Can experience with different types of writing system modulate holistic processing in speech perception?

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Abstract

Holistic processing (HP) is an expertise marker in visual perception; nevertheless, it can be modulated by writing experience (Tso, Au, & Hsiao, 2014). We have recently found that HP also indicates expertise in Cantonese speech perception (Liu & Hsiao, 2014). Nevertheless, Cantonese has a logographic writing system where one syllable corresponds to one character, whereas in alphabetic languages, each syllable can be decomposed into phonemes that correspond to letters. This distinction between logographic and alphabetic languages may also modulate HP effects in speech perception. Here we tested HP effects through the composite paradigm with Korean syllables. In contrast to Cantonese speech perception, native Korean speakers were less holistic than novices in Korean syllable perception. Thus, experience with an alphabetic language may promote analytic processing of its spoken syllables. Similar to visual perception, our results suggest that HP as an expertise marker in speech perception depends on the listeners' learning experience.

Keywords: holistic processing, speech perception, isolated Korean syllable processing.

Introduction

In vision research, holistic processing (HP), i.e., combining features together and process them as a whole, has been consistently found as a behavioral expertise marker for face processing across numerous studies through the composite paradigm (for review, see Richler & Gauthier, 2014). In a composite face task, participants are shown pairs of composite faces and asked to do same/different judgments about the top halves of the faces and ignore the irrelevant bottom halves; participants are likely to report identical top halves to look different when they are aligned with different bottom halves. This phenomenon is termed the composite illusion, and it disappears when the top and bottom halves are misaligned. The amount of interference they get from the irrelevant parts in the aligned condition, measured by either a decrease in accuracy or sensitivity, or an increase in response time as compared with the performance in the misaligned conditions, reflected the degree of holistic processing. In expert face processing, HP binds the two halves of the faces together so that experts' flexibility to access the information of individual parts is attenuated (Maurer, LeGrand, & Mondloch, 2002). The same paradigm has been used to examine other fields of visual expertise, including the recognition of cars, birds (Gauthier, Skudlarski, Gore & Anderson, 2000), and fingerprints (Busey & Vanderkolk, 2005), and HP has been consistently found as an expertise marker.

More recent research suggests that, although HP has been found as an expertise marker for face/object recognition, it can be modulated by experts' sensorimotor experience. For example, it was shown that in Chinese character recognition, as compared with novices, expert readers with limited writing experience showed increased HP whereas readers who were expert in both reading and writing showed reduced HP (Tso, Au & Hsiao, 2014). Similarly, Zhou, Cheng, Zhang, and Wong (2012) showed that face drawing artists had reduced holistic face processing as compared with non-drawers. Through computational modeling, Galmar and Hsiao (2013) showed that the reduced HP in face artists might be due to engagement of local attention required in drawing faces. These results suggest that HP as an expertise marker in visual recognition can be modulated by experts' learning experience.

Auditory processing expertise in speech perception refers to one's ability to rapidly and accurately identify and discriminate individual sounds within a particular language (Chartrand, Peretz & Belin, 2008). In contrast to the research on visual perception, where different types of expertise have been studied extensively, expertise studies in speech processing has been largely neglected. A recent study adopting the composite paradigm to examine the processing of Cantonese syllables in experts and novices suggested that HP might also be an expertise marker in the auditory domain (Liu & Hsiao, 2014). It was found that experts' perception of Cantonese syllable parts were more influenced by neighboring segments, especially in the perception of syllable initials. This result is consistent with the literature on visual perception, suggesting that HP may also be an expertise marker in speech perception.

