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THE DEVELOPMENT OF PHONOLOGICAL REPRESENTATIONS AMONG CHINESE-SPEAKING CHILDREN*

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ABSTRACT

Two experiments were conducted to test the hypothesis that implicit and explicit phonological representations of Chinese-speaking children undergo restructuring with reading experience. Implicit representations refer to those that are automatically handled by the language module; explicit representations refer to those that are explicit control units in speech manipulation. Experiment I studied the restructuring process among a group of pre-schoolers who had little knowledge of printed words when they were first tested. Experiment II studied a group of novice readers from the beginning of the first grade until the end of the third grade. The results revealed that children's memory errors contained more errors in transposing subsyllabic units available in the stimulus strings than errors in misordering entire syllables. The proportion of transposition errors increased significantly from the pre-school age to the first grade and was related to the rapid increase in the children's ability to read *Zhuyin fuhao*. The developmental sequence of explicit representations parallels that of implicit representations in that pre-schoolers could not cope with the phonological awareness task at the subsyllabic level at a time before they could demonstrate any ability in reading whereas first-grade children demonstrated fundamental control over the task. Children's performances on phonological awareness were related to *Zhuyin fuhao* reading ability at the last testing session of the pre-school age and continued to be evident till the third grade. Though parallel in developmental sequence, there was no evidence that the development of explicit representations depended on the development of implicit representations. The

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notion of modularity was adopted to account for the gap between the developments.

1. INTRODUCTION

Recently, there has been growing interest in the relationship between phonological ability and early reading ability in Chinese (Ho & Bryant, 1997, 2000; Hu & Catts, 1998; Huang & Hanley, 1995; Siok & Fletcher, 2001). Most research has found a measurable relationship between children's ability to process the phonological component of the language and their ability to learn to read the Chinese alphabet or Chinese characters. However, very few studies have been concerned with how the two abilities are related developmentally. The interpretation of the relationship tends towards the conclusion that phonological ability plays an important role in the development of Chinese reading ability. The reverse direction of the influence, i.e., the potential of reading experience in setting stages for the development of phonological awareness, has often been recognized but seldom elaborated.

The issue is further complicated by the fact that phonological ability is not a single, homogeneous ability. From a developmental point of view, it is necessary to make a distinction between implicit and explicit phonological representations. The more *implicit phonological representations* refer to those that are unconsciously or automatically handled by the language module during speech perception and production. This can be measured by tasks which do not require an individual to break up the speech stream, such as recall of syllable lists, where participants' recombination errors may reveal how phonological representations are implicitly structured (Geudens & Sandra, 2003). The more *explicit phonological representations* refer to those that are explicit, accessible control units in speech processing, such as the segments used in isolating and manipulating for decoding novel words.

1.1 Implicit Representations

It has long been assumed that a speaker's implicit phonological representations are organized at the phonemic level at the very start. However, evidence is emerging that implicit phonological representations undergo growth and change among speakers of an alphabetic language (Ferguson, 1986; Studdert-Kennedy, 1987; Studdert-Kennedy & Goodell,

1995; Walley, 1993). Children's early phonology is not, as is often assumed, represented in a subsyllabic form of phonemes, but are instead represented as holistic patterns of interacting elements such as features, gestures or articulatory routines corresponding to syllables, which only become more segmental with age (Browman & Goldstein, 1989; Nittrouer, Studdert-Kennedy, & McGowan, 1989; Stemberger, 1989).

Exactly what drives phonological representation to be more segmental is unclear. One view asserts that the development is driven by vocabulary growth, i.e., by the need to discriminate a growing number of lexical items quickly and accurately (Fowler, 1991; Metsala, 1999; Storkel, 2003; Walley, 1993). Yet it is hard to see why it takes normal children so long to develop phonological representations with phoneme-size segments considering the many minimal pairs in the expressive vocabularies of children as young as three years old (Elbro, 1996). The other view assumes that the segmental course is partly driven by reading experience (Elbro, 1996; Morais & Kolinsky, 1995). Studies have shown that the phonological output in non-readers and poor readers is usually variable and underspecified, in which only the overall phonological shape or the most salient features are handled (Cornelissen, Hansen, Bradley, & Stein, 1996; de Gelder & Vroomen, 1991; Katz, 1986). This is also true when speech recognition data is considered. For example, Morais et al. (1987) found that illiterates, semi-literates, and literates made different types of errors in a dichotic listening task, with illiterates making proportionally fewer single-segment errors (such as giving *pano* for *cano*) and more global errors (such as *dono* for *cano*) than literates and semi-literates.

1.2 Explicit Representations

Echoing the findings in implicit phonological representations, researchers have found that children’s explicit representations of phonology develop from a more syllabic level to a more segmental level (e.g., Liberman et al., 1974; Stanovich, Cunningham, & Cramer, 1984). Explicit phonological awareness has been found to relate a wide variety of language learning abilities, such as naming objects and pictures (Wolf & Bowers, 1999), holding verbal information in working memory (Brady, 1991), perceiving fine speech distinctions (Adlard & Hazan, 1998), and learning new words (de Jong, Seveke, & van Veen, 2000; Hu, 2003). The exact nature of the transition from implicit to explicit control of the phonemes is not fully known. Basically, two views have been put forth.

One asserts that explicit awareness of phonemes does not develop spontaneously during the normal course of linguistic development but only in the specific context of learning to read an alphabetic script (Morais, Cary, Alegria, & Bertelson, 1979; Morais et al., 1987). The ability to explicitly manipulate the sounds of spoken language is, to a greater or lesser degree, an index of orthographic skill developed from reading (Castles & Coltheart, 2004). The other view assumes that phonemic awareness can be developed without reading instruction if adequate training is provided (Lundberg, 1991).

