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The relative contributions of phonological awareness and vocabulary knowledge to deaf and hearing children's reading fluency in Chinese

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ABSTRACT

Background: It is unclear whether phonological awareness and vocabulary knowledge are independent predictors of reading fluency for deaf children in different grades.
Aims: This study examined the relative contributions of phonological awareness and vocabulary knowledge to Chinese deaf children's reading fluency in grades 3–4 (lower grades; mean age 14.08 years) and 5–6 (higher grades; mean age 15.05 years).
Methods and procedures: One hundred and forty-one deaf children and 163 hearing children were enrolled. All children completed assessments of general cognitive ability, onset and tone awareness, vocabulary knowledge and reading fluency.
Outcomes and results: The results showed that for lower-grade deaf children, the unique effect of onset awareness on reading fluency was not statistically significant, but it was an independent predictor in higher grades; for lower-grade hearing children, onset awareness accounted for variance in reading fluency, but its effect was not significant in higher grades. No significant effect of tone awareness was found in deaf or hearing children. However, vocabulary knowledge significantly explained the variance in reading fluency for all subgroups.
Conclusions and implications: The predictive patterns of phonological awareness on reading fluency are complex and depend on many factors, while vocabulary knowledge is an important and consistent predictor for both deaf and hearing children.

What this paper adds?

Reading fluency is an essential component of every reading activity but has been paid little attention, especially in the research on deaf children's reading. The role of phonological awareness (phonological processing skill) is controversial, but vocabulary knowledge (non-phonological broader language skill) has been shown to be important in previous research into deaf children's reading. The current study has extended these relationships to reading fluency, and examined the unique contribution of phonological awareness and vocabulary knowledge to reading fluency in different stages of reading development, including onset awareness and tone awareness at the same time. The results showed that the effect of onset awareness on deaf children's reading fluency was only significant in higher grades (grades 5–6), while for hearing children, the significant effect was only found in lower grades (grades 3–4). However, for both deaf and hearing children, tone awareness could not explain the variance in reading fluency, while

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vocabulary knowledge was a consistent predictor. Importantly, findings suggest that deaf children may develop phonological awareness after some years of schooling, which supports their reading development. The effect of phonological awareness on reading fluency depends on many factors, but vocabulary is an important broader language skill during grades 3–6. There are some similarities and differences in the mechanisms underlying reading development in deaf and hearing children.

1. Introduction

Reading plays a vital role in an individual's academic performance and social success. However, most deaf children with severe or profound deafness experience significant difficulties in learning to read. Their reading outcomes often lag far behind that of hearing children who have the same years of schooling, reading ages or chronological ages (e.g., Lederberg, Schick, & Spencer, 2013; Torres & Santana, 2005; Wauters, Bon, & Tellings, 2006). Reading builds fundamentally on primary language processes, and the low reading levels among deaf populations are partly due to the discrepancy between their incomplete language system and the demands of reading system (Perfetti & Sandak, 2000). That is, a lack of access to language in general can result in delayed reading ability in deaf children. A study by Wauters et al. (2006) examined the reading comprehension of 464 Dutch deaf children, and the results showed that deaf children's scores were far below those of hearing children. Similarly, Liu (2010) indicated that Chinese deaf graduates from the nine-year schools appeared to be slightly below fifth-to-sixth grade hearing students in a proficiency test in Chinese. Most previous research, however, has focused on reading comprehension of deaf people (e.g., Kyle & Harris, 2010; Wauters et al., 2006), and compared to reading fluency, there is more agreement about deaf children's poor performance in reading comprehension.

Although comprehension is the ultimate purpose of reading, the role of reading fluency in integrating information, constructing meaning and comprehending the whole text should not be ignored. Reading fluency is an essential component of every reading activity (Hudson, Lane, & Pullen, 2005). It is defined here as the ability to read connected text quickly and accurately, a seemingly straightforward task underpinned by complex processes (Hudson, Pullen, Lane, & Torgesen, 2009). Reading fluency relies on an individual's grapheme-phoneme transformation speed and the efficiency of text meaning construction and integration. According to the Automaticity View of Reading, the capacity of attention is limited; fluent reading can free the cognitive resources for higher order thinking and thus facilitate reading comprehension (LaBerge & Samuels, 1974). Otherwise, when readers read in a disconnected fashion, insufficient cognitive resources are available to construct the meaning from the text, which leads to difficulty in comprehension. Therefore, reading fluency is necessary for successful reading. Many researchers have investigated deaf children's reading comprehension and its associated underlying processes (Luckner & Handley, 2008; Luft, 2018; Wang, Paul, Falk, Jahromi, & Ahn, 2017), but less attention has been paid to reading fluency.

Given the importance of fluency in reading and the challenges deaf children experience in becoming proficient readers (Luckner & Urbach, 2012; Marschark, Spencer, Adams, & Sapere, 2011), the main purpose of the present study was to investigate the achievement of deaf children in reading fluency, exploring the relative contributions of two kinds of predictors: phonological processing skill (phonological awareness) and non-phonological broader language skill (vocabulary knowledge). As deaf children get older, the dominance of these skills may vary, enabling them to read successfully across different phases of reading development (Badian, 2001; Chall, 1983). It is therefore also imperative to gain a better understanding of how these two language skills contribute to reading fluency at different reading stages. Some similarities and differences may exist in the underlying mechanisms between deaf and hearing children.