Nevertheless, Cantonese has a logographic writing system (Chinese) that uses individual characters to represent meaning, and components of the characters do not map to components of the pronunciation. In addition, in Hong Kong, where Hsiao & Liu's (2014) participants were recruited from, students learn to read characters in a "look and say" method, and no phonics instruction is given to aid in reading (McBride-Chang et al., 2005). Consequently, the language experience in Hong Kong Cantonese speakers may prompt them to process each syllable as a whole as compared with novices. In contrast, in learning to read alphabetic languages, children are explicitly taught with grapheme-phoneme (letter-sound) correspondences (Ellis, et al., 2004), and the

awareness of smaller sound units within a syllable is a critical predictor of children's reading development (Goswami & Mead, 1992). Thus, children with an alphabetic language background may learn to break down a syllable into smaller parts, in contrast to Hong Kong Cantonese speaking children.

In visual recognition, experts' learning (i.e., sensorimotor) experience can modulate HP effects (e.g., Tso et al., 2014). Similarly, in auditory processing, the differences between the nature of logographic and alphabetic languages may also modulate HP effects in speech perception. Learning to read in an alphabetic language may involve engagement of local attention to components of the syllables, leading to reduced HP effects. Thus, here we aimed to examine whether HP is also an expertise marker in the processing of isolated syllables of an alphabetic language. Here we chose Korean as our research focus for two reasons. Firstly, Korean is a less popular alphabetic language than English, and thus is novel to the majority of people in Hong Kong, whereas English is an official language in Hong Kong. Secondly, although Korean is an alphabetic language, written Korean characters consist of letters (Hangul) arranged in a similar square shape as Chinese characters. Each character corresponds to one syllable, and is composed of Hangul letters. Hangul is an alphabet in which one letter maps onto one phoneme, and arranged from left-to-right and top-to-bottom to form a character, as illustrated in Figure 1 (Perfetti & Liu, 2005). Korean syllables have four types: V, VC, CV, and CVC, with the latter two being more dominant types (Kim, 2001). In South Korea, Hangul is a compulsory part of the official literary education from as early as kindergarten, so by the time they graduate from primary schools, they are already proficient in decoding skills (Cho & McBride-Chang, 2005). We hypothesize that since native Koreans learn to read Korean characters with extensive practice in decomposing characters, they may engage more local attention to individual units within a syllable than novices. Thus, expert Korean speakers may be more analytic than novices in the processing of Korean syllables.

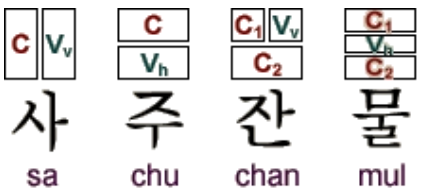

Figure 1: Examples of Korean syllables arranged into four different structures

Methods

Participants

Twenty-four native Korean speakers and 24 native Cantonese speakers who were novices of Korean were recruited from the University of Hong Kong. A questionnaire was designed to collect information about their language background and exposure. All expert participants were native Korean who were exchange or full-time students at the University of Hong Kong. All Cantonese speakers were born and grew up in Hong Kong and had no formal education about Korean language except for watching Korean dramas (on average less than one hour per week). The two groups were matched in age (novice: *mean* = 25.00, *S.E* = .93; expert: *mean* = 24.58, *S.E* = 1.38, $t(46) = .25$, $p = .80$) and years of education (novice: *mean* = 16.41, *S.E* = .64; expert: *mean* = 15.56, *S.E* = .65, $t(46) = .86.$, $p = .39$). Note that the official language for instruction at University of Hong Kong is English, so both experts and novices of Korean were bilinguals in their mother tongue and English.

Materials

Baseline Auditory Processing We adopted the birdsong discrimination task developed by Liu and Hsiao (2014) to tap on participants' baseline auditory processing abilities. All birdsongs used were downloaded from *New Zealand bird songs and calls* corpus (Te Papa Atawhai, 2013) and trimmed to 1.5s each from the beginning of the articulation.