1.3 The Representations of Chinese-Speaking Children

What implications do these studies have on the development of phonological representations among Chinese-speaking children? For implicit phonological representations, most researchers in the literature based on alphabetic languages propose that representations based on thousands of syllables function less efficiently than the representations based upon dozens of phonemes (Fowler, 1991; Studdert-Kennedy & Goodell, 1995). Given that Chinese is a syllabic language with very simple syllabic structures (mostly CV) and a limited number of syllables, theoretically, not too much economy will be achieved by a segmental representation over a syllabic representation. This raises the question as to whether the implicit phonological representations of Chinese-speaking children undergo segmentation as well. Does reading experience facilitate the segmentation development of Chinese speakers?

For explicit representations, a similar question can be asked as to whether Chinese-speaking children attain an explicit control over manipulating subsyllabic units of speech sounds with reading experience. One line of evidence suggests that for Chinese speakers, explicit representations develop in and only in the alphabetic experience. For example, Read, Zhang, Nie, and Ding (1986; see also Cheung, Chen, Lai, Wong, & Hills, 2001) found that Chinese speakers who knew only the traditional logographic system had greater difficulty in phoneme deletion than those who knew that system and also knew the pinyin alphabet, suggesting that the ability to delete phonemes depended on the knowledge of pinyin. However, because the non-alphabetic literates were 16 years older in age and had received fewer years of education than the alphabetic literates, the differences could be a result of some other factors. More importantly, some non-alphabetic literates had non-negligible scores in

the phoneme deletion task.

The other line of evidence suggests that phonological representations for explicit control can grow spontaneously among Chinese speakers. This evidence comes from some examples of Mandarin-based "secret languages". Secret languages are a form of word play, in which phonological structure is manipulated by deleting, replacing, or reversing certain phonological units. Data on secret languages predates the use of the pinyin alphabet (Chao, 1931; Yip, 1982). In one of the Mandarin-based secret languages, *ma* 'mother' becomes *may-ka*, *pey* 'north' becomes *pay-key*, and *hwey* 'meeting' becomes *hway-kwey*. It has been suggested that Mandarin-based secret languages involve manipulations of C- and V-sized units of syllables (Yip, 1982; see also Bao, 1990), indicating an awareness of the segments of the language. Other researchers such as Morais (1991), however, pointed out that secret language might involve intentional control of the articulatory gestures without involving the conscious manipulation of the segments in a syllable. Thus, the precise nature of how Chinese-speaking children develop an explicit control over the segmental units of their speech is still unresolved.

To address these issues, two experiments were conducted to examine the nature of implicit and explicit phonological representations of Chinese-speaking children before and after reading instruction commenced. The first experiment examined the role of reading on the development of phonological representations among a group of pre-schoolers, who had little knowledge about printed words in Chinese. The second experiment examined the development of phonological representations among a group of first-graders, who had already learned to read words printed in *Zhuyin fuhao* and Chinese characters when they were tested. The second experiment was part of a three-year longitudinal study, which examined the causal/reciprocal relationship between phonological abilities and early word reading abilities in Chinese. The two developmental experiments with participants from different age groups could provide valuable information concerning the effects of reading experience on the development of phonological representations.

2. EXPERIMENT ON PRE-SCHOOLERS

2.1 Method

Participants

Fifty-eight children in two pre-schools participated in the study. One pre-school was located in a suburb of the Taipei City and the other was in Taojuan County. The children were first tested when they were 57.1 months old (SD = 3.8; Ranges 50-63 months), and they were followed up for another year with the same set of tasks. According to classroom teachers, the children had not and were not receiving special attention due to speech or hearing problems. These children were first tested in January and again in June/July of the school year. At each time of testing, each child was tested individually in a quiet area in the school.

Tasks and Procedure

Phonological memory. Each child was given a list of three bisyllabic pseudowords for recall. Each of the six syllables was constructed by combining one of the six consonants *b, d, k, g, zh, sh* with one of the six vowels *u, a, ai, au, an, ang*. These consonants and vowels can be freely combined with each other without violating the phonological rules of Mandarin. Two syllables were combined into a bisyllabic pseudoword and each pseudoword was assigned a tonal structure. None of the successive syllables in a pseudoword were assigned Tone 3. Pseudowords were used because they had to be maintained and processed in memory with little lexical support. None of the three bisyllabic pseudowords in each trial was assigned the same tonal structure. For example, if a pseudoword in a trial had a tonal structure with Tone 4 for the first syllable and Tone 3 for the second, neither of the other two pseudowords in the same trial would have the same structure of tones. This would allow for an examination of whether the child kept the tonal structure of the pseudowords even when he or she made errors in segments.

There were a total of six trials preceded by two practice trials, during which the child repeated the bisyllabic word first one by one, then three together in a sequence, and the experimenter documented any pronounced articulatory errors. The child's responses were audio-recorded and were later transcribed by two independent college graduates. The child’s performance was scored in terms of the number of errors made in the task.

An error was a syllable which was either incorrectly recalled or was recalled in an incorrect position (Max = 6 x 6 trials).

Syllable substitution. The child was asked to change a syllable in a given word. For each trial, the child was presented with a bisyllabic word containing the syllable /feng/ and the child had to replace the /feng/ with a /dou/. The task was given a context by the introduction to the child of a stuffed toy, who had invented a secret language and always said /dou/ instead of /feng/. The child was asked to repeat what the toy said instead of the given word. There were 20 test trials with 10 requiring the substitution of the first syllable and 10 requiring the substitution of the second syllable.

Vowel substitution. The child was asked to change a vowel in a given monosyllabic word. For each trial, the experimenter provided a monosyllabic word containing the vowel /a/ and the child replaced the /a/ with an /u/. This task was introduced by another different stuffed toy, who had also invented a secret language and always said /u/ instead of /a/. The child had to repeat what the toy said instead of the given word. There were ten test trials preceded by three practice trials.

