Brain Bases of Chinese Literacy:
Measure of Morphological and Phonological Awareness Abilities for Reading in Chinese

Nikita Desai

Mentor: Ioulia Kovelman, PhD, Assistant Professor of Psychology

Reader: Priti Shah, PhD, Professor of Psychology

Reader: Twila Tardif, PhD, Professor of Psychology

College of Literature, Science and the Arts

University of Michigan

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Abstract

Which brain regions become selectively sensitive to phonological versus morphological manipulations as a factor of reading in Chinese? In order to answer this question, we investigated the brain bases of morphological awareness in connection with phonological and orthographic processing as all three are foundational for reading in Chinese. Unlike reading in alphabetic languages, such as English, reading in Chinese requires greater morpho-phonological processing. Native Chinese adults (N = 15, ages 19 - 28) completed phonological, morphological, and verbal word control judgment tasks during fMRI imaging. Neuroimaging results revealed five main regions of interest: left ventral IFG, dorsal IFG, Insular, Parietal, and MTG. The left vIFG and dIFG showed activation across both morphological and phonological awareness tasks. The remaining three ROIs showed task-specific differences: insular activated by phonology, MTG activated by morphology, and parietal activated by orthography. Exploration of the left STG region was conducted, revealing higher activation during morphological processing. Relative to alphabetic readers, Chinese readers showed a higher degree of neurological overlap with greater activation in the left posterior temporal regions during morphological awareness and in the left frontal regions during phonological awareness. The findings offer new insight for developing a comprehensive model of the brain bases that support reading across languages.

Key words: Chinese literacy, morphological awareness, phonological awareness, reading acquisition

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Correspondence concerning this article should be addressed to Nikita Desai.
Contact: nikidesa@umich.edu.

Introduction

Proficient literacy requires rapid recognition of sounds and meanings in print (C. Perfetti, Cao, & Booth, 2013). Not surprisingly, literacy research consistently finds that individuals' *phonological* and *morphological* awareness abilities, the ability to actively manipulate the units of sound and meaning (respectively), are the fundamental components of word reading fluency (Deacon, Chen, Luo, & Ramirez, 2013; Ziegler & Goswami, 2005). Phonemes are the smallest units of sound and morphemes are the smallest units of meaning; metalinguistic awareness is our ability to actively manipulate these units (Geva & Wang, 2001). Research into phonological awareness in alphabetic languages like English has provided a consistent link between phonological awareness and functionality of the left superior temporal region, STG (Pugh et al., 2013). This link remains largely unclear for phonological awareness in Chinese (Brennan, Cao, Pedroarena-Leal, Mcnorgan, & Booth, 2013; Siok, Niu, Jin, Perfetti, & Tan, 2008).

Moreover, little is known about the brain bases of morphological awareness for learning to read across languages, including Chinese (L. Liu et al., 2013). Newly emerging evidence suggests a tighter interconnection between phonological and morphological awareness abilities in Chinese than in English (Zhao et al., 2014). Therefore, a comparison of morphological and phonological awareness within fluent Chinese readers should not only illuminate the lesser known component of literacy, morphological awareness, but also disambiguate the link between left STG functioning and Chinese literacy. We hypothesized that the salience and the high predictability with which Chinese morpho-syllabic units map onto characters should result in significant left STG activation during morphological awareness as compared to a verbal word control task and possibly even as compared to phonological awareness. To test this hypothesis, we asked proficient adult Chinese readers to complete tasks of morphological and phonological awareness across both auditory and visual modalities during functional Magnetic Resonance Imaging (fMRI).

There is now a wealth of evidence supporting the critical contributions of phonological and morphological language abilities towards proficient reading processing across orthographies (Carlisle & Stone, 2003; Deacon et al., 2007; Geva & Wang, 2001; Ziegler & Goswami, 2005). However, disproportionately more is known about the brain bases of phonological awareness. To uncover these brain bases, neuroimaging studies often use rhyme judgment tasks that require individuals to segment the word into constituent units and decide if those units sound the same or not (e.g., *cat-hat* rhyme and *dog-table* do not). The left STG region has become prominent in phonological awareness inquiry since this region is known to support phonological processing across spoken and sign languages (Petitto, Holowka, Sergio, & Ostry, 2001). Using rhyme and similar phonological awareness tasks, alphabetic language studies generally find the left STG region active in typical readers (Kovelman et al., 2012). Conversely, left STG gray matter volume is thinner and hypoactive in readers with dyslexia who display phonology-related reading deficits (Hoeft et al., 2007).

Yet, the few studies of phonological awareness and dyslexia in Chinese have not found reduced levels of gray matter volume or activation in the left STG of readers with dyslexia (Siok et al., 2009). Importantly, comparisons between English speaking adults and children have revealed an increase in left STG activation in older and more proficient readers. This type of increase in activation is *not* found for Chinese readers (Brennan et al., 2013; Cao, Brennan, & Booth, 2015), suggesting that the left STG region undergoes an orthography-specific adaptation. It is important to note however, that orthographic characteristics of Chinese take root in Chinese language structure.

In speech and in print, English syllables can be meaningful (e.g., -*er* and *player*) or meaningless (e.g., –*er* in *flower*). In Chinese, however, most syllables are meaningful morphemes, often with multiple possible meanings, and often mapping onto meaning-related characters (e.g. "儿子 (*érzi*)" = son –"兔子 (*tùzi*)" = rabbit) (C. A. Perfetti, Liu, & Tan, 2005). In considering these spoken and orthographic characteristics of Chinese, it is logical that morphological awareness makes a powerful, early-emerging, and long-lasting contribution to Chinese literacy (Pan et al., 2015). Unfortunately, little is known about the brain bases of morphological awareness in Chinese or other languages in both the spoken and written modalities (Arredondo, Ip, Shih Ju Hsu, Tardif, & Kovelman, 2015; L. Liu et al., 2013). The study by Arredondo et al. (2015) suggests both overlapping (IFG [BA 45]) as well as distinct neurological bases for phonological and morphological awareness in English (ventral IFG [BA 47]). This pattern of activation is typical of phonological versus semantic word processing. Intriguingly, newly emerging work with Chinese suggests that this overlap might be greater for Chinese speakers (Zhao et al., 2014; Zou, Packard, Xia, Liu, & Shu, 2016). This is consistent with both theoretical and empirical research findings that relative to English speakers, Chinese speakers form stronger sound-to-print associations in addition to having stronger meaning-to-print associations (C. A. Perfetti et al., 2005).

In sum, morphemes are a salient unit of both spoken and orthographic processing in Chinese, with stronger links to phonological and orthographic representations in Chinese than in English (Guan, Perfetti, & Meng, 2015). Theoretical frameworks aiming to explain learning to read across orthographies emphasize the importance of morpho-phonological processing. The variation in how morphological and phonological processing relate to each other across languages is foundational in understanding the universal principles of orthographic processing

(Frost, 2012). Theoretical frameworks aiming to explain language organization in the brain further suggest that left posterior temporal regions, including superior and middle temporal regions, are especially sensitive to abstract linguistic representations of word sounds and meanings (Hickok & Poeppel, 2007). Finally, the morphological awareness neuroimaging study by Arredondo et al. (2015) finds significant correlation between participants' phonological awareness ability and brain activation during morphological awareness in the left STG region. This finding suggests the left STG region is multifunctional in supporting children's improvement in phonological and morphological abilities for learning to read. We ask would it then be possible that morphological awareness tasks in Chinese are more effective at eliciting left STG activations.

