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fMRI evidence for the interaction between orthography and phonology in reading Chinese compound words

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Compound words make up a major part of modern Chinese vocabulary. Behavioral studies have demonstrated that access to lexical semantics of compound words is driven by the interaction between orthographic and phonological information. However, little is known about the neural underpinnings of compound word processing. In this functional magnetic resonance imaging study, we asked participants to perform lexical decisions to pseudohomophones, which were constructed by replacing one or both constituents of two-character compound words with orthographically dissimilar homophonic characters. Mixed pseudohomophones, which shared the first constituent with the base words, were more difficult to reject than non-pseudohomophone non-words. This effect was accompanied by the increased activation of bilateral inferior frontal gyrus (IFG), left inferior parietal lobule (IPL), and left angular gyrus. The pure pseudohomophones, which shared no constituent with their base words, were rejected as quickly as non-word controls and did not elicit any significant neural activation. The effective connectivity of a phonological pathway from left IPL to left IFG was enhanced for the mixed pseudohomophones but not for pure pseudohomophones. These findings demonstrated that phonological activation alone, as in the case of the pure pseudohomophones, is not sufficient to drive access to lexical representations of compound words, and that orthographic information interacts with phonology, playing a gating role in the recognition of Chinese compound words.

Keywords: compound word, pseudohomophone, reading, lexical processing, Chinese, fMRI

INTRODUCTION

严革

严唯

范唯

MATERIALS AND METHODS

PARTICIPANTS

STIMULI AND PROCEDURES

Table 1

Table 2

fMRI DATA ACQUISITION AND ANALYSIS

Table 1 | Experimental design.

	Pseudo		Control	
Mixed	严革	yan[2]ge[2]	严唯	yan[2]wei[2]
	范唯	fan[4]wei[2]	范革	fan[4]ge[2]
Pure	砚蒈	yan[2]ge[2]	研唯	yan[2]wei[2]
	饭唯	fan[4]wei[2]	饭革	fan[4]ge[2]

Note: Pseudohomophones in the table are derived from the base words 严格 (yan[2]ge[2], strict) and 范围 (fan[4]wei[2], scope). The first characters in the "mixed" group are also the first characters of base words.

Table 2 | Properties of stimuli.

	First character			Second character		
	Number of strokes	Character frequency	Total productivity	Number of strokes	Character frequency	Total productivity
Mixed	8.4	756	54.9	8.1	648	37.7
Pure	8.8	784	36.7	8.1	648	37.7

Number of strokes measures visual complexity of the character; Total productivity refers to the number of words contain this character as a constituent.

RESULTS

BEHAVIORAL RESULTS

Figure 1

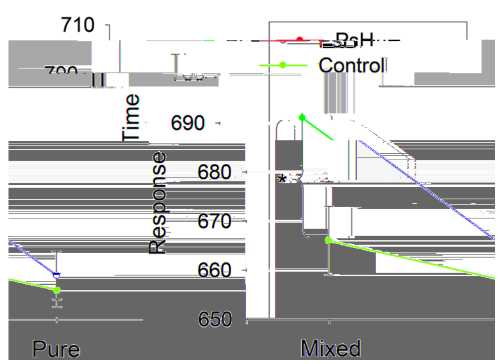

FIGURE 1 | Mean response times of lexical decision to two mixed and pure pseudohomophones and their respective controls. *$p < 0.05$.

fMRI RESULTS

General linear model analysis

Figure 2A)