1.1. Phonological awareness

The literature shows that phonological awareness is necessary for children's reading development and the close relationship between phonological awareness and reading achievements is well documented in hearing children, including the prediction of phonological awareness on reading fluency (e.g., Landerl et al., 2019; Shu, Peng, & Mcbride-Chang, 2008; Xue, Shu, Li, Li, & Tian, 2013). Skilled and fluent reading relies on one's ability to conceive of words not only as meaningful items but also as units that have internal phonological structure. The widespread agreement of the importance of phonological awareness is in line with Ehri (1995, 2005) Reading Phase Model, which distinguishes four phases in the development of sight word reading. According to Ehri (1995, 2005) model, knowledge of the alphabetic system including the knowledge of grapheme-phoneme relations and phonological awareness is vital for children's reading development; this model also indicates that phonological awareness is more important at the earlier stage of learning to read than at the later stage of reading to learn.

Evidence shows that deaf children often have poorer phonological awareness than their hearing peers even though they have received the same (or more) years of formal education (e.g., Kyle & Harris, 2011; Lund, Werfel, & Schuele, 2015). There are still many controversies about the importance (or otherwise) of phonological skills for deaf children's reading proficiency (Luft, 2018). Deaf children may develop phonological awareness via sign language, speechreading, residual hearing and literacy instruction, or through the help of cochlear implants or digital hearing aids (Alegría & Lechat, 2005; Dodd, 1987; Kyritsi, James, & Edwards, 2007). Half of the studies in a meta-analysis showed significant evidence of some level of phonological coding and awareness in deaf participants, while half did not; phonological coding and awareness skills were a low to moderate predictor of deaf readers' reading achievements (Mayberry, Del Giudice, & Lieberman, 2011). Although the study by Mayer and Trezek (2014) suggested that there is stronger empirical evidence for the argument for the role of phonology in deaf individuals' reading than for the counterargument, two longitudinal studies conducted by Kyle and Harris (2010, 2011) reached a similar conclusion that earlier phonological awareness was not a significant correlate or predictor of deaf children's reading ability at least when deaf children were in the stage of learning to read. On the contrary, as the deaf children got older, the two variables seemed to become related and the patterns of concurrent

correlation at the last assessment in Kyle and Harris (2010) were similar to the results of a study on younger hearing children (Muter, Hulme, Snowling, & Stevenson, 2004).

In the case of deaf children, decoding written words phonologically is of little value if they don't know the words initially, while some good readers often seem to have a grasp of the rules of sound code of English (Goldin-Meadow & Mayberry, 2001). It can be speculated that deaf children may develop phonological awareness over the course of learning to read, and their phonological processing ability is not typically the precursor to reading ability in the early phase of learning to read, which is different from hearing children (Goldin-Meadow & Mayberry, 2001; Kyle & Harris, 2010, 2011; Musselman, 2000). After a period of schooling and being exposed to reading, deaf children are able to comprehend phonological units, manipulating phonological structure in order to map phonology to the corresponding printed text. However, the role of phonological awareness in reading fluency among deaf children is unclear. Although reading fluency refers to speed and automaticity (effortlessness and requiring few attentional resources), it is a complex activity with no loss of comprehension (Kim, 2015). Phonological awareness is important to hearing children's reading ability including reading fluency especially in the earlier stage (Ehri, 1995, 2005; Shu et al., 2008), but just like the relation between phonological awareness and other reading ability (e.g., reading comprehension) in deaf children (Kyle & Harris, 2010, 2011), the effect of it on reading fluency may not be apparent in beginning deaf readers. Therefore, we hypothesized that phonological awareness significantly predicts reading fluency in higher-grade deaf children in elementary school, while the prediction patterns for hearing children may be reversed.

It is also worth mentioning that different types of phonological awareness may have different development points and speed. In particular, onset awareness and tone awareness increases apparently with schooling (Shu et al., 2008). On the one hand, onset awareness was once used to represent Chinese children's phonological awareness successfully, and was a significant predictor of word reading in beginning readers (Liu et al., 2017). On the other hand, tone is a suprasegmental unit. Chinese children have to rely on tones to distinguish the meaning of words (McBride-Chang, Tong et al., 2008), and the perception of tones is difficult for deaf children even those with cochlear implants (Tse & So, 2012). Thus, both onset awareness and tone awareness were included in the present study to investigate the different roles of these two types of phonological awareness in reading fluency across the grades in elementary school.