Sound detection. The sound detection task required the child to identify a target sound /a/ in a syllable such as /da/ or /fei/. This task was expected to put a less heavy strain on the child's cognition than the vowel substitution task. An awareness of the similarity of the acoustic features of the two syllables /a/ and /da/ is sufficient for a response to come out right in the sound detection task. This task was included in the hope that a more incipient or primitive phonological awareness could be detected. There were ten test trials preceded by three practice trials.

Symbol Recognition. In this task, the child read a list of ten *Zhuyin fuhao* symbols. Children who failed to correctly name half of the symbols were not required to take the alphabetic word reading task, which was expected to pose great difficulty to them.

Alphabetic word reading. In this task, the child read word-like materials written in *Zhuyin fuhao*. The fact that a "word" written in *Zhuyin fuhao* symbols corresponds to a large number of homophones did not pose a problem to the study because this task was aimed to measure the child's ability to break the printed code rather than to access the meaning. There were 12 real words and 10 pseudowords that do not occur in Mandarin Chinese but that are allowed in the language such as *pou* (Wang, 1994). The presentation of real words preceded that of pseudowords. The child was required to initiate a correct verbal response to each word/pseudoword within 10 seconds of its appearance.

Native vocabulary. The Chinese version of the Peabody Picture Vocabulary Test-Revised (PPVT-R) was used to measure the child's receptive vocabulary of the native language. The test was included to evaluate the hypothesis that the segmentation of phonological representations is driven by the growth of vocabulary. The PPVT-R consists of a series of 175 plates, each containing four line drawings of objects or actions. For each plate, the experimenter provided a stimulus word orally. The child was asked to respond by pointing to the line drawing on the plate that best illustrated the meaning of the stimulus word.

2.2 Results

Implicit Representations

Fifty-eight children completed the tasks at in Testing Session 1 (T1). Three had moved to other communities before T2 and another seven had left the pre-schools before T3. A small number of children were excluded from the analyses of phonological memory either because their erroneous responses were unintelligible murmurs or because they gave correct responses only and avoided the syllables of which they were not sure. Means and standard deviations of the major variables and the number of the subjects are presented in Table 1.

As shown in Table 1, the pre-school children could read, on an average, 2.31 (out of 10) *Zhuyin fuhao* symbols when they were first tested. Regardless of whether they had some knowledge of *Zhuyin fuhao* symbols, virtually none of the children could read words written in *Zhuyin fuhao*, indicating that the participants had certain knowledge of *Zhuyin fuhao*, but only to the extent of naming individual symbols. At T2, the pre-school children started to demonstrate some incipient ability to read words written in *Zhuyin fuhao* (1.1 out of 10 on an average), but 83.6% of the children still scored zero on the task. The percentage of children scoring zero on the alphabetic word reading task dropped sharply to 35.4 at T3 and further to 14.6 at T4. Children's performances improved significantly from T1 to T4 both on symbol recognition ($F(3, 135) = 90.9$, $p < .001$) and on alphabetic word reading ($F(3, 135) = 40.1$, $p < .001$).

Table 1
Means and Standard Deviations of Tasks Administered to Pre-schoolers

Measures	Testing Sessions	Mean	SD	N
Symbol recognition	T1	2.31	3.18	58
	T2	3.31	3.94	55
	T3	7.08	2.79	48
	T4	8.56	1.61	48
Alphabetic word reading	T1	.00	.00	58
	T2	1.11	3.37	55
	T3	4.73	5.99	48
	T4	8.83	7.04	48
PPVT raw score	T1	37.86	11.36	58
	T2	42.45	9.57	55
	T3	45.38	11.16	48
	T4	54.71	12.79	48
Phonological memory errors	T1	3.52	.89	49
	T2	3.29	.78	49
	T3	3.06	.96	44
	T4	2.97	1.09	46
Syllable substitution	T1	3.60	5.65	58
	T2	5.98	5.99	54
	T3	11.40	7.20	48
	T4	15.23	6.47	48
Sound detection	T1	5.67	2.39	58
	T2	6.78	2.11	55
	T3	7.02	2.15	48
	T4	7.77	1.78	48
Vowel substitution	T1	.14	1.05	58
	T2	.04	.19	54
	T3	.50	1.88	48
	T4	.90	2.63	48

In order to understand the nature of children's implicit phonological representations, their errors in the memory task were subject to four categories for analyses: (1) segmental transposition (TRANS) — the syllable formed by recombining the consonants and the vowels available in the stimulus string; (2) entire syllable misordering (MISORD) — the syllable recalled in the wrong position of the stimulus string but having correct phonological shape; (3) substitution (SUBS) — the syllable

containing consonants or vowels not in the stimulus string; (4) omission (OMIT). Table 2 presents examples of each error category.

Table 2
Examples of Error Categories

Error type	Target	Examples of errors
TRANS	*shao^{1}ga^{1} ban^{4}zhu^{4} kang^{1}dai^{3}*	***sha^{1}gao^{1}*** *ban^{4}zhu^{4} kang^{1}dai^{3}*
		gao^{1}sha^{1} *ban^{4}zhu^{4} kang^{1}dai^{3}*
	zhan^{4}da^{1} shu^{4}gao^{3} bai^{1}kang^{4}	*zhan^{4}da^{1} shu^{4}**kao^{3}** bai^{1}**gang^{4}***
MISORD	*ga^{1}shao^{3} bang^{4}ku^{3} dan^{3}zhai^{1}*	***bang^{4}****shao^{3}* ***ga^{1}****ku^{3}* ***ga^{3}****zhai^{1}*
	ba^{3}gan^{1} zhao^{1}dai^{3} ku^{4}shang^{4}	*ba^{3}**dai^{1}** zhao^{1}**gan^{3}** ku^{4}shang^{4}*
SUBS	*ga^{1}shao^{3} bang^{4}ku^{3} dan^{3}zhai^{1}*	*ga^{1}shao^{3}* ***mai^{4}****ku^{3}* ***mai^{3}chai^{1}***