Prior studies have examined the degree of neurological overlap between morphological, orthographic, and phonological processing with mixed results. Devlin et al. (2004) asked participants to match a presented word to one of two choices and to read presented words out loud. It was found that every English reader showed overlap between morphological, orthographic, and semantic processing (Devlin, Jamison, Matthews, & Gonnerman, 2004). This finding is significant because it indicates morphological processing is convergent with form and meaning rather than a separate network of processing. In contrast, studies conducted by Bick et al. (2008; 2010) with adult Hebrew readers have suggested morphological and phonological processing occur independent of each other. Participants completed five tests measuring phonological, morphological, orthographic, and semantic processing skills plus a visual control task in which they determined whether two lines were the same or not. During these tasks participants were required to judge whether two words rhymed, were derived from the same root, looked the same, or were related in meaning (Bick, Goelman, & Frost, 2008). Bick et al. (2010)

tested the same abilities, but looked at them implicitly through tasks involving phonologically-, morphologically-, orthographically-, and semantically-related primes. Participants indicated whether a letter string was an existing Hebrew word following a prime. Both studies found Hebrew readers engage separate brain regions during morphological processing that are independent from the neural bases responsible for orthographic and phonological processing (Bick et al., 2008; Bick, Frost, & Goelman, 2010). This finding is significant because it suggests that depending on language structure, readers may engage brain regions differently.

Studies conducted on adult Chinese readers have revealed a greater degree of neurological overlap for morphological, phonological, and orthographic processing than observed in English readers. More specifically, when Chinese adult readers were tested on phonological and semantic processing, both tasks recruited similar brain regions in the left hemisphere indicating an even divide in labor during reading. This is unlike in English, where readers showed a greater division in brain activation depending on semantic or phonological processing demands (Zhao et al., 2014). Furthermore, adult Chinese readers who were asked to judge whether the first syllable of two stimuli were the same following morphemic, orthographic, or both morpho-orthographic manipulations showed considerable overlap in neurological activation across all conditions (Zou et al., 2016). These findings support the significance of the tight relationship between sound-and-meaning along with meaning-and-print in Chinese as compared to English. In sum, the language structure of Chinese leads to overlap in neural networks during morphological and phonological processing. The question of which brain regions become selectively sensitive to phonological versus morphological manipulations and to what degree as a factor of reading in Chinese remains generally unknown leading to the present investigation.

The present study examined the brain bases of phonological and morphological awareness in Chinese to illuminate the impact of learning a morphology-salient language on individuals' neural organization for lexical processing. A key feature of this study was the use of phonological and morphological awareness tasks that were modeled after measures typically used with young Chinese-speaking children to predict their gains in learning to read and dyslexia. This was done to offer evidence that could inform theories aiming to explain literacy and learning to read across orthographies.

We hypothesized that both morphological and phonological awareness tasks in Chinese would engage similar brain regions (Zhao et al., 2014), but that these regions would be differentially affected by the salience and degree of language-to-print predictability offered by morphological versus phonological information. To test this hypothesis, we asked proficient Chinese adult readers to complete tasks of morphological and phonological awareness, as well as a control word-matching task. All tasks were presented in both the auditory and visual modalities. First, we predicted that proficient *morphological* processing, the processing that has its focus on syllabic processing with the greatest language-to-print predictability in Chinese, should be associated with greater activation in regions typically associated with more automated and rule-governed language-to-print associations, especially left posterior temporal regions (Meschyan & Hernandez, 2006; Paulesu et al., 2000). Second, we predicted that proficient *phonological* processing, the processing that has lesser language-to-print predictability in Chinese, should engage greater activation in left frontal regions typically associated with analytically-complex language-to-print assembly (Das, Padakannaya, Pugh, & Singh, 2011; Siok et al., 2008).

The study used fMRI imaging of Chinese adults. Participants performed behavioral and in-scanner tasks designed to measure their morphological and phonological awareness, reading proficiency, and mastery of Mandarin. Unlike previous studies which used lexical judgment tasks (L. Liu et al., 2013; Zhao et al., 2014; Zou et al., 2016), we chose to use morphological awareness tasks modeled after those used by child literacy studies, including those used to identify dyslexia in preliterate children (Newman, Tardif, Huang, & Shu, 2011). During the phonological awareness task, participants saw or heard two words and decided if they rhymed or not (modeled after Liu et al., 2009). During the morphological awareness task, participants saw or heard two words. The first word was a real compound word and the second word was a similar but novel compound word that either confirmed or violated the structural constraints of morphological compounding in Mandarin (modeled after developmental tasks that presented children with a compound word and then asked them to produce a novel compound word that was similar to the first one; McBride-Chang et al., 2003; pilot work with 60 Chinese-speaking children ages 6-12 showed that the task is a significant predictor of children's literacy after controlling for age, phonological awareness, and vocabulary; Hsu et al., under review). During the control task, participants saw or heard two words and decided if the words were the same, thereby engaging phonological and lexicosemantic word processing, but without the additional phonological or morphological manipulations.

Methods

Participants

Fifteen right-handed, neurotypical adult native speakers of Chinese (7 females; mean age = 23.60 years; standard deviation [SD] = 2.92; age range = 19 - 28) participated in the study. The participants were international students from China studying in the United States for a bachelor's or master's degree and had lived in the US for 2-5 years at the time of testing. The participants were born, raised, and educated in China. All participants completed a background screening questionnaire in which they reported being highly proficient in Chinese without a history of language, literacy, or hearing impairments. Participants also completed behavioral measures (detailed below) that confirmed the normative levels of participants' Chinese proficiency. All participants reported having high to moderate levels of English speaking, reading and writing fluency. One participant failed to complete the entire experiment and therefore only 14 participants were used for subsequent data analyses.

Behavioral Measures

All participants completed published experimental measures of literacy, language and cognitive abilities in Chinese. These included:

Morphological awareness. Participants completed a Morphological Construction task that had been used in a previous study (McBride-Chang et al., 2003; *total items*= 20). Participants were required to combine known morphemes in new ways (e.g., If a ball made from snow is called "snowball" */xue1qiu2/*, what would a ball made from mud be called? The correct answer would be "mudball" */ni2qiu2/*). The maximum score for this test was 30.

Phonological awareness. Participants completed the Chinese phoneme deletion task (Newman et al., 2011; *total items= 54*) that was adapted from the elision subtest of the Comprehensive Test of Phonological Processing (CTOPP). Participants were asked to pronounce a word while omitting a phonetic unit from a word, starting with simple items such as syllables and then moving to smaller phonetic units with greater complexity and different positioning within the word (e.g., */xi1gua1/*, meaning watermelon, without */xi1/* would be *gua1/*). The maximum score for this test was 48.

Reading fluency. The reading fluency task was modeled after a previous study (Lei et al., 2011; total items= 90) whereby participants were asked to read as many sentences as possible within 3 minutes while indicating if the sentence was correct or incorrect. The maximum score for this test was 98. Scores from this task were used as an indication of the participants' level of proficiency in Mandarin. Higher score indicated better performance.

Digit Span. Participants completed forward and backward digit span from the Chinese Wechsler Adult Intelligence Scale–Revised in China (WAIS-RC; Gong, 1992). Forward digit span measures attention and concentration. Participants were asked to orally repeat digit sequences of increasing length in the same order that the experimenter presented them. Backward digit span measures short-term working memory. Participants were asked to orally repeat digit sequences of increasing length in the reversed order that the experimenter presented them. This task was scored by number of digits correctly repeated in the forward and backward sequence. Higher score indicated better performance.

fMRI Tasks

During neuroimaging, participants completed tasks of morphological awareness, phonological awareness as well as verbal and perceptual control conditions. Each condition included auditory and visual trial types. During the auditory trials, participants heard two words or two tones, during the visual trials participants saw two words or line stimuli.

