

Brain Functional Differences in Language Processing between Gifted and Non-Gifted Children

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Children's language ability is the basis for learning and literacy development. One typical trait of gifted children is their early-matured language and thought. To examine the language ability and brain function of gifted children (GT) during the processing of language tasks, 22 gifted students and 18 non-gifted (NG) students were recruited for this study. The research instruments included the Wechsler Intelligence Scale for Children IV (WISC IV)-Chinese Version, Reading Comprehension Screening Test (RCST), Chinese Character Recognition Test (CCRT), Phonological Awareness Task (Tone Awareness test and Onset-Rime Awareness test), and an fMRI task modified from "Auditory Responsive Naming Task" (picture matching task, word detection task, and beep detection task). The results confirmed that the GT group performed significantly better on the intelligent scale, reading comprehension test and Chinese character recognition test; regarding phonological awareness, the GT group outperformed the NG group particularly in tone awareness and onset awareness, but not in the rime awareness test. The Full Scale IQ of WISC IV was significantly correlated with all linguistic performance measures; the score of Verbal Comprehension Index (VCI) was also significantly correlated with all linguistic performance measures except for Rime Awareness (RA), and the stepwise analysis indicated that the subtests of VCI predict linguistic performance well. The fMRI results showed that during the word detection task the GT group had higher and more widespread bilateral brain activation involving language processing brain regions while the NG group had more unilateral brain activation during different tasks; more activation was also found in the post cingulate cortex in the GT group than the NG group during the word detection task.

Keywords: Auditory responsive naming task; brain function; giftedness; language processing; phonological awareness

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Intelligence and Verbal Ability

Advanced verbal development is an important indicator for identifying young gifted children (Abraham & Hartwell, 1985; Jackson, 2002; Piirto, 1999). Children with higher IQs developed language at a younger age and at a faster pace; they demonstrated a better reading ability and had a larger and more sophisticated vocabulary; better reading comprehension and stronger ability to learn foreign language (Clark, 2013; Bailey, 1996; Gallagher & Gallagher, 1994; Nikolova & Taylor, 2003; Van Tassel-Baska, 1996). At four or five years of age, they were able to create complicated sentences and response faster to questions asked by teachers (Kuo, Maker, Su, & Hu, 2010). They also can use a greater variety of words and phrases than other children of the same age, communicating proficiently and quickly, and understand jokes and riddles (Cukierkorn, Karnes, Mannings, Houston, & Besnoy, 2007). Jen, Tseng and Kuo (2015) in comparing performances of storytelling of verbally talented preschoolers and their regular counterparts found that verbally talented children demonstrated their linguistic talents at the age of four and that they used more clauses and different words and modifiers to complete the tasks.

Phonological Awareness and Reading Ability

There have been a multitude of studies on the relationship between phonological awareness and reading ability in alphabetic languages (Melby-Lervåg, Lyster, & Hulme, 2012; Vandermosten, Hoefft, & Norton, 2016). In fact, phonological awareness does not cause children to be able to read, but it assists them and “causes them to be better at learning to read”. It is “a distal, not proximal, cause of reading ability” (Castles & Coltheart, 2004, p. 79). Phonological awareness therefore has been considered “a key to unlocking the process by which children learn the relationship between spoken and written words” (Castles & Coltheart, 2004, p. 77). McBride-Chang, Tong, Shu, Wong, Leung, & Tardif (2008) also pointed out that “the importance of phonological awareness lies primarily in its link to word recognition” (p. 172). Such importance applies both to first and second

language learning (McBride-Chang & Kail, 2002).

Phonological awareness, defined as “awareness of and access to the sound structure of a language” (McBride-Chang & Kail, 2002, p. 1393), refers to the ability of a language speaker to conceive of spoken words as sequences of smaller units of sound segments, such as syllables, onsets, rimes, or phonemes (Goswami, 2002) and to identify and manipulate them (Castles & Coltheart, 2004; Ziegler & Goswami, 2005). Phonological awareness enables speakers of a language to dissect the language they hear into smaller units and to detect deviation in these small units from the existing system of their language. As spoken words of a language can be further divided into smaller units, phonological awareness can be manifested at different levels, such as the levels of syllable, onset and rime and phoneme, each of which is a larger unit than the one that follows. Research has shown that children build up phonological awareness starting from the larger units to the smaller ones (Ho & Bryant, 1997). Children’s development of phonemic awareness depends on the language they are exposed to (McBride-Chang et al., 2008).

There is also a link between phonological awareness and character recognition in Chinese children. McBride-Chang and Ho (2000) studied Chinese preschoolers’ (aged from 3 to 4) phonological processing skills and Chinese character recognition ability. The results suggested that the measure of phonological awareness and syllable deletion appeared to be the strongest predictor of character recognition. McBride-Chang et al. (2008) examined the performances of tasks of word reading in Chinese and English among 211 Chinese children aged from 4 to 5 in Hong Kong. The results suggested that syllable awareness was equally associated with Chinese and English word recognition. They also found that syllable onset awareness was uniquely associated with English reading only and that tone awareness was uniquely associated with Chinese reading only. Shu, Peng, and McBride-Chang (2008) examined Chinese children’s phonological awareness at the levels of syllable, rime, onset and tone in children aged from 3 to 6. They found that rime and syllable awareness may depend primarily on maturational age, while onset awareness may develop primarily as a

result of formal educational experience and that onset sensitivity and tone awareness increase dramatically with schooling. They also found that syllable awareness and tone awareness independently explain variability in early Chinese character recognition. Similar results were found by McBride-Chang and Kail (2002). In summary, these studies indicate that children's phonological awareness develop from the larger unit of syllable to the smaller unit of rime and tone together, to rime and tone separately and then to syllable onset.

Cortical Regions and Their Functions on Processing Language

For over two decades, neuroscientists and linguists have investigated the cortical areas that enable humans to speak and comprehend. However, a clear picture of how these cortical processing areas are connected for information propagation has remained elusive. Dong et al. (2005) in their fMRI studies found that the right BA18, right BA19 and right cerebellum were activated when subjects recognizing novel words, familiar words, reading words and recognizing novel faces.

Evidence also indicated that lesions in five left hemisphere brain regions affected performance on the Curtiss-Yamada Comprehensive Language Evaluation-Receptive (CYCLE-R), including the posterior middle temporal gyrus (pMTG) and underlying white matter, anterior superior temporal gyrus (aSTG), superior temporal sulcus (STS) and angular gyrus (AG), mid-frontal cortex in BA46, and BA47 of the inferior frontal gyrus (IFG). Lesions in the Broca's and Wernicke's areas did not significantly alter language comprehension on this particular measure. Further analysis suggested that the middle temporal gyrus (MTG) may be more important for comprehension at the word level, while the other regions may play a greater role in comprehension at the sentence level (Dronkers, Wilkins, Van Valin, Redfern, & Jaeger, 2004).

Naming deficits, particularly for proper nouns and emotionally charged objects can occur with lesions of the BA21, BA20, and BA38 in the anterior temporal lobe. The inferior temporal lobe is involved in processing the visual characteristics of objects, and there are widespread

connections between different regions of the inferior temporal lobe and the language areas of the superior temporal lobe which are involved in the production of names for different objects and attributes (Aboitiz & García, 1997). Another study using the "Auditory Responsive Naming task" discovered that 8-year-old children produced strong activation bilaterally, with greater activations on the left hemisphere in the superior and middle temporal gyri (Balsamo et al., 2002).