Note. TRANS = errors of segmental transposition; MISORD = errors of entire syllable misordering; SUBS = errors of substitution; OMIT = errors of omission; 1 = level tone; 2 = rising tone; 3 = falling-rising tone; 4 = falling tone

Proportions of each error category rather than absolute number of errors were examined because the children did not make equal number of errors. The assumption underlying this analysis is that error categories reflect different phonological representations or the extent the various representations are used. If the Chinese syllable is a cohesive unit and the segments of a syllable are well integrated, we expect to find relatively more MISORD errors. If, on the other hand, each segment is relatively independent of all the others, we expect to see more TRANS errors. Table 3 presents the proportions of error categories at each testing session. As shown in Table 3, the predominant type of errors was TRANS. The proportions of TRANS errors increased significantly from T1 to T4 ($F(3, 96) = 6.8$, $p < .005$) whereas proportions of MISORD errors did not differ from T1 to T4 ($F(3, 96) = 1.1$, $p > .05$). The proportion of SUBS errors differed from T1 to T4 ($F(3, 96) = 3.6$, $p < .05$) but no general tendency to either an increase or a decrease was detected. Errors of OMIT decreased significantly ($F(3, 96) = 6.74$, $p < .001$).

The decrease of OMIT errors made the increase of TRANS errors open to at least two interpretations. First, the increase of TRANS errors might have reflected a gradual segmentation process of the phonological representations in the children. Second, the increase of TRANS might

well just be another facet of the decrease of the occurrence of OMIT errors. OMIT errors decreased proportionally because the functional capacity of memory increased, not because phonological representations underwent qualitative changes. As such, a large portion of errors originally shared by the OMIT category shifted to the TRANS category, making the number of errors in the latter increase in proportion. To disentangle the segmentation hypothesis from the functional capacity hypothesis, the proportions of each error type were adjusted by dividing the number of a particular error type by the sum of the TRANS, MISORD, and SUBS, excluding OMIT. The means and standard deviations of the adjusted proportions are displayed in the second part of Table 3. After being adjusted, the proportion of TRANS errors still demonstrated an incremental trend of development from T1 to T4 ($F(3, 96) = 3.1$, $p < .05$).

Table 3
Proportions of Error Categories (Standard Deviation) for Pre-schoolers

%	TRANS	MISORD	SUBS	OMIT
T1	53.5 (19.2)	11.3 (8.5)	12.9 (11.1)	22.6 (22.2)
T2	57.9 (17.7)	11.0 (9.1)	15.7 (11.3)	15.4 (18.5)
T3	64.8 (17.2)	13.7 (8.7)	12.9 (9.3)	8.8 (13.2)
T4	70.0(14.2)	12.0 (8.7)	10.2 (9.1)	8.1 (9.8)
Adjusted proportions				
T1	69.0 (13.3)	15.1 (10.8)	15.9 (12.5)	--
T2	68.7 (14.3)	13.0 (10.8)	18.3 (12.7)	--
T3	70.2 (15.9)	15.3 (10.2)	14.6 (11.9)	--
T4	75.7(12.3)	13.2 (9.5)	11.1 (9.8)	--

Note. TRANS = errors of segmental transposition; MISORD = errors of entire syllable misordering; SUBS= errors of substitution; OMIT = errors of omission

It has been suggested that segmental restructuring of phonological representations of a word begins with the spurt in vocabulary growth in late infancy and extends over the pre-school years (Walley, 1993). Walley, however, did not specify whether it is the overall vocabulary size or the spurt of the vocabulary (frequent and rapid additions to the lexicon) that drives the segmentation process. Correlational analyses revealed that children's TRANS errors were not correlated with their PPVT raw scores at any time of testing (all $p > .05$). Nor was the amount of the increase in

TRANS correlated with the amount of the increase in PPVT raw scores (all $p > .05$).

To investigate the relationship between segmental restructuring and reading in the present study, correlational analyses were performed on TRANS and children's *Zhuyin fuhao* reading abilities. Results of the analyses revealed that the proportion of TRANS was not correlated with scores in symbol recognition (all $p > .05$). TRANS and alphabetic word reading were not significantly correlated at T2 and at T3, but the correlation reached the significant level at T4 ($r = .38$, $p < .01$) and remained evident after controlling for PPVT raw scores ($r = .37$, $p < .05$).

Also related to our understanding of the role of reading on segmental restructuring is whether the "spurt" in reading ability is related to the "growth" in segmental restructuring. The amount of increase in reading ability was calculated by the combined *z* scores of the increases in symbol recognition and in alphabetic word reading. The combined reading scores were not correlated with the amount of increase in TRANS from T1 to T2 or from T3 to T4. However, the relationship was significant from T2 to T3 ($r = .42$, $p = .01$), a period during which rapid growth in reading ability was observed (see Table 1). Furthermore, the correlation remained evident even after controlling for the amount of increase in PPVT raw scores during the same period ($r = .42$, $p = .01$).

Finally, there was indication that a more segmental representation was a more efficient representation for verbal memory performance, as evidenced by the negative correlation between the proportions of TRANS errors and the total number of memory errors at T4 ($r = -.52$, $p < .001$).

Explicit Representations

As shown in Table 1, children's performances in syllable substitution increased significantly from T1 to T4 ($F(3, 132) = 64.3$, $p < .001$). The percentage of children who scored zero on syllable substitution dropped from 53.4 at T1 to 8.4 at T4. Their performances in sound detection also improved from T1 to T4 ($F(3, 132) = 8.4$, $p < .001$). 5.2% of the children scored zero on the sound detection task at T1 and none at T4. In contrast to performance on syllable substitution and sound detection, vowel substitution appeared to pose great difficulty. Although the average scores on vowel substitution increased with age, the increase was not significant ($F(3, 132) = 2.1$, $p > .05$). Furthermore, 98.3% of children scored zero on the vowel substitution task at T1 and a substantial 85.4% scored the same

at T4.

