Available online at www.sciencedirect.com
SCIENCE DIRECT
Cognitive Brain Research 25 (2005) 531 – 536
COGNITIVE BRAIN RESEARCH
www.elsevier.com/locate/cogbrainres

Research Report

Foveal splitting causes differential processing of Chinese orthography in the male and female brain

Janet Hui-wen Hsiao*, Richard Shillcock

School of Informatics, University of Edinburgh, 2 Buccleuch Place, Edinburgh, UK

Accepted 10 August 2005
Available online 8 September 2005

Abstract

Chinese characters contain separate phonetic and semantic radicals. A dominant character type exists in which the semantic radical is on the left and the phonetic radical on the right; an opposite, minority structure also exists, with the semantic radical on the right and the phonetic radical on the left. We show that, when asked to pronounce isolated tokens of these two character types, males responded significantly faster when the phonetic information was on the right, whereas females showed a non-significant tendency in the opposite direction. Recent research on foveal structure and reading suggests that the two halves of a centrally fixated character are initially processed in different hemispheres. The male brain typically relies more on the left hemisphere for phonological processing compared with the female brain, causing this gender difference to emerge. This interaction is predicted by an implemented computational model. This study supports the existence of a gender difference in phonological processing, and shows that the effects of foveal splitting in reading extend far enough into word recognition to interact with the gender of the reader in a naturalistic reading task.

Theme: Neural basis of behavior
Topic: Cognition

Keywords: Chinese character pronunciation; Foveal splitting; Gender difference; Connectionist modeling; Phonological processing

1. Introduction

Male and female brains have been shown to differ in many aspects of language development and impairment, in imaging studies of normal language processing, and in behaviors elicited by non-naturalistic language processing tasks (e.g., divided visual field studies [35]), but reliable gender differences have previously not been visible in naturalistic studies of the normal orthographic processing of skilled adult readers. Chinese orthography contains different elements that relate to the phonological and semantic aspects of the individual characters. The recent appreciation of the role of the anatomy of the fovea, and subsequent cortical projections, in visual word recognition suggests that the spatial arrangement of information in major character types may lead to differential processing in the male and female brain. Here, we show, for the first time, a robust effect of the gender of the reader in a naturalistic reading task.[1]

Chinese phonetic compound characters comprise about 81% of the 7000 frequent characters in Chinese orthography [25]. A majority of these characters have a distinct structure that provides a unique opportunity, as we will show, for differential hemispheric processing to arise in reading: they consist of two radicals, a semantic radical and a phonetic radical, standing side by side (Fig. 1). Some 90% of them have the semantic radical on the left and the phonetic radical on the right (SP characters); the remainder have the

* Corresponding author.
E-mail address: h.hsiao@sms.ed.ac.uk (J.H. Hsiao).

[1] We thank the editor and two anonymous referees for helpful comments.

0926-6410/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.cogbrainres.2005.08.005

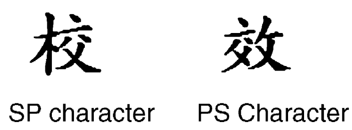

Fig. 1. Examples of phonetic compounds. The SP and PS characters, meaning "school" and "effect", respectively, share the same phonetic radical. Both characters are pronounced as 'xiao4' in Pinyin, a spelling system based on the Latin alphabet.

semantic radical on the right and the phonetic radical on the left (PS characters). In other words, the ratio between the number of SP and PS character types is about 9 to 1. In the usage of characters, as reflected in the token frequency of the characters, the ratio between the number of SP characters and PS characters is about 5.5 to 1. Thus, on average, the minority PS characters tend to have higher token frequency than SP characters. The semantic radical usually carries information about the meaning of the character, and the phonetic radical typically provides partial information about the pronunciation of the character. Among both SP and PS characters, the phonetic radical types outnumber the semantic radical types; the ratio is about 10 to 1 [13]. Hence, given that SP characters also hugely outnumber PS characters, the overall information distribution of Chinese phonetic compounds is skewed to the right.