Gierhan (2013) educed a neurocognitive model of the pathways for auditory language processing by reviewing the available language-related literature and detailed the precise anatomy of the fiber tracts and their roles in phonological, semantic and syntactic processing, articulation, and repetition. He provided an overview of fiber tracts supporting transmission of linguistic information during auditory language processing and implicated the various distant cortical areas connected via long-range tracts in language processing, for example, the vPMC, vPFC (BA6/44) thru SMG were related to articulation; the SMG through pSTG were related to reception and modulation of audio-spatial information; the pSTG thru BA40 (SMG) were related to processing segmental information; the BA44 (Broca area) through pSTG/MTG (Wernicke area) were related to phonologically based language functions; the vPMC through IPL were related to semantically based language functions; BA44 through m/pSTG were related to processing of syntactic complexity; BA44 and BA6 through pSTG (BA22) were related to phonological processing; BA44, parts of BA45, BA6, and BA9 through pMTG (BA21/37) were related to lexical-semantic processing; PMC (BA6), pars opercularis through aSTG and pSTG were related to mapping sound to articulation; pars opercularis and dPMC through aSTG, and pSTG were related to phonological processing; frontal and opercular areas thru AG, SMG, frontal areas thru STG/MTG were related to syntactic processing and articulation; pMTG/STG thru AG were related to phonological processing and auditory-motor mapping.

A picture arising from this review is that the various language processes involve brain networks engage distinct areas widespread in the cortex beyond the classical

regions implicated in language such as the Broca's or Wernicke's area, suggesting that language processing requires cooperativity of multiple neural resources. Given the widespread language networks gathered from the non-gifted general population, it would be interesting to know how gifted people may engage their brain in language processing, e.g. whether they would devote more or less neural resources to verbal behavior, an issue previous studies seldom addressed.

Intelligence and Brain

The neural basis of intelligence has been investigated for many years. Researchers have found, using various neuroimaging paradigms ranging from structural (Colom, Jung, & Haier, 2006; Gong et al., 2005; Haier, White & Alkire, 2003; Haier et al., 1988; Shaw et al., 2006) to functional assays (Boivin, et al., 1992; Esposito, Kirkby, Van Horn, Ellmore, & Berman, 1999; Fangmeier, Knauff, Ruff, & Sloutsky, 2006; Gray, Chabris & Braver, 2003; Haier et al., 2003; Haier et al., 1988; Lee et al., 2006; Prabhakaran, Smith, Desmond, Glover, & Gabrieli, 1997), that both the frontal and posterior brain regions are involved in intelligence. Neuroimaging studies on the intelligent brain do indicate that individuals with superior intelligence differ from their normal counterparts in neuro-architecture both qualitatively and quantitatively.

Among a few studies exploring the brain of gifted persons, some measured blood oxygen-level-dependent brain activation by a 3D mental rotation task in math-gifted and average-ability adolescents (O'Boyle et al., 2005). Others explored inter-hemispheric interaction in math-gifted adolescents, average-ability youth, and college students (Singh & O'Boyle, 2004). The results of these studies indicated that enhanced interhemispheric interaction is a unique functional characteristic of the mathematically gifted brain. Another study investigating the brain activation between math-gifted adolescents and controls with average mathematical skills during an executive functioning task and a fluid reasoning task also reported more extensive and bilateral frontal-parietal network in the math-gifted adolescents than in the controls (Desco et al., 2011). Geake (2008) summarized the literatures with characteristics of gifted

brain. He pointed out that a gifted person's high ability at fluid analogizing as a cognitive process enables his or her more efficacious working memory, the most critical consequence of high-level prefrontal cortical functioning. Kalbfleisch and Gillmarten (2013) also concluded that giftedness or superior general cognitive ability is associated with higher connectivity of brain regions and more hemispheric cooperation.

To examine the relation between language learning and the gifted brain, Kuo et al. (2012) compared the brain structure of math-and-science-talented students and found their Chinese achievement scores were positively correlated to the right BA18, BA19, and the right cerebellum. It suggests that the lingual gyrus, cuneus, and cerebellum are related to language learning. However, few studies explored relationship between the gifted brain function and verbal ability. According to the above review, we noticed that there are differences of brain functions between highly intelligent and average individuals. We wonder if the students with a high IQ would process language with a different pattern of brain activation compared with typically developing students. This research thus addressed the following questions:

1. How do Chinese children with giftedness and their typically developing counterparts differ in cognitive abilities of reading comprehension, character recognition and phonological awareness in their first language?
2. How are the scores of Verbal Comprehension Index of the Wechsler Intelligence Scale for Children correlated with scores of the three language tests in these two types of children?
3. Do brains of gifted children function differently from those of typically developed ones in processing the Chinese language?

Method

Participants

There were 27 GT students and 27 NG students participating in the behavioral study. Among them, 22 GT students and 18 NG students joined in the fMRI session.

All the children were monolingual Mandarin Chinese speakers. The GT group included 3rd and 4th graders who were recruited from elementary schools engaging in gifted education in Taipei City, New Taipei City and Hsinchu County; their average age was 10.08 years old and average IQ was 136.70. Students in the NG group were 3rd and 4th graders who were also recruited from the aforementioned areas with an average age of 10.05 years old and average IQ was 111.15. The study was approved by the Institutional Review Board of National Taiwan University, and the consent forms were signed by all the participants and their parents. All the participants were administered the four behavioral measures at National Taiwan Normal University that included the WISC-IV-Chinese version (120-150 minutes), Reading Comprehension Screening Test (25 minutes), Chinese Character Recognition Test (20 minutes), and Phonological Awareness Composite (20 minutes). Then the participants received an fMRI session for approximately 1.5 hours on various tasks at the Imaging Center for Integrated Body, Mind and Culture Research in National Taiwan University.

Instruments

Instruments for behavioral measures include Wechsler Intelligence Scale for Children 4th edition-Chinese version (WISC-IV-Chinese version), Reading Comprehension Screening Test (RCST) (Ko, 1999), Chinese Character Recognition Test (CCRT) (Huang, 2001), and Phonological Awareness Composite.

WISC-IV-Chinese version

The Wechsler Intelligence Scale for Children 4th Edition-Chinese version has been in clinical use in Taiwan since 2007 (Chen & Chen, 2007). The scale has 10 core subtests (Similarities, Vocabulary, Comprehension, Block Design, Picture Concepts, Matrix Reasoning, Digit Span, Letter-Number Sequencing, Coding, Symbol Search) and four supplemental subtests (Information, Picture Completion, Arithmetic, and Cancellation). The Profile analyses can be used to evaluate scatter within or among full-scale IQ (FSIQ), Index Scores and Subtests. For the 10-subtest version, the four Index include: a.

verbal comprehension subtests (Similarities, Vocabulary, Comprehension); b. perceptual reasoning subtests (Block Design, Picture Concepts, Matrix Reasoning); c. working memory subtests (Digit Span, Letter-Number Sequencing); and d. processing speed subtests (Coding, Symbol Search). The split half reliability is .85~.96; the test-retest reliability (time interval 21~35 days); criterion validity related to WISC III Chinese version is .58~.89.

Reading Comprehension Screening Test (RCST)

This instrument was developed by Ko (1999) to examine reading comprehension of students from the 2nd to 6th grades. There are two sections including paragraph review and text comprehension. Children were asked to name the topics, find out the synonyms, reason and interpret the writing. The accuracy of their responses was reported. The test-retest reliability coefficient of this test was .87.

Chinese Character Recognition Test for Graders (CCRT)

In this character recognition measure devised by Huang (2001), children were asked to read a series of 200 words aloud that got progressively lower in printed word frequency. All characters are irrelevant in meaning with typical orthographic correspondences (real characters). The accuracy of children's responses was reported. For this timed test, its split-test reliability coefficient was .99.

Phonological Awareness Composite (PA)

PA was a self-developed instrument, comprised of Tone Awareness (TA) and Onset-Rime Awareness (ORA) (Wang, Wang, Chen, & Tsao, 2019). Each test item was randomly presented. The options as a whole included an equal number of genuine speech sounds and segment combinations which did not exist in Chinese (i.e., fake speech sounds); half of the options were two-segment combinations and the other half were three-segment combinations. Participants' answers and response times were recorded by a test interface developed via MATLAB.

1. Tone Awareness Test (TA)

This test had four practice trials and twenty testing trials. Each trial contained three different syllables.

Among the 20 testing trials, ten of them were nonsense syllables. Children were required to select the syllable with the odd tone after listening to the administrator. One point was given if they answered correctly. The coefficient of internal consistency (Cronbach's α) in the test is .75. Material of the test is shown in Figure 1.

