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The Explicit and Implicit Phonological Processing of Chinese Characters and Words in Taiwanese Deaf Signers*

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This study investigates the phonological processing that Taiwanese deaf signers engage in when recognizing Chinese characters and words. The deaf participants' orthography–phonology transformation (OPT) abilities were tested using an explicit Chinese homophone judgment task, and their implicit phonological activations were tested using lexical decision tasks. Chinese characters, whose phonetic radicals are not always reliable guides to pronunciation, are a useful tool for dissociating the influence of phonology and orthography. Experiment 1 manipulated sound-based phonological similarity (similar, dissimilar) and orthographical similarity (similar, dissimilar). Accuracy, sensitivity (d'), and reaction times (RTs) were recorded for hearing participants, but only accuracy and sensitivity (d') recorded for deaf participants, who are fluent signers of Taiwanese Sign Language (TSL). Additionally, the predictive abilities of log word frequency and the consistency values for homophone judgment performance were analyzed. Experiment 2-1 was designed to compare the effects of three primes (semantically related, sound-based phonologically related, and unrelated primes) on the performance of deaf and hearing participants on a lexical decision task. In Experiment 2-2, TSL phonologically related primes were compared with unrelated primes for deaf and hearing subjects. The results of Experiment 1 show that the accuracy of deaf subjects was poor (.66) and was lower than that of hearing subjects (.87). Particularly, the deaf subjects' accuracy and sensitivity in the orthographically dissimilar condition were significantly lower than in the orthographically similar condition. For hearing subjects, log word frequency significantly predicted their accuracy and RTs, whereas the consistency values predicted only the RTs. For the deaf participants, the accuracy could be efficiently predicted by both log word frequency and consistency values, which reflect knowledge of OPT rules. We suggested that although deaf individuals had acquired knowledge of OPT rules, this knowledge was neither complete nor sufficiently robust to make homophone judgments. In Experiment 2-1, the results show that there was a semantic priming effect but no sound-based phonological priming effect for the deaf participants. The results further reveal that deaf people with a limited hearing ability did not automatically process the sound-based phonological representations under time-constrained conditions. In Experiment 2-2, there was an action-based phonological priming effect for deaf signers but not for hearing subjects, indicating that deaf signers automatically activated related action-based phonology to access the semantic meaning of words when reading Chinese. This study finds that deaf signers acquire OPT rules but that their OPT rules are not sufficiently robust or complete to allow them to make explicit phonological judgments and homophone judgments.

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Deaf signers automatically activated action-based representations rather than sound-based phonological representations when reading Chinese characters.

Key words: consistency, deaf reading, orthography–phonology transformation, phonological processing, Taiwanese Sign Language

1. Introduction

Reading is a highly complex cognitive activity that involves the development and mapping of orthographical and phonological representations. For most hearing people, the phonological representation refers to the sound constituent elements of spoken languages; namely, consonant phonemes, vowel phonemes, and tones. The spoken lexicon provides the foundation for phonology processing. For spoken languages, phonological processing may refer to phonological awareness, phonological recoding in lexical access, and phonetic recoding to maintain information in working memory. Phonological awareness—the ability to perceive and manipulate the word segments—is an especially strong predictor of early reading success, even for deaf people (Colin et al. 2007). For deaf people in Taiwan, the languages that they most often need to acquire are Mandarin Chinese and Taiwanese Sign Language (TSL). However, deaf individuals, especially prelingually and profoundly deaf signers, do not have a sufficiently accurate or robust Chinese spoken lexicon, which is typically established through residual hearing ability or lip-reading. What type of mapping rules for Chinese words do deaf people develop?

Traditionally, phonological representation refers to the mental representation of sounds and combinations of sounds that form words in spoken languages. In this paper, we consider ‘phonological representation’ to be a general, modality-independent concept. Furthermore, we use ‘sound-based’ and ‘action-based’ to refer to the phonological representations developed from spoken languages and signed languages, respectively. As a consequence, when considering the Mandarin Chinese used in Taiwan, the sound-based phonological representations reflect the features of Chinese syllables composed of an initial consonant, a vowel, a final consonant, a tone, and combination rules. By contrast, when considering TSL, the constituent components of action-based phonological representations can include hand-shape, location, movement, and combination rules (Smith & Ting 1979, 1984; Stokoe 1960).

The issue of what phonological representations deaf readers create is highly controversial, especially for those who have greater hearing loss and use a signed language as their primary means of communication. Do deaf people engage in sound-based phonological decoding when reading? Are action-based phonological representations activated when deaf signers read? In this study, we examined the processes employed by deaf signers who use TSL as their primary means of communication when reading the Chinese language, in which orthographic and sound-based phonological mappings are not always regular. Two levels of phonological processing—explicit processing and implicit processing—are investigated in this study. Experiment 1 investigates the explicit orthographic and sound-based phonological mapping knowledge using a homophone judgment task. Experiment 2 studies the participants’ implicit sound-based and action-based phonological decoding processes using lexical decision tasks. This study provides a more complete overview of phonological processing for deaf signers. We define sound-based, phonologically related words as those with the same syllables, such as consonant and vowel phonemes and tones. Action-based phonologically related pairs refer to those sharing some of the components, such as the hand-shape, location, and movement.

2. Orthography–phonology transformation

In alphabetic writing systems, the dual-route cascaded (DRC) model of reading comprises a lexical/direct route and a sublexical/indirect route for developing quick and accurate word-recognition skills (Coltheart et al. 2001). In the sublexical route, the mechanism that translates orthographic strings into phonological codes is known as the script-to-sound rules, or orthography–phonology transformation (OPT). By acquiring OPT knowledge, early readers can recognize words more easily and develop other reading strategies.

Mappings between orthography and phonology can be defined according to their regularity and consistency. Chinese has a low level of orthographic transparency. The OPT of Chinese characters is not always regular or consistent. Chinese characters are composed of a semantic radical that provides cues regarding the semantic category of a character, and a phonetic radical that encodes the sound of a character but is not always a reliable indicator of pronunciation. A regular word that follows the OPT rules can be named more accurately and quickly than an irregular word (Bauer & Stanovich 1980; Waters & Seidenberg 1985). The consistency in Chinese characters is dependent on whether a character’s pronunciation is the same as those of its orthographic neighbors with the same phonetic radicals. In general, the consistency value of a character is calculated based on the relative ratio of the number of characters sharing the same pronunciation to the total number of characters sharing the same phonetic radicals (Fang et al. 1986). A high-consistency word is composed of a word body that is always pronounced the same as all of its orthographic neighbors; a word body within a low-consistency word has more than one possible pronunciation. High-consistency words are named more accurately and quickly than low-consistency words, and this pattern is found for both high-frequency words (Jared et al. 1990) and low-frequency words (Waters & Seidenberg 1985). In an analysis of errors, consistency effects were found for both high- and low-frequency words (Jared 2002). The orthographic consistency of a language also affects its users’ development of orthography–phonology recoding abilities (Frith et al. 1998; Ziegler et al. 2010; Ziegler & Goswami 2005). Consistency provides better predictions of naming performance than regularity does (Glushko 1979; Lee 2008). In this study, we measured the application of OPT rules to lexical access via the consistency effect.