Recent understanding about how the structure of the retina, in particular the fovea, interacts with visual word recognition suggests that SP and PS characters might present the brain with different processing problems. The fovea is the part of the retina across which a fixated word is projected. It is responsible for fine-grained, focal visual processing. From anatomical and behavioral studies, it has become increasingly clear that the human fovea is precisely vertically split [10,11,24]. This fact has fundamental implications for visual word recognition [4,32]: when a word is fixated, the left part of the word is initially projected to the right hemisphere (RH) and the right part to the left hemisphere (LH). Thus, visual word recognition can be reconceptualized in terms of coordinating the information in the two hemispheres. If foveal splitting was sufficiently precise, a single Chinese character might have its semantic and phonetic radicals contralaterally projected initially to different hemispheres, under normal reading conditions (Fig. 2).

If the two hemispheres are receiving qualitatively different input, we might expect such a processing task to be carried out differently in male and female readers. There are longstanding observations about gender differences in language, from the social use of language [6,14] to cognitive processing abilities [8,12,35] and language development [2] and impairment [9,23]. Observed gender differences have been claimed to reflect anatomical differences in the brain [1,22,36] and functional differences in hemispheric lateralization, particularly with respect to phonological processing, as revealed by functional magnetic resonance imaging (fMRI) [20,28,30,34]. There is converging evidence showing more left-lateralization of phonological processing in the male brain than in the female brain. Nevertheless, the implications of this difference for the naturalistic study of normal reading behavior are still unclear, in that laterality studies standardly employ visual hemifield presentations, in which the word is not directly fixated but is initially projected to one or other hemispheres [35]. Chinese SP and PS characters offer a unique opportunity to examine this issue in a task as simple as pronouncing a centrally presented character. Naming has been shown to produce robust laterality effects [35]. Providing our assumptions about the precision of foveal splitting are correct, we may expect differential processing of the semantic and phonetic radicals in the two halves of the brain in male and female readers. Hence, in the current study, we conducted a behavioral experiment examining gender differences in the time taken to generate the pronunciation of single, centrally presented characters; we tested the hypothesis that there would be significantly different processing in male and female readers of Chinese.

This hypothesis also arose from a computational simulation of Chinese character pronunciation, which contrasted differences between a split cognitive architecture, which had two interacting processing domains (i.e., two connected sets of hidden units), and an otherwise comparable non-split architecture, which had a single processing domain (i.e., a single group of hidden units) [16]. The two models behaved differently and the split model was identified with the female brain, in that it allowed a mapping between orthography and phonology to be carried out in two partially

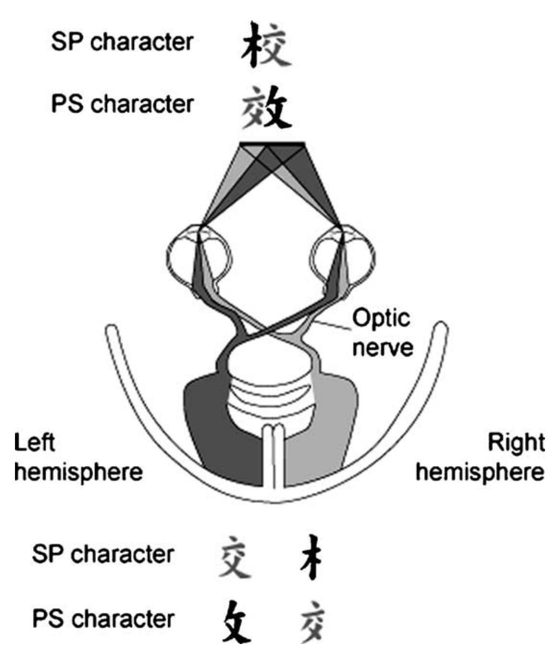

Fig. 2. Illustration of foveal splitting and contralateral projection of the two radicals of an SP character and a PS character. The phonetic and semantic radicals are shown in grey and black, respectively.

encapsulated domains (cf. the RH and LH), whereas the non-split model required the mapping to be conduced in only one processing domain (cf. the LH). We return to the details of this simulation when we compare it with observed human behavior.

