brain activation in these regions. The first ROI was the left superior temporal gyrus shown in Fig. 1a. The second ROI was the left superior temporal gyrus shown in Fig. 1b and c. The third ROI was the left primary motor cortex shown in Fig. 1b and c. The remaining three ROIs, the left middle frontal gyrus, the left superior parietal lobule, and the left PITG, were all taken from the activated regions identified in Fig. 1d, that is from the direct contrast between character writing and pinyin writing. Except for the first ROI where the IRF for the target word presentation event was plotted, the IRFs for the character writing and for pinyin writing were plotted separately for all the other ROIs.

Discussion

In light of the event-related design, the brain activations for the target word presentation event reflect transient processes associated with processing the target word. For example, the superior temporal gyrus (Fig. 2a) showed a temporal profile with early peaking and fast decay, consistent with its expected function in speech perception. This same area was also activated for the cueing events (Fig. 2b) with a similar temporal profile, presumably in response to the presentation of the auditory instruction cue. In comparison, activations in regions including premotor area, supplementary motor area, basal ganglia, and cerebellum were likely for preparation for and carryout of the mental movements [14,15]. Consequently, the BOLD signal in these regions, shown with the primary motor area as an example in Fig. 2c, demonstrated a sustained temporal response profile extending till participants finished mental writing around 8 s following the cue.

Other regions identified in the cueing for writing events were interpreted as reflecting more central processes for writing, such as retrieving the written form for character and pinyin and transforming it to sequences of spatial movement patterns [16]. These regions, including left posterior middle frontal gyrus, superior parietal lobule, and PITG, show a pattern that replicates the typical results in the imaging literature of writing [17,18]. Their temporal profiles, as shown in Fig 2d–f for left posterior middle frontal gyrus, superior parietal lobule, and PITG, being sustained but terminating earlier than that for the motor areas, were consistent with such an interpretation.

For left PITG, we found it was significantly activated for pinyin writing but not for character writing. Time course plot of the BOLD signal from this area (Fig. 2f) did show some response to character writing, albeit at a lower level, relative to that for pinyin. Still, this result was very different from what was found in Japanese where the PITG was strongly activated for kanji writing but not for kana writing. Our result, therefore, presents difficulty for the proposal that the left PITG is specific to the visual form of kanji or Chinese characters [5]. Further, we did not find any angular gyrus activation for either pinyin writing or for the pinyin vs. character writing comparison. Essentially, we were unable to find any dissociation between character and pinyin writing, parallel to that in Japanese between kanji and kana. Rather, character and pinyin writing seem to have recruited a highly similar set of brain regions. Note that pinyin showed an overall stronger activation – in all the three brain regions typically associated with writing, the middle frontal gyrus, the superior parietal lobule, and the PITG, pinyin writing elicited greater activity than character writing whereas no brain region showed the opposite effect. This pattern of difference cannot be explained with task difficulty as the writing time was slightly shorter for pinyin than for character writing (8.05 vs. 8.83 s).

It is possible that the assumption of parallel relationship we made in the introduction (between Chinese character vs. pinyin and kanji vs. kana) was incorrect. Indeed, even though pinyin was a highly accessible phonogram for Chinese characters, it was never used intermixed with Chinese character in reading or writing, different from the case of kana and kanji in Japanese.

We, however, tend to explain this different pattern with a frequency factor – writing less frequently used symbols elicits stronger brain activation. Indeed, while Chinese character is more frequently used than pinyin, the opposite is true for kanji for Japanese, relative to kana [19]. This may imply that different types of symbol writing activate a similar network of brain regions but to different extent, depending on their frequency of use, or that research to show distinct pathways for writing with different types of symbols, for example, logograph vs. phonogram, would make a more convincing case if frequency of use is controlled.

Conclusion

Examination of the time course of the activated regions in our mental writing task suggested that left posterior middle frontal gyrus, superior parietal lobule, and PITG were more central in the writing process. No evidence stating that distinct brain regions were involved for Chinese character and pinyin writing. Earlier research showing dissociation between writing of logographic and phonogram in Japanese may need further validation by controlling frequency of symbol use.