As to the role of reading in the development of explicit phonological representations, correlational analyses revealed that children's alphabetic word reading was not related to syllable substitution at all testing sessions (all *p*s > .05). It was, however, related to sound detection (r = .45, p = .001) and vowel substitution (r = .31, p < .05) at T4, but not at earlier testing sessions. These results were similar to those for implicit representations: not until at T4 was the correlation between alphabetic word reading and proportions of TRANS statistically significant. Children's ability to read *Zhuyin fuhao* symbols was not related to syllable substitution or vowel substitution. It was related to sound detection at T4 (r = .31, p < .05) and at T3 (r = .28, p =.05).

To seek to understand the relationship between the development of implicit representations and that of explicit representations, correlational analyses were performed on phonological awareness measures and proportions of error types in memory. If the segmentation process of implicit representations had set the stages for the development of explicit representations, then we should be able to see children's performances on the measures of the two variables (i.e., proportions of error types in memory and phonological awareness) were correlated. The results showed that children's performances on the phonological awareness tasks, including syllable substitution, sound detection, and vowel substitution, were not related to the proportions of TRANS errors. The only exception was that children's performance on syllable substitution was related to the proportions of TRANS errors at T1 (r = 40, p < .01). These results suggested that the development of explicit phonological representations was not contingent upon the development of implicit phonological representations.

3. EXPERIMENT ON FIRST-GRADERS

3.1 Method

Participants

Seventy-two first-graders were recruited from five classrooms in a predominantly middle-class elementary school in Taipei. Fifteen children moved to other neighborhoods during the following two years of the study, leaving a total of 57 children completing the study. According to

classroom teachers, the children did not have any evidence of neurological damage, emotional problems, or sensory deficits. The children also had no history of articulation or language impairments. These children were tested individually in November and in April of the first two academic years and in April of the third.

Tasks and Procedure

Phonological memory. The task was the same as the memory task administered to the pre-school children, allowing for a direct comparison across groups. The only difference was that there were ten trials for the first-graders.

Phonological Awareness. The task was not the same as those used for pre-schoolers because it was not originally designed to be comparable to the study on pre-schoolers. In the task, the child had to choose from a set of three words (e.g., *jia*, *xia*, *hua*) the word that sounded differently from the others (*hua*). There were sixteen test trials. Half of the trials required the child to contrast the stimulus words according to their onset consonants. The other half required the child to contrast the stimulus words according to their rimes.

Alphabetic word reading. In this task, the child read a list of 60 monosyllabic words written in *Zhuyin fuhao*. Twenty-four of the words were familiar to young children and another 24 words were less familiar. The remaining 12 words were pseudowords.

3.2 Results

Means and standard deviations of the tasks are presented in Table 4. The mean number of memory errors decreased from 2.77 at T1 to 2.17 at T5 ($F(4, 224) = 10.1$, $p < .001$), indicating an improvement in children's pseudoword memory. Children's performances on the phonological awareness task also improved from T1 to T5 ($F(4, 224) = 15.4$, $p < .001$). In contrast to the incremental trend of development on phonological memory and phonological awareness, the trend of development on alphabetic word reading was less obvious ($F(4, 224) = 2.42$, $p = .05$).

Table 4
Means and Standard Deviations of Tasks Administered to First Graders

Measure	Testing Sessions	Mean	SD
Phonological memory errors	T1	2.77	1.02
	T2	2.39	1.00
	T3	2.39	.92
	T4	2.23	1.10
	T5	2.17	1.14
Phonological awareness	T1	7.72	2.28
	T2	7.44	3.10
	T3	8.14	2.92
	T4	8.89	2.76
	T5	10.35	3.27
Alphabetic word reading	T1	49.95	7.37
	T2	48.79	8.30
	T3	48.67	7.37
	T4	50.30	6.24
	T5	48.39	7.78

Implicit representations

To seek to understand the development of implicit phonological representations among first-graders, children's memory errors were subject to four categories as depicted earlier for pre-schoolers. Table 5 shows that the predominant type of error was TRANS. The second most frequent type of error was MISORD, but in much smaller proportions than for TRANS. SUBS and OMIT together, accounted for less than 10% of the errors at all testing sessions except at T1.

When errors were viewed developmentally, the proportion of TRANS errors increased significantly from T1 to T2 ($t(56) = 2.9$, $p < .01$), the very initial stages of reading acquisition, and stayed at approximately the same level thereafter ($t(56) = .25$, .63, and .34 for T2-T3, T3-T4, and T4-T5, respectively, all $p > .05$). On the other hand, the proportion of MISORD errors decreased significantly from T1 to T2 ($t(56) = 2.7$, $p = .05$) and then stayed at roughly the same level from T2 to T4 ($t(56) = 1.2$, $p > .05$ from T2 to T3; $t(56) = 1.4$, $p > .05$ from T3 to T4), and increased from T4 to T5($t(56) = 3.3$, $p < .01$).

Table 5
Proportions of Error Categories (Standard Deviation) for First-Graders

%	TRANS	MISORD	SUB	OMIT
T1	75.7 (21.4)	10.3 (8.6)	3.3 (5.2)	10.8 (19.9)
T2	84.3 (9.7)	6.7 (7.2)	4.8 (4.9)	4.2 (7.8)
T3	84.5 (13.9)	8.3 (7.1)	5.0 (11.0)	2.6 (6.5)
T4	85.9 (9.9)	6.5 (6.5)	4.8 (6.3)	2.8 (7.3)
T5	85.3 (10.9)	11.1 (8.7)	3.1 (4.6)	0.7 (2.0)
Adjusted proportions				
T1	84.4 (13.8)	11.5 (10.1)	4.1 (9.1)	--
T2	88.1 (7.8)	7.0 (7.4)	4.9 (5.0)	--
T3	86.4 (13.1)	8.4 (7.2)	5.1 (11.5)	--
T4	88.4 (8.0)	6.8 (6.7)	1.8 (6.3)	--
T5	85.7 (10.7)	11.2 (8.7)	3.2 (4.6)	--

Note. TRANS = errors of segmental transposition; MISORD = errors of entire syllable misordering; SUB = errors of substitution; OMIT = errors of omission

The adjusted scores displayed a similar pattern of development as the unadjusted scores, with errors of TRANS increasing from T1 to T2 ($t(56) = 2.0$, $p < .05$), but with no differences observed at other adjacent points ($t(56) = .9$. 1.0, and 1.5, for T2-T3, T3-T4, and T3-T5, respectively, all $p > .05$).