2. Materials and methods

2.1. Materials

The material consisted of 75 pairs of SP and PS characters sharing the same phonetic radical (see Fig. 1). Each pair was matched in terms of pronunciation and token frequency; the two groups of characters were matched as closely as possible according to syntactic class, semantic concreteness, and visual complexity of semantic radical as defined by number of strokes. Of the 75 pairs of Chinese phonetic compound characters, 31 were regular or semi-regular and 44 were irregular. Regular characters have the same pronunciation and tone as their phonetic radical; characters having the same pronunciation but a different tone from their phonetic radical are referred to as semi-regular; irregular characters are pronounced differently from their phonetic radical, but may still share phonological segments. For current purposes, we refer to both regular and semiregular characters as regular characters. The mean number of strokes of the semantic radical of the SP characters was 4.45, and that of the PS characters was 4.76. Character frequencies were within a mid to high range [17]; very low frequency characters were avoided. In a further test of the materials, eight male and eight female native Chinese speakers judged whether the characters had a male- or female-oriented meaning. There was no significant gender bias between the meanings of the SP and PS character pairs ($F(1, 24) < 1$). A further 40 SP and 20 PS characters, half regular and half irregular, were used as fillers during the experiment. Their phonetic radicals did not appear in any of the 75 SP–PS character pairs.

2.2. Participants

We recruited 16 female and 16 male native Chinese speakers from Taiwan, with similar (graduate) educational background and normal or corrected vision. All were right-handed according to the Edinburgh handedness inventory [27] and with ages matched between the male (mean = 27.25 years) and female (mean = 27.69 years) groups. All subjects gave informed consent to participate in the study which was approved by the Ethics Committee of the Department of Psychology, University of Edinburgh.

2.3. Design

The design of this study had two within-subject variables: position of the phonetic radical (left vs. right) and character regularity (regular vs. irregular), and a between-subject variable: gender (male vs. female). The dependent variable was the time taken to begin a correct pronunciation. Characters were presented in a standard calligraphic font, each measuring approximately 1×1 cm^2. Participants sat in front of a screen, at a viewing distance of 92 cm. Hence, each character subtended less than one degree of visual angle and fell within foveal vision. The experiment was conducted using E-Prime v1.1 software tools.

2.4. Procedure

Each naming trial began with two short vertical lines presented on the screen for 500 ms. Participants were told to look at the midpoint between the two lines, which was approximately the middle of the boundary between the phonetic and semantic radicals when a character was presented. The two lines were followed by a 150 ms presentation of the target character, which did not allow time for refixation. Occasionally, a 9 pt. digit was presented, instead of a character, exactly between the two lines where participants should be fixating, to ensure that participants were foveating the stimuli; data from any participant who did not report the digits to an acceptable accuracy were rejected [3]. After each presentation of a target character or a digit, participants were asked to name the character or digit as fast and as accurately as possible. We measured the response time as the time difference between the onset of the character presentation and the onset of the participant's pronunciation. After the presentation, the stimulus was replaced by a mask, which disappeared after the onset of the participant's pronunciation. The screen then turned blank until the experimenter pressed a button to start the next trial. The SP and PS characters in the same pair did not appear in the same block. Participants were put into two groups, with males and females evenly distributed. The presentation order of each pair of PS and SP characters was counter-balanced across the two groups. Characters in each block were presented in a random order.

3. Results

Table 1 summarizes the participants' mean correct response times and standard errors as a function of character type (SP vs. PS characters), character regularity, and gender. The results showed that there were no significant main effects of gender ($F < 1$) or character type ($F < 1$). There was a significant main effect of character regularity ($F(1, 30) = 30.904$, MSe = 568.167, $P < 0.001$): participants responded to regular characters significantly faster than irregular characters. The regularity effect has been demonstrated in the literature concerning Chinese character recognition [18,29]; this effect did not interact with other variables in the current experiment. There was a significant interaction

Table 1
Summary of the mean response times and standard errors as a function of gender, character type, and character regularity

	Males		Females	
	SP characters	PS characters	SP characters	PS characters
Regular characters				
Mean response time in ms	501	510	513	510
Standard error	20	18	20	18
Irregular characters				
Mean response time in ms	526	535	541	527
Standard error	22	21	22	21

between character type and gender ($F(1, 30) = 7.867$, MSe = 317.262, $P < 0.01$, see Fig. 3): males responded to SP characters significantly faster than to PS characters ($F(1, 15) = 6.333$, MSe = 207.953, $P = 0.024$), whereas females responded nearly equivalently to the two character types, with an insignificant difference in the opposite direction ($F(1, 15) = 2.768$, MSe = 426.571, $P = 0.117$).