Morphological awareness. Participants completed a Chinese compound morphology task which was modeled after the Chinese Morphological Construction task previously shown to predict reading acquisition in Chinese (McBride-Chang et al., 2003). During this condition, participants heard or saw two words consecutively. The first word was a real word [e.g., "病人" (sick-man) or "雪人" (snow-man)]; while the second word was a pseudoword that resembled the first real word and either confirmed [e.g., “病花” (sick-flower)] or violated [e.g., “貓雪” (cat-snow)] the structural constraints of morphological compounding in Mandarin. Participants were instructed to indicate as quickly and as accurately as possible via button press whether the pseudoword was “good” or “bad” (i.e. whether it confirmed or violated morphological constraints). For instance, “病人” (sick-man) - “病花” (sick-flower) is acceptable because the two morphemes were arranged such that the morpheme “病” (sick) can modify the noun “花” (flower); conversely for “雪人” (snow-man) - “貓雪” (cat-snow) word pair, “貓雪” (cat-snow) is unacceptable because the arrangement of the two morphemes is ungrammatical. The words in this condition had an average of 2.6 ± 0.5 syllables, 7.2 ± 1.6 phonemes, 2.6 ± 0.5 characters, and 20.9 ± 6.3 strokes.

Phonological awareness. Participants completed a rhyme judgment task during which they either heard or saw two words consecutively and were instructed to respond as quickly and as accurately as possible with a button press indicating whether the two words rhymed or not based on the last character (e.g., “银行 (*yin1hang2*)” - “新郎 (*xin1lang2*)” = rhyme; “打鼓 (*da2gu3*)” - “头发 (*tou2fa3*)” = do not rhyme) (L. Liu et al., 2009). The words in this condition had an average of 2.0 ± 0 syllables, 5.9 ± 0.8 phonemes, 2.0 ± 0 characters, and 17.7 ± 4.2 strokes.

Verbal Control Word-Match. During the verbal control condition, participants either heard or saw two words, consecutively, and decided if the words were the same or different (e.g. “家乡 (*jia1xiang1*)” - “家乡 (*jia1xiang1*)” = same; “海盗 (*hai3dai4*)” - “地球 (*di4qiu2*)” = different). Similar to the morphological and phonological awareness conditions, the participants had to make a judgment about the two words. Unlike the morphological and phonological awareness conditions, the control condition did not require any additional manipulation upon the words' morphemic or phonemic units. We created two versions of the verbal control task, one to match the morphological awareness stimuli and one to match the phonological awareness stimuli. This was done because the morphological awareness words were significantly longer than the phonological awareness words. The control condition that matched the morphological stimuli included an average of 2.6 ± 0.5 syllables, 7.4 ± 1.9 phonemes, 2.6 ± 0.5 characters, and 20.2 ± 6.6 strokes. The control condition that matched the phonological stimuli included an average of 2.0 ± 0 syllables, 5.6 ± 0.8 phonemes, 2.0 ± 0 characters, and 16.8 ± 4.3 strokes.

Note that as can be seen in Table 1, although the morphological awareness words were longer, participants were more accurate and took less time to complete morphological than phonological awareness judgment tasks. See Appendix 1 for a complete listing of experimental word stimuli.

Procedure. Prior to neuroimaging, participants completed practice trials of the experimental measures (with words that differed from in-scanner word stimuli). Participants were asked to respond as quickly and as accurately as possible with a button press. The study used a block design, with 12 blocks per condition, with auditory and visual trials separated between blocks, resulting in 6 blocks per modality per condition. For instance, there were 12 blocks of morphology, 6 of which were auditory and 6 of which were visual. Each 24s block included 6 trials. Within each 4s trial, the first word was presented at the beginning of the trial, followed by the second word after 1.5s, then followed by a question mark. There was a 20s rest period between each experimental block and during this rest period participants saw a white fixation cross on a black background.

The participants completed four experimental runs: visual morphology, auditory morphology, visual phonology, and auditory phonology. Each run included the experimental task, a verbal control task of the same modality, plus a perceptual filler condition to optimize the hemodynamic response (during the visual filler condition participants saw an array of lines and decided if those were the same or different; during the auditory filler condition participant heard two tones and decided if those were the same or different). For example, the visual morphology run included blocks of visual morphology, visual verbal control and visual perceptual filler condition. The order of the blocks was randomized within each run and preceded by a 2s reminder of the type of block the participants were about to complete (e.g., “rhyme judgment now”) as well as a specific background color for the 4 types of tasks (phonology, morphology, verbal control, fillers). Finally, the order of the runs was randomized across participants.

fMRI Data Acquisition and Analyses

fMRI Data Acquisition & Processing. All fMRI images were collected on a 3-T GE MR750 scanner with an 8HRBRAIN head coil (General Electric, Milwaukee, WI). Functional T2*images that were acquired using a reverse spiral sequence (43 mm slices, 64 x64 resolution) were then captured (TR = 2000 ms, TE = 30 ms, FA = 90°, FOV= 22 cm). Anatomical images were acquired using a 3D BRAVO Sequence echo image (TR = 12.2 ms, TE = 5.2 ms, TI = 500 ms, FA = 15°, FOV = 26 cm, 1.2mm slice thickness, 124 axial slices).

SPM8 (Wellcome Department of Cognitive Neurology, London, UK), implemented in Matlab R2012a (matworks Inc, Sherborn, MA) was used for standard pre-processing and statistical analyses. Pre-processing included slice timing correction, realignment, co-registration of the anatomical to the functional images, normalization of the images to the SPM template in MNI space, and smoothing with an 8 mm FWHM Gaussian kernel (see Weng, Xiao, & Xie, 2011 for further details). Each subject's data were high-pass filtered at 128s.

fMRI Data Analyses. Each subject's data was then analyzed using a fixed-effects model that included morphology and control conditions as the two factors. For each participant, BOLD impulse response was then modeled using the dual-gamma canonical hemodynamic response function. Statistical images for the following contrasts were generated for each condition, including condition > verbal control and condition > resting baseline contrasts. Second-level analyses were performed to obtain group-level contrast images, which were then examined using one-sample *t*-tests for whole-brain activations at FDR-corrected threshold of $p < 0.001$ and extent threshold (ET) of > 25 voxels. The main effects of morphology versus phonology were examined using a 2 X 2 ANOVA with condition > verbal control contrasts, thresholded at $p < 0.001$ and extent threshold (ET) of >25 voxels, uncorrected for multiple comparisons.

ROI Extraction. We used MarsBaR toolbox (Brett, Anton, Valabregue, & Poline, 2002) in SPM8 to create 8-mm spheres. We extracted these regions' beta values from the experimental conditions > verbal control contrasts for each task in each modality as these contrasts were most conservative in terms of revealing the brain activations for morphological and phonological awareness that were incurred by these tasks over and above the typical word processing requirements. During ROI extraction, the data was normalized using a hemodynamic response function and the temporal derivate to extract the percent signal change of contrast images (see http://marsbar.sourceforge.net/ for more details).

ROI Identification & Analyses: Conjunction Analyses and ANOVA with a Mask. Our a-prior hypotheses included semantic regions of vIFG and MTG as well as phonological regions of dIFG and STG. Given that our hypothesis was that all four regions should be active during the phonology and morphology tasks, but possibly differentially so across those tasks, we used two approaches to identifying those regions. The first was the conjunction analysis and the second was a 2 X 2 ANOVA that included a mask for common activations between the two tasks.

Conjunction Analysis. For the conjunction analysis we used task > control contrasts for each of the four experimental conditions, thresholded at $p < 0.005$ with an extent threshold > 150.

ANOVA with a Mask. The 2 X 2 ANOVA included task > resting baseline contrasts for each of the four conditions. First we created a mask of common regions of activation. To uncover regions that were common to the four conditions but selectively modulated by either morphology or phonology we conducted the subsequent main effect of task and condition analyses with the use of the mask. The mask was thresholded at $p < 0.001$ uncorrected and the contrasts were further thresholded at $p < 0.01$ uncorrected, extent threshold > 25.