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References

1. Roeltgen DP. Agraphia. In: Heilman K, Valenstein E, editors. *Clinical Neuropsychology*. Oxford: Oxford University Press; 1988. pp. 116–130.
2. Harrington GS, Farias D, Davis CH, Buonocore MH. Comparison of the neural basis for imagined writing and drawing. *Hum Brain Mapp* 2007; **28**:450–459.
3. Sugihara G, Kaminaga T, Sugishita M. Interindividual uniformity and variety of the 'Writing center': a functional MRI study. *NeuroImage* 2006; **32**:1837–1849.
4. James KH, Gauthier I. Letter processing automatically recruits a sensory-motor brain network. *Neuropsychologia* 2006; **44**:2937–2949.
5. Tokunaga H, Nishikawa T, Ikejiri Y, Nakagawa Y, Yasuno F, Hashikawa K, *et al*. Different neural substrates for Kanji and Kana writing: a PET study. *Neuroreport* 1999; **10**:3315–3319.
6. Nakamura K, Dehaene S, Jobert A, Le Bihan D, Kouider S. Subliminal convergence of Kanji and Kana words: further evidence for functional parcellation of the posterior temporal cortex in visual word perception. *J Cogn Neurosci* 2005; **17**:954–968.
7. Chen Y, Fu S, Iversen SD, Smith SM, Matthews PM. Testing for dual brain processing routes in reading: a direct contrast of chinese character and pinyin reading using FMRI. *J Cogn Neurosci* 2002; **14**:1088–1098.
8. Fu S, Chen Y, Smith S, Iversen S, Matthews PM. Effects of word form on brain processing of written Chinese. *NeuroImage* 2002; **17**:1538–1548.
9. Soma Y, Sugishita M, Kitamura K, Maruyama S, Imanaga H. Lexical agraphia in the Japanese language: pure agraphia for Kanji due to left posteroinferior temporal lesions. *Brain* 1989; **112**:1549–1561.
10. Tanaka Y, Yamadori A, Murata S. Selective Kana agraphia: a case report. *Cortex* 1987; **23**:679–684.
11. Xiao ZW, Zhang JX, Wang XY, Wu RH, Hu XP, Weng XC, *et al*. Differential activity in left inferior frontal gyrus for pseudo and real words: an event-related fMRI study on auditory lexical decision. *Hum Brain Mapp* 2005; **25**:212–221.
12. Zang YF, Jin Z, Weng XC, Zhang L, Zeng YW, Yang LI, *et al*. Functional MRI in attention deficit hyperactivity disorder: evidence for hypofrontality. *Brain Dev* 2005; **27**:544–550.
13. Talairach J, Tournoux P. *Co-planar Stereotaxic Atlas of The Human Brain*. New York: Thieme Medical Publishers; 1988.
14. Kato C, Isoda H, Takehara Y, Matsuo K, Moriya T, Nakai T. Involvement of motor cortices in retrieval of kanji studied by functional MRI. *Neuroreport* 1999; **10**:1335–1339.
15. Rektor I, Rektorova I, Mikl M, Brazdil M, Krupa P. An event-related fMRI study of self-paced alphabetically ordered writing of single letters. *Exp Brain Res* 2006; **173**:193–194.
16. Rapp B, Caramazza A. From graphemes to abstract letter shapes: levels of representation in written spelling. *J Exp Psychol Hum Percept Perform* 1997; **23**:1130–1152.
17. Sugishita M, Takayama Y, Shiono T, Yoshikawa K, Takahashi Y. Functional magnetic resonance imaging (fMRI) during mental writing with phonograms. *Neuroreport* 1996; **7**:1917–1921.
18. Nakamura K, Honda M, Okada T, Hanakawa T, Toma K, Fukuyama H, *et al*. Participation of the left posterior inferior temporal cortex in writing and mental recall of kanji orthography: a functional MRI study. *Brain* 2000; **123**:954–967.
19. Sakurai Y, Momose T, Iwata M, Sudo Y, Kumakura Y, Ohtomo K, *et al*. Cortical activation in reading assessed by region of interest-based analysis and statistical parametric mapping. *Brain Res Brain Res Protocol* 2001; **6**:167–171.