4. Discussion

In the current study, we have shown that, when asked to pronounce two different orthographic forms of character, adult male and female Chinese readers had different performances, with opposite patterns of ease and difficulty: males responded to SP characters significantly faster than PS characters, whereas females showed a non-significant tendency in the opposite direction. Given previous demonstrations of gender differences in the lateralization of phonological processing, the interaction between participant gender and the position of the phonetic radical in naming single foveated characters is most parsimoniously explained by foveal splitting being sufficiently precise to divide a single phonetic compound character. These characters are the smallest orthographic unit for which foveal splitting has been demonstrated [24]. In the current experiment, each briefly presented character appeared with the boundary between the semantic and phonetic radicals aligned with the participants' initial fixation point; under the split-fovea hypothesis, the two radicals would initially be projected to different hemispheres: the phonetic radical of a centrally presented SP character will be projected directly to the LH, whereas the phonetic radical of a centrally presented PS character will be projected directly to the RH (Fig. 2). We interpret the data in Fig. 3 as showing that the male brain, with its typically greater degree of lateralization of phonological processing, tends to excel in the processing of the majority SP characters, in which the phonetic radical is projected directly to the LH, at the expense of the minority PS characters. In contrast, the female brain, typically with less lateralization in phonological processing, tends towards more equivalent processing of PS and SP characters.

Elsewhere, we have presented a study of connectionist modeling of Chinese character pronunciation and showed that Chinese SP and PS characters provide a unique opportunity for the differences between a split architecture and a non-split architecture to emerge in cognitive modeling of word recognition [16]. We created a split model [31,32] of Chinese character pronunciation, and compared its performance with a corresponding non-split model (Fig. 4). The task of the models was to map an orthographic input, defined by basic stroke patterns in Chinese orthography, to the corresponding phonological featured-based output [15]. During training, the characters were presented in three different idealized fixation positions (Fig. 4). The results showed that, when characters were centrally presented, with the fixation point between the two radicals, there was a significant interaction between model architecture and character type (SP vs. PS characters): the split model performed better on PS characters than SP characters, whereas the non-split model performed better on SP characters than PS characters (Fig. 5). A separate simulation involving an artificial lexicon in which the distribution of SP and PS characters was balanced showed that the previous interaction disappeared. The original interaction reflected the overall information profile of the characters – the right-hand side was typically more informative – in conjunction with the split/non-split architecture.

In the non-split architecture, the phonetic radicals of both SP and PS characters were processed through the same hidden layer; the unrepresentative PS characters thus encountered more processing difficulties than the majority SP characters. In contrast, in the split architecture, when the input character is centrally presented, the phonetic radicals of SP and PS characters were processed in different hidden layers. Due to the imbalanced overall distribution of information in the characters, the left hidden layer received less processing load and hence was able to devote more resources to the processing of PS characters. Consequently, Chinese SP and PS characters provide a unique opportunity for the differences between a split architecture and a non-split architecture to emerge [16].

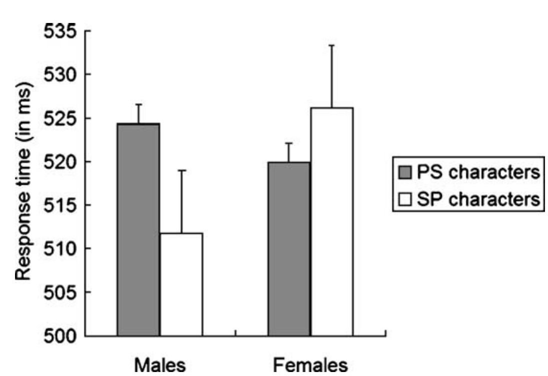

Fig. 3. Error bars of males' and females' naming times to SP and PS characters. The error bars show standard errors.