Correlational analyses were performed to investigate the relationship between the segmental level of phonological representations and reading. The results showed that the concurrent correlations between the adjusted proportions of TRANS errors and alphabetic reading ability were significant at T1 ($r = .45$, $p < .001$) and at T2 ($r = .35$, $p < .01$), though not thereafter (all ps $> .05$). Of particular interest was that the proportion of TRANS measured at T1 was also related to subsequent alphabetic word reading ability measured at T2, T3, T4, and T5 (r ranged from .36 to .49).

Errors children made in the memory task were negatively correlated with the proportions of TRANS errors at all testing sessions, except at T4 (r = -.28, -.29, -.56, and -.43 at T1, T2, T3, and T5, respectively, all $p < .05$).

Explicit Representations

In reference to Table 4, children's performance on the phonological awareness task improved from T1 to T5 ($F(4, 244) = 15.41$, $p < .001$). At all testing sessions, children's performances on the phonological awareness task were better than the chance level (all *p*s < .001). Children's phonological awareness scores were correlated with their alphabetic word reading ability at all testing sessions except at T2 ($r = .33$, .30, .32, and .42 at T1, T3, T4, and T5, respectively, all $p < .05$). However, their phonological awareness scores were not correlated with the proportions of TRANS measured at the same testing session ($r = .10$, .02, .06, -.11, and .04 at T1, T2, T3, T4, and T5, respectively, all $p > .05$), indicating that the two phonological representations might have developed independently along two different courses.

Compared with the pre-schoolers, the first-graders did not seem to have superior performance on the phonological memory task measured at T1 than the pre-schoolers' performance measured at T4 ($t(94.4) = .84$, $p > .05$). However, the nature of errors differed between the two groups ($X^2(2) = 55.3$, $p < .001$). Compared with pre-schoolers, first-graders made proportionally more TRANS errors ($t(100) = 3.37$, $p = 001$) but fewer SUBS errors ($t(93) = 3.74$, $p < .001$). The proportions of MISORD errors did not differ between these two groups of participants ($t(98.6) = .84$, $p > .05$).

Finally, related to our understanding of the nature of phonological representations in Chinese-speaking children is the question as to whether the tonal features are well integrated with the segments in a syllable. If the tonal features and the segments are well integrated, it is expected that tonal features will be wiped out and changed when the content of the segments changes. Yet, the results showed that most of the memory errors preserved the tonal structure of the stimulus string (e.g., one child recalled *chuan*^{2}*guo*^{3} ***mian***^{4}***tuei***^{1} *shi*^{4}*shuei*^{3} for *chuan*^{2}*guo*^{3} *mu*^{4}*tian*^{1} *shi*^{4}*shuei*^{3}). The errors that preserve the tonal structure of the target strings ranged from 84% to 89% for first-graders and 72% to 85% for pre-schoolers. These results suggest an autonomous status for the tonal features in the memory of Chinese.

4. DISCUSSION

The study investigated the developmental changes of phonological representations among Chinese-speaking children and the role of reading experience on such changes. Three questions were asked. First, how do the implicit phonological representations unfold before and after reading instruction commences? Second, how do the explicit, conscious representations used in speech manipulation develop? Third, how do implicit and explicit phonological representations interact in relation to reading experience?

4.1 The Development of Implicit Phonological Representations

In the analyses of the memory errors, we found that when recalling failed, Chinese-speaking children were more likely to recombine the consonants and vowels available in the stimulus string than to move the entire syllable around. This was true for both the pre-schoolers and the first-graders. If the Chinese syllable is an intact, cohesive processing unit, we should have observed that the phonological shapes of the syllables were well preserved even when they were not recalled in the right position. Yet, the results showed that the syllables wrongly recalled were mostly constructed by the segments available in the stimuli, but the segments were not linked cohesively as a syllable in a way such as they were in the original stimuli. Therefore, even though Chinese has very simple syllabic structures and a limited number of syllables, the syllable does not appear to be the only processing unit available in memory. Representations at the subsyllabic level are also available to Chinese-speaking children as young as 5 years old given that 69% of their memory errors were segmental transposition errors.

Does reading experience play a role in the restructuring process of the implicit phonological representations? The results of the present study indicate that reading experience is not the initiator of the restructuring process. A large portion of children's memory errors was related to segmental transposition at the time at which they displayed no evidence of reading ability. However, the proportion of segmental transposition errors did change in succession to the development of reading ability, as evidenced by the larger proportion of transposition errors committed by first-graders when compared to pre-schoolers. Moreover, for the first-graders, the increase in segmental transposition and the concomitant

decrease in entire syllable misordering from T1 to T2 suggested a shift away from a more syllabic level of representation towards a more subsyllabic, segmental level of representation. This shift occurred at the time formal, intensive reading instruction began.