1.2. Vocabulary knowledge

The vitally important role of vocabulary knowledge in reading written connected text has been demonstrated from the early stages of reading research. According to Perfetti's (2007) Lexical Quality Hypothesis, specific lexical representation refers to the knowledge a reader has about the words, and higher quality of lexical representation is helpful for children's reading ability. For hearing children, it is widely acknowledged that vocabulary knowledge is one of the most consistent correlates and predictors of reading achievement (e.g., Dickinson, McCabe, Anastasopoulos, Peisner-Feinberg, & Poe, 2003; Protopapas, Mouzaki, Sideridis, Kotsolakou, & Simos, 2013; Song et al., 2015), which is also in line with the Simple View of Reading (SVR, Gough & Tunmer, 1986; Hoover & Gough, 1990). In the SVR, decoding and language comprehension are two essential elements of reading activity, while vocabulary knowledge is often regarded as the part of language comprehension (e.g., Braze et al., 2016). In contrast to phonological awareness, vocabulary knowledge is a broader language skill linked to overall reading development. This relationship also holds true for deaf children.

Although children who are deaf or hard of hearing often show poor spoken vocabulary, lack deeper knowledge of vocabulary, and are delayed in their vocabulary knowledge acquisition (Coppens, Tellings, Verhoeven, & Schreuder, 2011; Paul & Gustafson, 1991), significant correlations between productive vocabulary and reading ability have been found in deaf participants (Harris, Terlektsi, & Kyle, 2017; Kyle & Harris, 2006, 2010). Twenty-nine deaf children with a mean age of 7 years 10 months and 31 reading-age matched hearing children with a mean age of 6 years 9 months were tested on a number of tasks to assess their phonological awareness, productive vocabulary, reading, spelling, nonverbal intelligence, and so on (Kyle & Harris, 2006). The results showed that productive vocabulary was a significant predictor of reading when controlling for hearing loss and nonverbal intelligence in deaf children. In addition to the concurrent prediction, earlier vocabulary also had long-lasting effects on different levels of reading components. A longitudinal study (Kyle & Harris, 2010) found that the strongest and most consistent longitudinal predictor of later word reading, sentence comprehension and text comprehension, and their growth across all time periods measured, was vocabulary. Just as for hearing children, limited knowledge of words and the lack of conceptual frameworks related to word meaning may affect all kinds of reading activities in deaf children.

As reading fluency not only requires readers to extract the meanings from the text, but also relies heavily on processing speed, it is not surprising that high quality lexical representation and quick meaning access will affect reading fluency (Lane et al., 2009). How well readers comprehend written text is determined by vocabulary knowledge (Nagy, 2005). An 8-year longitudinal study by Song et al. (2015) examined how vocabulary growth of Chinese hearing children predicted their future reading skills. Hierarchical regression showed that variations in reading fluency at age 11 were explained by the intercept and slope of vocabulary from ages 4 to 10 even after non-verbal IQ and mothers' education levels were controlled for. To our knowledge, there is no direct empirical study on the unique predictive effect of vocabulary knowledge on text-level reading fluency for deaf children. Based on the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990), reading efficiently is very difficult without vocabulary knowledge. Given the importance of vocabulary knowledge as frequently reported in the research on deaf children's reading (Luckner & Cooke, 2010; Välimaa, Kunnari, Laukkanen-Nevala, Lonka, & National, 2018), we hypothesized that vocabulary knowledge could significantly predict reading fluency in deaf and hearing children. Compared to phonological awareness, the significant effect of vocabulary knowledge may remain relatively stable across different periods of reading development.

1.3. The present study

Studies on the contributing factors of reading in Chinese deaf children are still scarce and there is no study specifically on the effect of phonological awareness and vocabulary knowledge on reading fluency. Phonological awareness and vocabulary knowledge are two important reading-related factors for hearing children and may have distinct roles in deaf children's reading performance. Deaf children have less access to phonological information in comparison to hearing children, which could possibly have an impact on their reading ability, while vocabulary knowledge is a broader language skill and essential for reading development. The relationship between phonological processing skills and vocabulary knowledge has been proposed (Dillon, De Jong, & Pisoni, 2012), because children with abundant vocabulary knowledge can make more generalizations about the phonological structure of language, and vice versa.

To provide an opportunity to compare the unique contribution of these two skills in deaf and hearing children in different stages of reading development, some hearing children at the same grade level were included in the present study. If the unique contribution of phonological awareness and vocabulary knowledge occur differently to reading fluency for deaf children in different stages, there may be reason to differentiate instruction to children in different grades. Furthermore, both onset and tone awareness were considered as indicators to systematically reflect the effect of phonological awareness. In summary, the main questions addressed in this study were: (1) Do deaf children show poorer phonological awareness (onset awareness and tone awareness), vocabulary knowledge and reading fluency compared to hearing children? (2) Do phonological awareness and vocabulary knowledge contribute independently to reading fluency? (3) Does the unique contribution of phonological awareness and vocabulary knowledge to reading fluency in deaf and hearing children change across different stages of reading development? If so, how?

2. Method

2.1. Participants

This study is part of a large study, and was undertaken in accordance with research principles for human participants. Ethical approval was obtained from the appropriate agency in Beijing Normal University. All deaf children have been exposed to spoken Chinese from a young age, and hearing children were Chinese native speakers. Informed consent was obtained from the school principals, classroom teachers, and parents before the test. Parents and teachers completed background questionnaires detailing each child's chronological age, hearing, rehabilitation, and other basic information. Some children achieved low scores on measures of cognitive skills and could not complete all of the tasks, thus were not included in the study. Therefore, four groups of children who complete all the measurements presented in this study, were included in the following analyses.