Morphological and Phonological Exploratory Analysis. Our alternate plan for identifying the four ROI loci in case the above-mentioned methods of identifying study-specific ROIs should fail, was to use phonology-specific coordinates reported by Brennan et al. (2013) and morphology-specific coordinates reported by P. D. Liu et al. (2013). These studies were effective at identifying brain regions that changed (or failed to change, P. D. Liu et al., 2013) in functionality as a measure of learning to read in Chinese in typical development and dyslexia. Two types of analyses were conducted with the ROIs:

(1) Main Effects of Conditions:

Brain Bases of (a) Morphological and (b) Phonological Awareness. First we used a-prior t-tests to identify which of the four regions were significantly active during the experimental task relative to the control task ($p < 0.05$).

(2) Brain-behavior correlations:

Brain-behavior and front-temporal correlations. For regions that were significantly active, we conducted brain-behavior correlations with in-scanner rhyme and morphological awareness RT values. We also conducted fronto-temporal correlations of the frontal (IFG, Insular) and temporal (MTG) regions to identify whether those would be significant for each task. Participants were either pursuing an undergraduate or master's degree with native proficiency in the Chinese language. Consequently, a ceiling effect of task performance was observed and thus correlations could not be performed for behavioral tasks and in-scanner performance nor fronto-temporal regions.

Results

Main Effects of Conditions

(a) Brain Bases of Morphological Awareness. The first step in our analyses was to investigate the brain bases of morphological awareness relative to the control condition. As can be seen in Figure 1, t-test comparisons for the morphological awareness minus the verbal control contrasts revealed greater left IFG activation during both auditory and visual conditions as well as greater left MTG activation for the auditory condition and greater left MFG and parietal activations for the visual condition (see Table 2 for the coordinate listings).

(b) Brain Bases of Phonological Awareness. As can be seen in Figure 1, t-test comparisons for the phonological awareness minus the control contrasts revealed greater activations in left IFG, MFG and parietal across both auditory and visual conditions, as well as greater activation in MTG/STG and occipital-temporal regions during the visual condition (see Table 2).

Brain Bases of Morphological Awareness relative to Phonological Awareness. In order to directly identify brain regions more specifically related to morphological relative to phonological awareness processes, we compared the two conditions using three 2 (morphology/phonology) X

2 (auditory/visual) repeated measures ANOVAs, one with task > control contrasts and one with task > resting baseline contrasts. Neither of the two analyses revealed any main significant effects of experimental task or interactions. Both analyses revealed the main effect of modality in left STG region (x = -50, y = -30, z = 12) for the task minus control comparison and in bilateral STG (x = 56, y -12, z = 4 and x = -46, y = -18, z = 4) and occipital (x = 18, y = -90, z = 0 and x = -44, y = -80, z = -4) regions for the task minus resting baseline comparison.

In sum, matching our prediction regarding regions of neural activation during morphological awareness, the t-test revealed significant left temporal activations for the auditory morphology (regions typically associated with the retrieval of phonological and semantic representations; Hickok & Poeppel, 2007) but not the visual morphology condition. Further supporting our predictions, the t-test comparison also revealed a significant and extensive activation in the left frontal lobe during the visual phonology condition, especially the dorsal aspect of left IFG typically associated with phonological processing (Hickok & Poeppel, 2007). Frontal lobe activations appeared smaller during the visual morphology condition (Table 2). Yet, the 2 X 2 ANOVA comparison of the morphology and phonology conditions to each other did not reveal any significant differences. This corroborates our third prediction that the two conditions likely engage highly overlapping brain regions of the word processing network.

ROI Identification: Conjunction Analysis and ANOVA with a Mask

As specified in the methods section above, we used conjunction analysis and a 2 X 2 ANOVA with a mask that was common to the phonology and morphology activations to identify the four regions of interest that would be common to the two tasks but yet differentially modulated by the two (Figure 2).

Conjunction ROIs. Conjunction analysis revealed two ROIs that were common to all conditions, left dIFG and left Parietal (see above). Specifically, the left Parietal BA 7 (x = -30, y = -62, z = 38) showed greater activation during the visual morphology and phonology conditions, particularly phonology. The extracted parietal region of activation encompassed both inferior and superior parietal lobules. Concomitantly, the conjunction analysis across both auditory and visual morphology and phonology also revealed activation in the left dIFG BA 44-46/9 (x = -46, y = 12, z = 24).

ANOVA with a Mask. The results from the mask revealed a main effect of task (morphology and phonology combined) in left vIFG BA 47 (x = -46 y = 38 z = 12). The results further revealed greater activation in the left posterior MTG region during morphological relative to phonological awareness (x = -66, y = -34, z = -6). Additional activation was revealed in the Insular region with greater activation during the phonological relative to the morphological awareness task (x = -38, y = 22, z = 4).

ROI Analysis: Conjunction Analysis and ANOVA with a Mask

In sum, the conjunction and the ANOVA analyses identified a total of 5 regions of significant activation: vIFG, dIFG, Insular, MTG and Parietal regions. Following the ROI extraction, we compared participants' activation within each region using 2 (morphology/phonology) X 2 (auditory/visual) repeated measures ANOVAs.

Conjunction Analysis. In the left dIFG, participants showed activation across all four tasks. For the left parietal region, participants showed a main effect of modality for visual relative to auditory ($F(1, 12) = 9.320$, $p = 0.01$, effect size = .437). No significant interactions between task and modality for parietal and dIFG were observed.

ANOVA with a Mask. In the left vIFG, participants showed a main effect of condition indicating activation across all morphological tasks. In the Insular region, a marginal main effect of modality for visual relative to auditory was observed ($F(1, 12) = 4.009$, $p = 0.07$, effect size = .250). There were no significant interactions between task and modality for the left vIFG and the Insular regions. A significant interaction between task and modality was observed for the MTG region ($F(1, 12) = 5.700$, $p = .034$, effect size = .322; Figure 2). We followed up the significant interaction with Bonferroni post-hoc t-tests corrected for multiple comparisons in the MTG, which revealed that the auditory modality predominantly drives the interaction ($t(12) = 2.581$, $p = 0.024$).

Strength of Activation in ROIs during morphological and phonological awareness tasks. As can be seen in Figure 1, participants had significantly greater activation during the morphology relative to the control condition in left vIFG ($t(13) = 2.6$, $p = 0.02$), and MTG ($t(13) = 2.9$ $p = 0.01$)). Greater activation during the phonological relative to the control task occurred in left dIFG ($t(13) = 5.2$, $p < 0.001$), Parietal ($t(13) = 5.3$, $p < 0.001$), and Insular ($t(13) = 2.6$, $p = 0.04$). The region that was significantly more active during the phonological relative to the control task was the left Insular region ($t(13) = 5.7$, $p < 0.001$).

Exploratory Analysis of STG. Left pSTG was one of the a-priori regions of interest. Unfortunately, neither the ANOVA 2 X 2 nor the conjunction analyses revealed a pSTG region, which we therefore, as planned, selected from Brennan et al., 2013. This STG location ($x = -48$, $y = -44$, $z = 8$) is of particular interest because it is one in which only English but not Chinese speakers have shown a developmental change (increase in activation with age) during a phonological awareness task, prompting the authors to suggest that this region was sensitive to the cross-linguistic experiences. Here we further investigated this idea by asking whether this region might be selectively sensitive to morphological tasks rather than phonological tasks in Chinese. Indeed, a t-test comparison between participants' activation during the morphology and phonology tasks (combined across modality) revealed greater left pSTG activation during the morphology task ($t(13) = 2.272$, $p = .041$). As can be seen in Figure 3, this effect generalizes across modalities.