Holistic Processing of Korean Syllables To examine holistic processing of Korean syllables, the complete composite paradigm (Gauthier & Bukach, 2007) commonly used in vision research and modified in Liu and Hsiao (2014) to examine holistic processing in speech perception was adopted. In each trial, participants were presented with a pair of Korean syllables sequentially, and told to attend only to either the initial or the final segment, and judge whether they were the same or different. In congruent trials, the attended and irrelevant segments led to the same response, i.e., both were "same" or both were "different" (see Table 1 for examples), whereas in incongruent trials, they led to different responses (i.e., there was interference from irrelevant segments). Holistic processing was assessed by the performance difference between the congruent and the incongruent trials.

Table 1: Examples of the Korean syllable stimuli.

		Attend to Initial	Attend to Final
Congruent	Same	[k]oo – [k]oo	l[ah] – l[ah]
	Different	[n]eu – [g]eh	p[yi] – n[oo]
Incongruent	Same	[k]yi – [k]eh	p[ah] – s[ah]
	Different	[n]eo – [g]eo	j[yi] – j[oo]

In order to apply the composite paradigm, only CV and CVC structured Korean syllables were used for the current study. Similar to Liu and Hsiao (2014)'s study, we created three types of stimuli, namely original, separated, and disconnected Korean syllables. The original Korean syllables were recorded from a native female Korean speaker at the Phonetic laboratory, University of Hong Kong, using *Praat* with 44100 Hz sampling rate and 16-bit resolution, mono channel. They were in total 160 pairs of original syllables, and equally divided into four trial types: same congruent, different congruent, same incongruent, and

different incongruent. Due to co-articulation phenomenon where the same initial may sound a bit different when paired up with different final segments (i.e., the segments in an original syllable are already integrated to form a holistic representation), we created separated Korean syllables by concatenating isolated initials and finals recorded by the same female speaker corresponding to the original syllables with no time delay (Figure 2b) to eliminate the co-articulation effect. In addition, we created disconnected syllables (Figure 2c) by adding a 0.5s gap between the initial and the final of the separated syllables. This disconnected condition is analogous to the misaligned condition in the composite paradigm used in vision research. The original and separated stimuli were about 1s long, whereas the disconnected stimuli were about 1.5s long.

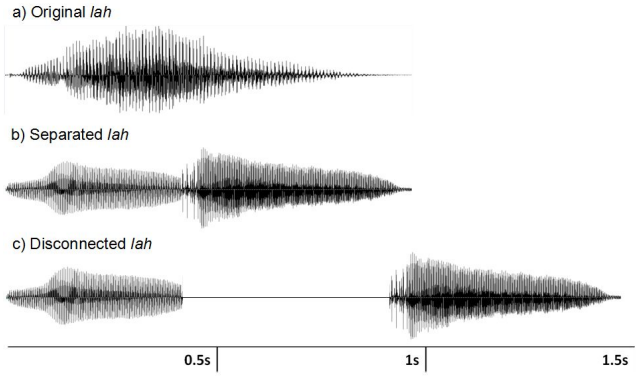

Figure 2: Examples of a) original Korean syllables, b) separated and c) disconnected syllables.

Design

The design had one between-subject variable: group (expert vs. novice); and three within-subject variables: congruency (congruent vs. incongruent), stimulus type (original vs. separated vs. disconnected), and attended syllable segment (initial vs. final). The dependent variable was discrimination sensitivity measured by A', which is a bias-free nonparametric measure of sensitivity[1]. The degree of holistic processing was indicated by the performance difference between congruent and incongruent trials.

Procedure

Baseline Auditory Processing 30 birdsong discrimination trials were carried out before the holistic processing tasks. In each trial, participants first saw a fixation cross for 500 ms at the center of the screen to signal the start of the trial. They then heard two birdsongs sequentially, each of which lasted for 1.5s, with a 1s interval between the two stimuli. They were asked to judge whether the two birdsongs were the same or different with a response box. Half of the trials were "same" trials, and the other half were "different" trials. All birdsongs were drawn from the 60 birdsong clips; the presentation of a birdsong in a "same" or "different" trial was counterbalanced across participants.

