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ABSTRACT

Background and aims: Children with good phonological awareness (PA) are often good word readers. Here, we asked whether Swedish deaf and hard-of-hearing (DHH) children who are more aware of the phonology of Swedish Sign Language, a language with no orthography, are better at reading words in Swedish.

Methods and procedures: We developed the Cross-modal Phonological Awareness Test (C-PhAT) that can be used to assess PA in both Swedish Sign Language (C-PhAT-SSL) and Swedish (C-PhAT-Swed), and investigated how C-PhAT performance was related to word reading as well as linguistic and cognitive skills. We validated C-PhAT-Swed and administered C-PhAT-Swed and C-PhAT-SSL to DHH children who attended Swedish deaf schools with a bilingual curriculum and were at an early stage of reading.

Outcomes and results: C-PhAT-SSL correlated significantly with word reading for DHH children. They performed poorly on C-PhAT-Swed and their scores did not correlate significantly either with C-PhAT-SSL or word reading, although they did correlate significantly with cognitive measures.

Conclusions and implications: These results provide preliminary evidence that DHH children with good sign language PA are better at reading words and show that measures of spoken language PA in DHH children may be confounded by individual differences in cognitive skills.

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What this paper adds:

This paper introduces a new set of materials for assessment of phonological awareness across the language modalities of sign and speech in a Swedish context. It validates the materials for the Swedish version of the task and shows that the Swedish Sign Language (SSL) version can be successfully administered to deaf and hard-of-hearing (DHH) children who are attending Swedish deaf schools and are at an early stage of reading. Moreover, it shows for the first time that a better grasp of the phonology of SSL is associated with better Swedish word reading, thus generalizing results from a North American context. The task is quick and easy to administer and could easily be adapted for clinical use. The paper also discusses the pitfalls of assessing spoken language phonology in DHH children and provides evidence that such measures may be confounded by individual differences in cognitive skills.

1. Introduction

Reading is vital for academic achievement and social participation. Deaf and hard-of-hearing (DHH) children usually lag behind their peers with normal hearing in reading development (Mayberry, del Giudice, & Lieberman, 2011; Miller & Clark, 2011; Trezek, Wang, & Paul, 2011). However, it is as yet unresolved, despite several decades of scientific inquiry, which specific mechanisms cause this gap, and what can be done to close it. In the present work we address the role of language-modality specific phonological awareness (PA) in word reading. We introduce a new set of materials, the Cross-modal Phonological Awareness Test (C-PhAT) that can be used to assess PA in both Swedish (C-PhAT-Swed) and Swedish Sign Language (C-PhAT-SSL). In study 1 we validate C-PhAT-Swed in children with normal hearing. In study 2, we investigate how C-PhAT-Swed and C-PhAT-SSL are related to word reading in DHH children.

1.1. Phonological awareness and reading

PA usually refers to sensitivity to the sound structure of words (Wagner & Torgesen, 1987). Spoken languages include a finite set of sounds which are combined at the sublexical level to construct the words of a language; the language-specific patterning of these sounds comprises the phonology of that language. When children learn to read, a crucial step is learning to recode written symbols into the correct sounds (Ziegler & Goswami, 2005). Individual letters are matched with their corresponding phonemes, which can then be combined into longer sequences. This allows written words to be connected to the phonological forms of lexical items already established in long-term memory. When access to lexical items is successful, that is, when written words are efficiently decoded (Stanovich, 1982), the meanings of separate words are unraveled and comprehension of sentences and passages can be achieved. Children who are strong word readers typically also comprehend text better than relatively weaker word readers, especially at the early stages of reading development (Garcia & Cain, 2013; Ripoll Salceda, Alonso, & Castilla-Earls, 2014). A relationship between word reading and reading comprehension has also been established in DHH children (Hermans, Knoors, Ormel, & Verhoeven, 2008; Kyle & Harris, 2006, 2010; Transler & Reitsma, 2005; Wauters, Bon, & Tellings, 2006). Hence, learning to read single words is an important part of becoming a skilled reader, regardless of hearing status. Even though recoding written words into their sound structures is probably not the only way to access their meaning (Leinenger, 2014), PA is a robust predictor of word reading for hearing children (for reviews, see Melby-Lervåg, Lyster, & Hulme, 2012; National Institute for Literacy, 2008). Thus, it is important to understand the role of PA in word reading by DHH children.