2. Onset-Rime Awareness Test (ORA)

Similar to the Tone Awareness Test children were required to choose the odd syllable which had a distinct initial or final sound from the other two syllables. There

were four practice trials and 24 testing trials. Within the testing trials, half of the trials are initial oddity tests and the rest are final ones. Among the 24 testing trials, 12 of them use nonsense syllables. The coefficient of internal consistency (Cronbach's α) in the test was .64. Samples of the test material are shown in Figure 1 and Figure 2.

Functional MRI task

The task we used was modified from the "Auditory Responsive Naming task" in previous neuroimaging studies (Bookheimer et al., 1998; Balsamo et al., 2002;

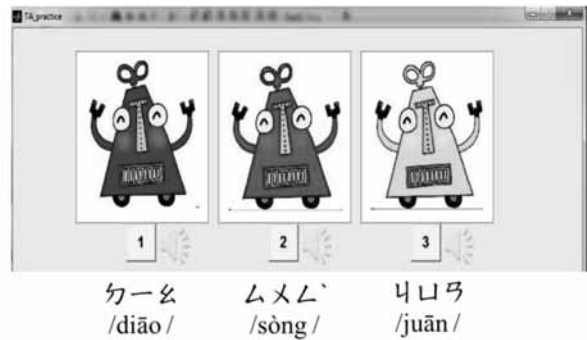


Figure 1. Tone Awareness Test

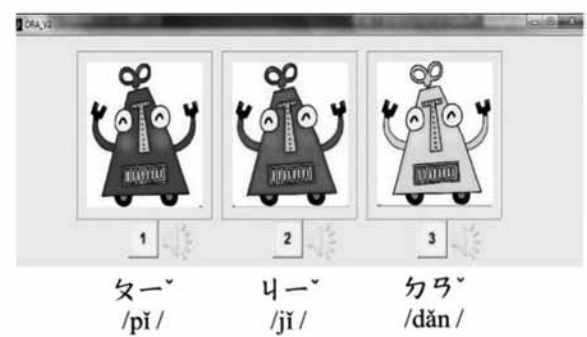


Figure 2. Onset-Rime Awareness Test (ORA)

de Guibert et al., 2011) to examine the brain activation patterns of the higher-order processing of language comprehension. In order to minimize mouth motion artifacts of the overt responses of naming and to keep children's attention on the task, we modified the naming task to request children to listen and respond to the auditory stimuli and afterwards press the corresponding button.

There are three conditions in our experiment (see Figure 3). In the picture matching condition, participants would first hear a sentence stimulus which provided the definition of concepts (e.g., the person who delivers the mails), and then they were asked to judge the coherence between the following presented picture (e.g. banana, postman) and the previous sentence content. Participants were instructed to press a button indicating their answer if the picture and the sentence content were "coherent".

Two control conditions, word detection and beep detection, were included for the delineation of language semantic processing by contrasting with the picture matching condition. In the word detection condition, after listening to a sentence, participants were asked to judge, for example, whether the target word "工具" (gong qu), meaning "tool" was in the sentence. In the beep detection condition, participants heard a meaningless strings of auditory signal and they were asked to detect whether the stimulus contained a beep triplet. In these two control conditions, children were required to listen and detect the presence of the target stimuli (i.e., the word "工具" or the "beep triplet"); they did not need to comprehend the language through semantic processing.

In each block, six trials of the same condition were presented. Each condition had four blocks which were pseudo-randomly distributed in the experiment so that no condition was presented consecutively. The total trial number is 24 for each condition.

MRI data acquisition

The MRI data were acquired using a 3-Tesla Prisma Siemens scanner with a 20-channel head coil at Imaging Center for Integrated Body, Mind, and Culture Research in National Taiwan University. The visual stimuli were

presented to the participants by goggles and the auditory stimuli were presented to them by MR-compatible headphones. The optical response box was placed on participants' right hands. Gradient-echo localizer images were acquired to determine the placement of following images. T1-weighted images were acquired using following parameters: TR = 2000 ms, TE = 2.3 ms, flip angle = 8°, matrix size = 256 × 256, FOV = 240 mm, slice thickness = 0.94, number of slices = 192. T2-weighted images were acquired using following parameters: TR = 8890 ms, TE = 99 ms, flip angle = 150°, matrix size = 288 × 384, FOV = 256 mm, slice thickness = 3, number of slices = 42. Whole-brain T2*-weighted echo-planar images were acquired by interleaved order and using following parameters: TR = 2000 ms, TE = 24 ms, flip angle = 90°, matrix size = 64 × 64, FOV = 256 mm, slice thickness = 3, number of slices = 42. Each participant performed one functional run. Each run had 512 volumes which took about 17 minutes.

(1) Data analysis

Functional MRI data were analyzed by using Statistical Parametric Mapping software (SPM8). In the data preprocessing, the functional images were corrected for slice timing to the middle volume, realigned to the first volume in the scanning session, co-registered to the coplanar T2 structural images first, then to the T1 structural images. Individual anatomical images were normalized to the standard Montreal Neurological Institute (MNI) template. The resulting transformation parameters were applied to the functional images and then these functional images were normalized to the MNI space. Finally, these normalized functional images were smoothed with an 8mm full-width at half maximum (FWHM) of the Gaussian kernel.

After preprocessing, data from individual participant were entered into a general linear model. Event-related analysis was used in the first level model. The onsets of three conditions were time-locked to the presentation of auditory stimuli and convolved with a canonical hemodynamic response function (HRF). The six motion parameters were also included as regressors in the GLM model.

The whole brain analysis was used in both within-

group and between-group analyses. In the within-group analysis, results were set to the $p < 0.0001$ uncorrected with clusters greater than or equal to 20 voxels. In the between-group analysis, results were set to the $p < 0.001$ uncorrected with clusters greater than or equal to 20 voxels.

Results

Age and IQ Differences between Groups

There was no significant age difference between two groups as Table 1 shows. The IQ mean score and standard deviation of the two groups are also shown in Table 1. There were significant differences in FSIQ and Verbal Comprehension Index (VCI) between the two groups ($p < .05$), showing that the GT group has superior intelligence.