2.1.1. Deaf children

In China, deaf children would be normally educated in mainstream schools or special education schools. Deaf children with poor early hearing and language rehabilitation even though they had received cochlear implants or been fitted with digital hearing aids, as well as deaf children without any hearing aids, would be educated in special education schools. A total of 141 participating deaf children were recruited from four special education elementary schools in Hunan and Zhejiang, China. Two of them are comprehensive special education schools including deaf, blind and students with intellectual disabilities, one is also a comprehensive special education school including deaf and students with intellectual disabilities, and one is a special education school especially for deaf students.

Due to delayed reading ability in consequence of a lack of access to language in general, reading connected text is difficult for deaf children in grades 1 and 2. Therefore, they were not included in the current study. Two subgroups of deaf children focused on were: 43 children (24 male and 19 female) from grades 3 and 4 (lower grades) with chronological age from 11 to 19 years (M = 14.08 years, SD = 1.69 years); 98 children (62 male and 36 female) from grades 5 and 6 (higher grades), with chronological age from 10.42 years to 18.92 years (M = 15.05 years, SD = 1.70 years). Phonological awareness was not measured for lower-grade deaf children in some schools, which led to the relatively limited sample compared to higher-grade children.

Deaf children would have the Certificate of Disabled by China Disabled Persons' Federation once diagnosed in China. There are four levels of deafness according to the standard assessment for hearing disabilities. Based on the hearing level in the better ear, severity of deafness was categorized as level one (≥ 91 dB HL, profound deafness), level two (81–90 dB HL, severe deafness), level three (61–80 dB HL, moderate-severe deafness), and level four (41–60 dB HL, moderate deafness). Thirty-five (81.40%) of the lower-grade deaf children and 89 (90.82%) of the higher-grade children were reported to be profoundly deaf, and 2 (2.04%) deaf children in higher-grade were unreported (severe to profound deafness according to their teachers' report). Table 1 represents the categorization of degrees of deafness. In addition, the main reason for deafness was congenital development (82, 58.16%), and Table 2 shows

Table 1
The categorization of degrees of deafness in grades 3–4 and grades 5–6.

Categorization of deafness	Profound (≥ 91 dB HL)	Severe (81–90 dB HL)	Moderate-severe (61–80 dB HL)	Moderate (41–60 dB HL)
Grades 3–4 (n = 43)	35 (81.40%)	4 (9.30%)	4 (9.30%)	0
Grades 5–6 (n = 98)	89 (90.82%)	6 (6.12%)	1 (1.02%)	0

Table 2
The reason of deafness in deaf participants.

Reason	Congenital	Genetic	Drug	Illness	Unknown	Unreported
n	82	10	14	7	14	14
Percentage	58.16%	7.09%	9.93%	4.96%	9.93%	9.93%

the specific reason of deafness. It is worth mentioning that deaf children who can communicate effectively with hearing children and teachers using spoken language due to good hearing and language rehabilitation effect would be normally educated in mainstream schools rather than special education schools. Therefore, even though some children (29, about 20%) had received cochlear implants or been fitted with digital hearing aids, they reported seldom using them and preferring to communicate using sign language. All of the deaf children's language and communication preference is sign language. The majority of teachers are people with typical hearing, but they are competent to communicate with deaf students using sign language fluently. Teachers mainly rely on sign language, and also use the combination of sign language and spoken language to teach students in class, where spoken language is an auxiliary means to help deaf students to develop the ability of lip-reading.

2.1.2. Hearing children

Hearing children were recruited from one mainstream school in Hunan, China, located close to the special education schools. There were 163 children in this group in total. These children did not have any obvious cognitive or linguistic developmental delays. Two subgroups were: 85 children (49 male and 36 female) from grades 3 and 4 (lower grades), with chronological age from 8.42 years to 12.08 years (M = 10.49 years, SD = 0.72 years); 78 children (37 male and 41 female) from grades 5 and 6 (higher grades), with chronological age 10.92 years to 14.25 years (M = 12.47 years, SD = 0.63 years).

2.2. Measures

2.2.1. General cognitive ability

Children's general cognitive ability was measured using Raven's standard progressive matrices (Zhang & Wang, 1985). In this task, all of the items were presented in printed format. There were 60 items in total, and each item consisted of a target visual matrix with a missing part. Students were required to complete the target pattern by choosing the best part from six to eight alternatives, and a correct answer was given 1 point. The internal consistency coefficients α were 0.93 and 0.89 for deaf and hearing children respectively.

2.2.2. Phonological awareness

Using the oral testing format to assess deaf children's phonological awareness would be obviously inappropriate (Kyle & Harris, 2010), because deaf individuals have difficulty in accessing and producing spoken phonological information. Thus, following Liu et al. (2017), phonological awareness was measured using a test of onset and tone judgment. Children were given a number of characters arranged in two 11 × 14 matrices. In the onset judgment task, each matrix included 50 target characters whose pronunciation started with the onset "b" (irrespective of tone). The others (104 in each matrix) were non-target characters. Children were required to cross-out the target character in order, such as */bu4/* 步 [*step*], within 90 s. Similarly, in the task of tone judgment, children needed to cross-out the target characters with falling tone (tone 4) in order, such as */ye4/* 夜 [*night*], within 100 s. There was an example and a practice trial before each formal test to ensure that all children were able to understand the instructions. The scores of the two subtests were calculated by subtracting the number of missed and falsely chosen characters from the number of correctly identified and correctly rejected characters. The onset judgment task has been shown to effectively measure Chinese children's phonological awareness in the study by Liu et al. (2017), where test-retest reliability ranged from 0.81 to 0.94 with a sub-sample of Chinese children from grades 1 to 6.

