Bilinguals' ACC and *pars triangularis* reflect L1 and L2 norms during L1 production

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Introduction

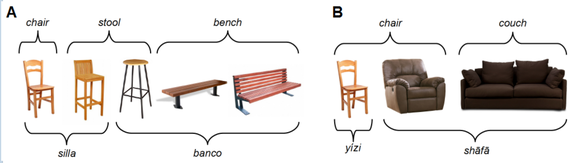
Lexical Categorization

Language provides a finite set of words for an infinite set of referents.

- Referents deviate from prototypes on multiple dimensions
- Lexical categorization demonstrates that categories are not easily summarized by one feature

Lexical Categories (English)

- Inter-personal and inter-language variation in these categories

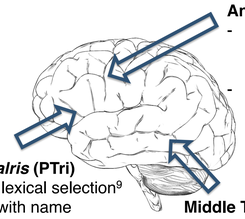


(A) Spanish vs. English[3] (B) Chinese vs. English[8]

- Behavioral research indicates that both languages are active in bilinguals' L1 lexical categorization[12]

Neurocognitive Models of Word Production

Several current theories link stages of production/naming with specific anatomical regions:



Anterior cingulate (ACC)
- involved in selection (within language)[6] and control (across languages)[1]
- more generally associated with conflict monitoring

***Pars triangualris* (PTri)**
- involved in lexical selection[9]
- correlated with name agreement[6]

Middle Temporal Gyrus (MTG)
- Involved in semantic integration[4,10]
- involved in lexical retrieval[4,5,6]
- responsive to semantic interference

Research Question & Hypothesis

How is interaction between lexical categories in bilinguals' L1 production represented in brain regions associated with lexical competition and selection?

Hypothesis: Functional activity in ACC, MTG, and PTri will reflect the cumulative influence of both languages during L1 production. After accounting for effects of Chinese predictors in bilingual imaging data, significant effects of English predictors remain in these ROIs.

Acknowledgments
Thanks to Anqi Li, Emily Fricke, Xun Sun, Yacong Zhou, Shin-Yi Fang, and Debra Weston for assistance with data collection.
Thanks to Michele Diaz, Eleonora Rossi, and Xiaoxiao Bai for assistance with MRI protocol.

We are grateful for the financial support of:
Penn State Social, Life, and Engineering Sciences Imaging Center and the **Pennsylvania Space Grant Consortium**.

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Methods

Participants

Two groups completed same object-naming task in L1 (Chinese) in China and United States:
- Chinese **monolinguals** at South China Normal University
- Chinese-English **bilinguals** at Penn State University

Sample	N	Age	L2 Onset	L2 LOR	L2 Prof.
Monolingual	11 (6 F)	20.4y (2.2)	8.7y (2.9)	0	3.5 / 7 (0.8)
Bilingual	11 (7 F)	23.9y (4.5)	9.8y (4.0)	3.3y (0.8)	5.2 / 7 (0.8)

Right-handed[11]
Language History Questionnaire[7]

Stimuli

- Balanced set of 183 photographic stimuli across five semantic domains (clothing, dishes, tools, vehicles, and furniture) selected from 407 normed objects[13]

Sample images from the stimulus set (183 total images)

English and Chinese predictors (Agreement & Names) were:
- Balanced across languages for range and median
- Uncorrelated across languages (see table below)

to improve estimation of each language's effects on imaging data.

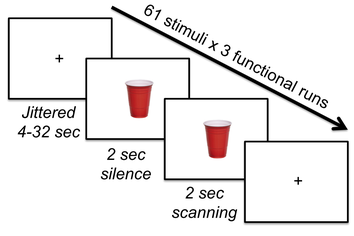
	English Ratings			Chinese Ratings			X-Lang. Corr.	
	Min	Max	Median	Min	Max	Median	*R*	*p*
Agreement	0.40	1.00	0.85	0.42	1.00	0.88	-0.03	0.68
# Alt. Names	1	6	2	1	6	2	0.09	0.24

Also controlled for: visual complexity, Chinese frequency, English frequency, exemplar typicality, concept familiarity

Procedure

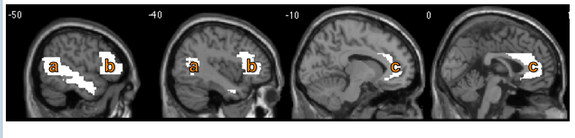
Session 1:
Handedness screening, LHQ, practiced naming in simulated MRI

Session 2:
Chinese naming task in three fMRI runs with different stimuli:
- Participants instructed to guess if unsure
- Participants encouraged to name the object within 2 sec
- Stimulus is presented for 2 sec silence + 2 sec scanning
- Each TA = 2 s, TR = 4 s throughout



Imaging Analysis

Three *a priori* left hemisphere ROIs selected for analysis:
(a) middle temporal gyrus **(b)** *pars triangularis* **(c)** anterior cingulate



GLM fit to BOLD signal (SPM8)[2], one condition for all naming trials:

Responses to naming trials modulated based on 11 regressors:
1. Visual Complexity
2. Chinese: Frequency, **Agreement**, **Names**, Typicality, Familiarity
3. English: Frequency, **Agreement**, **Names**, Typicality, Familiarity

Results

Behavioral Responses

Any object name or description accepted as a valid response– unintelligible, irrelevant, or non-responses were coded separately

Sample	Valid Resp. Rate	Non-Resp. Rate
Monolingual	0.97 (0.02)	0.01 (0.02)
Bilingual	0.83 (0.11)	0.14 (0.08)

Chinese-English bilingual participants were more sensitive to variation in Chinese stimuli than the monolinguals:
- Items with low Agreement and more Names were significantly less likely to elicit a response from bilingual participants.
- All naming trials are included in bilingual analysis