Holistic Processing of Korean Syllables There were 160 trials of original syllables, 160 trials of corresponding separated syllables, and 160 trials of corresponding disconnected Korean syllables. In each stimulus condition, there were four blocks, two for syllable initial discrimination and two for final discrimination; each block contained 40 trials. The sequence of presenting the initial and final discrimination blocks was counterbalanced across participants. In each trial, after a 0.5s central fixation, they listened to two sequentially presented Korean syllables with a 1s interval in between, and then judged whether the initials (or the finals in the final discrimination blocks) of the two syllables were the same or different with a serial response box compatible with E-Prime (Figure 3). They performed a practice session with 24 trials consisting of all three types of stimuli (8 trials respectively for each type shown in Figure 2, 4 initial and 4 final discrimination trials) not used in the materials before the experiment.

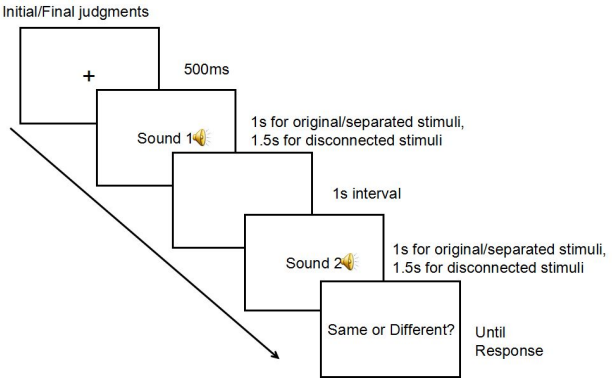

Figure 3: Procedure of the holistic processing task

Results

Bird Song

Both expert and novice groups had high and similar performance in the birdsong discrimination task, they did not differ in accuracy (experts, *mean* = .94, *S.E* = .02; novices, *mean* = .94, *S.E* = .02, $t(46) = ..16$, $p = .87$), nor response time (experts, *mean* = 1.60s, *S.E* = .13s; novices, *mean* = 1.50s, *S.E* = .14s, $t(46) = .61$, $p = .61$), suggesting both groups had no impairment in the baseline auditory temporal processing.

Holistic Processing

Repeated measures ANOVA in A' revealed significant main effects of stimulus type ($F(2, 92) = 43.11$, $p < .001$, η_p^2

[1] $A' = .5 + \left[sign(H-F)\frac{(H-F)^2 + |H-F|}{4\max(H,F) - 4HF} \right]$, where H and F present hit rate and false alarm rate respectively. Better performance is indicated by a higher *A'*. Here we used *A'* instead of *D'* because it can be calculated when the hit rate or the false alarm rate is 1 or 0, which was present in the data we collected.

= .48), congruency ($F(1, 46) = 71.16$, $p < .001$, $\eta_p^2 = .61$), and attended syllable segment ($F(1, 46) = 85.57$, $p < .001$, $\eta_p^2 = .65$). Participants performed the worst in perceiving original Korean syllables (planned paired-sample t-test, original vs. separated: $t(47) = 4.89$, $p < .001$; original vs. disconnected, $t(47) = 4.88$, $p < .01$), and had similar performance in the separated and disconnected conditions ($t(47) = 0.19$, $p = .85$). They were better in congruent than incongruent trials ($t(47) = 6.68$, $p < .001$), and in processing finals than initials ($t(47) = 7.63$, $p < .001$).

There was also a significant four-way interaction between stimulus type, congruency, attended segment, and group ($F(2, 92) = 11.23$, $p < .01$, $\eta_p^2 = .20$), a three-way interaction between stimulus type, congruency and attended segment ($F(2, 92) = 29.00$, $p < .001$, $\eta_p^2 = .39$), and a two-way interaction between stimulus type and congruency ($F(2, 92) = 98.79$, $p < .001$, $\eta_p^2 = .69$). The above results indicated that the level of holistic processing in the perception of the syllable initials and finals differed between the two groups. To further investigate the effect, we examined the data in the syllable initial and syllable final discrimination tasks separately[2].