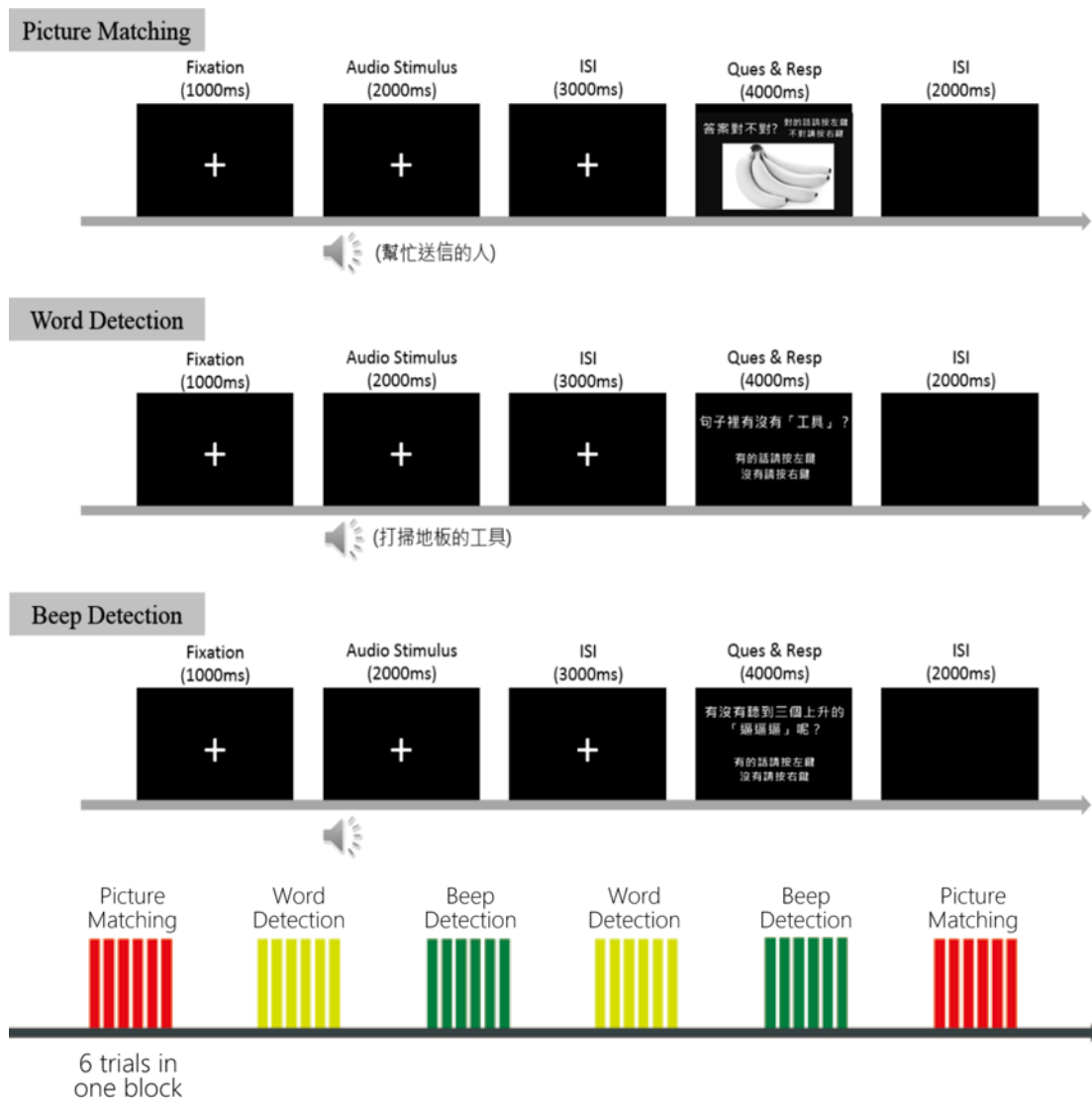


Figure 3. Illustrations of three experiment conditions and the arrangement of event-related block design during the task

Table 1. Age and IQ Difference between GT and NG

	GT (<i>N</i> = 27)		NG (<i>N</i> = 27)		<i>df</i>	<i>t</i>
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
Age (year)	10.08	0.43	10.05	0.78	52	0.16
Full Scale Intelligence	136.70	7.15	111.15	7.48	52	12.83***
Verbal comprehension index	134.89	15.34	112.22	9.50	52	6.53***
Similarities	15.96	1.63	13.37	1.96	52	5.28***
Vocabulary	15.44	2.38	11.52	1.95	52	6.64***
Comprehension	14.11	2.86	11.56	2.19	52	3.69**

* $p < .05$, ** $p < .01$, *** $p < .001$.

Linguistic Performance Differences between Groups

Table 2 shows the linguistic performance differences between the two groups. The GT group significantly outperformed the NG group in most of the measures ($2.74 < t < 4.32$, $p \leq .01$), including Chinese Character Recognition Test (CCRT), Reading Comprehension Screening Test (RCST) and two subtests of the Phonological Awareness Composite (PA). Among PA, the GT group significantly outperformed the NG group except for Rime Awareness (RA) score ($t = 1.53$, $p > .05$). Note the two measures within the Onset-Rime Composite within the two groups. The NG group did better in the Rime Awareness task than in the Onset Awareness task (OA), whereas the GT group got a lower score for RA than OA.

Correlations between IQ and Linguistic Performance

Table 3 shows the correlations between IQ and linguistic performance. FSIQ was significantly correlated with all linguistic performance measures ($.273 < r < .545$, $p < .05$); VCI was also significantly correlated with all linguistic performance measures ($.290 < r < .525$, $p < .05$) except for RA ($r = 1.77$, $p > .05$).

Table 4 shows the results of stepwise regression analysis, which indicates that among the three VCI subtests, similarities significantly predicted CCRT score ($F = 23.483$, $p < .001$); vocabulary significantly predicted RCST score ($F = 25.583$, $p < .001$); similarities significantly predicted TA score ($F = 10.588$, $p < .01$), and vocabulary significantly predicted ORA score ($F = 4.698$, $p < .05$).

Table 2. Linguistic Performance Differences between GT and NG Groups

	GT (<i>N</i> = 27)		NG (<i>N</i> = 27)		<i>df</i>	<i>t</i>
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
CCRT accuracy	69.74	10.13	59.44	10.02	52	3.76***
RCST accuracy	87.06	6.9	73.83	14.34	52	4.32***
TA accuracy	87.22	7.89	80.00	11.18	52	2.74**
Onset-Rime accuracy	82.25	9.78	72.53	14.63	52	2.87**
OA accuracy	83.02	10.46	70.06	16.87	52	3.39***
RA accuracy	81.48	13.34	75.00	17.45	52	1.53

Note. CCRT: Chinese Character Recognition Test; RCST: Reading Comprehension Screening Test; TA: tone awareness; ORA: onset-rime awareness; OA: onset-rime awareness; RA: rime awareness

* $p < .05$, ** $p < .01$, *** $p < .001$.

Table 3. The correlations between IQ and Linguistic Performance Measures

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. FSIQ	1.0									
2. VCI	.822**	1.0								
3. Similarities	.766**	.807**	1.0							
4. Vocabulary	.767**	.882**	.657**	1.0						
5. Comprehension	.565**	.819**	.493**	.552**	1.0					
6. CCRT T-score	.533**	.525**	.558**	.509**	.276*	1.0				
7. RCST accuracy	.545**	.501**	.476**	.574**	.266	.550**	1.0			
8. TA accuracy	.491**	.400**	.411**	.237	.385**	.136	.224	1.0		
9. OA accuracy	.469**	.320*	.320*	.368**	.143	.362**	.270*	.403**	1.0	
10. RA accuracy	.273*	.177	.162	.126	.196	.182	.077	.379**	.456**	1.0
11. ORA accuracy	.433**	.290*	.282*	.288*	.199	.317*	.202	.458**	.849**	.857**

Note. FSIQ: Full scale intelligence quotient; VCI: verbal comprehension index; CCRT: Chinese Character Recognition Test; RCST: Reading Comprehension Screening Test; TA: tone awareness; OA: onset awareness; RA: rime awareness; ORA: onset-rime awareness.

* $p < .05$, ** $p < .01$, *** $p < .001$.

Table 4. Predictability of IQ indices Regarding Linguistic Ability

Variables	Predict variables	R	R ²	Adjusted R ²	F	β	t
CCRT	Similarities	.558	.311	.298	23.483***	.558	4.846***
RCST	Vocabulary	.574	.330	.317	25.583***	.574	5.058***
TA	Similarities	.411	.169	.153	10.588**	.411	3.254**
ORA	Vocabulary	.288	.083	.065	4.698*	.288	2.167*

Note. CCRT: Chinese Character Recognition Test; RCST: Reading Comprehension Screening Test; TA: tone awareness; ORA: onset-rime awareness.

* $p < .05$, ** $p < .01$, *** $p < .001$.

Descriptive Results of Behavioral Performances on Functional MRI Tasks

The present study used fMRI to specify how children with giftedness may differ from their typically developing counterparts in terms of brain activation when they are engaged in different kinds of language processing tasks. Behaviorally, both groups had high accuracy rates in the three conditions and showed no significant difference (see Table 5 and Table 6). In the three tasks, neither in accuracy nor in reaction time did the GT group significantly outperform the NG group.