2.2.3. Vocabulary knowledge

Children's vocabulary knowledge was assessed using the vocabulary definition task. In this task of expressive vocabulary, children were asked to explain a range of words (McBride-Chang, Tardif et al., 2008). They were allowed to give the definition using signing or speech, whichever was their preferred communication mode. This measure is in line with a number of previous studies on Chinese children and suggested as a reasonable indicator of Chinese children's vocabulary development (e.g., Song et al., 2015; Zhao et al., 2019). Children did the practice item prior to testing. In addition, 37 test words were listed in ascending order of conceptual difficulty and decreasing word frequency. The task was stopped when children failed on five consecutive items. The signed or oral responses were recorded on an answer sheet. Then two trained experimenters rated responses on a scale of 0–2 according to whether the exact meaning of the words was expressed. The internal consistency coefficients α were 0.88 and 0.87 for deaf and hearing children respectively.

2.2.4. Reading fluency

The task of reading fluency tests the ability to read connected-text fluently (Xue et al., 2013). Children were asked to read simple sentences silently and judge whether the statement was true after each sentence. They had to read as many sentences as possible in

Table 3
Descriptive statistics on all the measures for deaf and hearing children.

Grades	Variables	Deaf		Hearing		*t*
		M	SD	M	SD	
3–4 (Lower grades)	General cognitive ability	33.19	10.46	36.15	7.41	1.66
	Onset awareness	36.78	28.36	59.67	20.29	4.72***
	Tone awareness	18.85	15.83	38.72	16.72	6.47***
	Vocabulary knowledge	14.37	9.77	32.05	8.13	10.85***
	Reading fluency	257.35	313.23	769.25	361.80	7.90***
5–6 (Higher grades)	General cognitive ability	36.35	9.60	43.22	6.90	5.52***
	Onset awareness	44.75	26.62	75.62	22.61	8.16***
	Tone awareness	18.58	17.54	43.09	20.55	8.53***
	Vocabulary knowledge	17.94	8.64	40.23	8.42	17.19***
	Reading fluency	259.80	305.22	951.15	321.04	14.59***

Note. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$, two-tailed.

3 min. There were three practice items and 100 test sentences in total, increasing in length. The characters and meanings of sentences were familiar to children, such as 燕子会飞(√) [*Swallows can fly*] and 老虎喜欢吃青草(×) [*Tigers like to eat grass*]. To minimize the effect of guessing, children's scores were the number of characters in correctly marked sentences minus the number of characters in incorrectly marked sentences. The internal consistency coefficients α for deaf and hearing children were 0.74 and 0.92 respectively.

2.3. Procedure

All the measures were conducted by trained experimenters. For deaf children, their teachers were trained as experimenters because sign language was their preferred communication mode. The tests of phonological awareness and vocabulary knowledge were administered to the children individually, while the tests of general cognitive ability and reading fluency were administered in groups in children's classrooms.

3. Results

3.1. Comparison of mean scores for deaf and hearing children

Table 3 summarizes the means and standard deviations of general cognitive ability, phonological awareness, vocabulary knowledge and reading fluency scores obtained from deaf and hearing children in different grades. Independent-sample *t* tests were used to assess group difference on all task scores for the children in lower and higher grades. As shown in Table 3, the scores for deaf children, both in lower and higher grades, were significantly lower than those for hearing children on all the tasks except for the scores of general cognitive ability in lower grades (*p*s < 0.001).

3.2. Factors contributing to reading fluency in deaf and hearing children

3.2.1. Correlation analyses

Next, we examined the relationships among phonological awareness, vocabulary knowledge and reading fluency in deaf and hearing children in different grades. The results are shown in Tables 4 and 5. The lower half of the table is for children in grades 3–4, and the upper half for grades 5–6.

On the one hand, only onset awareness correlated with reading fluency significantly in deaf and hearing children in lower grades ($r_d = 0.41$, $p_d = 0.007$; $r_h = 0.24$, $p_h = 0.027$, respectively), while both onset awareness ($r_d = 0.54$, $p_d < 0.001$; $r_h = 0.27$, $p_h = 0.018$, respectively) and tone awareness ($r_d = 0.34$, $p_d = 0.001$; $r_h = 0.30$, $p_h = 0.009$, respectively) correlated significantly with reading fluency in higher grades. Different from onset awareness, the correlations between tone awareness and reading fluency

Table 4
Correlation coefficients among all tasks in deaf children.