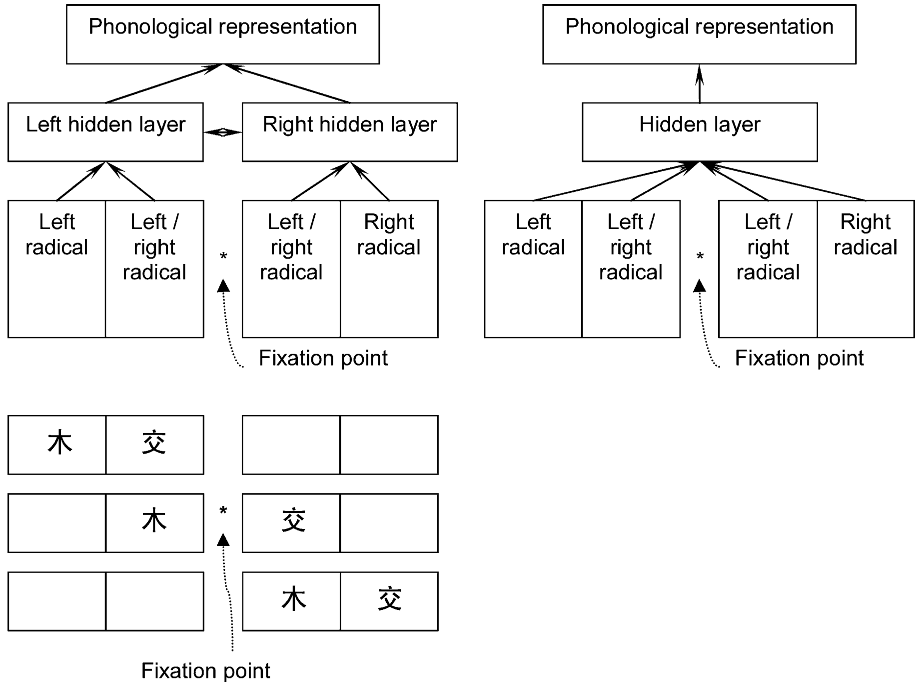

Fig. 4. Architectures of the split foveal model of Chinese character pronunciation (left) and the corresponding non-split model (right). Arrows represent patterns of complete connectivity and directional flow of activation during testing; boxes represent sets of processing units. See [15,16] for further details. The three fixation positions in the input layer are shown at the bottom. The example shows how the character 校 is presented in three fixation positions.

The connectionist modeling of Chinese character pronunciation proposed by Hsiao and Shillcock [16] involved an idealization of real fixation behavior and made a number of simplifying assumptions. Nevertheless, the results in the current study are consistent with our modeling predictions; the same interaction occurred in the model and in the human data.

Given the precision of foveal splitting, the phonetic radicals of SP and PS characters were projected to the LH and the RH, respectively. When the mapping between orthography and phonology was mediated by a single, undifferentiated processing domain (as in the male participants and in the non-split model), the minority PS characters were processed less effectively than the majority SP characters. When the same mapping was mediated by two, partially encapsulated processing domains (as in the female participants and in the split model), the processing of the minority PS characters was facilitated and the previous interaction was reversed. Thus, our split-fovea hypothesis, together with an implemented computational model, correctly predicted the gender by character–type interaction in the current study. The distinct structures and the imbalanced distribution of information overall in Chinese characters have allowed this gender difference to emerge in a naturalistic reading task.

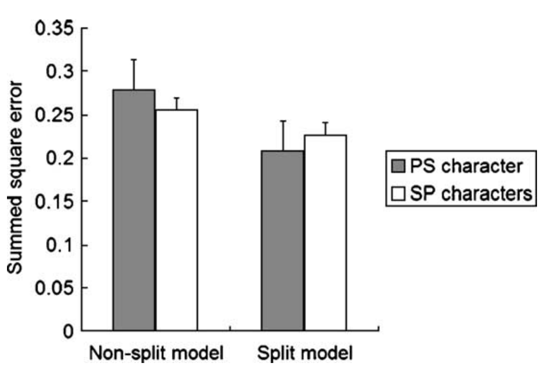

Fig. 5. Error bars of non-split and split models' performance on SP and PS characters. The error bars show standard errors.