Results of Within-Group Analysis for Picture Matching Versus Beep Detection Comparison

In the within group analysis, we first examined the activation differences of the picture matching condition to the beep detection condition as a control baseline. Compared to the beep detection condition, the brain was activated more in the left inferior frontal gyrus, left middle temporal gyrus, and left medial frontal gyrus in the NG group in the picture matching condition (see Table 7 and Figure 4). While in the GT group, compared to the beep detection condition, the brain was also activated more and showed greater and more extensive activation in the left middle frontal gyrus, left middle temporal gyrus, fusiform and left medial frontal gyrus in the picture

Table 5. The Accuracy (%) on fMRI Tasks

	GT (<i>n</i> = 22)		NG (<i>n</i> = 18)		<i>t</i> -test	Sig.
	Mean	<i>SD</i>	Mean	<i>SD</i>		
Picture matching	96.40	3.92	96.30	4.01	.083	.934
Word detection	98.86	2.29	98.61	2.48	.334	.740
Beep detection	94.13	9.15	91.90	12.58	.649	.521

Table 6. The Reaction Time (ms) on fMRI Tasks

	GT (<i>n</i> = 22)		NG (<i>n</i> = 18)		<i>t</i> -test	Sig.
	Mean	<i>SD</i>	Mean	<i>SD</i>		
Picture matching	1360.02	338.40	1469.77	289.88	-1.087	.284
Word detection	699.92	263.33	740.68	199.12	-.542	.591
Beep detection	678.05	199.26	688.69	199.51	-.168	.868

matching condition (see Table 7 and Figure 4).

Results of Within-Group Analysis for Word Detection Versus Beep Detection Comparison

Under the word detection condition compared to the beep detection condition as the control baseline, the NG group showed more brain activations in the frontal regions (inferior frontal gyrus, middle frontal gyrus, and superior frontal gyrus) and temporal regions (superior temporal gyrus and middle temporal gyrus) in the left hemisphere and also in the posterior cingulate gyrus and right lingual gyrus (see Figure 4 and Table 8).

In the same condition, the GT group showed greater and more extensive brain activation in the posterior cingulate, frontal and temporal brain regions in the left hemisphere. In addition, activation of other brain areas was also found in the GT group, such as the postcentral gyrus, angular gyrus, cingulate gyrus, fusiform, putamen in both hemispheres, left inferior temporal gyrus, left pre-cuneus, and right insula (see Figure 4 and Table 8).

Results of Within-Group Analysis for Word Detection Versus Picture Matching Comparison

We further compared the differences between the picture matching condition and the word detection condition. There were no significant activation differences between the two conditions in both groups. However, compared to the picture matching condition, the word detection condition appeared to have more brain activation in the middle and superior occipital gyri in the NG group. Conversely in the GT group, compared to the picture matching condition, the word detection condition had elicited greater and wider-spreading activation in the frontal gyrus, the temporal gyrus, the occipital gyrus, the parietal lobule, and the cingulate gyrus bilaterally (see Figure 4 and Table 9).

Table 7. Brain Regions of Activation for the Picture Matching Versus Beep Detection Comparison in the GT Group and NG Group

Brain regions	H	BA	Voxels	Z-score	<i>p</i> (FDR-corr)	MNI coordinates		
						x	y	z
GT group								
Posterior Cingulate	L	23	461	5.85	0.000	-8	-58	14
Middle Frontal Gyrus	L	8	1084	5.31	0.000	-36	24	52
Superior Frontal Gyrus	L	8		5.10	0.047	-14	46	48
Middle Temporal Gyrus	L	21	1563	5.31	0.000	-54	-4	-20
Superior Temporal Gyrus	L	38		5.20	0.047	-44	22	-30
Inferior Temporal Gyrus	R	21	110	5.07	0.000	64	-2	-20
Middle Temporal Gyrus	L	21	328	5.03	0.000	-64	-40	-2
Precentral Gyrus	R	6	355	4.96	0.000	26	-24	70
Postcentral Gyrus	R	3	291	4.79	0.001	48	-18	58
Precentral Gyrus	R	4		4.62	0.001	48	-16	40
Supramarginal Gyrus	L	39	409	4.77	0.001	-56	-70	30
Fusiform Gyrus	L	20	232	4.60	0.001	-30	-36	-22
Fusiform Gyrus	L	37		4.29	0.001	-38	-38	-16
Medial Frontal Gyrus	L	11	166	4.38	0.001	-10	56	-12
Superior Temporal Gyrus	R	38	58	4.09	0.002	54	14	-30
Parahippocampal Gyrus	R		46	4.28	0.001	40	-36	-18
Parahippocampal Gyrus	R		32	3.95	0.002	26	-14	-26
NG group								
Middle Temporal Gyrus	L	21	197	4.54	0.031	-56	-4	-20
Middle Temporal Gyrus	L	21	217	4.49	0.031	-52	-46	-4
Inferior Frontal Gyrus	L	47	28	4.18	0.031	-40	32	-10
Medial Frontal Gyrus	L	11	20	3.89	0.033	-4	56	-12

Note..All the reported areas were set to $p < 0.0001$ uncorrected threshold with clusters greater than or equal to 20 voxels. H: hemisphere; L: left; R: right; p (FDR-corr), p -value with false discovery rate (FDR) correction.

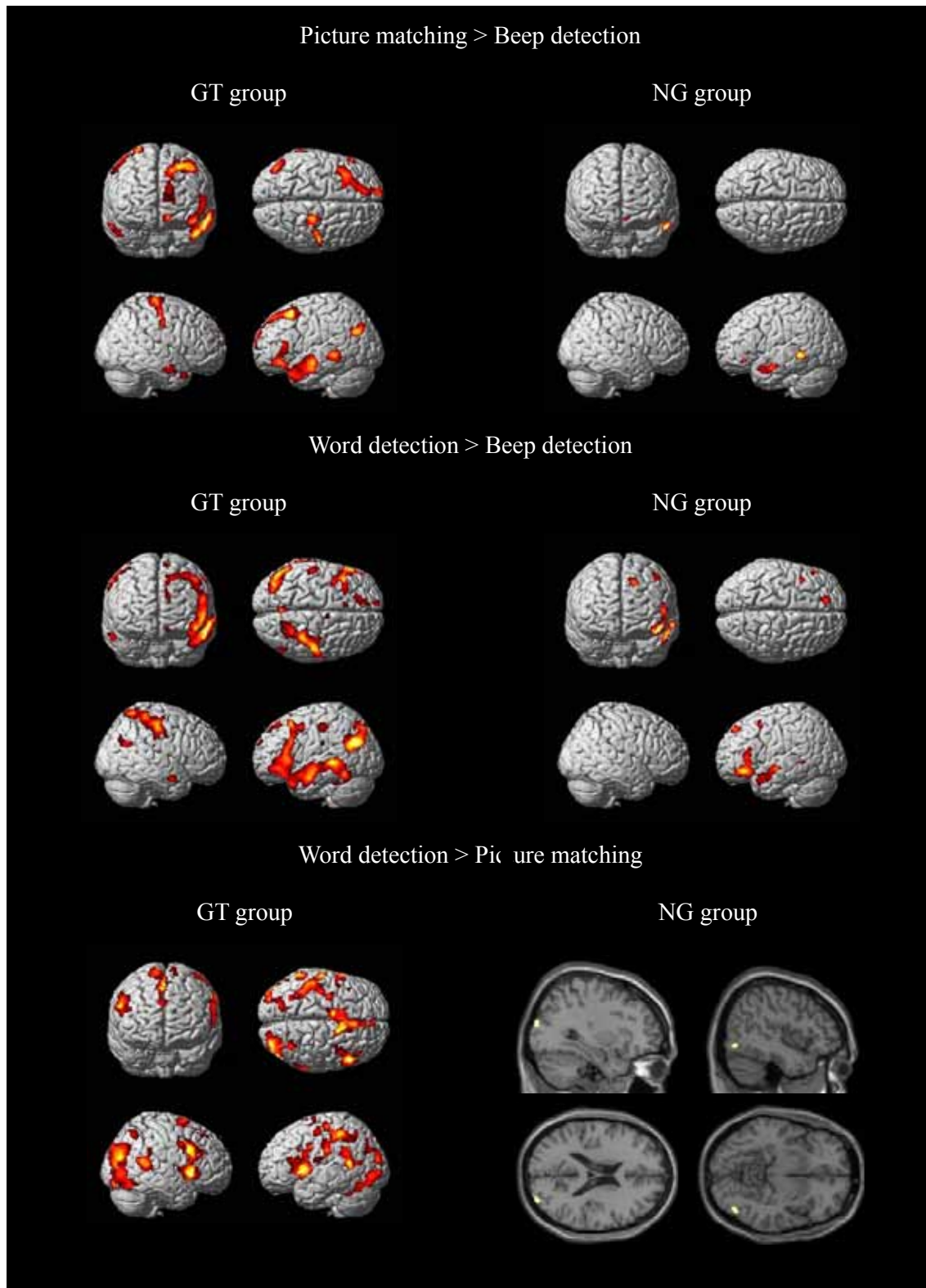


Figure 4. Results of within-group analyses of GT group and NG group, the activation threshold was set to $p < 0.0001$ uncorrected with clusters greater than or equal to 20 voxels.