Discussion

The present study investigated the brain bases of reading in Chinese adults by asking them to perform morphological and phonological awareness tasks in the auditory and visual modalities. We used these tasks of language and literacy in both modalities to determine specific sensitivity of brain regions in Chinese readers to phonological versus morphological manipulations. We hypothesized that both morphological and phonological awareness tasks in Chinese would engage similar brain regions (Zhao et al., 2014), but that these regions would be differentially affected by the salience and degree of language-to-print predictability offered by morphological versus phonological information. Supporting our hypothesis, we found considerable overlap during morphological and phonological processing in the left vIFG and dIFG. Morphology-specific activation was found in the left MTG and exploratory analysis further revealed preferential STG activation during morphology. The left insular region showed phonology-specific activation and the parietal region showed orthography-specific activation across tasks. Our tasks thus confirmed that Chinese readers have considerable overlap of brain activation during morphological and phonological awareness with specific sensitivity in the left posterior temporal regions during morphological awareness and in the left frontal regions during phonological awareness.

Our finding of high neurological overlap in Chinese readers is consistent with prior research. Devlin et al. (2004) found that English adult readers who performed tasks measuring morphological, orthographic, and semantic awareness showed a limited degree of overlap in brain activation. Unlike English, the close relationship between sound-and-meaning as well as meaning-and-print in Chinese leads to this greater observed overlap of brain regions during morphological and phonological processing (Devlin et al., 2004). However, our findings are unlike those seen in adult Hebrew readers, who also completed morphological, phonological, and orthographic manipulation tasks. Rather than revealing a separate neural network of activation for each type of processing (Bick et al., 2008; Bick et al., 2010), we found Chinese readers showed a high convergence of neural networks likely due to the morphological processing engaged across tasks. Similar to previous findings looking at Chinese adults, as described in the introduction (Zhao et al., 2014; Zou et al., 2016), our findings revealed that Chinese readers had similar brain regions activated for both morphological and phonological awareness tasks.

We observed common activation across tasks in both the left vIFG and dIFG. Our finding of activation in these regions during both morphological and phonological processing aligns with previous research findings. Chinese adult readers who were tested on semantic awareness through a meaning association judgment task that required identifying if the second word presented matched the first, and phonological awareness through a rhyme judgment task, showed common activation in the left vIFG and dIFG regions across tasks (L. Liu et al., 2009). The semantic nature of Chinese due to the clear sound-to-meaning and meaning-to-print associations, support our expectation of seeing the vIFG and dIFG regions involved in both phonological and morphological processing.

We also expected to see task-specific activation with morphological awareness tasks activating the left posterior temporal regions and phonological awareness tasks activating the left frontal regions. In support of our hypothesis, we found task-specific activations in the left MTG for morphology and in the insular region for phonology. The role of the left MTG region in morphological awareness for Chinese is consistent with prior findings. Chinese adult readers who performed a morphological judgment task accessing concepts of whole word semantics and initial morpheme meaning, demonstrated high activation in the left MTG region (Zou et al., 2016). The insular region's role in phonological processing matches previous findings as well. Young Chinese dyslexic readers who were asked to perform rhyme judgment tasks showed reduced insular activity compared to normal Chinese readers, implicating the insular region's role in phonological processing (Siok et al., 2008).

Beyond the activation seen in the left posterior temporal and frontal regions, we found significant parietal activation during both morphological and phonological awareness tasks with greatest activation during visual presentation of stimuli. This indicates the parietal's role in orthographic processing. Prior research has established the role of the parietal region in Chinese literacy. Perfetti et al. (2013) described the role of the parietal region in supporting orthographic judgment in order to engage in phonological processing upon reading printed script. The parietal region is engaged in cross-modal integration of speech-to-print mapping, which is especially salient for reading in Chinese (C. Perfetti et al., 2013). Another study that also found consistent activation within the left Parietal (BA 7) region, asked participants to compare the semantic processing of Chinese characters and pictures, demonstrating the parietal's role in morphological awareness (Chee, Tan, & Thiel, 1999). A similar study also testing semantic judgment required participants to complete a semantically-related word generation and precision task and resulted in engagement of the left superior parietal lobule, implicating its role in Chinese literacy (Tan et al., 2000). In support of these findings, our data corroborates the role of the parietal region in Chinese reading ability.

Uniquely, we sought to identify a link between reading in Chinese and left STG functionality with the expectation that morphological awareness tasks would require greater STG sensitivity. Confirming our hypothesis, we found that in the auditory modality the left posterior STG (pSTG) region was more active during morphological awareness versus control tasks, but not during phonological awareness versus control tasks. Since the auditory modality precedes and predicts learning to read, the left STG activation observed during morphological awareness tasks indicates the sensitivity of the region to automated, intuitive and early-emerging morphological awareness computations. We further confirmed the relationship between STG and morphological awareness in Chinese based on participants' performance on the behavioral tasks. Participants showed higher accuracy and faster reaction time for the morphological judgment task compared to the phonological. The fact that participants performed higher and faster during morphological processing indicates its ease relative to phonological processing. This, combined with the selective STG activation seen during the in-scanner morphological awareness task compared to during the in-scanner phonological task, which led to high overall brain activation indicating the task's difficulty, demonstrates the sensitivity of STG activation in Chinese to morphological awareness independent of task difficulty.

Importantly for our study, ROI analyses performed on the left STG were conducted based on Brennan et al. (2013). Through the use of a phonological judgment task asking whether two stimuli rhymed in Chinese and English, Brennan et al. (2013) found greater STG activation for English adults as compared to English speaking children, while not observing higher activation in Chinese adults as compared to Chinese-speaking children. Based on these results, the authors inferred that the pSTG is selectively modulated by literacy experiences. Indeed, ROI analyses of our findings for the pSTG region identified by Brennan et al. (2013) did not reveal significantly greater activation for the phonological awareness task relative to the verbal control task (across both visual and auditory modalities). In contrast, this region did show greater activation for the morphological awareness task relative to the verbal control task (also across both visual and auditory modalities). In this manner we have both confirmed and extended the Brennan et al. (2013) findings to suggest that the pSTG region is selectively impacted by linguistic experiences, and in the case of Chinese this might mean greater sensitivity to the morphological than the phonological tasks. Taken together, both the lack of pSTG activation during phonological awareness and the presence of pSTG activation during morphological awareness in Chinese supports the hypothesis that parts of the left STG should be selectively sensitive to morpho-phonological units that are most salient to Chinese language and orthographic structure. Specifically, the left posterior temporal regions should show greater activation in response to morphological processing which focuses on syllabic processing and has the greatest language-to-print reliability in Chinese.

In addition to understanding the brain bases of morphological awareness within proficient Chinese readers, we were interested in brain activation resulting from phonological awareness. We expected to see higher engagement within the left frontal regions during phonological processing due to the lesser language-to-print predictability of Chinese (Das et al., 2011; Siok et al., 2008). Supporting our expectation, we found that auditory presentation of stimuli during phonological awareness tasks compared to control tasks selectively activated frontal regions. Likewise, visual presentation of the rhyme task led to giant bilateral activation of the frontal regions. This pattern of activation was observed because Chinese is a phonologically-opaque language with poor sound-to-print correspondences. In contrast, morphemes map onto characters, so Chinese can be seen as "morphologically-transparent," meaning it has high meaning-to-print predictability. Therefore, phonological awareness tasks involve complex computations due to the low predictability in sound-to-print processing therefore leading to whole brain activation. Additionally, the visual rhyme pattern of brain activation is in accordance with prior research where Chinese readers performed a similar visual rhyme judgment task (Siok et al., 2008) and further extends beyond that prior data by placing it in context together with morphology. This allows for a more sensitive understanding of the brain regions involved in phonological processing.