Variables	1	2	3	4	5
1. General cognitive ability	—	0.30**	0.17	0.27**	0.20*
2. Onset awareness	0.53***	—	0.45***	0.53***	0.54***
3. Tone awareness	0.06	0.39**	—	0.29**	0.34**
4. Vocabulary knowledge	0.51***	0.46**	−0.02	—	0.53***
5. Reading fluency	0.22	0.41**	0.10	0.61***	—

Note. The lower half of the table is for children in grades 3–4, and the upper half for grades 5–6. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$, two-tailed.

Table 5
Correlation coefficients among all tasks in hearing children.

Variables	1	2	3	4	5
1. General cognitive ability	—	0.10	0.12	0.15	0.11
2. Onset awareness	0.07	—	0.46***	0.15	0.27*
3. Tone awareness	0.08	0.53***	—	0.14	0.30**
4. Vocabulary knowledge	0.18	0.07	0.02	—	0.26*
5. Reading fluency	0.24*	0.24*	0.04	0.45***	—

Note. The lower half of the table is for children in grades 3–4, and the upper half for grades 5–6. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$, two-tailed.

were only significant in higher grades. On the other hand, the correlations between vocabulary knowledge and reading fluency were significant both in lower ($r_d = 0.61$, $p_d < 0.001$; $r_h = 0.45$, $p_h < 0.001$, respectively) and higher grades ($r_d = 0.53$, $p_d < 0.001$; $r_h = 0.26$, $p_h = 0.021$, respectively). The patterns of correlation between phonological awareness and reading fluency, and the correlation between vocabulary knowledge and reading fluency, are similar in the two groups of children across grades.

In addition, the correlations between two kinds of phonological awareness were also significant both in lower grades ($r_d = 0.39$, $p_d = 0.01$; $r_h = 0.53$, $p_h < 0.001$, respectively) and higher grades ($r_d = 0.45$, $p_d < 0.001$; $r_h = 0.46$, $p_h < 0.001$, respectively). However, the pattern of correlation between phonological awareness and vocabulary knowledge in deaf children was different from hearing children. Deaf children's onset awareness correlated with vocabulary knowledge in lower grades ($r_d = 0.46$, $p_d = 0.002$), and significant correlations were found for both onset awareness ($r_d = 0.53$, $p_d < 0.001$) and tone awareness ($r_d = 0.29$, $p_d = 0.004$) in higher grades. The significant correlations between hearing children's phonological awareness and vocabulary knowledge were found neither in lower nor higher grades.

3.2.2. Hierarchical regression

The correlations among onset awareness, tone awareness, and vocabulary knowledge across different grades necessitate clarification over which variable is an independent predictor of reading fluency. To investigate the unique contribution of phonological awareness, including onset awareness and tone awareness, and vocabulary knowledge to reading fluency, hierarchical regression analysis was used with general cognitive ability and chronological age as the control variables (in step 1). Onset awareness, tone awareness and vocabulary knowledge were entered into the multiple regression analysis predicting reading fluency when accounting for the effect of the other two variables (in step 2).

The upper panel of Table 6 shows that in step 3, in lower grades, onset awareness uniquely explained 5% ($\beta_h = 0.26$, $p_h = 0.026$)

Table 6
Regression equation predicting reading fluency for deaf and hearing children.

Grades	Steps	Variables	Reading fluency					
			Deaf			Hearing		
			$\triangle R^2$	β	*t*	$\triangle R^2$	β	*t*
3–4 (Lower grades)	1	General cognitive ability	0.05	0.19	1.19	0.09*	0.23	2.21*
		Chronological age		0.09	0.56		0.17	1.62
	2a	Tone awareness	0.37***	0.15	1.11	0.16**	0.04	0.41
		Vocabulary knowledge		0.75	4.69***		0.40	4.06***
	3a	Onset awareness	0.06	0.35	1.96	0.05*	0.26	2.27*
	2b	Onset awareness	0.43***	0.37	2.29*	0.20***	0.20	2.15*
		Vocabulary knowledge		0.66	4.28***		0.39	4.04***
	3b	Tone awareness	0.001	0.04	0.26	0.01	−0.10	−0.85
	2c	Onset awareness	0.16*	0.56	2.63*	0.06	0.28	2.29*
		Tone awareness		−0.10	−0.58		−0.10	−0.82
	3c	Vocabulary knowledge	0.27***	0.67	4.17***	0.15***	0.39	4.03***
5–6 (Higher grades)	1	General cognitive ability	0.04	0.21	2.08*	0.04	0.05	0.41
		Chronological age		−0.003	−0.03		0.17	1.36
	2a	Tone awareness	0.27***	0.20	2.25*	0.13**	0.25	2.26*
		Vocabulary knowledge		0.46	4.95***		0.24	2.22*
	3a	Onset awareness	0.06**	0.33	3.07**	0.02	0.14	1.16
	2b	Onset awareness	0.33***	0.37	3.70***	0.12**	0.22	2.04*
		Vocabulary knowledge		0.33	3.29**		0.25	2.22*
	3b	Tone awareness	0.01	0.10	1.09	0.03	0.18	1.51
	2c	Onset awareness	0.27***	0.48	4.81***	0.10*	0.16	1.32
		Tone awareness		0.11	1.15		0.20	1.65
	3c	Vocabulary knowledge	0.07**	0.32	3.26**	0.05*	0.23	2.11*