The current study also supports the claim that gender differences in language processing exist at the level of phonological processing. Gender differences in language processing have been frequently reported and argued to be a consequence of more bilateral language processing and representation in the female brain than in the male brain [7,19,26]. However, due to inconsistent results from various behavioral and brain-imaging studies [33], this argument remains controversial. Some have argued that the inconsistent results may be because the bilateral language processing in the female brain is task specific [21]. Indeed, in recent years, there seems to have been convergent evidence showing a gender difference in the functional organization of the brain for language at the level of phonological processing [5,28,30]. The current study hence provides further support for the existence of a gender difference in the functional organization of the brain for phonological processing, through an examination of Chinese characters, a radically different orthography from any alphabetic language.

In conclusion, a robust gender effect is demonstrated in skilled adult readers, for the first time to the best of our knowledge, at the level of reading behavior in a naturalistic isolated-character reading task. The distinction between PS and SP characters in Chinese is a well-known aspect of the orthography, occurring in the dominant character type in a major language of the world. To show this effect, we required only to test the correct stimulus materials in the appropriate orthography. This effect relies on our assumption concerning the precision of foveal splitting. It remains a controversial question as to exactly how far the effects of foveal splitting extend from the retina into the process of word recognition. We have demonstrated that the effects of foveal splitting in reading reach far enough into word recognition to interact with the gender of the reader. The results obtained here may also have interesting implications for reading in alphabetic languages. Researchers should now consider the possibility of hemisphere and gender interactions within even the smallest fixated orthographic units.

Acknowledgment

The second author was supported by ESRC fellowship R/000/27/1244.