Consistency effects in Chinese that have been found in studies of naming latency (Lee et al. 2005), eye movement (Tsai et al. 2004), event-related potentials (ERPs) (Lee et al. 2007), and functional magnetic resonance imaging (fMRI) (Lee et al. 2004; Lee et al. 2010) have provided researchers with a trusted marker of phonological assembly. Given the apparent role of the translation mechanism in word recognition, this study aims to determine whether deaf adults can use OPT to read written languages. Previous studies of the reading processes of deaf individuals have focused primarily on whether deaf people access sound-based phonological representations. However, although the deaf do engage in sound-based phonological processing, they might rely on the lexical/direct route instead, exerting great effort to memorize a word form and its phonology. This study investigated the properties of phonological processes and the use of OPT among deaf signers.

3. Sound-based phonological processing and use of OPT among deaf individuals

Decoding is the ability to rapidly derive a phonological representation from written words, which allows the reader to access the mental lexicon and retrieve semantic information. However, do deaf signers have robust phonological representations for Chinese characters? Most research on reading ability of the deaf has studied written English, and the evidence derived from this research is controversial. Several studies have suggested that the deaf, even those who have been orally educated, have poor explicit sound-based phonological abilities. One study shows that deaf children produced fewer sound-based phonological misspellings than hearing children (Aaron et al. 1998). In a rhyme judgment task, the performance of deaf participants was much lower than that of hearing participants. The deaf participants' performance was better for the rhyming orthographically similar pairs (.72) than for the nonrhyming orthographically similar pairs (.29) (Hanson & Fowler 1987). Moreover, the performance of orally-trained deaf children on a picture rhyme judgment task was better when judging rhyming orthographically similar items (.84) and nonrhyming lip-reading dissimilar items (.96), but poorer when judging rhyming orthographically dissimilar items (.74) and nonrhyming lip-reading similar items (.68) (Leybaert & Charlier 1996). These results suggest that deaf participants tend to make their rhyme judgments based on orthographic and lip-reading similarity, rather than sound-based phonological similarity.

Several studies have found that deaf readers activate sound-based phonological representations when reading English. In lexical decision studies, target recognition was found to be facilitated by phonologically related words (Hanson & Fowler 1987) and pseudo-homophones (Friesen & Joanisse 2012; Transler & Reitsma 2005). In categorization task, words were asked to classify according to their similarity. For deaf children, word pairs were classified more similar when they were phonologically similar pseudo-words (Transler et al. 2001) and phonologically similar words (Miller 2002, 2006) but not phonologically dissimilar words. When encountering incongruence between the pseudo-homophones of color names and the colors of words in the Stroop paradigm, the vocal responses of deaf children created interference (Leybaert & Alegria 1993). In a printed sentence semantic judgment task, Hanson et al. (1991) found that both hearing participants and deaf signers of American Sign Language (ASL) made more errors on the tongue twister than on the control sentences. However, although positive evidence of sound-based phonological representations has been found for deaf readers, speech-based phonological encodings might be more coarse-grained and less automatic for deaf readers (Friesen & Joanisse 2012; Stanovich 1994; Waters & Doehring 1990).

A study investigating OPT knowledge found that deaf individuals with poor speech skills did not show a regularity effect in a lexical decision task. By contrast, deaf individuals with better speech skills did demonstrate orthographic regularity in their reading (Waters & Doehring 1990). In addition, in a rhyme judgment task using pairs of pictures to eliminate the directly orthographic cues presented in printed words, the performance of orally-trained deaf subjects when judging both words and pictures was affected by spelling incongruence, and their word judgments were more affected than their picture judgments (Campbell & Wright 1988). These findings indicate that orally trained deaf people can use letter–sound correspondences when spelling and reading (Campbell et al. 1992; Hanson et al. 1983). However, although the evidence suggests that deaf people did not obtain the orthographic information directly from the pictures, it is possible that deaf individuals can still rely on memorized orthographical information to make phonological judgments in an alphabetic language system. Nevertheless, it is difficult to dissociate sound-based phonological effects from orthographical cues when studying alphabetic writing systems. Thus, studying a language with low orthographical transparency, such as Chinese, might provide a better understanding of deaf individuals' internal representations of reading.

Several studies have examined deaf individuals' phonological decoding of Chinese. Tzeng (1998) investigated the lexical access and short-term retention of Chinese characters among orally-trained and TSL-trained deaf adults. The orally-trained deaf adults showed little evidence of relying on phonological representations in the lexical decision task, but did use phonological codes in the short-term memory task. In contrast, the TSL-trained deaf adults did not use sound-based phonological representations for either task (Tzeng 1998). However, Tzeng's study used only 16 pairs of stimuli in the lexical decision task, which is unlikely to represent the mental lexicon of any person. Furthermore, an eye-tracking study investigated the sound-based phonological preview benefits for orally-trained and TSL-trained deaf individuals (Chiu & Wu 2013). While using a boundary and display change technique (Rayner 1975) in which a preview word is replaced by a target when a reader's eyes cross an invisible boundary, the researchers observed sound-based phonological preview benefits for orally-trained deaf individuals, but not for TSL-trained deaf individuals (Chiu & Wu 2013). Both studies reveal that a participant's language training background significantly influences his or her use of inner representation, and the deaf signers in those studies showed little use of sound-based phonological representations. If deaf signers do not activate sound-based phonological representations, are they able to learn the OPT rules for Chinese and activate the action-based code when reading?

The goal of the current study was to investigate the sound-based phonological representations and OPT rules used by deaf signers. We used a homophone judgment task in Experiment 1, a sound-based phonological priming task in Experiment 2-1, and an action-based phonological priming task in Experiment 2-2 to determine whether deaf signers use OPT rules and implicit sound-based or action-based phonological processing at the syllable level.

4. Experiment 1: Explicit homophone judgment

Experiment 1 manipulated sound-based phonological similarity and orthographical similarity and recruited both deaf and hearing participants. The deaf participants used TSL as their primary means of communication. We hypothesized that if deaf people can accurately judge the sound-based phonologically similar pairs, particularly the sound-based phonologically similar–orthographically dissimilar (PsOd) pairs, this would indicate that deaf individuals can rely on their knowledge of spoken phonology to judge homophones in Chinese characters. However, if they cannot judge the PsOd pairs as well as hearing participants, we posited that they would have relatively less developed knowledge of sound-based phonology. Furthermore, we conducted a series of regressions using two predictors (word frequency and consistency value) and two dependent variables of homophone judgment performance (accuracy for deaf participants and reaction times for hearing participants). If consistency is an efficient predictor of homophone judgment behavior, we posited that deaf participants have knowledge of Chinese OPT.

4.1 Methods

4.1.1 Subjects

This study examined 24 deaf people (13 males and 11 females; age range: 19 to 57 years) who were prelingually and profoundly deaf, with a hearing loss of 85dB or more. Fifteen of the deaf participants had acquired TSL as their first or prominent language before puberty. Two deaf participants had deaf parents, and the other participants were from hearing families. These deaf participants had received oral language training in elementary school, but exhibited little or poor speech ability in the present, according to their self-reports. Although the deaf participants can speak some Chinese words, their pronunciations are not sufficiently clear for strangers to recognize and comprehend. All deaf participants had completed at least senior high school level, and 12 of them had obtained a college degree, which is an above-average level of education among Taiwanese deaf people. Twenty-two hearing participants who were undergraduate or graduate students (11 males and 11 females; age range: 20 to 30 years) also participated in this study, and they were all native Chinese speakers. All participants had normal or corrected-to-normal vision.