1.2. Deafness and sign language phonology

Congenital deafness occurs in between 1 and 2 individuals per thousand live births. These days, the majority of children born deaf in developed countries are fitted with cochlear implants (CI), technical devices that convey electrical stimulation based on sound into the cochlear nerve, in most cases allowing differentiation of speech sounds and interpretation of auditory input (for a review see Kral & Sharma, 2012). Children with less severe hearing loss may be fitted with hearing aids (HA). Many DHH children achieve remarkable speech development with technical devices (Kral & Sharma, 2012) and achieve academically in mainstream schools. Others, however, do not develop functional levels of spoken language (Campbell, MacSweeney, & Woll, 2014). Irrespective of whether or not they develop spoken language skills, many DHH children rely on sign language communication at least in some situations (Campbell et al., 2014).

Despite the fact that signed languages are generated manually and perceived visually, they share abstract linguistic qualities with spoken languages that are generated orally and usually perceived aurally (for a review, see Emmorey, 2002). The finite set of sublexical manual-visual features that defines the signs in a sign language can be described as its phonology (Sandler & Lillo-Martin, 2006). Sign language phonology consists of five manual-visual parameters: handshape; location; movement of and within hand(s); orientation of the palm; and, nonmanual behaviors like facial gestures (Brentari, 2011). In relation to signed languages, PA refers to sensitivity to sublexical structure. This definition can be applied equally well to spoken languages.

Besides being a linguistic phenomenon in both signed and spoken languages, phonology has been shown to share structural properties and functional qualities across the language modalities of sign and speech when it comes to neural processing. For example, studies have shown that phonological processing recruits similar brain networks in both language modalities (for a review, see MacSweeney, Capek, Campbell, & Woll, 2008). Furthermore, electrophysiological studies indicate that at least some phonological effects on lexical retrieval are similar across language modalities (Baus, Gutiérrez, & Carreiras, 2014; Gutiérrez, Müller, Baus, & Carreiras, 2012; Gutiérrez, Williams, Grosvald, & Corina, 2012). Gutiérrez and colleagues (Gutiérrez, Müller et al., 2012; Gutiérrez, Williams et al., 2012) provided evidence that the location parameter initializes activation of lexical candidates in signed languages, on analogy with the notion that the onset of a word activates a set of lexical candidates in spoken languages (Luce & Pisoni, 1998). Furthermore, the handshape parameter seems to support later stages of lexical retrieval (Gutiérrez, Müller et al., 2012), possibly by constraining the set of activated lexical items, in much the same way as post-onset phonemes in spoken language (Luce & Pisoni, 1998).

Manual codes for alphabets, called fingerspelling, and manual numerals are frequently used to represent letters and digits in signed languages (Padden & Gunsauls, 2003). SSL makes extensive use of fingerspelling, in much the same way as American Sign Language (ASL), to represent proper names and terms without established lexicalizations in SSL, such as loan words (for an extended discussion see Andin, Rönnberg, & Rudner, 2014). Because fingerspelling is an integrated part of SSL, children who grow up with the language encounter fingerspelling early in life. It has been argued in relation to ASL that development of PA includes an awareness of the integrated role of fingerspelling in the language (Padden & Brentari, 2001) and the same is likely to be true of SSL. The Swedish Manual Alphabet is one-handed and the handshapes it exploits overlap with those of SSL as well as those of the Swedish Manual Numeral System. This overlap forms the basis for C-PhAT. In C-PhAT-SSL, phonological decisions are based on handshapes occurring in these two Swedish Manual Systems (SMS) and in C-PhAT-Swed, phonological decisions are based on rhymes among Swedish letters and digits.

1.3. Reading in deaf and hard-of-hearing children

According to the Qualitative Similarity Hypothesis (QSH; Paul & Lee, 2010; Trezek et al., 2011), learning to read builds on the same processes for DHH children who have limited access to speech sounds as it does for children with normal hearing; hence, the theory suggests that DHH children need to have speech representations to match with the written text in order to learn to read. When hearing is weak or non-functional, it has been suggested that such representations could develop via, for example, lip-reading, visual cueing systems or articulatory feedback (Perfetti & Sandak, 2000; Trezek et al., 2011). The QSH implies that PA of spoken language should predict reading in DHH individuals (Paul & Lee, 2010); in other words, in order to learn to read, DHH children should learn to analyze the sublexical structure of that language. However, findings are inconsistent (Mayberry et al., 2011; Miller & Clark, 2011). In the case of DHH children, some studies report a positive association between spoken language PA and reading (e.g., Colin, Magnan, Ecalle, & Leybaert, 2007; Harris & Beech, 1998; Transler & Reitsma, 2005), while others do not (e.g., Izzo, 2002; Kyle & Harris, 2006, 2010). Accordingly, the QSH has been challenged as a model of reading for children with limited access to speech sounds and it has been proposed that for DHH children, reading may be supported by sign language skills (Chamberlain & Mayberry, 2000; Hoffmeister & Caldwell-Harris, 2014). Correlational evidence does indeed indicate such an association (Chamberlain & Mayberry, 2008; Hermans et al., 2008; Strong & Prinz, 1997), and experiments suggest that deaf signing individuals automatically activate signs for written words when reading (Kubus, Villwock, Morford, & Rathman, 2014; Morford, Kroll, Pinar, & Wilkinson, 2014; Morford, Wilkinson, Villwock, Piñar, & Kroll, 2011; Ormel, Hermans, Knoors, & Verhoeven, 2012). Also in line with this theoretical position, recent studies have investigated the function of PA in signed languages (Andin et al., 2014; Corina, Hafer, & Welch, 2014; McQuarrie & Abbott, 2013). In particular, McQuarrie and Abbott (2013) found a positive association between ASL PA and both word reading and text comprehension in a group of DHH children spanning several reading levels.