Note. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$, two-tailed.

of the variance in reading fluency in hearing children, but this effect was not significant in deaf children; the prediction of tone awareness on reading fluency was not significant in deaf or hearing children; vocabulary knowledge uniquely and significantly explained 27% ($\beta_d = 0.67$, $p_d < 0.001$) and 15% ($\beta_h = 0.39$, $p_h < 0.001$) of the variance in reading fluency in deaf and hearing children respectively. As for higher grades, onset awareness uniquely explained 6% ($\beta_d = 0.33$, $p_d = 0.003$) of the variance in reading fluency in deaf children, but this effect was not significant in hearing children, which was different from the prediction pattern in lower grades. The prediction of tone awareness on reading fluency was not significant in deaf or hearing children; vocabulary knowledge uniquely and significantly explained 7% ($\beta_d = 0.32$, $p_d = 0.002$) and 5% ($\beta_h = 0.23$, $p_h = 0.038$) of the variance in reading fluency in deaf and hearing children, respectively.

4. Discussion

The main aim of this study was to examine the relative contributions of phonological awareness and vocabulary knowledge to reading fluency in deaf and hearing children with the same grade level, and determine if these relationships held across different stages of reading development in elementary school. The mean age of deaf and hearing children was 14.08 years and 10.49 years respectively in lower grades, and 15.05 years and 12.47 years respectively in higher grades. After controlling for general cognitive ability and chronological age, for deaf children the unique effect of onset awareness on reading fluency was not statistically significant in lower grades, but it was an independent predictor in higher grades. For hearing children, onset awareness accounted for the variance of reading fluency uniquely in lower grades, but its effect was not significant in higher grades. Significant predictive effect of tone awareness was found neither in deaf nor hearing children. However, vocabulary knowledge significantly explained the variance of reading fluency in all grades both for deaf and hearing children. We concluded that the relationship between phonological awareness and reading fluency depends on many factors like participants' hearing characteristics, developmental stages, and the types of phonological awareness, whereas vocabulary knowledge taps into a universal cognitive mechanism that is involved in reading fluency both in deaf and hearing children.

Replicating findings previously reported (Coppens et al., 2011; Luckner & Urbach, 2012; Lund et al., 2015; Marshall et al., 2018), deaf children lagged behind significantly on many language tasks, such as phonological awareness, vocabulary knowledge and reading fluency. Severe to profound deafness is likely to impede the development of awareness of phonological properties in spoken language as well as the ability to acquire phonological knowledge (Miller & Clark, 2011). Lack of deeper knowledge of words is a common phenomenon in deaf pupils, who not only know fewer words, but also know them less well (Coppens et al., 2011), which is due to impoverished access to language.

The relative contributions of phonological awareness (onset and tone awareness) and vocabulary knowledge to reading fluency were investigated in this study. The first consideration is how to select the comparison. It could be seen that although the predictive effect of chronological age in higher-grade children was negative, the coefficient was very small and not significant. It is not surprising given the great variation in chronological age of deaf children especially in special education schools in China. Other than chronological age (e.g., Marshall et al., 2018) or reading age (e.g., Dyer, Macsweeney, Szczerbinski, Green, & Campbell, 2003) matched in previous studies, the schooling years, which can be stated as grade level, were matched in the present study and chronological age was treated as a control variable. Based on this, we performed a comparison of the pattern of predictive relationships in different stages of reading development.

Two subtests of phonological awareness at onset and tone levels were used in this study. We expected that children's performance on phonological awareness would vary across groups and tasks. The regression models showed that the significant effect of onset awareness existed only in higher-grade deaf children and lower-grade hearing children, which was in line with our expectations. Relation between phonological awareness and reading has previously been reported in deaf children with cochlear implants, where 27 deaf school-age children's phonological awareness was measured on phoneme and syllable levels (Dillon et al., 2012). Our findings replicated and extended the different roles of phonological awareness in reading fluency of deaf children with severe to profound deafness in different grades. Only higher-grade deaf children's onset awareness was a significant predictor of reading fluency, the opposite of hearing children. The study of deaf preschoolers has shown that they can develop syllable awareness after 21 months of literacy instruction, where some of the children used sign language (Kyritsi et al., 2007). It has also been noted that syllable awareness develops earlier, and onset-rime awareness somewhat later in Chinese hearing children (Shu et al., 2008). Elementary students may thus rely mainly on the onset-rime awareness aspect of phonological awareness. However, the dominant role of phonological awareness will fade away in the later stage of reading development in elementary school. Reading ability is determined by phonological awareness in earlier years for hearing children (Ehri, 1995; Storch & Whitehurst, 2002), which can also be clearly seen from our results. On the contrary, as Kyle and Harris (2010) suggested, deaf children may develop their phonological awareness as they learn to read rather than prior to learning to read (like hearing children do) and this awareness supports later reading achievements.