4.1.2 Materials and design

We manipulated sound-based phonological similarity (similar, dissimilar) and orthographical similarity (similar, dissimilar). Each target character was monosyllabic and associated with four types of character stimuli: sound-based phonologically similar and orthographically similar (PsOs), sound-based phonologically similar and orthographically dissimilar (PsOd), sound-based phonologically dissimilar and orthographically similar (PdOs), and sound-based phonologically dissimilar and orthographically dissimilar (PdOd). A sound-based phonologically similar character was phonologically related to its prospective target character. An orthographically similar character shared a component, usually the phonetic component, with the target character. Eighty targets and their paired stimuli were used in the experiment, for a total of 320 stimulus pairs. Because of the highly variable reading abilities of deaf participants, the stimuli used in this experiment were high frequency. The frequency of stimuli in each condition was similar. The mean frequencies were 2234, 2231, 2772, and 3865 for PsOs, PsOd, PdOs, and PdOd, respectively [F (3, 79) = 1.00, $p > 0.05$]. Stimuli examples for Experiment 1 are listed in Table 1.

4.1.3 Task and procedure

Each trial consisted of two horizontally displayed characters: a target and its corresponding stimulus. These were displayed on a computer screen in white against a black background at a visual angle of 3–5º. Participants were asked to decide whether the characters were homophones and to indicate their answer by pressing keys on the keyboard. Hearing subjects were instructed to focus on both accuracy and speed in this task. Reaction times (RTs) were recorded from the onset of the characters until the subjects responded. Because the experiment task was difficult for the deaf

Table 1: Examples of the target character and its sound-based phonologically similar and orthographically similar character (PsOs), sound-based phonologically similar and orthographically dissimilar character (PsOd), sound-based phonologically dissimilar and orthographically similar character (PdOs), and sound-based phonologically dissimilar and orthographically dissimilar character (PdOd).

	Target	PsOs	PsOd	PdOs	PdOd
Chinese character	理	俚	禮	埋	費
Pronunciation	Li 3	Li 3	Li 3	Mai 2	Fei 4
Frequency	2010	1511	1977	1973	2288
Frequency range	10–36642	1–17306	11–75720	1–19179	5–15485
Consistency	0.46	0.46	0.55	0.46	0.49
Consistency range	.14–.93	.14–.93	.05–1.0	.14–.93	.05–1.0

participants, they were instructed to focus only on accuracy when performing the task. Only accuracy data were analyzed for the deaf participants. Each subject accepted 320 pairs/trials – 80 pairs in each condition. Each target was displayed a total of four times. The order in which the target appeared in four conditions was counterbalanced across subjects. The statistical analyses for means included across subjects (F_1), across items (F_2), effect size (η^2_G) for ANOVA analysis (Bakeman 2005; Olejnik & Algina 2003), and Cohen's *d* (*d*) for the *t*-test.

4.1.4 Apparatus

The experiment was controlled by an IBM T40 notebook. The experimental procedure was programmed and presented in Presentation Neurobehavioral Systems Presentation software (www.neurobs.com).

4.2 Results and discussion

4.2.1 Phonological and orthographical similarities

For hearing subjects, the correct rates (mean ± SD) were .88 ± .06, .89 ± .04, .84 ± .05, and .88 ± .05 for PsOs, PsOd, PdOs, and PdOd, respectively. The mean correct rate was .87. Because two deaf participants did not complete the experiment, only the data for 22 of the deaf participants were analyzed. For deaf subjects, the correct rates (mean ± SD) were .68 ± .17, .61 ± .23, .51 ± .16, and .84 ± .13 for PsOs, PsOd, PdOs, and PdOd, respectively. The mean correct rate was .66.

The accuracy performance of the hearing and deaf groups were directly compared. The results of a group (hearing, deaf) × sound-based phonological similarity (similar, dissimilar) × orthographical similarity (similar, dissimilar) ANOVA showed a significant three-way interaction [F_1 (1, 42) = 31.54, p < .01, η^2_G = .11; F_2 (1, 158) = 54.16, p < .01, η^2_G = .09]. Significant interactions were shown between group and orthographical similarity [F_1 (1, 42) = 20.97, p < .01, η^2_G = .04; F_2 (1, 158) = 16.55, p < .01, η^2_G = .03], and phonological similarity and orthographical similarity

[F_1 (1, 42) = 48.70, p < .01, η^2_G = .16; F_2 (1, 158) = 83.65, p < .01, η^2_G = .13]. The interaction between group and phonological similarity was not significant by subject [F_1 (1, 42) = 1.48, p > .05, η^2_G = .01; F_2 (1, 158) = 9.29, p < .01, η^2_G = .01]. There were main effects of group [F_1 (1, 42) = 62.37, p < .01, η^2_G = .39; F_2 (1, 158) = 340.54, p < .01, η^2_G = .32] and orthographical similarity [F_1 (1, 42) = 46.55, p < .01, η^2_G = .08; F_2 (1, 158) = 36.74, p < .01, η^2_G = .06], but not phonological similarity [F_1 (1, 42) = 1.48, p > .05, η^2_G = .01; F_2 (1, 158) = .45, p > .05, η^2_G = .00]. Furthermore, the deaf group was shown to have significantly better accuracy for orthographically similar words than for dissimilar words in the phonologically similar/yes response condition [F_1 (1, 84) = 19.81, p < .01, d = 1.03; F_2 (1, 316) = 9.75, p < .01, d = .49], but the hearing group did not [F_1 (1, 84) = 1.52, p > .05, d = –.05; F_2 (1, 316) = .01, p > .05, d = –.02]. In the phonologically dissimilar/no response condition, on the other hand, the deaf group was shown to have significantly better accuracy for orthographically dissimilar words than for similar words [F_1 (1, 84) = 34.86, p < .01, d = –1.28; F_2 (1, 316) = 176.94, p < .01, d = –2.48], but the hearing group did not [F_1 (1, 84) = .01, p > .05, d = –.93; F_2 (1, 316) = 3.57, p > .05, d = –.28]. The results demonstrate that deaf people relied more heavily on orthographical cues to accurately judge phonology than did the hearing participants.

For hearing subjects, the results of a two-way within-subjects ANOVA showed a significant interaction effect [F_1 (1, 21) = 5.40, p < .05, η^2_G = .04; F_2 (1, 79) = 1.31, p > .05, η^2_G = .01], a significant phonological similarity effect by subject [F_1 (1, 21) = 8.25, p < .01, η^2_G = .06; F_2 (1, 79) = 3.16, p > .05, η^2_G = .01], and a marginally significant orthography similarity effect [F_1 (1, 21) = 4.17, p = .05, η^2_G = .05; F_2 (1, 79) = 2.16, p > .05, η^2_G = .01]. A post-hoc analysis performed using a Tukey's honestly significant difference (HSD) test indicated that there was significant difference between PdOs and PdOd [F_1 (1, 42) = 9.23, p < .01, d = –.05] but not between PsOs and PsOd [F_1 (1, 42) = .03, p > .05, d = –.93]. The results revealed that hearing subjects were influenced by orthography to make 'no' decisions but not 'yes' decisions, indicating that hearing subjects were more tolerant of homophones with different orthographies.