1.4. Assessing phonological awareness

Picture-based rhyme tasks have frequently been used for assessing spoken language PA in DHH children (Colin et al., 2007; Harris & Beech, 1998; Kyle & Harris, 2006, 2010). In such tasks, the participant is typically asked to determine whether the lexical labels of two pictures overlap in vowel-sound and final consonant. In earlier studies of PA in the signed modality, analogous picture based sign similarity tasks have been used (Andin et al., 2014; MacSweeney, Capek, et al., 2008; McQuarrie & Abbott, 2013); in such tasks, the participant is typically asked to judge whether the lexical labels of two pictures in a particular sign language overlap considering one particular phonological parameter at a time that could be handshape (e.g., Andin et al., 2014), location (e.g., MacSweeney, Waters, Brammer, Woll, & Goswami, 2008), or movement (e.g., McQuarrie & Abbott, 2013, also incorporating handshape and location). To solve a picture based rhyme or sign similarity task, the participant has to be able to access the phonological representations of the depicted items and determine whether they match while maintaining them in working memory. Although rhyme tasks are generally considered valid measures of spoken language PA in hearing children (Melby-Lervåg et al., 2012), experimental data indicate that DHH children, regardless of age and reading level, adopt visual and/or articulatory rather than phonological strategies when solving such tasks (McQuarrie & Parrila, 2009). Words that sound alike often have similar orthographic forms and are also based on similar oral motoric patterns. McQuarrie and Parrila (2009) showed that both these aspects influence the performance on rhyme tasks of deaf children whose primary language was ASL. Indeed, when visual and motoric effects were controlled for, there was no evidence that the participants could make rhyme judgments and it was suggested that this finding might in part explain the inconsistencies in results regarding the association between spoken language PA and reading in DHH children (McQuarrie & Parrila, 2009). Furthermore, performance on both picture based rhyme and picture based sign similarity tasks may be confounded by visual-semantic recoding (i.e., extracting word/sign representation from ambiguous visual stimuli). In the present work, we eradicated this threat to validity by using text-based stimuli for C-PhAT.

1.5. The Cross-modal Phonological Awareness Test (C-PhAT)

The C-PhAT developed here is inspired by a task introduced by Andin et al. (2014). The C-PhAT is a set of materials that can be used to assess PA in both spoken (C-PhAT-Swed) and signed languages (C-PhAT-SSL). The materials are based on pairs of letters and digits. The C-PhAT-Swed task is to determine whether the two characters in each presented pair rhyme in Swedish (Table 1, Category RL) or not (Table 1, Categories SHS and NS). The C-PhAT-SSL task is to determine whether the two characters in each presented pair share a handshape in accordance with the two SMS: Swedish Manual Alphabet and Swedish Manual Numeral System (Table 1, category SHS) or not (Table 1, categories RL & NS). Neither task can be solved on the basis of low-level visual processing; thus, both tasks require the activation of appropriate phonological representations.

Each letter in the Swedish Manual Alphabet and each digit in the Swedish Manual Numeral System are represented with a handshape. Some of the characters share handshapes but are performed with a different orientation of the palm while others are differentiated by movement (see Fig. 1 for two examples). Similarly, the Swedish labels of letters sometimes rhyme with other letters (e.g., K, /koː/ - H, /hoː/) or digits (e.g., K, /koː/ - 2, /tvoː/). Using the same materials across language modalities eliminates performance differences caused simply by sensory and perceptual differences. Furthermore, phonological retrieval based on letters and digits restricts semantic interference; in comparison to pictorial material, letters and digits carry fewer semantic cues, and their phonological labels can thus be directly accessed. In Sweden, DHH children (Bergman, 2012) are, in general, exposed to manual systems before they begin to read and hearing children (Skoog, 2012) are exposed to the names of printed characters before they begin to read; hence, both groups are likely to have acquired corresponding mental representations of these symbols and their phonological labels. A further advantage of C-PhAT is that is does not require oral responses which DHH participants whose primary language is signed may be reluctant to give.