Another way to investigate the role of reading in the development of implicit phonological representations is to see whether they are correlated with each other. It should be noted that a lack of correlation does not necessarily mean that reading does not play a role in the development of implicit phonological representations. Reading may trigger the development but individual differences in the development of implicit representations may not necessarily be explained by individual differences in reading. Nonetheless, if the development of implicit phonological representations is correlated with reading ability, then we can say in a more definite way that reading plays a role in the development of implicit phonological representations. This is what was found in the present study. For example, at the pre-school age, children's reading ability began to develop rapidly from T2 to T3, and this was the time that the amount of increase in alphabetic word reading ability was significantly related to the amount of increase in the proportions of transposition errors. This correlation was evident even after controlling for individual differences in vocabulary growth. Moreover, the association between reading ability and proportions of transposition errors began to be evident at T4 of the pre-school age even after controlling for individual differences in vocabulary knowledge. The association continued to be evident at the first two testing sessions of the elementary school ages.

The question now is why reading ability and transposition errors were related to each other during the period of transition between the pre-school age and the elementary school age, but not at earlier or later testing sessions. It is speculated that it may take time for the effect of reading to emerge and the segmental restructuring process might be triggered by other factors initially. It is not clear what the other factors are. Vocabulary growth might be one of them as many other researchers have suggested (e.g., Walley, 1993), though the present study failed to identify it as a correlate. Nonetheless, the fact that the children's memory errors contained a large portion of segmental transposition before they started to learn to read indicated that reading could not be the factor that initiated the restructuring process. Rather, reading appears to be a factor which comes into play later and which in itself drives the restructuring process to go further. In addition, more than one-third of the pre-school children could

not read a single word written in *Zhuyin fuhao* before T4 may also be, in part, responsible for the lack of correlation before T4. It is hard to see why alphabetic word reading ceased to be a correlate of the transposition errors after T2 of the children at elementary school age. One possibility is that the alphabetic word reading measured at earlier times tapped more of the word decoding ability whereas that measured at later times tapped more of the sight word reading ability.

Another interesting finding of the study was that the efficiency of children's phonological memory was associated with the transposition errors at T4 of the pre-school age and thereafter occurred until T5 of the elementary school ages (except at T4). The children who operated at a more segmental level and made proportionally more transposition errors were more likely to have superior verbal memory performance than those who operated at a less segmental level and made proportionally fewer transposition errors. Note that the transposition variable *per se* is not dependent upon the variable of memory errors since it is a proportional score rather than a score based on an absolute number of errors. These results suggest that even though the number of syllables in Chinese is limited, phonological representations at a more sub-syllabic, phonemic level may still be easier to remember, to recall, and to articulate than the more holistic syllabic representations. As suggested by Fowler (1991), a segmental representation may enable a child to convert (or "encode") the acoustic signal into a sequence of well-known, refined prototypes of the segmental units for storage and later reproduction of the correct articulatory shape, whereas a less segmental representation may render it difficult to assign novel stimuli (pseudowords) into a recoverable representation.

Related to our understanding of the nature of phonological representations among Chinese-speaking children is whether tonal features are well integrated with segmental composition as a whole in a syllable. Two relevant views of phonological representations have been put forth. One view asserts that syllables are considered as chunks of information in which suprasegmental structure and segmental composition are not represented separately (Dell, Julliano, Govindjee, 1993). The other view asserts that syllables are represented as abstract frames that are separable from their segmental composition (Costa & Sebastian-Galles, 1998; Levelt, 1992; Meyer, 1991; Sevald, Dell, & Cole, 1995). This view is in accordance with Autosegmental Phonology, a non-linear approach to phonology, in which tones are represented on an

autosegmental tier in underlying representations (Goldsmith, 1990). Tones can shift, spread, and be deleted without affecting the quality of vowels or syllables to which they are linked. The first view that tones are integrated with segments (especially vowels) is more widely held to be true for the phonological representations of Chinese, given that Chinese has relatively simple syllable structures and not too many distinct syllables (Chao, 1966; Repp & Lin, 1990). However, the finding of the present study that tonal features are not an inseparable part of the segments supports the notion of the syllable as an abstract frame that is not inherently linked to the segments. Recall that in the present study the errors that preserved the tonal structure of the target strings ranged from 84% to 89% for first-graders and from 72% to 85% for pre-schoolers. These results suggest an autonomous status of the tonal features in the memory of Chinese speakers. To some extent, tonal features in Chinese are independently retrieved rather than parasitizing the segmental composition as a lexical integer. This finding is similar to the results of Chen (1999) and Wan and Jaeger (1998), where data collected from naturalistic slips of the tongue revealed that tones remained intact when the segments were moved. If we push our findings concerning tonal structure a little bit further, we may note that such findings in fact reinforce the suggestion that subsyllabic segmental representations are available in the memory of Chinese-speaking children. If tonal features are well integrated with the segments and make reference to the entire syllable, the tonal structure of the stimuli would not have been preserved to such an extent at the time when the segments were changed.

Errors in phonological memory might derive from lapses in auditory perception, imprecise encoding, a limited phonological storage, retrieval problems, or difficulties with articulation. From wherever the errors may come, the present work does not exclude a syllabic representation in favor of a segmental representation. A segmental representation should not be conceptualized as an all-or-nothing phenomenon, nor should segmental representations and syllabic representations be regarded exclusive to each other. The two representations may be assigned different weights in different individuals or even in different words. For some individuals, the constituents are more readily disassociated, providing a flexible and efficient representational code for encoding, storing, and retrieving phonological structure in the verbal memory. For others, the segmental constituents in the verbal memory may just be too non-distinctive to be functional. Familiarity of an individual item can also affect how

segmented the representation of the item is. More familiar items are more likely to have more segmented representations whereas less familiar items such as novel words or non-words are likely to have more holistic, syllabic representations (Metsala, 1999).