Incorrect responses and response latencies shorter or longer than two standard deviations from the mean were excluded from the RT data analysis for hearing subjects. The RTs (mean ± SD) were 1118 ± 138, 1083 ± 139, 1094 ± 145, and 1099 ± 138 msec for PsOs, PsOd, PdOs, and PdOd, respectively. The results of a two-way within-subjects ANOVA showed a significant interaction effect [F_1 (1, 21) = 5.60, p < .05, η^2_G = .00; F_2 (1, 79) = 6.13, p < .05, η^2_G = .01], a non-significant phonological similarity effect [F_1 (1, 21) = .12, p > .05, η^2_G = .00; F_2 (1, 79) = .07, p > .05, η^2_G = .00], and a non-significant orthographical similarity effect [F_1 (1, 21) = 1.35, p > .05, η^2_G = .01; F_2 (1, 79) = 3.19, p > .05, η^2_G = .01]. A post-hoc analysis performed using Tukey's HSD test indicated that the PsOs RTs were significantly longer than those of PsOd [F_1 (1, 42) = 5.17, p < .05, d = .56; F_2 (1, 158) = 7.70, p < .01, d = .40]. For hearing people, the results might show a trade-off between accuracy and RT. However, because of the high accuracy of the task for hearing participants, the RT data might reflect the orthographical and phonological processing more sensitively than the accuracy data. This outcome suggests that in phonologically similar pairs, hearing subjects inhibit their instinctive response to verify whether the 'yes' decision is influenced by orthographical similarity. The orthographical similarity slowed down the 'yes' decisions for homophones. However, there was no difference between PdOs and PdOd RTs, indicating that in phonologically dissimilar conditions, hearing subjects responded more directly without first verifying the orthographical information.

For deaf accuracy performance, the results of a two-way within-subjects ANOVA showed a significant interaction effect [F_1 (1, 21) = 43.38, p < .01, η^2_G = .27; F_2 (1, 79) = 174.81, p < .01, η^2_G = .33], a significant orthographical similarity effect [F_1 (1, 21) = 46.56, p < .01, η^2_G = .13; F_2 (1, 79) = 47.58, p < .01, η^2_G = .16], and a main effect of phonological similarity that was significant only in the analysis by-items [F_1 (1, 21) = .42, p > .05, η^2_G = 01; F_2 (1, 79) = 6.26, p < .05, η^2_G = .02]. A post-hoc analysis performed using Tukey's HSD test indicated that PsOs were significantly higher than PsOd [F_1 (1, 42) = 4.63, p < .05, d = 0.31; F_2 (1, 158) = 10.48, p < .01, d = 0.49], and that PdOd were significantly higher than PdOs [F_1 (1, 42) = 83.81, p < .01, d = –2.30; F_2 (1, 158) = 190.22, p < .01, d = –2.48]. The results revealed that deaf subjects were inclined to make 'no' decisions for orthographically dissimilar pairs and to make 'yes' decisions for orthographically similar ones. However, the accuracy of the deaf subjects was .66, which was higher than chance but much lower than the .87 attained by the hearing subjects, suggesting that the deaf subjects knew orthographical cues were not always a reliable indicator of pronunciation. In this homophone judgment task, our deaf subjects relied in part on orthographical cues to make homophone judgments. The results of Experiment 1 are shown in Table 2 and Figure 1.

Table 2: Among hearing and deaf subjects in Experiment 1, the means and standard deviations of accuracy and reaction times (RTs) of target character in sound-based phonologically similar and orthographically similar (PsOs), sound-based phonologically similar and orthographically dissimilar (PsOd), sound-based phonologically dissimilar and orthographically similar (PdOs), and sound-based phonologically dissimilar and orthographically dissimilar (PdOd) conditions.

		PsOs	PsOd	PdOs	PdOd
Hearing	Accuracy	.88 (.06)	.89 (.04)	.84 (.05)	.88 (.05)
	RTs	1118 (138)	1083 (1390)	1094 (145)	1099 (138)
Deaf	Accuracy	.68 (.17)	.61 (23)	.51 (.16)	.84 (.13)

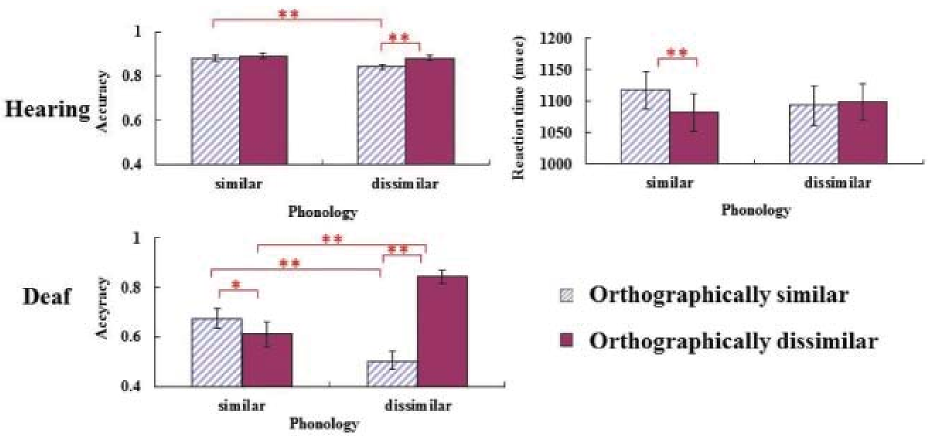


Figure 1: Accuracy and RT data of homophone judgment tasks are shown for hearing participants and accuracy data are shown for deaf participants. Error bars indicate the standard error of the mean. ***p** < .05; ****p** < .01.

To clarify the impact of orthography, we measured the sensitivity *d′* (*z* score (correct accept rates) – *z* score (false alarm rates)) in orthographically similar and dissimilar conditions among hearing and deaf participants. The results of a group (hearing, deaf) × orthographical similarity (similar, dissimilar) ANOVA showed a significant two-way interaction by subject [F_1 (1, 42) =13.46, $p < .01$, $\eta^2_G = .72$; F_2 (1, 158) = 1.64, $p > .05$, $\eta^2_G = .49$], a significant group main effect [F_1 (1, 42) = 49.44, $p < .01$, $\eta^2_G = .96$; F_2 (1, 158) = 319.89, $p < .01$, $\eta^2_G = .99$], and a significant orthographical similarity effect [F_1 (1, 42) = 38.65, $p < .01$, $\eta^2_G = .88$; F_2 (1, 158) = 34.61, $p < .01$, $\eta^2_G = .95$]. The simple main effects indicated that Os were significantly higher than Od among deaf participants [F_1 (1, 42) = 48.86, $p < .01$, $\eta^2_G = .98$], but there was no difference among the hearing group [F_1 (1, 42) = 3.25, $p > .05$, $\eta^2_G = .76$].

The results obtained from the hearing subjects agreed with previous findings showing that the performance of hearing individuals is influenced by orthographical similarity. Campbell & Wright (1988) found that among hearing subjects, picture rhyme judgment was more accurate than words rhyme judgment. In their findings, furthermore, the spelling congruency effect in hearing subjects was significant for word pairs but not for picture pairs, indicating that hearing people were influenced by printed orthographical information when accessing phonological information to make final rhyme decisions.

The poor performance of deaf individuals on homophone judgments in the PsOd condition revealed that they were unable to make homophone judgments on a primarily sound-based phonological basis. Although the results indicated that deaf subjects knew orthographical cues were not always reliable indicators of pronunciation, they still had to rely on orthographical cues to make homophone judgments to a greater degree than did hearing subjects. Deaf participants were also less tolerant of homophones with different orthographies than were hearing subjects. This result confirms other studies in which deaf subjects performed poorly on rhyme judgment tasks (Hanson & Fowler 1987; Leybaert & Charlier 1996). Altogether, these results suggest that deaf individuals do not use the sound-based phonological information available in alphabetic and non-alphabetic written systems to make correct rhyme judgments.

4.2.2 Regressions of word frequency and consistency values determining accuracy and RT among hearing participants and accuracy among deaf participants

Next, we used a multiple regression analysis to determine whether word frequency and consistency values predicted hearing participants' accuracy and RT and deaf participants' accuracy in the homophone task. The grapheme-to-phoneme consistency value was computed based on the ratio of the number of characters sharing the same pronunciation to the total number of characters sharing the same phonetic radical (no matter how it was pronounced). The frequencies were translated into log frequencies because of their large range. Only some of the targets and stimuli used in the experiment contained phonetic radicals. The number of words analyzed was 75, 60, 75, and 50 for PsOs, PsOd, PdOs, and PdOd, respectively.