Using cross-modal phonological similarity tasks that formed part of a complex symbol processing battery and were similar to the C-PhAT, Andin et al. (2014) showed that adult deaf signers and hearing non-signers matched on age, educational level and NVIQ performed at similar levels in the preferred language modality (SSL for deaf signers and Swedish for hearing non-signers), suggesting that language modality-specific PA was similar across groups.

1.6. The present work

Two studies were performed. In study 1 we validated C-PhAT-Swed in typically developing hearing children who attended grade one in mainstream schools in Sweden and were just beginning to read. We also investigated the association between C-PhAT-Swed and word reading in this group, as well as associations with cognitive variables. In study 2 we administered C-PhAT-Swed and C-PhAT-SSL to DHH children who attend Swedish schools for DHH children with a bilingual curriculum. We investigated the association between the two versions of C-PhAT as well as their associations with word reading and cognitive skills. There are no established measures of PA for DHH individuals either in the manual modality or in Swedish; hence, in study 2 it was not possible to assess whether the results of the two versions of C-PhAT converged with results of other tasks tapping the same underlying abilities. The present work was approved by the Regional Ethical Review Board in Linköping (dnr 2012/192-31).

We predicted an association between C-PhAT-SSL in individuals who attend Swedish schools for DHH children. Because these schools have a bilingual curriculum and many DHH children use technical devices that allow speech perception, we did not exclude the possibility that C-PhAT-Swed would also predict word reading.

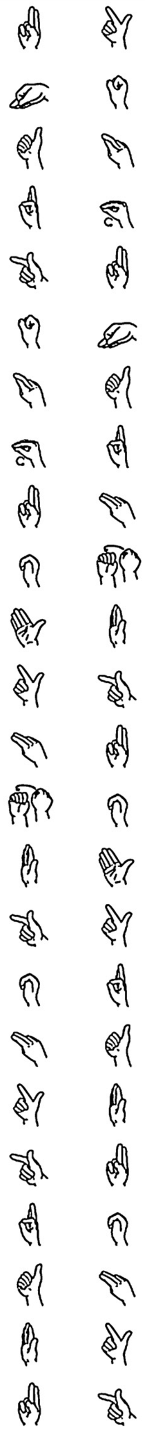
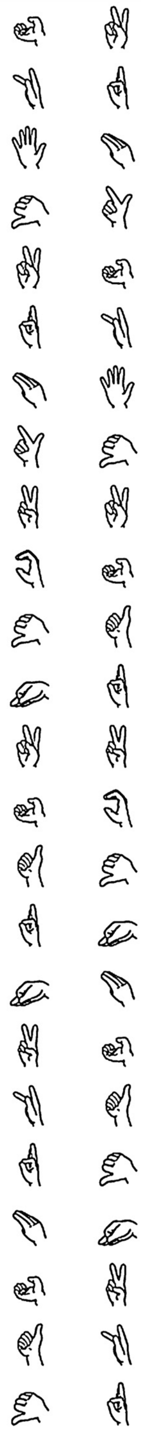
2. Study 1: Validation of C-PhAT-Swed in hearing children

2.1. Material and methods

2.1.1. Participants

Thirty-six typically developing children (20 girls) with no reported hearing impairment or knowledge of sign language attending first grade of primary school took part in study 1. In grade one, typically developing children are starting to learn to read. They were sampled from four different schools in a municipality in southeast Sweden with representative socioeconomic status. The mean age of the participants at testing was 7.5 years ($SD = 0.3$). Swedish was their first language. One of the participants had corrected to normal vision. NVIQ of the participants was screened using Raven's Coloured Progressive Matrices (Raven & Raven, 1994) and all were above the 5th percentile (raw score $M = 25.4$, $SD = 4.35$). All participants and their parents provided informed consent.

Table 1
Lists used in the Cross-modal Phonological Awareness Test (C-PhAT).