Table 8. Brain Regions of Activation for the Word Detection Versus Beep Detection Comparison in the GT Group and NG Group

Brain regions	H	BA	Voxels	Z-score	p (FDR-corr)	MNI coordinates		
						x	y	z
GT group								
Posterior Cingulate	L	23	9043	6.98	0.000	-6	-56	14
Middle Temporal Gyrus	L	21		6.31	0.001	-54	-4	-20
Inferior Frontal Gyrus	L	47		6.10	0.002	-56	24	0
Posterior Cingulate	R	23		6.05	0.002	4	-56	16
Fusiform Gyrus	L	20		5.47	0.015	-34	-40	-22
Inferior Temporal Gyrus	L	20		5.12	0.040	-50	-54	-16
Precuneus	L	7		5.08	0.041	-4	-66	40
Fusiform Gyrus	L	37		5.07	0.041	-48	-50	-16
Middle Frontal Gyrus	L	11		5.03	0.044	-44	48	-10
Angular Gyrus	L	39	1610	5.65	0.000	-48	-70	26
Superior Temporal Gyrus	L	39		4.85	0.074	-56	-58	26
Postcentral Gyrus	R	1	1667	5.28	0.000	58	-18	48
Postcentral Gyrus	R	2		5.27	0.024	40	-28	50
Middle Temporal Gyrus	R	21	99	4.54	0.000	60	0	-24
Putamen	R		148	4.46	0.000	32	-10	2
Postcentral Gyrus	L		60	4.41	0.000	-44	-24	26
Medial Frontal Gyrus	R	6	28	4.37	0.000	8	-2	56
Postcentral Gyrus	L	2	130	4.36	0.000	-56	-26	48
Fusiform Gyrus	R		93	4.36	0.000	38	-38	-18
Superior Frontal Gyrus	L	8	155	4.28	0.000	-20	36	52
Middle Temporal Gyrus	R	39	168	4.27	0.000	58	-68	28
Angular Gyrus	R	39		4.26	0.000	48	-60	26
Insula	R		35	4.24	0.000	44	-22	18
Putamen	L		26	4.05	0.001	-28	-6	-6
Superior Frontal Gyrus	L	10	56	4.05	0.001	-10	64	30
Paracentral Lobule	R	5	31	4.05	0.001	16	-42	50
Cingulate Gyrus	R	31		3.89	0.001	18	-36	44
Medial Frontal Gyrus	L		24	3.97	0.001	-10	58	-14
Cingulate Gyrus	L	31	25	3.88	0.001	-6	-36	40
NG group								
Inferior Frontal Gyrus	L	47	551	5.12	0.003	-46	30	-14
Inferior Frontal Gyrus	L	45		4.58	0.006	-50	30	8
Middle Frontal Gyrus	L	47		4.49	0.006	-38	44	-14
Superior Frontal Gyrus	L	8	97	4.54	0.006	-16	46	44
Middle Temporal Gyrus	L	22	279	4.51	0.006	-62	-8	-6
Superior Temporal Gyrus	L	38		4.37	0.420	-52	14	-26
Posterior Cingulate	L	23	215	4.40	0.007	-4	-56	14
Lingual Gyrus	R	18	42	4.21	0.009	14	-80	0
Middle Frontal Gyrus	L	6	46	4.19	0.009	-44	12	50
Middle Temporal Gyrus	L	22	21	3.89	0.012	-64	-48	2

Note. All the reported areas were set to $p < 0.0001$ uncorrected threshold with clusters greater than or equal to 20 voxels. H: hemisphere; L: left; R: right; p (FDR-corr), p -value with false discovery rate (FDR) correction.

Differences of Brain Activation between Groups

In the between group analysis, compared with the NG group, the GT group was found to have more activation in the word detection condition versus beep detection condition, more brain activation was found in the left posterior cingulate gyrus, left paracentral gyrus, and right postcentral gyrus (see Table 10 and Figure 5); however, only the difference in the posterior cingulate reached significant level ($p < .05$).

Discussion

Gifted Students Outperformed Typically Developing Students in Linguistic Performance

The results of this study showed that gifted students outperformed their typically developing counterparts in most of the linguistic measures. This verifies the advanced verbal development of gifted children (Abraham & Hartwell, 1985; Jackson, 2002; Piirto, 1999). Their precocity is not just manifested by their verbal performance but also at the level of phonological awareness. Gifted students in particular outperformed their typically developing counterparts in the onset awareness task and the onset-rime awareness task, which

Table 9. Brain Regions of Activation for the Word Detection Versus Picture Matching Comparison in the GT Group and NG Group

Brain regions	H	BA	Voxels	Z-score	p (FDR-corr)	MNI coordinates		
						x	y	z
GT group								
Insula	R	13	2466	5.38	0.000	42	16	2
Inferior Frontal Gyrus	L	44	1822	5.18	0.000	-54	8	6
Inferior Occipital Gyrus	L	19	545	5.11	0.000	-44	-84	-8
Medial Frontal Gyrus	R	6	2118	5.08	0.000	14	2	62
Superior Occipital Gyrus	R	19	2401	5.00	0.000	32	-72	30
Inferior Parietal Lobule	L	40	1375	4.99	0.000	-48	-38	52
Supramarginal Gyrus	L	40	548	4.77	0.000	-60	-48	30
Precuneus	L	7	767	4.72	0.000	-20	-72	38
Medial Frontal Gyrus	R	9	86	4.61	0.000	4	50	32
Superior Temporal Gyrus	R	22	547	4.39	0.001	56	-50	12
Middle Temporal Gyrus	L	19	44	4.16	0.001	-54	-66	12
Parahippocampal Gyrus	L		54	4.12	0.001	-30	-4	-20
Cuneus	R		61	4.05	0.001	18	-70	4
Lingual Gyrus	R		20	3.97	0.001	22	-90	0
NG group								
Middle Occipital Gyrus	R	19	25	4.21	0.162	46	-74	-8
Superior Occipital Gyrus	R	19	61	4.16	0.162	32	-92	20

Note. All the reported areas were set to $p < 0.0001$ uncorrected threshold with clusters greater than or equal to 20 voxels. H: hemisphere; L: left; R: right; p (FDR-corr), p -value with false discovery rate (FDR) correction.