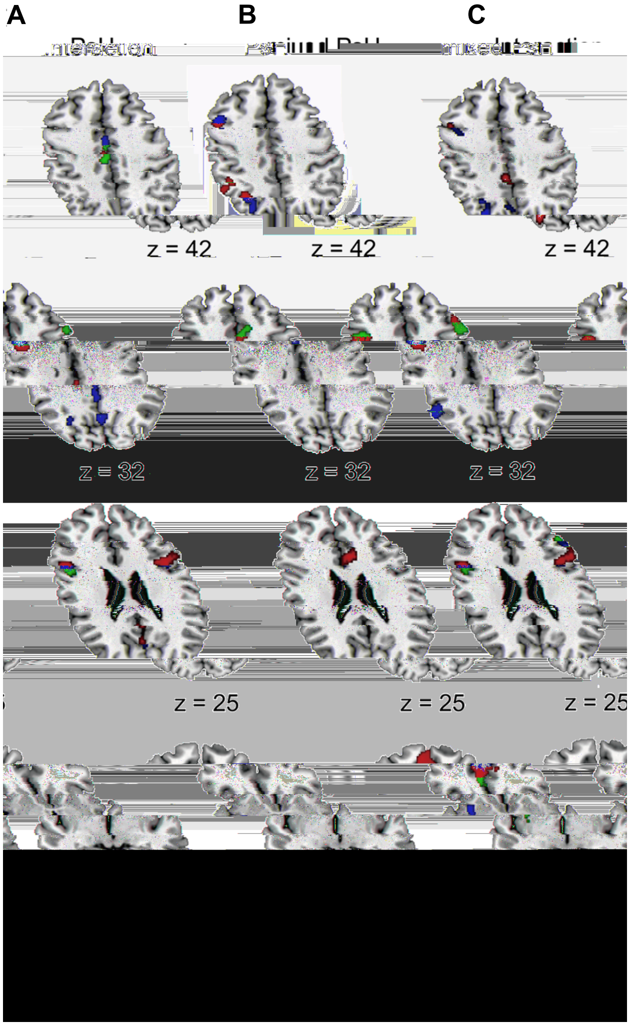

FIGURE 2 | The activated brain areas in different contrasts, PsH = pseudohomophone. (A) Significant clusters as revealed by "PsH > Controls"; **(B)** Significant clusters as revealed by "mixed PsH > Controls"; **(C)** Significant clusters as revealed "(mixed PsH > Controls) > (pure PsH > Controls)."

(Figure 2B)

(Figure 2C)

Table 3 Figure 3

Effective connectivity analysis

Figures 4A–D

(Figure 4E)

(Table 4 Figure 4F)

Table 3 | MNI coordinates of the activation foci revealed by three contrasts.

			PsH – control						Mixed PsH – control						Interaction					
						MNI coordinates						MNI coordinates						MNI coordinates		
Regions	H	BA	P_{FWE}	Max *z*-value	Voxel	*x*	*y*	*z*	P_{FWE}	Max *z*-value	Voxel	*x*	*y*	*z*	P_{FWE}	Max *z*-value	Voxel	*x*	*y*	*z*
IFG	L	44	0.000	4.82	490	−46	8	22	0.001	4.55	349	−46	8	24		–	–	–	–	–
	R	45	0.005	3.84	276	50	14	28	0.053	3.82	152	50	14	26		–	–	–	–	–
Insular	L	48		–	–	–	–	–	0.040	4.19	167	−30	18	−10		–	–	–	–	–
mOFG	L			–	–	–	–	–		–	–	–	–	–	0.000	4.24	795	−2	40	−8
ACC	L			–	–	–	–	–		–	–	–	–	–		4.05	[a]	−6	36	−8
	R			–	–	–	–	–		–	–	–	–	–		4.04	380	12	20	28
MCC	L			–	–	–	–	–	0.041	3.99	166	−4	−38	38	0.001	4.11	[a]	−6	20	44
PCC	L/R			–	–	–	–	–		3.27	[a]	0	−32	30		–	–	–	–	–
IPL	L	40	0.026	3.86	189	−46	−46	44			–	–	–	–		–	–	–	–	–
Angular	L	7	0.021	3.93	199	−34	−58	42	0.020	3.18	223	−32	−60	42		–	–	–	–	–

PsH, pseudohomophone; IFG, inferior frontal gyrus; mOFG, medial orbitofrontal gyrus; ACC, anterior cingulated cortex; MCC, middle cingulated cortex; PCC, posterior cingulated cortex; IPL, inferior parietal lobe.