	List 1						List 2					
Category	Print		SMS		Swedish		Print		SMS		Swedish	
RL	U	7			/ʉː/	/ɧʉː/	C	V			/ceː/	/veː/
	P	G			/peː/	/geː/	K	H			/koː/	/hoː/
	6	X			/sɛks/	/ɛks/	5	M			/fɛm/	/ɛm/
	H	Å			/hoː/	/oː/	Q	7			/kʉː/	/ɧʉː/
	7	U			/ɧʉː/	/ʉː/	V	C			/veː/	/ceː/
	G	P			/geː/	/peː/	H	K			/hoː/	/koː/
	X	6			/ɛks/	/sɛks/	M	5			/ɛm/	/fɛm/
	Å	H			/oː/	/hoː/	7	Q			/ɧʉː/	/kʉː/
SHS	U	N			/ʉː/	/ɛn/	2	V			/tvoː/	/veː/
	E	9			/eː/	/niʊː/	S	C			/ɛs/	/ceː/
	Y	J			/yː/	/jiː/	Q	6			/kʉː/	/sɛks/
	7	T			/ɧʉː/	/teː/	P	H			/peː/	/hoː/
	N	U			/ɛn/	/ʉː/	V	2			/veː/	/tvoː/
	9	E			/niʊː/	/eː/	C	S			/ceː/	/ɛs/
	J	Y			/jiː/	/yː/	6	Q			/sɛks/	/kʉː/
	T	7			/teː/	/ɧʉː/	H	P			/hoː/	/peː/
NS	E	H			/eː/	/hoː/	P	M			/peː/	/ɛm/
	N	6			/ɛn/	/sɛks/	2	C			/tvoː/	/ceː/
	7	J			/ɧʉː/	/jiː/	K	6			/koː/	/sɛks/
	T	U			/teː/	/ʉː/	H	Q			/hoː/	/kʉː/
	H	E			/hoː/	/eː/	M	P			/ɛm/	/peː/
	6	N			/sɛks/	/ɛn/	C	2			/ceː/	/tvoː/
	J	7			/jiː/	/ɧʉː/	6	K			/sɛks/	/koː/
	U	T			/ʉː/	/teː/	Q	H			/kʉː/	/hoː/

Note. RL = rhyming labels in Swedish; SHS = shared handshapes in Swedish manual systems; NS = no similarity in Swedish labels, or in handshapes in Swedish manual systems; SMS = Swedish manual systems.

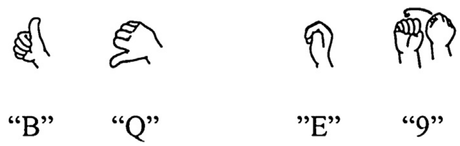


Fig. 1. To the left, two characters that share handshape in the Swedish manual systems (SMS) but have different orientations. To the right, two characters that share handshape in the SMS but only one includes a movement (the manual numeral for 9).

2.1.2. Development of the Cross-modal Phonological Awareness Task (C-PhAT)

The Cross-modal Phonological Awareness Test (C-PhAT) developed in the present study is based on a task introduced by Andin et al. (2014) and can be used to assess PA in Swedish (C-PhAT-Swed) and Swedish Signed Language (C-PhAT-SSL). The materials are based on pairs of digits and capital letters, excluding I and O to avoid confusion with the visually similar digits 1 and 0 (which were also excluded), but including the Swedish letter Å. The materials were constructed as follows: Firstly, all possible pairs with rhyming labels in Swedish and with shared handshapes in the Swedish manual systems were listed. The pairs "A – Å", "A – Ä" and "Å – Ä" which share a handshape in the Swedish manual alphabet were excluded because the visual properties of the printed characters made them confusable. Furthermore, all pairs including "W" were also discarded. This character is rarely used in Swedish and is pronounced in the same way as "V". After that, eight unique pairs were selected for categories Rhyming labels in Swedish (RL) and Shared handshapes in Swedish manual systems (SHS) using the criterion that the RL pairs should be as phonologically dissimilar as possible in the Swedish manual systems while the SHS pairs should be as phonologically dissimilar as possible in Swedish. The third category of eight unique pairs (no similarity in Swedish labels nor in handshapes in the Swedish manual systems, NS) was constructed by combining letters and digits from the pairs in categories RL and SHS in the same list. The number of letter–letter and letter–digit pairs was the same in each category. Once the eight unique pairs in each category had been obtained, four lists in each category were assigned to List 1 and the other four to List 2, see Table 1. It was ensured that pairs did not share phonological similarity within lists. Each unique pair occurred twice in each list but never with the same order.

2.1.3. Computerized tests

All computerized tests, including the C-PhAT, one of the word reading tests (lexical decision), the speed tests and the digit and letter decision tests, were administrated on a laptop (15.4 inches screen) with presentation software DMDX (version 4.1.2.0; Forster & Forster, 2003). DMDX registers responses and their timing with high accuracy (Garaizar, Vadillo, López-de-Ipiña, & Matute, 2014). Unless otherwise stated, stimuli were presented as text in black capital letters of 115 points in Times New Roman, on a white background on the computer screen. Participants responded by pressing one white and one black Jelly Bean Twist button (6.5 cm in diameter; "button" or "buttons"), that always corresponded to the same responses ("yes" and "no"). The "yes" button was placed close to the participant's dominant hand.