Table 10. Differences of Brain Activation under Three Conditions between Groups

Brain regions	H	BA	Voxels	Z-score	p (FDR-corr)	MNI coordinates		
						x	y	z
Word detection > Beep detection								
Posterior Cingulate	L	23	286	3.85	0.020	-8	-58	16
Postcentral Gyrus	R	2	137	3.78	0.091	36	-40	58
Postcentral Gyrus	R	2	29	3.62	0.427	52	-26	32
Paracentral Lobule	L	6	48	3.37	0.304	-8	-30	60

Note. All the reported areas were set to $p < 0.0001$ uncorrected threshold with clusters greater than or equal to 20 voxels. H: hemisphere; L: left; R: right; p (FDR-corr), p -value with false discovery rate (FDR) correction

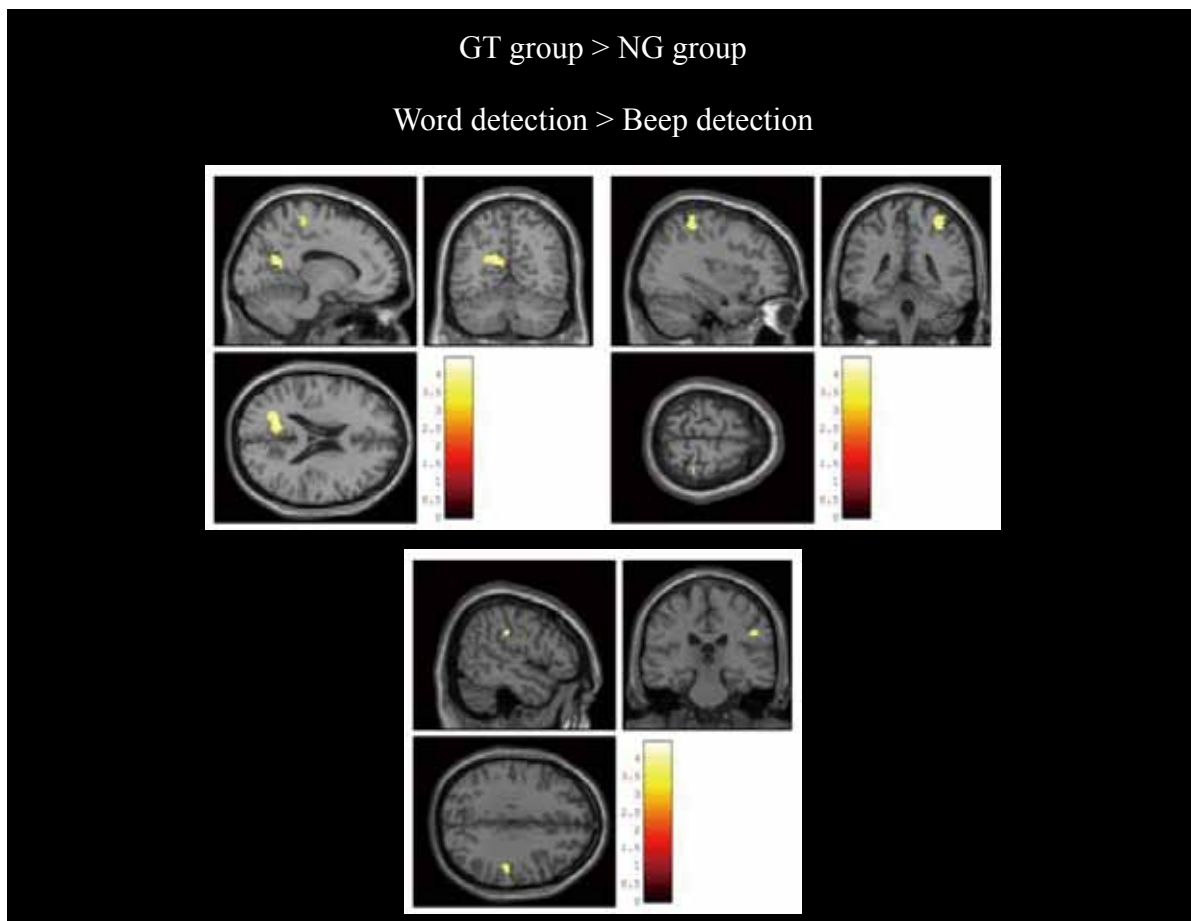


Figure 5. Results of between-group analyses for word detection versus beep detection in the GT group compared to NG group. The activation threshold was set to $p < 0.001$ uncorrected with clusters greater than or equal to 20 voxels.

were assumed to develop as a result of formal instruction (Shu et al., 2008). Shu et al. (2008) reported that rime together with syllable may depend on the maturational age. Accordingly, the fact that the GT group did not do significantly better than the NG group in the Rime Awareness task might be explained by the NG group's maturational development of rime awareness. This can also be explained by the fact that syllable is the smallest unit that can be stretched in speech and that rime is the core component of a syllable (Ladefoged & Johnson, 2014). Especially in the case of Mandarin Chinese, every character is manifested in the form of a syllable. Being able to pick up the core component of each syllable thus is essential in speech comprehension. Besides, given that phonological awareness progresses from larger units such as syllable to smaller units, it is reasonable to say that syllable awareness along with rime awareness is the phonological processing skill that first develops in children. When children are in the third or fourth grade of elementary school, their development of rime awareness may have reached a plateau. As a result, the difference between the two groups is not as big as that in other measures.

On the other hand, when it comes to onset awareness and onset-rime awareness, the GT group outperformed the NG group. Shu et al.'s (2008) findings may explain this. Syllable onset awareness is a phonemic level of phonological awareness, and onset is a smaller unit than a syllable not explicitly perceived in Mandarin Chinese. They also suggest that onset awareness may develop as a result of formal instruction. Generally speaking, GT students learn better than their NG counterparts. Given this, it is understandable that the GT group outperformed their NG counterparts in onset awareness tasks because doing such tasks successfully may rely on how well children learn from the instruction they are given. These findings not only attest to the validity of our tests in assessing the verbal ability but also verify the precocious verbal development of gifted children (Abraham & Hartwell, 1985; Jackson, 2002; Piirto, 1999).

Correlations between Verbal Comprehension Index and Language Performance

Our research found very significant correlations

between Verbal Comprehension Index and linguistic performance. Verbal Comprehension Index derives its scores from Similarities, Vocabulary and Comprehension. However, the correlations among Verbal Intelligence, Reading Comprehension, and Chinese Character Recognition differ from our expectation.

In our research, the score of Similarities correlates with the score of Chinese Character Recognition Test for Graders ($r = .558, p < .01$) higher than with the score of Comprehension Screening Test ($r = .476, p < .01$); the score of Vocabulary correlates with the score of Comprehension Screening Test ($r = .574, p < .01$) higher than with the score of Chinese Character Recognition Test for Graders ($r = .509, p < .01$) (see Table 3).

The results are surprising because the Similarities Test was designed to assess verbal reasoning and the development of concepts (Wechsler, 2004) and thus is supposed to predict the score of Comprehension Test the best. On the other hand, the score of Vocabulary was developed to measure word knowledge and verbal concept formation (Wechsler, 2004) and thus is supposed to predict the score of Chinese Character Recognition Test the best (see Table 4). Besides, the correlation between Comprehension test of VCI with and RCST ($r = .266, p > .05$) didn't reach significant level. Comprehension Test of VCI was developed to measure an individual's ability to understand complex questions and formulate answers (Wechsler, 2004).

The unexpected results of the correlation and step analysis may be due to the following reasons. Verbal Comprehension Index is a measure of an individual's ability to understand, learn and retain verbal information and to use language to solve novel problems (Wechsler, 2004). For example, the Comprehension test asks the individual to answer questions about social and other situations, such as: Why should children not be allowed to work in factories? Therefore, the ability to answer the complex questions may not totally similar to what the ability RCST measures. RCST includes paragraph review and text comprehension. Children are asked to name the topics, find out the synonyms, reason and interpret the writing (Ko, 1999). The Comprehension task of VCI is more related to solving situational problems. In the other

word, Comprehension task of VCI is more intelligent test oriented. Similarly, the score of Vocabulary correlates with the score of Comprehension Screening Test better than with the score of Chinese Character Recognition Test. The reason is that children are asked to explain the word, this requires not only word knowledge but also verbal concept formation and comprehension ability (Wechsler, 2004). The Similarities Test was designed to assess verbal reasoning and the development of concepts (Wechsler, 2004), however, children need to recognize the vocabularies first; thus the score of Similarities predict the score of Chinese Character Recognition Test for Graders better than predicting the score of Comprehension Screening Test. In conclusion, the tasks of the three verbal tests differ from each other, while they vary in content and the specific ability assessed, they are nonetheless all related with verbal ability as indicated by their high correlation with VCI.