Syllable Initials Repeated measure ANOVA in A' revealed significant main effects of congruency ($F(1, 46) = 98.63$, $p < .001$, $\eta_p^2 = .69$) and stimulus type ($F(1, 46) = 45.55$, $p < .001$, $\eta_p^2 = .49$): participants showed a congruency effect in syllable initial perception in general, and they performed better as we separated and disconnected the initials from finals. A significant three-way interaction between stimulus type, congruency, and group ($F(2, 92) = 42.18$, $p < .01$, $\eta_p^2 = .47$), and a two-way interaction between stimulus type and congruency, ($F(2, 92) = 97.62$, $p < .001$, $\eta_p^2 = .68$) were also found. The interaction effects indicated that the level of holistic processing differed across different types of stimuli and participant groups.

When we split the data by group, we found that among experts, there was a significant interaction between congruency and stimulus type ($F(2, 46) = 27.15$, $p < .01$, $\eta_p^2 = .54$), and this interaction was also found in novices ($F(2, 46) = 74.95$, $p < .001$, $\eta_p^2 = .77$). When we split the data by stimulus type, in processing original syllables, there was a main effect of congruency ($F(1, 46) = 110.98$, $p < .001$, $\eta_p^2 = .73$), and a significant interaction between group and congruency ($F(1, 46) = 51.19$, $p < .001$, $\eta_p^2 = .53$): novices showed a stronger congruency effect, i.e., were more holistic than experts in processing authentic Korean syllable initials. When we separated the initials from the finals, the effect of congruency became marginal ($F(1, 46) = 3.30$, $p = .08$), and there was no interaction between group and congruency ($F(1, 46) = 1.09$, $p = .30$, n.s.). The analysis with disconnected syllables yielded similar results to the separated condition: a marginal congruency effect ($F(1, 46) = 3.20$, $p = .08$), and no interaction between congruency and group ($F(1, 46) = .81$, $p = .37$, n.s.). As shown in Figure 4, in general, both groups showed strong holistic processing in the original condition, and separating/disconnecting segments reduced the congruency effect.

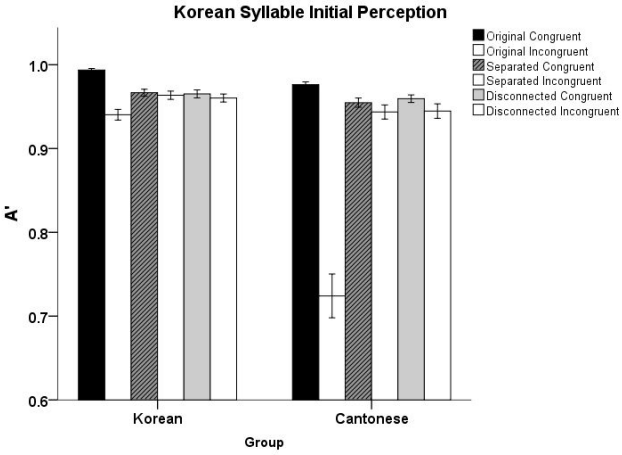

Figure 4: Performance of experts and novices of Korean in the HP task with Korean syllable initials (*$p < 0.05$; ***$p < 0.001$)

Syllable Finals There were significant main effects of congruency ($F(1, 46) = 36.41$, $p < .01$, $\eta_p^2 = .44$) and stimulus type ($F(1, 46) = 27.69$, $p < .01$, $\eta_p^2 = .38$), a two-way interaction between stimulus type and congruency ($F(2, 92) = 40.17$, $p < .01$, $\eta_p^2 = .47$), and a significant three-way interaction between stimulus type, congruency, and group ($F(2, 92) = 20.13$, $p < .01$, $\eta_p^2 = .30$) in A'. Similar to the results in the perception of syllable initials, the interaction effects indicated that the level of holistic processing differed across different types of stimuli and participant groups.