This study's innovation comes from fMRI imaging of proficient Chinese readers to investigate the brain regions involved in phonological and morphological awareness. The study incorporated measures of morphological and phonological judgment compared to a verbal word-matching control task. Similar to the experimental tasks, the control task also engaged phonological, morphological, and semantic processes necessary to access word form and meaning. Yet, some of the limitations of this study include a small sample size along with a narrow range of behavioral measures. The study also does not include a participant group of English adult readers, which would have allowed for greater comparison of brain activation during the morphological and phonological awareness tasks based on language structure. Nonetheless, the convergence between present and past behavioral, neuroimaging and cross-linguistic findings reinforces the idea that the reading brain network in non-alphabetic languages, such as Chinese, relies more significantly on morphological awareness than phonological. Another significant limitation is that this study only included behavioral tasks of a low level of difficulty. Thus correlations between behavioral and in-scanner task performance could not be completed as most participants hit ceiling on the behavioral measures.

Future Implications

In the future, developmental research and the study of dyslexia should incorporate both morphological and phonological processing tasks. A previous study in the field considering both morphology and phonology in Chinese readers, compared performance on a semantic relatedness task as well as a phonological control task. Participants were children who either had a reading disability or were typically developing. P.D. Liu et al. (2013) found children with the reading disability showed weaker morphological awareness with lower brain activation, but on the phonological task both groups showed similar levels of frontal brain activation. Once again, this demonstrates the importance of morphological awareness in Chinese literacy.

A second study using event-related potential (ERP) also asked participants to access morphological awareness during a semantic judgment task. Chinese dyslexic children performing the task lacked the N400 effect consistently seen across experimental conditions in Chinese readers of the control group. This finding implies a weakness in morphological processing likely contributed to the dyslexic children's poor reading performance (Tong, Chung, & McBride, 2014). Taken together, the performance of the dyslexic and control Chinese readers demonstrates the pivotal role of morphological processing in supporting Chinese reading ability. Overall, the results of our experiment combined with findings from studies in the field highlight the necessity of including both morphological and phonological processing tasks in future developmental research and studies of dyslexia.

Conclusion

The results of this study demonstrate that Chinese reading requires both morphological and phonological awareness with activation during reading occurring in the left hemisphere, particularly within the vIFG, dIFG, Insular, MTG, Parietal, and STG regions. Combined with new theoretical perspectives, the consideration of morphological awareness in addition to the typically considered phonological awareness can better allow for an understanding of the brain regions involved in reading ability across languages (Frost, 2012; Geva, Esther, Wang, 2001; Zhang et al., 2014). This study aimed to shed light on the brain bases of morphological and phonological awareness in Chinese-speaking adults. During the morphological awareness task relative to the verbal control word-matching task, participants showed significant STG activation. This finding suggests that sensitivity of the STG region is towards automated, intuitive and early-emerging morphological awareness computations. Moreover, the significant activation observed in the frontal brain regions during the phonological awareness task as compared to the verbal control word-matching task, highlights the lesser sound-to-print meaning found in Chinese. Taken together, these findings pave the way for new insights that allow for the development of a comprehensive model of the brain bases supporting reading across languages.

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Table 1. Behavioral Tasks (N = 14)

Task	Mean ± SD
Age (years)	23.64 ± 3.03
Behavioral Measures	
Orthological Judgment[2]	0.98 ± 0.02
CTOPP Elision Percentage	0.95 ± 0.04
Reading Fluency RT	168.2 ± 17.78
Reading Fluency Percentage	0.95 ± 0.07
Digit Span Forward Percentage[1]	0.99 ± 0.02
Digit Span Backward Percentage[1]	0.82 ± 0.11
In-Scanner Task Performance	
Auditory	
Accuracy	
Phonological Awareness	0.89 ± 0.14
Morphological Awareness	0.97 ± 0.05
Control for Phonology	0.97 ± 0.03
Control for Morphology	0.96 ± 0.05
Reaction time (ms)	
Phonological Awareness	1953.51 ± 160.74
Morphological Awareness	1683.89 ± 251.84
Control for Phonology	1695 ± 208.55
Control for Morphology	1416.97 ± 262.53
Visual	
Accuracy	
Phonological Awareness	0.89 ± 0.09
Morphological Awareness	0.98 ± 0.02
Control for Phonology	0.98 ± 0.04
Control for Morphology	0.99 ± 0.02
Reaction Time (ms)	
Phonological Awareness	1297.93 ± 325.66
Morphological Awareness	1279.96 ± 313.60
Control for Phonology	990.33 ± 345.66
Control for Morphology	977.53 ± 287.56

[1]Participants 14 and 15 did not complete the task
[2]Participant 1 did not complete the task

Table 2. Participant activation during Phonological and Morphological Awareness tasks relative to the Control task

		Auditory										*Visual*									
		Morphology					*Phonology*					*Morphology*					*Phonology*				
Regions	*H*	*x*	*y*	*z*	*T*	*Voxel*	*x*	*y*	*z*	*T*	*Voxel*	*x*	*y*	*z*	*T*	*Voxel*	*x*	*y*	*z*	*T*	*Voxel*
IFG/MFG	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	36	6	26	5.66	188
		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6	30	38	4.92	67
MTG/STG	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Parietal	R	—	—	—	—	—	—	—	—	—	—	20	-64	40	4.61	49	28	-52	40	5.23	144
Cuneus	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	-80	6	5.10	45
Cerebellum	R	6	-50	-20	9.08	92*	—	—	—	—	—	22	-68	-30	6.48	101	—	—	—	—	—
Anterior Cingulate Cortex/Cingulate	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Caudate	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	20	8	12	5.17	60
IFG/MFG	L	-54	20	26	5.27	54	-38	28	20	6.51	451	-52	14	2	6.21	75	-22	4	32	8.82	3981*
		—	—	—	—	—	-34	4	38	6.12	216	-46	14	24	5.41	460	—	—	—	—	—
MTG/STG	L	-56	-34	-2	7.17	669*	—	—	—	—	—	—	—	—	—	—	-62	-24	0	5.50	40
		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	-52	-60	-10	4.44	40
Parietal	L	—	—	—	—	—	-34	60	36	5.16	85	-36	-64	52	5.57	625	-34	-46	38	6.67	1278*
	L	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	-18	-34	56	4.69	49
Cuneus	L	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	-24	-94	2	5.07	149
Cerebellum	L	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Anterior Cingulate Cortex/Cingulate	L	—	—	—	—	—	-16	22	38	4.56	39	—	—	—	—	—	—	—	—	—	—
Caudate	L	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

H = hemisphere; L = left; R = right; *x, y, z*: Montreal Neurological Institute coordinates; *T* = *t* score; IFG = inferior frontal gyrus; MFG = middle frontal gyrus; STG = superior temporal gyrus; MTG = middle temporal gyrus
* $p < 0.05$