The GT Group Recruited More Resources in Both Hemispheres

Previous studies using auditory responsive naming task reported activation in the language related regions, including the inferior gyrus, temporal gyrus, superior temporal gyrus in the left hemisphere in healthy typical developing children (Badcock, Bishop, Hardiman, Barry, & Watkins, 2012; Balsamo et al., 2002; Bookheimer et al., 1998; de Guibert et al., 2011). Our present study has found similar patterns in the NG group, while greater and more extensive activation was found in the GT group.

The brain of the GT group was very active in the right inferior temporal gyrus, right central gyrus, right superior temporal gyrus, and right para-hippocampal gyrus. As we can see, when processing language tasks related to picture matching, the GT group recruited more resources not only in the left hemisphere but also in the right hemisphere. It seems they have a more widespread network activated and ready for any task waiting to be accomplished whether it is a challenging one or not.

More detailed brain regions of activation of the two groups in the picture matching condition are shown in Table 7. Compared with the beep detection condition,

both groups have more activation in the middle temporal gyrus (BA21), which as pointed out in Gierhan's (2013) review study is related to lexical-semantic processing. In the picture matching task, children were to judge whether the objects in the pictures they saw matched the key words in the sentences they heard previously. To successfully accomplish this task, children need to identify the object with a proper name and match the name with words appearing in the sentence previously heard. Apparently a task like this involves a lexical-semantic processing. Dronkers et al. (2004) further suggested that the middle temporal gyrus may play a more important role at the word level in linguistic processing. The result of our study is congruent with what suggested by those authors that the picture matching task engaged children more at the word level than at the sentence level (Dornkers et al., 2004). This is because the key to a correct judgment in the picture matching task is not to comprehend the whole sentence but to identify the object in the picture with a certain word in the sentence. What is different between the two groups is that the GT group demonstrated more activation in both the left and right BA21, while the NG group did not show more activation in the right BA21, suggesting that the GT brain devotes more neural resources to the task by recruiting a network spanning in both hemispheres.

Table 8 shows detailed brain regions of activation of the two groups in the word detection versus beep detection comparison. As can be seen on the table, more extensive brain areas were activated for both groups compared with the picture matching versus beep detection comparison. For the NG group, greater and more activation in the inferior frontal gyrus was found compared with the picture matching versus beep detection comparison. This can be explained by the fact that the word recognition task taxed more cognitive resources as the children were to read the Chinese characters on the slide and reflect if these certain characters appeared in the sentence they heard earlier on. This task may require more linguistic reasoning, and such processing engages the frontal gyrus (Geake, 2008). The GT group, on the other hand, had activation of even more extensive brain regions bilaterally in contrast to the picture matching

versus beep detection comparison. These brain regions are related to syntactic processing (i.e., the MTG), phonological processing (the MFG), linguistic reasoning (i.e., the SFG), and auditory motor mapping (the angular gyrus) (Gierhan, 2013), indicating that the GT group in doing the word detection task had their syntactic, lexical-semantic and phonological processing and auditory motor mapping resources ready. In other words, the linguistic stimulus of Chinese characters may have aroused an extensive network of linguistic reasoning and articulation, making the GT children ever ready for more than word detection.

A further examination of brain regions of activation for the word detection versus picture matching comparison as shown on Table 9 reveals that the GT group processed the two tasks very differently, while the NG group showed potential distinction only in the occipital gyrus that did not reach statistical significance. The brain regions with significantly more activation in the GT group are related to linguistic reasoning, lexical semantic processing, suggesting that the GT brain treated linguistic (i.e., words) and nonlinguistic stimuli (i.e., pictures) differently by recruiting more cognitive resources. These data suggest that the GT brain may be more sensitive to linguistic stimuli than the NG brain. As Kalbfleisch and Gillmarten (2013) mentioned, giftedness or superior general cognitive ability is associated with higher connectivity of brain regions and more hemispheric cooperation.

The PCC Played an Important Role on the word Detection Task in GT Group

In comparison of language processing between groups, the brain of GT activated more in the post cingulate cortex (PCC) on word detection task than on the beep detection task. This region is situated in the medial part of the inferior parietal lobe and lies within the posteromedial cortex, which also includes the precuneus and retrosplenial cortex (Parvizi, Van Hoesen, Buckwalter, & Damasio 2006). The PPC and medial prefrontal cortex (mPFC) form a central node in the default mode network of the brain (Buckner, Andrews-

Hanna, & Schacter, 2008); it also has been shown to communicate with various brain networks simultaneously and is involved in episodic memory. The PCC shows a complex pattern of interaction with other intrinsic networks (Leech, Braga, & Sharp, 2012). It has a central role in supporting internally-directed cognition (Leech & Sharp, 2014). This region is implicated as a key structure for both arousal and awareness (Laureys, Owen, & Schiff, 2004). It plays a more direct role in regulating the focus of attention (Gusnard & Raichle, 2001); its activity varies with the arousal state, and its interactions with other brain networks may be important for conscious awareness. When gifted students were carrying out the word detecting task, they may retrieve their episodic memory and simultaneously activate their arousal state more than their regular peers. Basically this suggests that gifted students are more alert and their brain networks are more engaged in processing complex tasks.

Conclusion

The present study examined phonological awareness of gifted children and typically developing children and their brain activation in processing language tasks. In comparing phonological awareness of the two groups, it was found that the GT group outperformed the NG group in onset awareness and onset-rime awareness, but not in rime awareness. Such results are congruent with Shu et al.'s (2008) results and support the assumption that rime awareness depends on maturation age while onset awareness develops as a result of formal instruction. We may assume that ten-year-old Mandarin speaking children might have reached a plateau regarding rime awareness. On the other hand, the development of onset awareness relies more on formal instruction, on which the gifted children have an advantage over the typically developing children. Thus their better performance in onset awareness and onset-rime awareness is explained.

In comparing brain activation of the two groups in processing language tasks, we found greater and more extensive bilateral activation in the GT group than in the NG group. It should be noted that the neuro-imaging data are correlative and thus the relation between structure and

function is simply indirect as other cognitive functions than what proposed in this study may as well activate these specific cortical regions. Bearing this caveat in mind, we may suggest that the GT brain appears to be more sensitive to linguistic stimuli than the NG brain. Our results indicate that the GT group would recruit more neurocognitive resources in both hemispheres during language processing. In other words, compared with the average brain, the gifted brain instead of conserving energy, devotes itself more in processing language.

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資優生與一般生語言處理時大腦功能差異比較

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語言能力是兒童學習與識字發展的基礎，早熟的語言發展和閱讀更是資優典型的特質。為能更瞭解資優兒童語言處理與一般兒童的差異，22位國小資優學生與18位一般學生參與本研究。評量工具包括：魏氏兒童個別智力量表第四版、閱讀理解篩選測驗、中文識字測驗、自編音韻知覺測驗（含聲調知覺、聲母知覺、與聲母—韻母知覺）、及自編聽覺反應命名的功能性磁性造影作業（含圖片配對、語詞偵測與嗶音偵測）。研究結果顯示資優組在個別智力量表、閱讀理解測驗及識字測驗得分均顯著優於普通組；在音韻知覺測驗部分，資優組在聲調知覺與聲母知覺測驗得分均顯著優於普通組，唯獨在韻母知覺測驗中，差異未達顯著水準。另外魏氏智力全量表及語文理解指數與各個語文測驗間相關多達到顯著水準，唯獨與聲母—韻母知覺測驗分數相關未達到顯著水準。逐步回歸分析結果顯示語文理解指數對於各個語文測驗的預測能力良好。在大腦活化影像掃描方面，聽覺命名作業施測結果顯示，資優組在處理語詞偵測作業時的大腦活化較普通組學生強，且活化範圍廣泛涉及語文處理相關腦區，同時左右腦並用；普通組學生在不同作業的比較則顯示單側活化較明顯。組別間的差異比較顯示資優組在語詞偵測作業中，後扣帶迴較普通組活化。

關鍵詞：聽覺命名作業、大腦功能、資賦優異、音韻知覺、語言處理