References

[1] F. Aboitiz, A.B. Scheibel, E. Zaidel, Morphometry of the Sylvian fissure and the corpus callosum, with emphasis on sex differences, Brain 115 (1992) 1521–1541.
[2] M.H. Bornstein, C. Hahn, O.M. Haynes, Specific and general language performance across early childhood: stability and gender considerations, First Lang. 24 (2004) 267–304.
[3] M. Brysbaert, Interhemispheric transfer and the processing of foveally presented stimuli, Behav. Brain Res. 64 (1994) 151–161.
[4] M. Brysbaert, The importance of interhemispheric transfer for foveal vision: a factor that has been overlooked in theories of visual word recognition and object perception, Brain Lang. 88 (2004) 259–267.
[5] J. Coney, Lateral asymmetry in phonological processing: relating behavioral measures to neuroimaged structures, Brain Lang. 80 (2002) 355–365.
[6] M. Crawford, Talking Difference: On Gender and Language, Sage, London, 1995.
[7] A.A. Dorion, M. Chantome, D. Hasboun, et al., Hemispheric asymmetry and corpus callosum morphometry: a magnetic resonance imaging study, Neurosci. Res. 36 (2000) 9–13.
[8] A. Feingold, Cognitive gender differences—Where are they and why are they there, Learn. Individ. Differ. 8 (1996) 25–32.
[9] E. Feldman, B.E. Levin, J. Fleischmann, et al., Gender differences in the severity of adult familial dyslexia, Read. Writ. 7 (1995) 155–161.
[10] R. Fendrich, M.S. Gazzaniga, Evidence of foveal splitting in a commissurotomy patient, Neuropsychologia 34 (1989) 637–646.
[11] L.G. Gray, S.L. Galetta, T. Siegal, et al., The central visual field in homonymous hemianopia-evidence for unilateral foveal representation, Arch. Neurol. 54 (1997) 312–317.
[12] D.F. Halpern, Sex Differences in Cognitive Abilities, Erlbaum, New York, 1992.
[13] R. Harbaugh, Chinese Characters: A Genealogy and Dictionary, Zhongwen.Com and Yale Far Eastern Publications, New Haven, 1998.
[14] N.M. Henley, Molehill or Mountain? What we know and don't know about sex bias in language, in: M. Crawford, M. Gentry (Eds.), Gender and Thought: Psychological Perspectives, Springer-Verlag, New York, 1989, pp. 59–78.
[15] J.H. Hsiao, R. Shillcock, Connectionist modelling of Chinese character pronunciation based on foveal splitting, Proceedings of the Twenty Sixth Annual Conference of the Cognitive Science Society, Lawrence Erlbaum Associates, Mahwah, NJ, 2004, pp. 601–606.
[16] J.H. Hsiao, R. Shillcock, Differences of split and non-split architectures emerged from modelling Chinese character pronunciation, Proceedings of the Twenty Seventh Annual Conference of the Cognitive Science Society, Lawrence Erlbaum Associates, Mahwah, NJ, 2005, pp. 989–994.
[17] S.K. Huang, Frequency counts of BIG-5 Chinese characters appeared on Usenet newsgroups during 1993–1994, http://www.geocities.com/hao510/charfreq/, 1995.
[18] C.W. Hue, Recognition processes in character naming, in: H.C. Chen, O.J.L. Tzeng (Eds.), Language Processing in Chinese, North-Holland, Amsterdam, 1992, pp. 93–107.
[19] J. Inglis, J.S. Lawson, Sex differences in the effects of unilateral brain damage on intelligence, Science 212 (1981) 693–695.
[20] K. Kansaku, S. Kitazawa, Imaging studies on sex differences in the lateralization of language, Neurosci. Res. 41 (2001) 333–337.
[21] S. Kitazawa, K. Kansaku, Sex difference in language lateralization may be task-dependent, Brain 128 (2005) E30.
[22] J.J. Kulynych, K. Vladar, D.W. Jones, et al., Gender differences in the normal lateralization of the supratemporal cortex: MRI surface-rendering morphometry of Heschl's gyrus and the planum temporale, Cereb. Cortex 4 (1994) 107–118.
[23] E.K. Lambe, Dyslexia, gender, and brain imaging, Neuropsychologia 37 (1999) 521–536.
[24] M. Lavidor, V. Walsh, The nature of foveal representation, Nat. Rev., Neurosci. 5 (2004) 729–735.
[25] Y. Li, J.S. Kang, Analysis of phonetics of the ideophonetic characters in Modern Chinese, in: Y. Chen (Ed.), Information Analysis of Usage of Characters in Modern Chinese, Shanghai Education Publisher, Shanghai, 1993, pp. 84–98.
[26] J. McGlone, Sex differences in human brain organisation: a critical survey, Behav. Brain Sci. 3 (1980) 215–227.
[27] R.C. Oldfield, The assessment and analysis of handedness: the Edinburgh inventory, Neuropsychologia 9 (1971) 97–113.
[28] K.R. Pugh, B.A. Shaywitz, S.E. Shaywitz, et al., Cerebral organization of component processes in reading, Brain 119 (1996) 1221–1238.
[29] M.S. Seidenberg, The time course of phonological code activation in two writing systems, Cognition 19 (1985) 1–30.
[30] B.A. Shaywitz, S.E. Shaywitz, K.R. Pugh, et al., Sex differences in the functional organization of the brain for language, Nature 373 (1995) 607–609.
[31] R.C. Shillcock, P. Monaghan, Connectionist modelling of surface dyslexia based on foveal splitting: impaired pronunciation after only two half pints, Proceedings of the 23rd Annual Conference of the Cognitive Science Society, Lawrence Erlbaum Associates, Mahwah, NJ, 2001, pp. 916–921.
[32] R.C. Shillcock, T.M. Ellison, P. Monaghan, Eye-fixation behavior, lexical storage, and visual word recognition in a split processing model, Psychol. Rev. 107 (2000) 824–851.
[33] I.E.C. Sommer, A. Aleman, A. Bouma, et al., Do women really have more bilateral language representation than men? A meta-analysis of functional imaging studies, Brain 127 (2004) 1845–1852.
[34] E.M. Vikingstad, K.P. George, A.F. Johnson, et al., Cortical language lateralization in right handed normal subjects using functional magnetic resonance imaging, J. Neurol. Sci. 175 (2000) 17–27.
[35] D. Voyer, On the magnitude of laterality effects and sex differences in functional literalities, Laterality 1 (1996) 51–83.
[36] S.F. Witelson, D.L. Kigar, Sylvian fissure morphology and asymmetry in men and women: bilateral differences in relation to handedness in men, J. Comp. Neurol. 323 (1992) 326–340.