2.1.3.1. Cross-modal Phonological Awareness Task (C-PhAT). Pairs of printed characters (see Table 1) were presented for a maximum of 20 s during which period the participant had to respond according to version-specific criteria. The interstimulus interval was one s. In C-PhAT-Swed, the task was to determine whether the Swedish labels of the characters rhymed. In C-PhAT-SSL (not administered in study 1), the task was to determine whether or not the labels of the characters shared a handshape according to the Swedish manual system. Assignment of lists (see Table 1) was randomized across participants. Within each list, pairs had been pre-randomized into blocks consisting of one pair from each category. Block order and pair order within blocks were randomized automatically during administration. The dependent measure was d', that is, the number of hits adjusted for correct rejections in accordance with signal detection theory (Swets, Tanner, & Birdsall, 1961).

2.1.3.2. Lexical decision. This task was one of the two word reading tasks used. A string of three printed lower case letters (two consonants and one vowel) were presented on the computer screen and the task was to determine whether they represented a Swedish word or not (a similar task was used by Wass et al., 2008). Each item was presented for a maximum of five s during which period the participant had to respond as quickly as possible. The interstimulus interval was one s. There were 40 trials of which half were targets. Of the other 20 items, half were pseudowords (orthographically legal but non-lexicalized items) and half were non-words (orthographically illegal items). Words were presented in the same order for all participants; the same type of item (i.e., targets, pseudowords or non-words) occurred at most twice in a row. The dependent measures was d'.

2.1.3.3. Motor speed. This task was included to ensure that the participants had adequate button-pressing skills to perform the other tasks in the computerized test battery and also provided a warm-up for those tasks. The participant pressed one button as fast as possible 30 times with his or her dominant hand. The dependent measure was mean response time in s for one button press.

2.1.3.4. Cognitive speed. This task was included to ensure that the participants had adequate skills in mapping a visual stimulus to a button-press response. The Swedish words for "yes" or "no" were presented on the computer screen for a maximum of five s during which period the participant pressed the corresponding button as fast as possible. The interstimulus interval was one s. The dependent measure was mean response time in s for correct trials.

2.1.3.5. Digit and letter decision. These tasks were included to ensure that the participants could recognize digits and letters. In the digit decision task, each of the digits 1–9 was presented on the computer screen once in its correct orientation and once rotated 45, 90 or 180 degrees (digits 1 and 3 were used as practice items). The task was to determine whether each item was correctly oriented or not. Each digit and letter was presented for a maximum of five s during which period the participant was instructed to press the corresponding button as fast as possible. The interstimulus interval was one s. Order of presentation was randomized. The letter decision task was identical to the digit decision task with the exception that the letters included in C-PhAT (see Table 1) were presented instead of digits (letters B and L were used as practice items). The dependent measure was percent correct answers.

2.1.4. Non-computerized tests

2.1.4.1. Phonological processing – NEPSY. The Phonological processing subtest from the Swedish version of NEPSY (A Developmental NEuroPSYchological Assessment, Korkman, Kirk, & Kemp, 1998) is an established test of PA. It consists of two parts, A and B. In Part A, Recognition of Word Segments, the test administrator points to each one of three pictures in turn and articulates its name. Then, the test administrator articulates the name of one of the pictures again, this time without the initial phoneme and without pointing to the picture in question. The task of the participant is to point to the corresponding picture. For example, the test administrator may first say "pang" [bang], "pall" [stool] and "plask" [splash], pointing to the appropriate pictures and then say "-all" without pointing. The correct response, in this case, would be for the participant to point to the picture of a stool, corresponding to "pall". In Part B, Phonological Segmentation, the participant first repeats a word spoken by the test administrator and then says the new word formed by removing a particular part of the word. For example, the participant may be asked to repeat the word "solsken" [sunshine] and then say the word form by removing the morpheme "sol" [sun]. In this case the correct response would be "sken" [shine]. Task difficulty increases and in the most advanced tasks, the participant is required to replace phoneme clusters. For example, the/älj/in "sälja" [sell] should be replaced with/aml/to form "samla" [collect]. The test was administered in accordance with standard procedure (Korkman et al., 1998) and testing ended if the participant made six incorrect responses in a row. The dependent measure was the number of correct responses and the maximum score for both parts of the test together was 36.

2.1.4.2. Wordchains. This task was the second of the two word reading tasks used. Sixty sequences of printed characters comprising three Swedish words but without spaces in between (i.e., Wordchains; Jacobson, 2001) were presented in a booklet and the task was to indicate by means of drawing a line between two characters at two places in each sequence how it could be divided into those three words (e.g., Leppänen, Aunola, Niemi, & Nurmi, 2008). Wordchains is an established measure of word decoding in Scandinavia. The Swedish version of the test has satisfactory levels of test–retest reliability ($r = .89$) and criterion based validity (Jacobson, 2001). Two minutes were allowed for the task. The dependent measure was the numbers of word chains correctly solved.