Tone awareness is relatively important in Chinese children's reading (Shu et al., 2008). In contrast with onset awareness, no significant effect of tone awareness on reading fluency was found in this study. However, tone detection was previously reported to be associated with Chinese, rather than English, reading in Hong Kong Chinese children with typical hearing (McBride-Chang, Tong et al., 2008). The discrepancy could be explained by the characteristics of the task. Considering the severe to profound deafness and that spoken language is not their preferred language, the task of tone detection where stimuli were orally produced is challenging to deaf children. Our study required children to cross out the target character (with the tone 4) in a limited time, and as for the study of Liu et al. (2017), may have been slightly difficult especially for lower-grade children. This may also be the reason why some non-significant coefficients of the predictive effect of tone awareness were very small and negative in lower grades. Furthermore, the

results of descriptive statistics indicated there was no significant increase in tone awareness of deaf children with increasing grades (18.85 and 18.58, respectively), and both sets of results were significantly lower than for hearing children. Even though tone awareness is difficult for deaf children, as concurs with previous studies (Tse & So, 2012), the scores of hearing children were not very high compared with onset awareness, which may have led to the nonsignificant effect even for hearing children. However, the coefficient was significant in higher grades when onset awareness was not controlled, which also indicated the predominant role of onset awareness.

Efficient text meaning construction and integration is necessary for fluent reading. Thus, just as for reading comprehension, reading fluency is not only related to phonological awareness, but also vocabulary knowledge. There is less argument about the importance of vocabulary knowledge for deaf children's reading ability. The findings in our study are largely consistent with previous findings in deaf children as well as further demonstrating the unique and significant effect of vocabulary knowledge across participants' groups and grades (Easterbrooks, Lederberg, Miller, Bergeron, & Connor, 2008; Luckner & Cooke, 2010; Mayberry et al., 2011). It is plausibly true that regardless of which component of reading is measured, vocabulary seems to be imperative for deaf reading (Kyle & Harris, 2006, 2010; Kyle, Campbell, & MacSweeney, 2016; Takahashi, Isaka, Yamamoto, & Nakamura, 2017). This also makes sense in the frame of the SVR and Lexical Quality Hypothesis (Gough & Tunmer, 1986; Hoover & Gough, 1990; Perfetti, 2007). Vocabulary knowledge enables the construction of semantic networks and facilitates word segmentation. Similar to hearing children, good vocabulary can help deaf children access and extract the meaning of words in the mental lexicon quickly, and benefits automatic connected-text reading, especially in Chinese script where there is no space between words.

The most important finding from this study concerned the different predictive patterns of onset awareness, tone awareness and vocabulary knowledge, some of which were stable and some of which changed across the grades. The prediction of phonological awareness on reading fluency was complex, whereas vocabulary knowledge was a consistent predictor of reading fluency in all groups of children. In hearing children with poor phonological processing skills, their problems with reading development may be compensated by good vocabulary or language skills (Snowling, Gallagher, & Frith, 2003). Correlation results from this study indicated that deaf children's onset awareness in lower grades, and onset and tone awareness in higher grades were related to vocabulary knowledge, while there was no significant correlation between phonological awareness and vocabulary knowledge in hearing children. Therefore, these two factors could interact in a complex manner, but both of them could feed into reading development independently in deaf children. For deaf children whose phonological awareness is not sufficient to facilitate reading ability, more extensive vocabulary knowledge can provide some kind of compensation mechanism within an interactive model of reading development.

4.1. Limitations and educational implications

Some limitations of the study should be noted. First, the sample size of deaf children in lower grades was limited because we failed to collect data of deaf children's phonological awareness in grade 3 in some schools. Second, although the test format of phonological awareness was appropriate for deaf children and the task of onset awareness was used successfully in Chinese hearing children (Liu et al., 2017), the task of tone awareness was slightly difficult. Its significant effects only existed in higher grades when onset awareness was not controlled. Different forms of testing should be considered carefully when interpreting the results in this study and comparing findings to other studies. Third, pupils in grades 1 to 2 were not included in the present study. The mechanisms underlying deaf children's reading development should be further investigated across the whole elementary school from the stage of learning to read to reading to learn (Chall, 1983; Ehri, 2005). Despite these limitations, there are several educational implications to be drawn from the findings. First, deaf children can develop phonological awareness through reading, which in turn is used to support their reading achievements. This is different from hearing children. Teachers working with deaf children need to have an understanding of the importance of phonological awareness, even for children who use sign language. Second, targeted intervention on different reading skills for deaf children in elementary school should take children's developmental stages into account. For example, vocabulary knowledge is a consistent and stable predictor, and onset awareness can support reading ability in higher grades, whereas the effect of tone awareness may not show up until adolescence.

5. Conclusions

This study extends our understanding of the mechanisms underlying reading fluency in deaf children by highlighting the different effects of phonological awareness and vocabulary knowledge on reading fluency in different grades. Onset awareness and vocabulary knowledge are important skills for reading fluency in deaf and hearing children, whereas tone awareness is not a significant predictor. The significant prediction of onset awareness was only found in higher-grade, not lower-grade, deaf children, but the significant and unique effect of onset awareness was only found in the lower-grade, not higher-grade, hearing children. However, vocabulary knowledge was found to consistently predict reading fluency both in deaf and hearing children in all grades. The pattern of observed predictive relationships between reading-related skills and reading fluency in deaf and hearing children suggests that these two groups might use slightly different reading strategies over grades 3–6 of elementary schooling.

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