Linear regression analyses were conducted to examine the contribution of word frequency and grapheme-to-phoneme consistency values to deaf participants' accuracy and hearing participants' accuracy and RTs. We also included the categorical variables, phonological similarity (similar, dissimilar) and orthographical similarity (similar, dissimilar), in the regressions. The results are listed in Table 3.

Table 3: In Experiment 1, regressions of stimuli log frequency and consistency values determining accuracy and RT among hearing participants and accuracy among the deaf participants in the homophone task.

Hearing people		Accuracy					Reaction times				
		R^2	F (2, 257)	β	t		R^2	F (2, 257)	β	t	
Stimuli		.04	6.74 **				.15	22.93 **			
	Log frequency			.19	3.03	**			–.30	–5.20	**
	Consistency			.12	1.95	—			–.27	–4.66	**
Stimuli		.18	15.11 **				.39	41.66 **			
	Log frequency			.22	3.85	**			–.26	–5.26	**
	Consistency			–.05	–.84	—			–.06	–1.04	—
	Phonology			.09	1.54	—			–.40	–7.78	**
	Orthography			–.35	–5.89	**			–.35	–6.80	**

Deaf people		Accuracy				
		R^2	F (2, 257)	β	t	
Stimuli		.18	28.46 **			
	Log frequency			.37	6.59	**
	Consistency			.23	4.08	**
Stimuli		.21	16.93 **			
	Log frequency			.35		**
	Consistency			.21		**
	Phonology			–.09		—
	Orthography			–.15		*

Note. R^2 values in this table are adjusted R^2 values. —p > .05, *p < .05; **p < .01.

Among the hearing group, the predictive abilities of log frequency values were significant for both accuracy and RT. However, the consistency values were significant predictors of RT only. When considering sound-based phonological similarity and orthographical similarity, the consistency values were not significant for either accuracy or RT. The consistency effect, which was found for low-frequency words, was not found for the high-frequency stimuli used in the experiment. In addition, the orthographical similarity facilitated hearing subjects' accuracy and RTs, a result shown in the previous analysis.

Among deaf participants, the results of two regression analyses showed that the predictive abilities of the log frequency and consistency values were universally significant. In other words, log frequency and consistency information efficiently predicted the accuracy of deaf participants' homophone judgments. Generally, the significant consistency values reflected a knowledge of OPT in deaf signers. However, some deaf subjects found it difficult to make accurate homophone judgments for characters (e.g. 姓 *xìng*, 幸 *xìng*) that were highly familiar to and easy for hearing participants. Thus, although deaf signers had acquired the OPT rules, their OPT knowledge may have been incomplete or different from that of hearing individuals. The results of the ANOVA and the regression analyses indicate that deaf signers have OPT knowledge but find it difficult to apply OPT rules when making homophone judgments.

It should be noted that the OPT capacity can be determined not only by the grapheme-to-phonological consistency values, or forward consistency, but also by the weights of the phonological-to-grapheme consistency values, or feedback consistency. A high feedback consistency word sound has no other word forms for that pronunciation, whereas a word sound with low feedback consistency does have alternative word forms (Ziegler et al. 1997). In Chinese, character sounds have a large number of alternative word forms. Future studies should investigate whether knowledge of the phoneme-to-grapheme consistency knowledge influences homophone judgments.

5. Experiment 2: Implicit sound-based and action-based phonological priming

In Experiment 2-1, we used a lexical decision task to determine whether participants experienced implicit activation of the sound-based phonological representations of the words they were asked to identify. The degree to which deaf participants and hearing participants showed the two marker effects (the semantic priming effect and the sound-based phonological priming effect) used to detect assembly were compared. The semantic priming effect occurs when words are identified faster if they are preceded by words with related meanings. The sound-based phonological priming effect occurs when words are identified faster if the prime's pronunciation is similar to that of the target. If the deaf participants' response for the sound-based phonologically related pairs is faster than for the unrelated pairs, we posited that deaf individuals do process related sound-based phonological knowledge when recognizing Chinese words. In Experiment 2-2, we further investigated whether there was a TSL action-based phonological priming effect for deaf signers when accessing their Chinese lexicon. If the deaf participants responded more quickly to the TSL phonologically related pairs during word recognition tasks, we posited that deaf people activate related TSL phonological knowledge when reading. We also predicted no difference for hearing people who do not have knowledge of TSL.

5.1 Methods

5.1.1 Subjects

The deaf signers who participated in this experiment were the same as those who participated in Experiment 1. The 24 hearing participants were other undergraduate or graduate students (13 males and 11 females; age range: 20 to 30 years). All hearing participants were native Chinese speakers and had no experience with TSL. All participants had normal or corrected-to-normal vision.

5.1.2 Materials and design for Experiment 2-1

Each meaningful target was associated with three types of primes: semantically related (SR), sound-based phonologically related (PR), and unrelated (U). A semantic prime was a meaningful word that was semantically, but not phonologically, related to its prospective target word. A sound-based phonological prime was a meaningful word that was only pronounced similarly, but not semantically related, to its prospective target word. An unrelated prime was also a meaningful word that was completely unrelated to the target word in any aspect. The word frequency of SR, PR, and U words was similar in each list. Each subject received 20 pairs in each condition and 120 trials in total. Half of the targets were meaningful, two-character Chinese words, and the other half were Chinese non-words composed of two real characters that were meaningless when together. Examples of the stimuli used in Experiment 2-1 are listed in Table 4.

Table 4: Examples of the target word and its semantically related (SR), sound-based phonologically related (PR), and unrelated (U) primes in Experiment 2-1.

	Target	Prime		
		Semantically related	Sound-based phonologically related	Unrelated
Chinese word	樹木	花草	數目	親切
Semantic meaning	Tree	Flowers and plants	Number	Kind
Chinese pronunciation	Shù-mù	Huā-cǎo	Shù-mù	Qīn-qiè

5.1.3 Materials and design for Experiment 2-2

Primes and targets were either TSL action-based phonologically related (APR) or unrelated (U). The APR pairs were words that shared the same hand-shapes in TSL. The U pairs were composed of completely unrelated words. The word frequency of APR and U words was similar in each list. Each subject received 20 APR pairs and 20 U pairs, and 80 trials in total. Half of the targets were meaningful, two-character Chinese words, and the other half were non-words. Examples of the stimuli used in Experiment 2-2 are listed in Table 5.

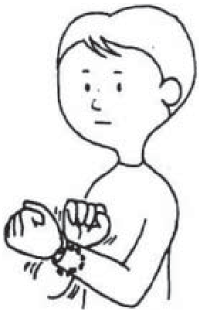
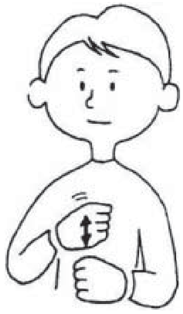
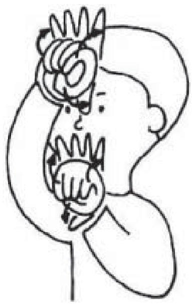
5.1.4 Tasks

The Chinese words were composed of two characters. They were vertically displayed with a visual angle of 2~3º on a computer screen in white against a black background. Each trial consisted of the following sequence of three stimuli: a fixation, presented for 500 msec; a prime word, presented for 100 msec; and, immediately following, a target word. The display duration of the target word was contingent on the participant’s response. Participants were asked to decide whether the target was a meaningful word or not. They indicated a positive response by pressing a corresponding key and a negative response by pressing another key. They were also instructed on the importance of accuracy and speed when completing the task.