2.1.4.3. Working memory. This task was included to determine associations between working memory and C-PhAT performance. A variant of the Mr. Peanut task (Kemps, De Rammelaere, & Desmet, 2000), called The Clown test (Birberg Thornberg, 2011; Sundqvist & Rönnberg, 2010), was used as a measure of working memory. First the participant was introduced to a drawing of a clown on a magnetic board. Then the experimenter placed brightly colored plastic-covered magnets at different locations on the clown. The participant was shown the clown with the magnets for as many seconds as there were magnets. Then the experimenter removed the magnets and asked the participant to state the color of the magnets, as a distractor. Then the participant was asked to replace the magnets on the clown. The first level had one magnet, and additional magnets were added for each subsequent level, up to a maximum of ten magnets. There were three trials with different predetermined fixed locations at each level. In order to progress to the next level, the participant had to respond correctly on at least two out of three trials. The dependent measure was the numbers of correct trials divided by three.

2.1.5. Procedure

Participants were tested individually at their schools and performed the tests in the following order: Motor speed; Cognitive speed; Digit decision; Letter decision; C-PhAT-Swed; Wordchains; Lexical decision; Working memory. Phonological processing – NEPSY (Korkman et al., 1998) was administered at a separate session. Administrators made sure that the participants understood each task before testing took place, and participants practiced on tasks using unique practice items before administration.

2.1.6. Data analysis

Firstly, normality assumptions were tested and background analyses were performed. As a second step, reliability estimates were calculated, and, finally, correlations between tasks were computed. Shapiro–Wilks test statistics indicated that several measures had non-normal distributions; non-parametric and parametric methods were therefore compared. One difference emerged regarding the association between the C-PhAT-Swed and Wordchains, with the parametric method

Table 2
Descriptive statistics.

Variable	Study 1, Hearing (N = 36)			Study 2, DHH (N = 13)		
	Mean	*SD*	95% CI	Mean	*SD*	95% CI
Age	7.69	0.31	[7.58, 7.79]	10.2	2.25	[8.82, 11.5]
NVIQ	25.4	4.35	[23.9, 26.9]	25.2	5.88	[21.7, 28.8]
WM	1.83	0.82	[1.55, 2.11]	2.08	0.67	[1.67, 2.48]
MS	0.18	0.07	[0.16, 0.21]	0.34	0.22	[0.20, 0.48]
CS	0.88	0.22	[0.81, 0.96]	0.76	0.18	[0.65, 0.87]
WC	8.28	4.34	[6.81, 9.75]	7.23	4.76	[4.35, 10.1]
LD[a]	0.47	1.03	[0.12, 0.81]	0.39	0.57	[0.05, 0.73]
PP	29.0	4.39	[27.5, 30.5]	–	–	–
C-PhAT-Swed[a]	2.16	1.22	[1.75, 2.57]	0.29	0.59	[−0.06, 0.65]
C-PhAT-SSL[a]	–	–	–	1.03	1.22	[0.29, 1.76]
SSLC	–	–	–	33.0	5.15	[29.7, 36.3]

Note. DHH = deaf and hard-of-hearing; NVIQ = non-verbal intelligence (raw score); WM = working memory (raw score); MS = motor speed (average button pressing speed in seconds); CS = cognitive speed (average response time in seconds); WC = Wordchains (raw score); LD = lexical decision; PP = phonological processing subtest from NEPSY (Korkman et al., 1998) (raw score); C-PhAT-Swed = Swedish version of the Cross-modal Phonological Awareness Task; C-PhAT-SSL = Swedish Sign Language version of the Cross-modal Phonological Awareness Task; SSLC = Swedish Sign Language comprehension (raw score).
[a] d' scores, 0 represents at chance performance.

showing a significant result while the non-parametric did not. In that case, an association was expected and the *p*-value was only marginally different between methods; hence, it was decided to present parametric analyses. All statistical computations were conducted in IBM SPSS Statistics (Version 22.0).

2.2. Results

Descriptive statistics are presented in Table 2. Performance on C-PhAT-Swed was better than chance, $t(35) = 10.6$, $p < .001$. There was no difference in performance on List 1 compared to List 2. No gender difference was observed on the C-PhAT-Swed, $t(34) = 0.99$, $p = .33$. Accuracy was high on the test of cognitive speed, $M = 96\%$ ($SD = 6\%$), and digit and letter decision, $M = 93\%$ ($SD = 5\%$); thus, we had no reason to suspect that the basic principles of the test procedure made the task too difficult for participants, or that they were unable to identify the letters and digits included in the C-PhAT. Hearing participants performed within ± 2 *SD* of the norms for hearing children in Grade 1 (Hogrefe Psykologiförlaget, 2010) on Wordchains.