Correlation of response rate with categorization variables		
$^{**}p \leq 0.001$	**Correlation to Item's Response**	
Correlates	Monolingual	Bilingual
Chi. Agree	0.10	** 0.24
Chi. Names	-0.12	**-0.26
Eng. Agree	0.07	-0.04
Eng. Names	-0.11	-0.08

Monolingual Imaging Results – Chinese Naming

- *Pars triangularis* and anterior cingulate are both related to Chinese lexical category variation
- English predictors are not significantly related to ACC or *Pars triangularis* in monolinguals (marginal effect in MTG)

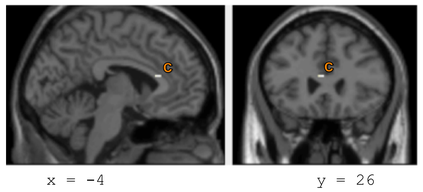
Chinese Monolinguals

Language	Predictor	ROI	cluster k (vox)	peak voxel *T*	*p* (uncorr)	MNI coord		
Chinese	Agreement	Pars triangularis	14	5.49	<0.001	-38	22	10
			34	5.27	<0.001	-52	26	14
	Names	Ant. cingulate	2	4.36	0.001	0	6	26
English	Agreement	*none at p<0.005*						
	Names	Mid. temporal	19	3.73	0.002	-50	-70	0
			1	3.21	0.005	-36	-68	12

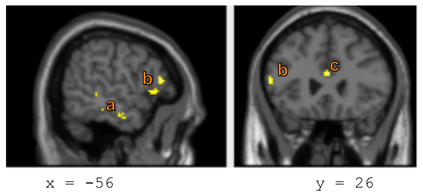
Bilingual Imaging Results – Chinese Naming

Are the effects of Chinese variables observed in Monolinguals also replicated in the Bilingual sample?

Chinese Names *p* < 0.005

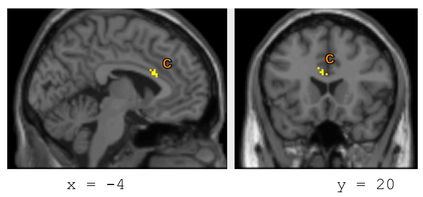


Chinese Agreement *p* < 0.005

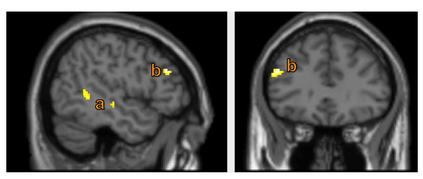


After accounting for effects of Chinese variables, are there further correlations in the same regions to English variables?

English Names *p* < 0.001



English Agreement *p* < 0.001



Discussion

L1 Naming Behavior

- Monolingual and bilingual Chinese speakers differ in their sensitivity to L1 norms (Agreement, Names).
- Results are consistent with previous behavioral research showing that low Agreement and more Names in L1 decreases L2-immersed bilinguals' monolingual-likeness[12].

Anterior Cingulate Cortex

- Previous models of monolingual[9] and bilingual[1] production associate ACC with conflict monitoring and language control.
- Both monolinguals and bilinguals showed effect of L1 Names in ACC, proportional to the number of name candidates.
- Bilinguals *also* show further effect of L2 (English) names.

Pars Triangularis

- Previously associated with lexical selection[9].
- English monolinguals' activity increases with lower Agreement[6].
- Chinese monolinguals and bilinguals show the same effect in L1.
- Chinese bilinguals also show significant additional effect of L2 (English) Agreement and Names.

Middle Temporal Gyrus

- Widely cited in production literature for conceptualization, lexical retrieval, and lexical selection[4,5,6,10].
- In the present study, showed marginal responsiveness to English norms in Chinese monolinguals, making baseline language effects difficult to interpret in this region.
- Also appears to be involved in bilingual L1 production, reflecting both L1 and L2 norms with large regions of significant activity.

Conclusions

- Bilinguals' native language and second language lexical semantics are involved in native language production.
- Neurocognitive models of bilingual production must allow for the simultaneous competition of within- and between-language lexical semantics (lexical categories, names).

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Chinese-English Bilinguals

Language	Predictor	ROI	cluster k (vox)	peak voxel *T*	*p* (uncorr)	MNI coord		
Chinese	Agreement	Ant. cingulate	134	4.3	0.001	2	28	18
				3.87	0.002	0	16	22
				3.56	0.003	2	40	16
		Mid. temporal	111	4.92	<0.001	-48	-34	4
				3.77	0.002	-64	-46	0
				3.42	0.003	-58	-36	0
			11	4.24	0.001	-48	-50	-6
			17	3.45	0.003	-58	-12	-24
		Pars triangularis	19	4.08	0.001	-56	26	12
			19	3.78	0.002	-56	22	2
	Names	Ant. cingulate	7	3.43	0.003	-4	26	16
English	Agreement	Mid. temporal	65	6.83	<0.001	-62	-56	6
			42	6.21	<0.001	-46	-48	6
			11	4.77	<0.001	-68	-38	2
			62	6.01	<0.001	-58	-18	0
				5.62	<0.001	-52	-12	-10
			12	5.89	<0.001	-46	-20	-4
		Pars triangularis	41	7.11	<0.001	-48	32	28
	Names	Ant. cingulate	23	4.64	<0.001	-4	20	24
		Mid. temporal	8	6.58	<0.001	-50	-50	-4
			59	5.21	<0.001	-44	-70	12
				4.9	<0.001	-40	-66	22
		Pars triangularis	6	4.89	<0.001	-34	26	0