5.2 Results and discussion

The error rates and RTs were recorded. The analyzed RTs excluded incorrect responses and response latencies that were shorter or longer than two standard deviations from the mean.

Table 5: Examples of target words and their TSL action-based phonologically related (APR) and unrelated (U) primes in Experiment 2-2.

	Target	TSL phonologically related prime	Target	Unrelated prime
Chinese word	木頭	工作	鳳梨	桌子
Meaning	Wood	Work	Pineapple	Desk
Chinese pronunciation	Mù-tóu	Gōng-zuò	Fòng-lí	Zhuō-zi
TSL hand-shape	Two hands, ‘QUAN’	Two hands, ‘QUAN’	Two hands, ‘ZEROFIVE’	Two hands, ‘SHOU’
TSL				

Note. The hand-shapes in TSL signs and the names of TSL hand-shapes were based on previous studies (Chang et al. 2005; Smith & Ting 1979, 1984).

5.2.1 Experiment 2-1

The error rates (mean ± SD) were .05 ± .03 and .04 ± .02 for the deaf and hearing subjects, respectively. The result of a *t*-test for error rates showed no significant difference between these two groups [t (46) = 1.79, $p > .01$, $d = .39$].

For deaf subjects, the RTs (mean ± SD) were 562 ± 66, 592 ± 71, and 594 ± 75 msec for SR, PR, and U, respectively. For hearing subjects, the RTs (mean ± SD) were 562 ± 68, 584 ± 68, and 594 ± 74 msec for SR, PR, and U, respectively. The results of a two-way group (hearing, deaf) × primes (semantically related, sound-based phonologically related, unrelated) mixed ANOVA showed a significant main effect of primes [F_1 (2, 92) = 75.83, $p < .01$, $\eta^2_G = .46$; F_2 (2, 76) = 85.21, $p < .01$, $\eta^2_G = .89$] and a significant interaction effect of subject and primes by subject [F_1 (2, 92) = 6.17, $p < .01$, $\eta^2_G = .06$; F_2 (2, 76) = 1.39, $p > .05$, $\eta^2_G = .12$]. There was a non-significant subject effect [F_1 (1, 46) = .08, $p > .05$, $\eta^2_G = .07$; F_2 (1, 38) = .22, $p > .05$, $\eta^2_G = .16$]. Because the significant interaction effect was only shown in the by-subject analysis, a Tukey’s HSD test indicated that there was a significant difference between SR and U for deaf subjects [F_1 (2, 92) = 31.96, $p < .01$, $d = .47$], but no significant difference between PR and U [F_1 (2, 92) = 1.94, $p > .05$, $d = .03$]. For hearing subjects, there was a significant difference between SR and U [F_1 (2, 92) = 31.19, $p < .01$, $d = .45$] and a significant difference between PR and U [F_1 (2, 92) = 13.67, $p < .01$, $d = .24$].

The high level of accuracy in the lexical decision task among deaf groups indicated that these deaf participants are highly skilled Chinese readers. In addition, the main differences between these two groups were that a semantic priming effect and a sound-based phonological priming effect were shown for hearing participants, while only a semantic priming effect was found in deaf people. Although both groups could retrieve the lexicons quickly and easily, the sound-based phonological representations of the words were not activated automatically among these deaf readers.

5.2.2 Experiment 2-2

The error rates (mean ± SD) were .06 ± .05 and .04 ± .05 for the deaf and hearing subjects, respectively. The results of a *t*-test for error rates showed no significant difference between these two groups [t (46) = 1.38, $p > .05$, $d = .40$].

The RTs (mean ± SD) were 533 ± 57, 569 ± 76, 558 ± 81, and 555 ± 78 msec for deaf APR, deaf U, hearing APR, and hearing U, respectively. The results of a two-way group × prime mixed ANOVA showed a significant main effect of prime [F_1 (1, 46) = 14.15, $p < .01$, $\eta^2_G = .01$; F_2 (1, 38) = 3.78, $p > .05$, $\eta^2_G = .05$] and a significant interaction effect between group and prime [F_1 (1, 46) = 18.76, $p < .01$, $\eta^2_G = .04$; F_2 (1, 38) = 6.38, $p < .05$, $\eta^2_G = .36$]. A post-hoc analysis performed using Tukey's HSD test indicated that there was a significant difference between APR and U among deaf subjects [F_1 (1, 46) = 32.75, $p < .01$, $\eta^2_G = .45$; F_2 (1, 38) = 9.99, $p < .01$, $\eta^2_G = .30$], but not among hearing subjects [F_1 (1, 46) = .16, $p > .05$, $\eta^2_G = .03$; F_2 (1, 38) = .17, $p > .05$, $\eta^2_G = .01$].

The high accuracy and fast reaction times among deaf participants were shown in Experiment 2-2 as well as in Experiment 2-1, again indicating their highly proficient reading abilities. In addition, the results of Experiment 2-1 and Experiment 2-2 showed that deaf participants experienced a semantic priming effect and a TSL action-based phonological priming effect, but not a sound-based phonological priming effect. This outcome suggests that deaf signers do not automatically process the sound-based phonological representations under certain time constraints. Instead, deaf signers automatically activate related action-based phonology to access the semantic meaning of words when reading. The results of Experiment 2-1 and Experiment 2-2 are presented in Table 6 and Figure 2.

Table 6: The means and standard deviations of the reaction times (RTs) in Experiment 2-1 of semantically related (SR), sound-based phonologically related (PR), and unrelated (U) conditions, and in Experiment 2-2 of TSL action-based phonologically related (APR) and unrelated (U) conditions for hearing and deaf groups.

	Experiment 2-1			Experiment 2-2	
	SR	PR	U	APR	U
Hearing	562 (68)	584 (68)	594 (74)	558 (81)	555 (78)
Deaf	562 (66)	592 (71)	594 (75)	533 (57)	569 (76)

6. General discussion

This study investigated the phonological processing of Taiwanese deaf signers using a Chinese homophone judgment task and lexical decision tasks. The results suggested that deaf signers do not automatically activate the sounds of words when reading, but they appear to have OPT knowledge and instead activate TSL phonological representations when accessing lexicons.

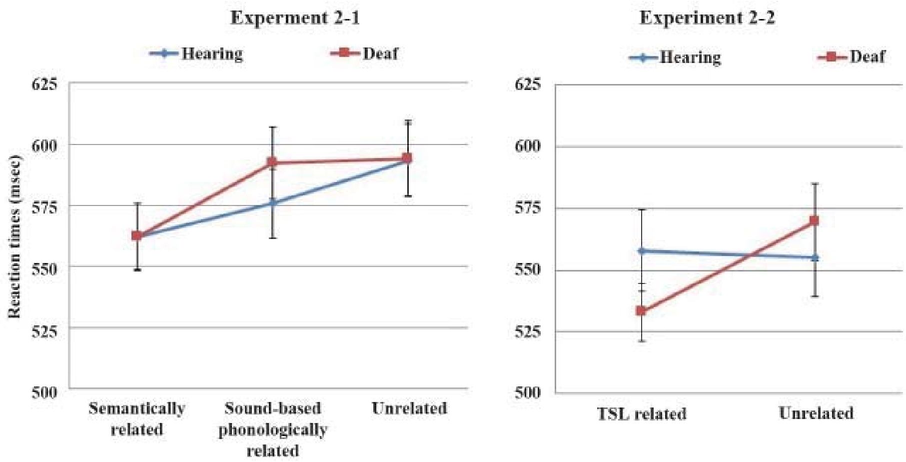


Figure 2: The reaction time performance of lexical decision in semantically related (SR), phonologically related (PR), and unrelated (U) conditions for Experiment 2-1 and TSL action-based phonologically related (APR) and unrelated (U) conditions for Experiment 2-2 for hearing and deaf people. In Experiment 2-1, for hearing people, the RTs in the SR and PR were both shorter than those in the U; for deaf people, only the RTs in the SR were faster than those in the U. The results demonstrated semantic priming effect in both groups, but no phonological priming effect among deaf subjects. In Experiment 2-2, the RTs in the APR were faster than those in the U only for deaf subjects. This demonstrated a TSL phonological priming effect among the deaf subjects.