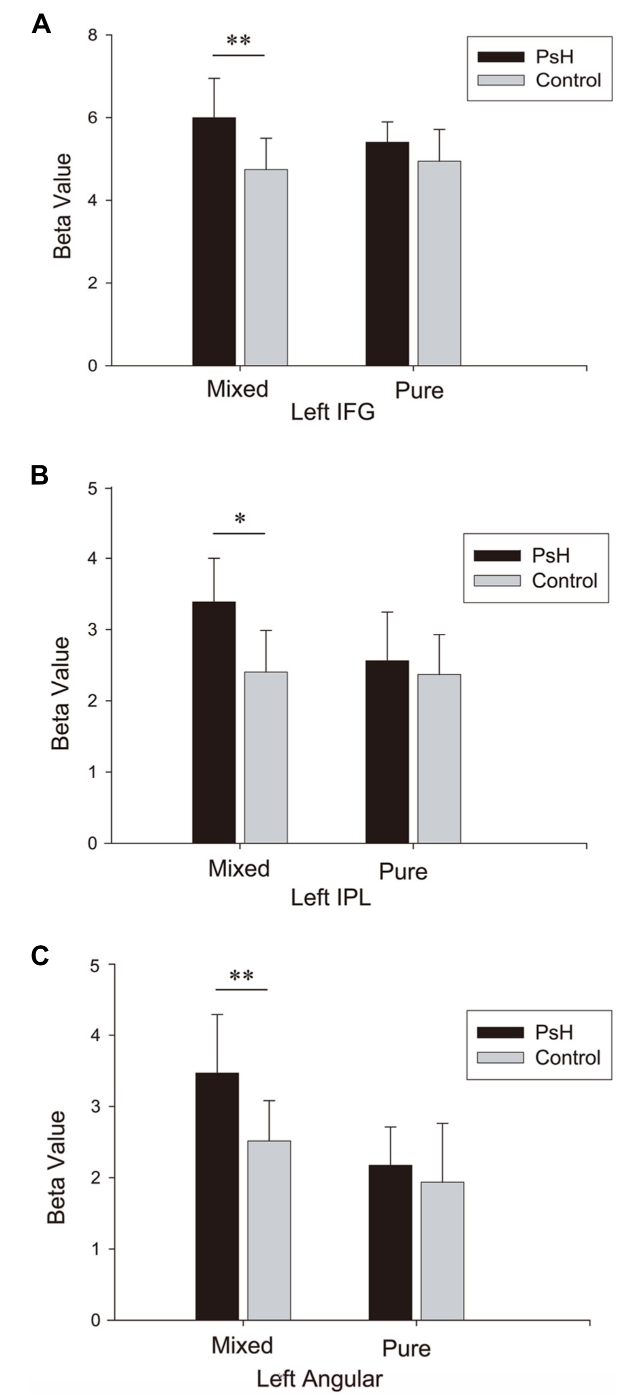

FIGURE 3 | Beta values for three regions of interest: left IFG (A), left IPL (B), and left angular gyrus (C), as revealed by the contrast "PsH > Controls."

DISCUSSION

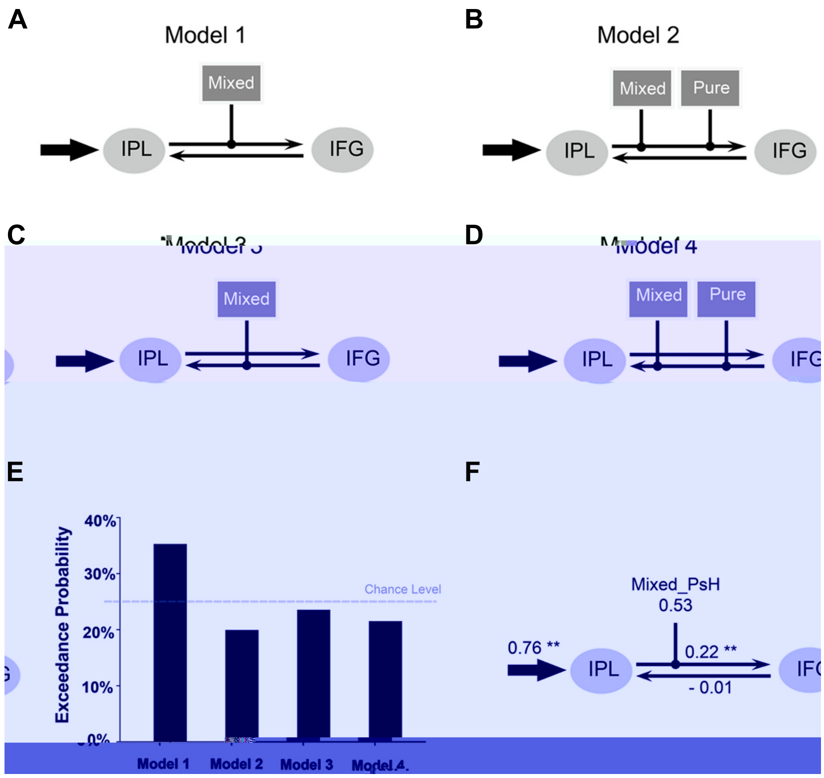

FIGURE 4 | Outline of the four DCM models tested in the present study. (A–D) Results of Bayesian Model Selection **(E)**. The estimated DCM parameters of the winning model **(F)**. Arrows represent driving input into regions, or intrinsic connections between regions. Lines with black dots at their ends indicate modulations of the intrinsic connections by the task. Mixed = mixed pseudohomophone; Pure = pure pseudohomophone. $^{**}p < 0.05$ (Bonferroni).

Table 4 | Average parameter estimates of Model 1, their standard error, and their significances in one-sample *t*-tests.

	Mean	Standard error	*t*	*df*	*p*
Input of mixed PsH into left IPL	0.76	0.17	4.41	15	<0.01
Input of pure PsH into left IPL	0.22	0.19	1.17	15	0.26
Intrinsic connectivity left IPL ? left IFG	0.22	0.22	2.56	15	<0.05
Intrinsic connectivity left IFG ? left IPL	−0.01	−0.01	−0.08	15	0.94
Effect of mixed PsH on connectivity left IPL ? left IFG	0.53	0.22	2.36	15	<0.05

PsH, pseudohomophone.

CONCLUSION

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