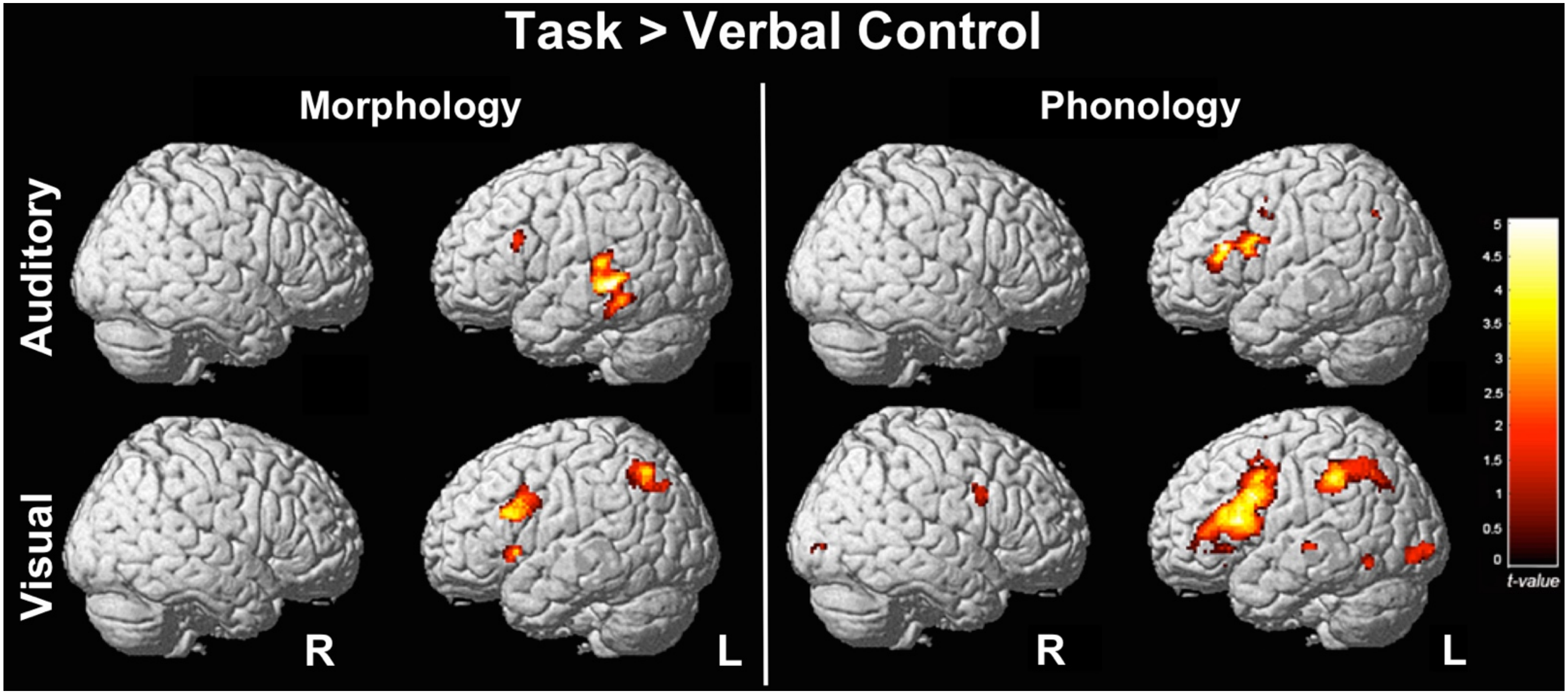

Figure 1. Task > Match. One sample t-test of activation across participants demonstrating common areas of activation across task and modality.

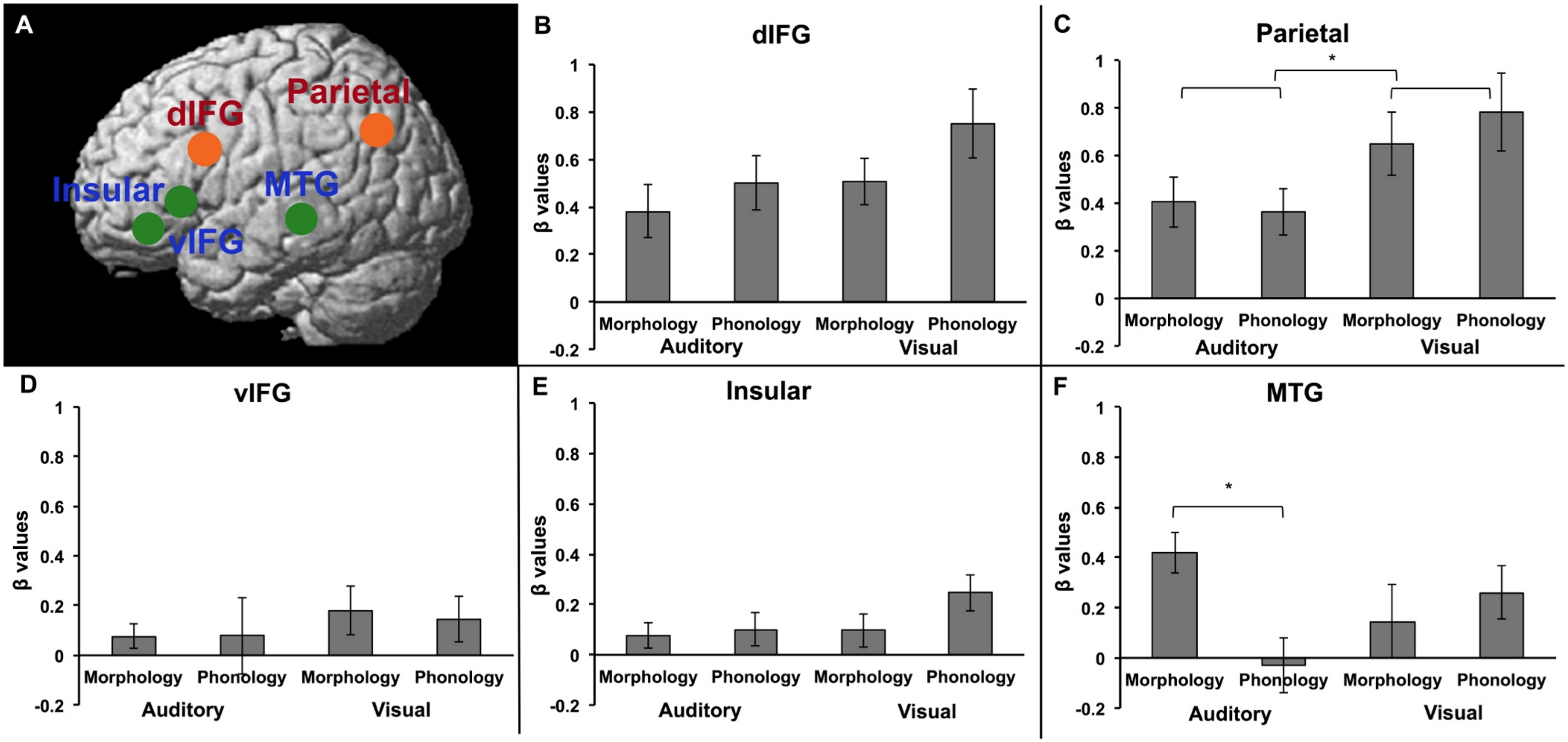

Figure 2. Task > Match. Exhaustive localization and activation of regions that appeared as Regions of Interest (ROIs). (A) Localization of ROIs (B-C) ROIs from conjunction analysis (D-F) ROIs from 2 x 2 ANOVA with mask for common activations (D) Main effect of condition indicating common activation across all four conditions (E) Main effect of task driven by phonology > morphology (F) Main effect of task driven by morphology > phonology.