Our findings are consistent with previous deaf studies. Researchers analyzing Chinese word writing errors made by deaf and hearing children found that hearing children tended to produce homophonic errors, whereas deaf children typically produced visually similar character substitutions (Bellugi et al. 1989). In a short-term memory study, orally-trained Chinese deaf participants were tested both with and without articulatory suppression (Chincotta & Chincotta 1996). The results showed that suppression greatly affected memory performance for hearing subjects, but no differences were observed for deaf subjects. These findings indicate that deaf individuals do not rely heavily on speech-based phonological processing when processing Chinese words.

Furthermore, our findings are consistent with the behavior results of a recent fMRI study of the semantic and phonological processing of skilled deaf readers (Emmorey et al. 2013). Similarly, those researchers found that the deaf participants' accuracies on the explicit phonemic awareness test (choosing two pictures with similar initial or final phonemes from four pictures) and the explicit phonological task (judging whether each word had two syllables or not) were significantly lower and that the tests were more difficult. The increased posterior inferior frontal gyrus and the ventral precentral gyrus activation during the phonological task are evidence of effortful speech-based phonological processing during print word processing.

Comparatively, the absence of sound-based phonological processing during Chinese word recognition in deaf subjects is consistent with the effects of the lexical decision task and the short-term memory task among TSL-trained deaf adults (Tzeng 1998). It is possible that deaf readers rely on the same procedures as hearing people but use less automatic and effortful sound-based phonological processing (Emmorey et al. 2013; Friesen & Joanisse 2012). Alternatively, this phenomenon could arise because deaf readers rely on mechanisms that differ from those used by hearing readers. The hypothesis that deaf readers rely on another mechanism, action-based phonological representation, was supported in Experiment 2-2 in our study. Other studies have also revealed the use of action-based recoding in deaf subjects. In short-term memory studies, deaf participants showed better memory performance for lists of signs with dissimilar formations than for lists with similar formations, suggesting an action-/sign-based phonological similarity effect (Klima & Bellugi 1979). Deaf subjects' memory of object pictures was suppressed by a dual competing manual task, indicating a manually-based articulation suppression effect (Wilson & Emmorey 1997a). Researchers have also suggested that a working memory system exists for sign languages (Emmorey & Wilson 2004; Wilson & Emmorey 1997b, 1998). Our findings are consistent with sign language studies that have revealed a significant priming effect for pairs of signs with similar hand-shapes (Corina & Emmorey 1993; Myers et al. 2005) and for pairs with a combination of similar hand-shapes, locations, and movements (Dye & Shih 2006). In a priming study of ASL, an action-/sign-based phonological priming effect was shown when deaf ASL–English bilinguals read word pairs (Morford et al. 2011). However, the positive evidence of action-based recoding in this study might also have resulted from the special meta-linguistic experiences of the deaf signers. Most of the participants had taught TSL courses for deaf associations; thus, they might have accessed TSL phonology automatically, regardless of the type of input that they received.

In addition, the positive discovery of action-based recoding in this study does not exclude the possibility that deaf individuals use multiple encoding strategies, such as weak sound-based phonological codes, action-based codes, or visual lip-reading codes. According to bilingual studies, lexical access is non-selective, and the inter-lingual homophones (words that share lexical form but not meaning) in both languages are active (Dijkstra et al. 1998), especially in sign–speech bimodal bilinguals (Emmorey et al. 2005).

The inconsistency of our findings with prior studies of positive sound-based phonological representations might result from two factors: the different characteristics of written languages and the participants. Chinese is a language with low orthographical transparency. A Chinese character provides relatively little information regarding pronunciation, especially for a beginner or for an individual with limited sound input. In addition, although people may incorrectly pronounce a Chinese word, they might still be fully able to access its meaning. Therefore, Chinese reading for deaf people might provide a clearer image in research on deaf reading. Likewise, our findings cannot be generalized to more orally-trained members of the deaf population and to those without sign language experience. Language experience significantly affects phonological processing among the deaf population (Chiu & Wu 2013; Tzeng 1998). Future studies should also include orally-trained deaf participants to gain more insight into reading in the deaf population.

In addition, our findings cannot differentiate whether action-based representations are pre-lexically activated, simultaneously activated, or post-lexically activated. Other methodologies or research tools, such as eye movements, should be used to enhance our understanding of dynamic linguistic processing.

In conclusion, learning to read is never easy, even for a hearing person who is used to spoken language. However, limited hearing ability does not limit one's ability to learn to read. Although most written systems are not developed for signed languages, the appropriate associations between written symbols and action/sign-based representations can be developed. Meanwhile, deaf people must acquire sufficient and complete representations, such as manually-based representations, to associate written symbols with their existing lexicon. This study found that deaf signers acquired OPT knowledge, but their OPT knowledge was not sufficiently robust or complete enough to make explicit sound-based homophone judgments. Under time-constrained conditions, the deaf signers did not automatically activate sound-based phonological codes, but rather activated action-based representations when reading.

Appendix A: Stimuli for Experiment 1

Target	PsOs	PsOd	PdOs	PdOd	Target	PsOs	PsOd	PdOs	PdOd
技	妓	記	肢	螢	佔	站	暫	貼	素
晤	悟	物	語	犬	伯	柏	勃	怕	廖
賭	堵	篤	諸	爺	坡	波	潑	彼	承
讀	瀆	毒	續	震	泥	妮	霓	呢	蓉
錯	措	挫	惜	簽	倚	椅	以	崎	罕
腹	複	負	愎	峽	訣	決	爵	快	果
幕	慕	睦	摹	翠	煤	媒	眉	謀	奪
理	俚	禮	埋	費	擇	澤	則	釋	髮
俊	峻	菌	梭	倖	秒	眇	藐	抄	胞
汗	扞	漢	奸	煤	軀	嶇	屈	嘔	笠
銀	齦	吟	狠	紗	疏	梳	抒	琉	犀
錄	碌	路	綠	蕉	諷	楓	烽	颯	蔭
紅	虹	宏	江	巢	輻	幅	符	逼	罪
揮	輝	恢	渾	晃	艦	鑑	薦	濫	盟
積	績	基	債	角	穫	獲	貨	護	雖
抒	舒	書	野	凶	峭	鞘	竅	梢	刻
級	汲	疾	吸	帶	渡	鍍	妒	踱	蕭
河	何	合	阿	訊	曠	礦	況	擴	謎
炫	眩	絢	紘	曳	諒	晾	輛	掠	荀
浩	皓	號	酷	乞	住	注	助	往	岸
陵	綾	玲	崚	彗	姓	性	幸	牲	原
儒	孺	茹	懦	勇	弧	狐	葫	呱	禽
祠	詞	慈	飼	巷	絡	烙	落	略	穿
陷	餡	縣	掐	煩	鐲	濁	卓	觸	藩
棟	凍	洞	陳	荒	構	購	夠	講	席
碑	婢	悲	脾	遊	墳	憤	汾	噴	詹
精	睛	驚	猜	嶺	灼	酌	濁	釣	嘗
灌	罐	貫	權	翁	池	弛	遲	她	虎
媛	援	圓	緩	惠	怡	貽	夷	胎	柴
伴	拌	辦	胖	歪	臘	蠟	辣	獵	羅
流	琉	劉	梳	塞	佛	拂	孚	沸	差
悔	誨	毀	侮	緒	抖	蚪	陡	斜	餘
晚	輓	琬	娩	蘇	搏	博	勃	傅	畢
浴	裕	育	俗	笑	柚	鈾	祐	妯	棗
拘	駒	居	鉤	莽	餽	潰	匱	槐	裳
綢	稠	愁	凋	厭	愉	揄	於	偷	忌
淨	靜	竟	掙	乘	址	趾	旨	扯	茂