4.2 The Development of Explicit Phonological Representations

In contrast to the development of implicit phonological representations where segmental restructuring may take place before reading ability develops, the development of explicit segmental awareness appears to be dependent on reading experience. The results of the study indicated that children did not attain full development of explicit phonological awareness until they learned to read words written in discrete symbols representing speech segments. For example, almost none of the pre-school children were able to perform the vowel substitution task when they were first tested even though some could cope with the simpler syllable substitution task and the sound detection task. The first-graders had basic command over the sound categorization task even though there was a wide range of individual differences. Thus, explicit phonological representations at a subsyllabic level do not seem to emerge spontaneously; rather, they appear to emerge during learning to read. Such association is demonstrated by the correlation between alphabetic word reading ability and children's performances on the phonological awareness tasks at T4 of the pre-school ages and at most testing sessions of the elementary school ages.

4.3 Interaction Between Explicit/Implicit Representations and Reading Experience

How do explicit/implicit phonological representations and reading experience interact? Recall that our pre-school children made proportionally more errors of transposition than errors of entire syllable misordering on the phonological memory task, indicating that subsyllabic units were already available to the children at the time of testing, yet they still demonstrated difficulties in performing the vowel substitution task. Thus, it appeared that the pre-school children in the present study have developed subsyllabic representations without simultaneously developing the ability to manipulate the subsyllabic representations. Furthermore, the lack of the correlations between phonological awareness and the TRANS error in memory suggests that the structure of the implicit phonological

representations does not play a determining role in the development of the explicit representations.

The lack of synchronicity in developments may be explained by the notion of modularity. Modular systems are usually conceptualized as those that are fast, automatic, and informationally encapsulated (Fodor, 1983; Liberman & Mattingly, 1985; Stanovich, 1992). The process taking place in the module is not penetrable by higher-order cognitive processes such as context, strategies, or expectations. It is the output of the module that is influenced. In the present study, it is possible that a highly subsyllabic representation is generated within the language module for identifying words (or pseudowords), remembering them, and pronouncing them, but such a representation is not accessible or recoverable for one to solve the phonological awareness task at the subsyllabic level.

It should be noted that the notion of modularity does not exclude the possibility that the output of the implicit phonological representations can be elaborated through other cognitive growth such as reading. The results of the correlational analyses in the present study indicated that performances on the phonological awareness task were related to alphabetic word reading ability at the last testing session for the pre-schoolers and at most testing sessions of the elementary school ages. Moreover, the pre-schoolers in the present study could not read any words written in *Zhuyin fuhao* when they were first tested and had great difficulty solving the vowel substitution task which requires explicit awareness of the sound structure at the segmental level. All these points suggest that reading experience plays an important role in the development of explicit phonological representations. Alphabetic word reading experience appears to make the structure of spoken words clear: spoken words contain phonemes; written words contain discrete symbols corresponding to phonemes. Thus, an old familiar word written in discrete letters or *Zhuyin fuhao* symbols provides a new way to represent the phonology of the word and at the same time helps develop extra-modular strategical processes for explicit manipulation.

By the account of model of modularity, the picture becomes clearer regarding the relationship among the developments of implicit/explicit phonological representations and reading experience. Here we have implicit phonological representations, which are self-contained, informationally encapsulated and not accessible through conscious control (Fodor, 1983; Liberman & Mattingly, 1985; Stanovich, 1992). The implicit representations undergo restructuring from a more holistic

syllabic unit to a more discrete subsyllabic unit probably due to the increase in vocabulary and reading experience. The output of the module, which operates on the implicit phonological representations, is open to consciousness. For non-readers or pre-readers, the subsyllabic constituents of the syllable are hidden under the global representations of the output and could not be freely accessed and manipulated unless certain strategies are first learned. The strategies, as far as we can know, are best learned through printed words that represent the hidden subsyllabic components with discrete units.

Finally, a caution should be made. Given the developmental nature of the study, any observed changes after formal reading instruction begins may reflect nothing but a common factor of cognitive maturation. One way to resolve the problem is to introduce a group of first-graders who do not have any reading experience. However, such a control group is hard, if not impossible, to obtain in Taiwan. Another way to disentangle the age-related effects from the experience-related (e.g., schooling) effects is to adopt a natural experiment using "school cut-off methodology" as suggested by Bowey and Francis (1991), Ferreira and Morrison (1994), and Morrison, Smith, and Dow-Ehrensberger (1995). This method takes advantage of the fact that children whose birth date precedes some specified date (e.g., September 1 in Taiwan) are allowed to go to first grade whereas other children who just miss the cutoff are not. These two groups are theoretically matched in cognitive maturation but will differ in the amount of reading experience. By comparing the changes in phonological representations in children who just make versus those who just miss the cutoff, one can assess the impact of the reading experience on the restructuring of phonological representations more conclusively.

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本研究以兩項實驗探討中國孩童隱性與顯性音韻表徵是否會隨閱讀經驗之增長而產生結構性之變化。隱性音韻表徵（implicit phonological representations）乃隱含於聽與說中無法直接操控之音韻表徵，顯性音韻表徵（explicit phonological representations）則為語音操弄時可直接操控之音韻表徵。實驗一以剛上幼稚園中班、無閱讀經驗的孩童為研究對象。實驗二則以一年級初學閱讀的孩童為對象，觀測其由一年級至三年級的發展。結果顯示：中國孩童音韻記憶主要的錯誤形式，為將目標字串中的音節內容（子音、母音）重新組合，形成新音節；就比例而言，這種音節內容重組的錯誤較把整個音節誤植的錯誤為高。其比率在學齡前後顯著增加，且與認讀注音符號能力的增長量相關。顯性表徵之發展順序與隱性表徵相彷：學前孩童在識字之前無法直接操弄語音音節之內在結構；一年級孩童則有此基本能力。此外，操弄語音內在結構的能力與認讀注音符號能力在學齡前最後一次施測時呈顯著相關，此關係並持續至學齡後三年。隱性與顯性音韻表徵之發展順序雖然類似，但並無證據顯示後者之發展建構於前者之上。本文試以語言模組（modularity）的概念解釋兩種音韻表徵發展之異同。