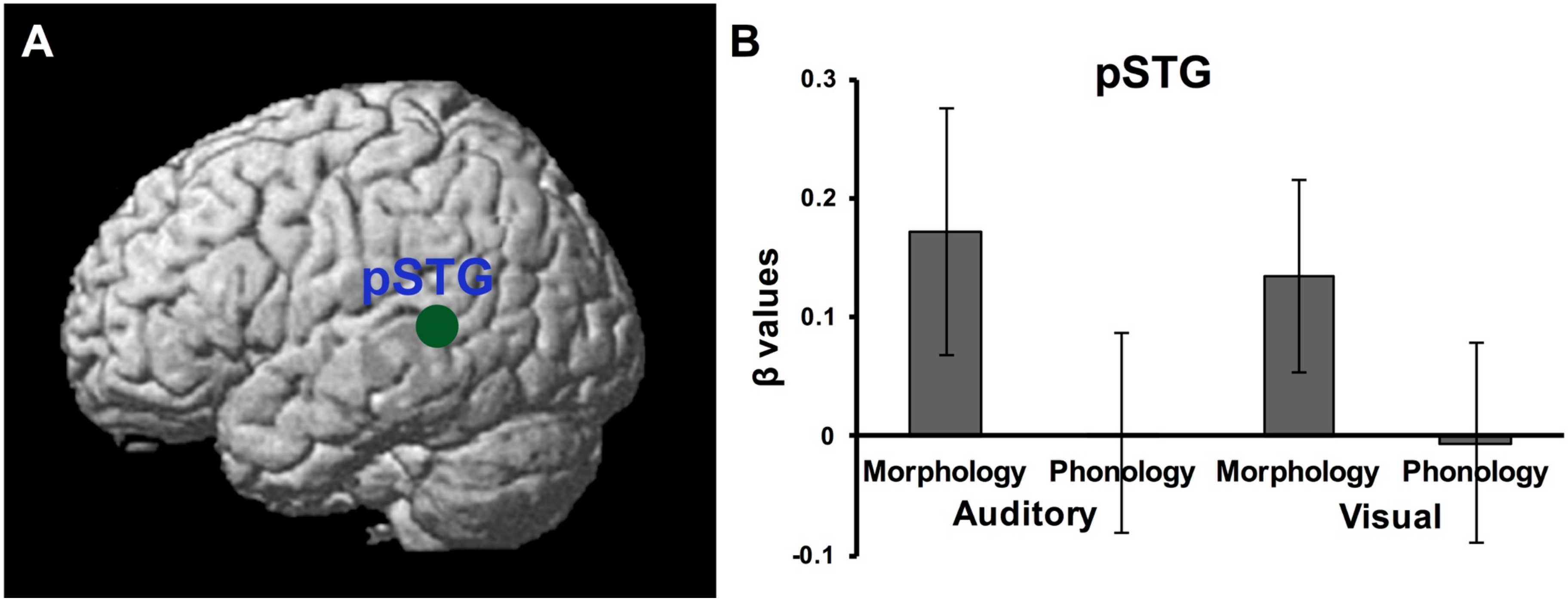

Figure 3. Task > Match. (A) Localization of pSTG (B) Activation across pSTG region. ROI derived from Brennan et al., 2013 coordinates.

Appendix A.

Experimental Stimuli for in-scanner behavioral imaging tasks

1a. Auditory Rhyme			2a. Visual Rhyme			3a. Auditory Morphology			4a. Visual Morphology		
Stimuli 1	**Stimuli 2**	**Decision**	**Stimuli 1**	**Stimuli 2**	**Decision**	**Stimuli 1**	**Stimuli 2**	**Decision**	**Stimuli 1**	**Stimuli 2**	**Decision**
漏斗	身高	NO	菜篮	愚笨	NO	火車站	站車水	NO	日出	月出	YES
银行	新郎	YES	个性	名胜	NO	手推车	车推脚	NO	手提包	包頭提	NO
肩膀	渔翁	NO	遭殃	倒映	NO	手机	脚机	YES	香皂	皂臭	NO
鸡蛋	书本	NO	湖畔	搅拌	YES	洗衣机	洗鞋机	YES	雨伞	伞雪	NO
淳朴	迷糊	YES	打鼓	头发	NO	停车场	停船场	YES	喷火龙	龙泥喷	NO
鲜花	兄弟	NO	方法	挨打	YES	指南针	指北针	YES	海草	海花	YES
相同	开朗	NO	拥抱	汽泡	YES	斑点狗	斑点羊	YES	自行车	行船自	NO
坦白	舞台	YES	环绕	破晓	NO	雪人	貓雪	NO	山羊	山鱼	YES
芝麻	琵琶	YES	迷恋	改变	YES	病人	病花	YES	收音机	机信收	NO
奔跑	颠倒	YES	借贷	送货	NO	外星人	外星猫	YES	稻草人	草猪稻	NO
代沟	羽毛	NO	足够	冒昧	NO	钓鱼竿	竿钓鸭	NO	衣櫃	櫃紙	NO
野猫	领带	NO	彩券	家眷	YES	天鹅	鸭天	NO	长颈鹿	长颈兔	YES
做梦	闲晃	NO	手枪	船舱	YES	萤火虫	水虫萤	NO	摇蓝	盒摇	NO
板凳	门缝	YES	城堡	报导	YES	牧羊犬	羊豬牧	NO	饮水机	饮酒机	YES
前门	伤痕	YES	买卖	财宝	NO	山羊	山鱼	YES	爆米花	爆麦花	YES
矛盾	穷困	YES	大海	酸梅	NO	潜水艇	潜车水	NO	食人鱼	食人马	YES
稻米	窗户	NO	勇敢	饱满	YES	猫头鹰	狗头鹰	YES	手指	头指	YES
碗盘	面粉	NO	彩虹	灯笼	YES	白菜	菜黑	NO	鱼骨头	虫骨头	YES
姐妹	小费	YES	病痛	明朗	NO	青蛙	蛙红	NO	红萝卜	卜蓝萝	NO
北方	乒乓	YES	高楼	计谋	YES	袋鼠	袋猪	YES	水族馆	火族馆	YES

Word-match control stimuli for in-scanner behavioral imaging tasks

1b. Auditory Rhyme Match			2b. Visual Rhyme Match			3b. Auditory Morphology Match			4b. Visual Morphology Match		
Stimuli 1	**Stimuli 2**	**Decision**	**Stimuli 1**	**Stimuli 2**	**Decision**	**Stimuli 1**	**Stimuli 2**	**Decision**	**Stimuli 1**	**Stimuli 2**	**Decision**
太阳	太阳	YES	捷径	珍珠	NO	黑狗	黑狗	YES	考试题	音乐厅	NO
车厢	车厢	YES	翻译	奥妙	NO	货车	斑马	NO	暑假	暑假	YES
氣質	自由	NO	长寿	蓬松	NO	故事书	巴士站	NO	游泳池	天然气	NO
雨伞	草原	NO	烦恼	烦恼	YES	棉花糖	棉花糖	YES	计算机	计算机	YES
画家	画家	YES	家乡	家乡	YES	博物馆	玫瑰花	NO	睡袋	树叶	NO
费用	稻米	NO	亲友	亲友	YES	小学生	太空船	NO	羽毛球	羽毛球	YES
房东	房东	YES	雕刻	作弊	NO	大海	大海	YES	飛蛾	拉面	NO
学费	派對	NO	牙刷	赌博	NO	动物园	动物园	YES	火炉	火炉	YES
田地	高手	NO	祈祷	祈祷	YES	围巾	围巾	YES	许愿池	老人家	NO
高山	过去	NO	积极	骄纵	NO	水壶	水壶	YES	千里马	千里马	YES
主导	认识	NO	岩壁	晚饭	NO	笔记本	笔记本	YES	时钟	时钟	YES
老虎	老虎	YES	军舰	军舰	YES	手套	火山	NO	无线电	无线电	YES
松鼠	题目	NO	车辆	狐狸	NO	洗手间	洗手间	YES	手电筒	天花板	NO
乐谱	危險	NO	悬崖	悬崖	YES	电风扇	游戏车	NO	葱油饼	压岁钱	NO
恐龙	恐龙	YES	谐星	蚱蜢	NO	電燈泡	電燈泡	YES	电视剧	管理员	NO
花瓶	花瓶	YES	隧道	隧道	YES	海盗	地球	NO	眼镜	眼镜	YES
树木	树木	YES	服装	服装	YES	剪刀	冰箱	NO	见面礼	见面礼	YES
經濟	植物	NO	雪花	游泳	NO	种西瓜	糖果屋	NO	降落伞	降落伞	YES
高尚	高尚	YES	果汁	果汁	YES	机器人	照相机	NO	月饼	律師	NO
主办	主办	YES	瘟疫	瘟疫	YES	打火机	打火机	YES	书包	温泉	NO