Target	PsOs	PsOd	PdOs	PdOd	Target	PsOs	PsOd	PdOs	PdOd
玲	羚	零	冷	忘	侍	恃	勢	峙	烹
綿	棉	眠	錦	宰	聒	括	瓜	活	室
瀑	曝	舖	爆	惹	詐	炸	柵	酢	器

Note. Stimuli of target and its sound-based phonologically similar and orthographically similar (PsOs), sound-based phonologically similar and orthographically dissimilar (PsOd), sound-based phonologically dissimilar and orthographically similar (PdOs), sound-based phonologically dissimilar and orthographically dissimilar character (PdOd).

Appendix B: Stimuli for Experiment 2-1

Target	Prime			Target	Prime		
	sound-based phonological	semantic	control		sound-based phonological	semantic	control
鋒利	風力	刀劍	鞋底	復健	附件	中風	鄉村
贏取	迎娶	獲得	預感	樹木	數目	花草	親切
玉照	預兆	相片	樣本	政見	證件	選舉	優待
幽會	優惠	情侶	元素	旺季	忘記	熱鬧	數量
山洞	煽動	火車	門禁	街道	接到	馬路	開槍
上尉	尚未	軍官	目標	儀器	遺棄	設備	慘劇
魄力	破例	擔當	碩士	保健	寶劍	衛生	專訪
艱鉅	兼具	困難	機車	嘗試	常識	練習	感慨
飯粒	範例	稻米	煞車	弱勢	若是	少數	知識
近視	進士	眼鏡	雨傘	繪畫	會話	美術	嚴厲
紳士	身世	淑女	陶土	電力	奠立	能源	家世
手勢	首飾	動作	進攻	文明	聞名	進步	騎士
歧視	騎士	低等	能源	交代	膠帶	吩咐	待遇
毅力	屹立	恆心	慶生	藥物	要務	治療	聲音
抱負	報復	志向	車庫	現實	限時	理想	文件
畜牧	序幕	農場	配角	意識	議事	清醒	身份
堅固	兼顧	耐用	求助	球員	求援	裁判	時機
童話	同化	故事	會議	首長	手掌	官員	插座
食宿	時速	旅遊	重量	逃逸	陶藝	消失	核准
錯失	措施	良機	酒瓶	涉及	射擊	有關	收到
店員	電源	老闆	手臂	形成	行程	演變	命運
公式	攻勢	數學	天母	銷售	消瘦	販賣	求助
筆試	鄙視	通過	假如	結束	劫數	停止	配件
衛冕	未免	冠軍	結婚	注意	助益	小心	股票
封殺	風沙	出局	拋棄	措施	錯失	方法	勇氣
主婦	囑咐	家庭	支配	事實	適時	真相	協調
利器	力氣	剪刀	郵寄	程式	城市	電腦	帳戶
墓地	目的	死人	特殊	元首	援手	國家	水流
言行	嚴刑	舉止	車身	香蕉	相交	猴子	軌道
功課	公克	筆記	王牌	檢肅	減速	流氓	數字

Appendix C: Stimuli for Experiment 2-2

Target	TSL phonologically related prime	Target	Unrelated prime
手錶	耳環	管子	茶杯
木頭	工作	棉被	醫院
香菸	筷子	眼淚	建築
會議	考試	處罰	味道
經濟	關係	誤會	國際
年輕	新穎	發燒	交通
生氣	常常	糖果	放假
站立	解釋	檳榔	房間
洗澡	練習	鳳梨	桌子
老鼠	懶惰	系統	健康
知道	記得	剪刀	卡通
獅子	忙碌	電影	湯圓
計畫	遠近	西瓜	紀錄
幫助	服務	眼鏡	簽名
討厭	麻煩	清潔	曠課
證明	碗	隨便	影子
欺騙	狐狸	游泳	服從
郵票	相信	房子	賺錢
名字	邀請	道路	鬍子
照顧	檢查	鼓勵	鈕釦

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台灣聾人手語使用者於中文字詞之外顯與內隱音韻運作情形

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本研究的目的在瞭解使用台灣手語的聾人於閱讀中文字詞時的音韻運作情形。由於中文字聲旁的表音情形時常是不規則與不一致，透過中文字詞的研究可以有效釐清聾人讀者如何受到字形與字音的個別影響。研究中運用屬於音韻外顯作業的同音判斷作業來評估聾人手語者的中文字形字音轉換規則的知識，並使用音韻促發作業來評估聾人手語者內隱的音韻運作。**研究方法**：實驗一中，參與者必須對同時呈現的兩個中文字作出中文音韻相同與否的判斷，實驗操弄中文音韻相似性（相似、不相似）以及中文字形相似性（相似、不相似），並分析聽人的正確率、敏感度與反應時間，但僅分析聾人手語者的正確率與敏感度；實驗二之一則運用詞彙判斷作業，操弄中文雙字詞中，促發詞與目標詞之間的關係（語意相關，中文音韻相關，完全無關）；實驗二之二仍舊使用詞彙判斷作業，但操弄中文雙字詞轉換爲台灣手語後，促發詞與目標詞之間的關係（台灣手語音韻相關，完全無關）。**結果**：實驗一結果顯示聾人手語者的正確率 (.66) 顯著低於聽人參與者 (.87)，尤其是在字形不相似的情境中，聾人的正確率與敏感度顯著較低，再者，在聽人的同音字判斷中，頻率對數可以顯著預測其正確率與反應時間，而發音一致性則僅能預測反應時間，相對的，聾人手語者於同音判斷作業的正確率可以同時由頻率對數與發音一致性，此結果顯示出聾人手語者具有中文字形字音轉換規則的知識。於實驗二之一的促發作業中，聾人手語者僅呈現出語意的觸發效果，但沒有中文音韻的促發效果，這顯示出聾人手語者在有時間限制情境下，口語音韻訊息並非自動地激發。在實驗二之二結果中，台灣手語的音韻促發效果僅在聾人手語者中顯現，進一步顯示出聾人手語者在閱讀中文字詞時，會透過台灣手語的音韻訊息來觸接心理詞彙。**結論**：本研究發現使用台灣手語的聾人是具有中文字形字音轉換規則的知識，但這樣的知識不夠完整以完成中文同音字的判斷，同時，台灣手語音訊息在閱讀中文詞時可被自動地激發，以達詞彙判斷理解之目的。

關鍵詞：台灣手語，形音轉換，音韻運作，發音一致性，聾人閱讀