When we examined the data separately by group, novices exhibited a significant interaction between congruency and stimulus type ($F(2, 46) = 34.23$, $p < .001$, $\eta_p^2 = .60$), as well as among experts ($F(2, 46) = 6.13$, $p < .05$, $\eta_p^2 = .21$). When we separated the data by stimulus type, in the original syllable condition, there was a significant main effect of congruency ($F(1, 46) = 44.71$, $p < .001$, $\eta_p^2 = .49$), and a significant interaction between congruency and group ($F(1, 46) = 17.86$, $p < .01$, $\eta_p^2 = .28$). Novices of Korean were in general more holistic than experts in the original syllable condition. In the separated condition, no significant congruency effect ($F(1, 46) = 1.36$, $p = .25$, n.s.) or interaction between congruency and group ($F(1, 46) = .19$, $p = .67$, n.s.) was found. Similarly in the disconnected condition, there was no main effect of congruency ($F(1, 46) = 2.38$, $p = .13$, n.s.) or interaction effect ($F(1, 46) = 1.09$, $p = .30$, n.s.; Figure 5). These results were in general consistent with the results with syllable initials, suggesting that experts exhibited reduced holistic processing effect as compared with novices; as shown in Figure 5, in general separation/disconnection of the segments reduced the congruency effect in both groups.

[2] In the response time data analysis, only significant main effects of congruency and attended segment, and a marginal main effect of congruency were found. No significant interaction effects were observed.

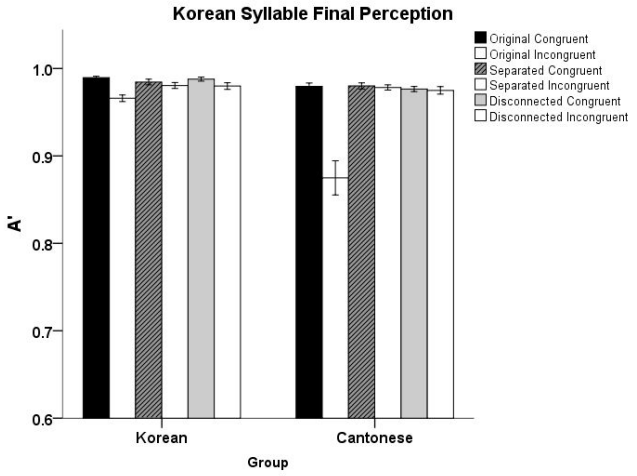

Figure 5: Performance of experts and novices of Korean in the HP task with Korean syllable finals (**$p < 0.01$)

Discussion

To examine whether experience with languages that have different types of writing systems (i.e., logographic vs. alphabetic) can influence holistic processing (HP) in speech perception, here we extended our research on HP in Cantonese to the processing of Korean, an alphabetic language. We adopted a modified composite paradigm to examine the perception of Korean syllables in native Korean speakers and novices whose first language is Cantonese.

Firstly, in contrast to the findings in Cantonese syllable processing (Liu & Hsiao, 2014), we found that Korean experts were more analytic than novices in Korean syllable perception. In perceiving Korean syllable initials and finals, both experts and novices showed decreased HP when the segments were separated or disconnected from each other, reflecting the baseline behavior in which sound segments were less likely to be perceived as a whole when they were separate or disconnected. The main difference in their perception of syllable initials and finals lay in the original syllable condition. Similar to how novices of Cantonese perceived Cantonese syllable initials, novices of Korean were very holistic when perceiving Korean syllable initials. These effects suggest that the default mode of human perception of syllable initials in a novel language may be holistic. However, comparing with novices of Korean, native Korean speakers were relatively less holistic in the processing of syllable initials, presumably due to their experience with Korean language. In contrast, in the perception of Cantonese syllable initials, expert Cantonese speakers were even more holistic than novices, and their perception was still affected by syllable finals even when the finals were separated or disconnected from the initials.

This contrast of how expertise in Korean and Cantonese manifest through the HP paradigm may reflect the modulation of the writing system on speech perception. In learning an alphabetic language such as Korean, children learn to read words through identifying sounds for spelling using grapheme-phoneme (letter-sound) correspondences. This learning process may require engagement of local attention to graphemes and phonemes, making them more and more proficient in identifying individual sound units within one syllable. In contrast, children learning to read a logographic language such as Chinese do not need to decompose a character pronunciation into phonemes since they do not map to components in the character. Thus, it is possible to learn to read Chinese through "look and say", pairing one character with one syllable (such as children in Hong Kong). This learning experience may blur the boundaries between syllable initials and finals, resulting in a more holistic way of processing Cantonese syllables. These effects converge with some recent findings in visual perception. For example, face artists who are expert in drawing faces demonstrate reduced HP in face perception (Zhou et al., 2012); a recent computational modeling study suggests that this effect may be due to engagement of local attention in face artists when drawing faces (Galmar & Hsiao, 2013). Similarly, in Chinese character processing, learning only to read but write Chinese lead to increased HP among expert readers as compared to novices, whereas learning to both read and write Chinese resulted in reduced HP (Tso et al., 2014). Together these results suggest that in perceptual expertise development, HP effects can be modulated by different learning experiences. Using the same paradigm in both visual and auditory processing allows us to compare and examine expertise effects that may be universal across different modalities.

Although in general Korean speech expertise demonstrated different HP effects from Cantonese expertise, here we replicated one finding from Cantonese syllable processing (Liu & Hsiao, 2014): both participant groups processed syllable initials more holistically than syllable finals. This effect may be attributed to the typical lengths of syllable initials and finals, and the differences in the acoustic properties of consonants and vowels.

In the literature of speech processing, the term "holistic processing" has often been defined as processing at the level of syllable or a global unit of speech (Charles-Luce & Luce, 1990), which is considered as a less efficient and immature form of speech processing. On the contrary, analytic processing, i.e., processing a word as a combination of individual sounds from the beginning to the end, emerges with more exposure to the language and accelerates with explicit teaching of the internal structure of the words, and marks the maturation of phonological encoding and expertise in the language (Byrd, Conture, & Ohde, 2007). Note that although we also found native Korean speakers are less holistic than novices in processing Korean syllables, the definition of HP used here is different from the one in the auditory processing literature. The HP measured by the composite paradigm refers to voluntary combination of features and inability to selectively attend to parts. Thus, our results suggest that, not only can experts of an alphabetic language process words or syllables phoneme by phoneme, but also can they selectively attend to part of the syllables without being interfered by other segments. Readers of

logographic languages such as Chinese are also shown to have better phonological awareness as they progress to become better readers (Shu, Peng, & McBride-Chang, 2008); nevertheless, Hsiao and Liu's (2014) results suggest that they may still process syllables holistically due to their learning experience. It remains unclear whether explicit instructions on the phonemic structures of Chinese/Cantonese syllables through a phonetic system are able to enhance analytic syllable processing and reading development. Research on visual expertise has suggested that both holistic and analytic skills maybe required for mastering a recognition skill. For example, in Tso et al's (2014) study, the best readers were those who were proficient in both reading and writing. Similarly, Galmar, Chung, and Hsiao (2014) showed that face drawing experts, who showed reduced HP in face processing, performed better than non-drawers in face identification. These results suggest that the development of analytic skills may also be beneficial for speech processing.

In conclusion, here we show that experts demonstrated weaker HP than novices in Korean syllable perception as assessed by the composite paradigm, in contrast to Liu and Hsiao's (2014) finding that Cantonese experts showed stronger HP than novices. This result suggests that experience with different writing systems may modulate HP effects in speech perception. Similar to the literature on visual expertise, HP as an expertise marker in speech perception depends on the listeners' learning experience.

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