2.2.1. Reliability estimate

Equivalent form reliability estimate for C-PhAT-Swed (i.e., the correlation between scores on List 1 and List 2) was acceptable, $r(36) = .70$, $p < .001$, which indicates that task performance was stable across lists.

2.2.2. Correlations

Correlations are presented in Table 3. Importantly, C-PhAT-Swed performance was strongly associated with performance on the Phonological processing subtest from NEPSY (Korkman et al., 1998), $r(36) = .54$, $p = .001$, demonstrating validity of C-PhAT-Swed. Further, performance on C-PhAT-Swed was significantly associated with both tests of word reading: Wordchains, $r(36) = .36$, $p = .030$, and lexical decision, $r(36) = .37$, $p = .028$. There was no significant association between C-PhAT-Swed and cognitive performance.

Table 3
Correlations (Pearson *r*) between both versions of the Cross-modal Phonological Awareness Task (C-PhAT) and word reading, Swedish Sign Language comprehension and cognitive variables.

	Study 1, Hearing (N = 36)						Study 2, DHH (N = 13)					
	WM	MS	CS	WC	LD	PP	WM	SSLC[a]	MS[a]	CS[a]	WC	LD
C-PhAT-Swed	.19	.16	.07	.36*	.37*	.54**	.60*	.47	−.47	−.68*	.38	.39
C-PhAT-SSL	–	–	–	–	–	–	.18	.39	−.30	.06	.66*	.63*

Note. DHH = deaf and hard-of-hearing; C-PhAT-Swed = Swedish version of the Cross-modal Phonological Awareness Task; C-PhAT-SSL = sign language version of the Cross-modal Phonological Awareness Task; WM = working memory; SSLC = Swedish Sign Language comprehension; MS = motor speed; CS = cognitive speed; WC = Wordchains; LD = lexical decision; PP = phonological processing subtest (NEPSY; Korkman et al., 1998).
[a] $n = 12$.
* $p < 05$.
** $p < 01$.

2.3. Discussion

The pattern of results in study 1 suggests that C-PhAT-Swed is a valid and reliable test of Swedish PA.

3. Study 2: Phonological awareness and word reading in deaf and hard-of-hearing children

3.1. Material and methods

3.1.1. Participants

In order to recruit participants to study 2, we contacted all five of the Swedish state special schools for DHH pupils. Hearing impairment is the criterion for admission to these schools, and pupils are taught in both Swedish Sign Language (SSL) and spoken and/or written Swedish (The National Agency for Special Needs Education, 2014). Two of those schools agreed to participate. Staff members identified 17 potential participants that were at an early stage of reading development; that is, they did not yet read fluently, but showed an interest in text and were able to identify written words at a level corresponding to typical readers in Grade 1. The sample was heterogeneous, reflecting the growing diversity of pupils attending Swedish state primary schools for DHH children (Svartholm, 2010). Four potential participants were excluded because of an additional severe medical or developmental disability; 13 children (7 girls) from grades 1–7 with a mean age of 10.2 years (SD = 2.3) were included. The distribution of gender categories did not differ from that of study 1, $\chi^2(1) = 0.34$, $p = .560$. However, ten of the DHH participants were older than all hearing participants in Study 1.

The wide age range reflects the difficulties some DHH pupils have with learning to read (Mayberry et al., 2011; Miller & Clark, 2011; Trezek et al., 2011). All 13 participants had a hearing impairment; eleven used technical aids and thus had at least some access to speech sounds: five used only hearing aids (HA, four bilateral); five used only cochlear implants (CI, four bilateral) and one had a CI on one ear and a HA on the other. Up-to-date audiological records were not available and because the association between sign language skills and reading was at the focus of this study, audiological measurements were not made. Two of the participants had a vision deficit which was corrected.

Background data was collected from the parents of the participants by questionnaire and interview. In some cases the parents omitted to provide information and thus background data is incomplete. The mean age of fitting of technical aids based on ten reports was 4.1 years (SD = 2.3, range 0.3–8.0).

Nine participants primarily used SSL, four of whom had at least one deaf native signing parent. Based on the six available parental reports for these nine individuals, mean age of first exposure to SSL was 2.8 years (SD = 3.3, range 0.0–8.0), and mean age of first exposure to Swedish was 2.4 years (SD = 3.3, range 0.0–8.0). Three participants used both SSL and Swedish. Data for these three individuals showed that the mean age of first exposure to SSL was 4.3 years (SD = 1.8, range 3.0–6.3), and the mean age of first exposure to Swedish was 2.0 years (SD = 3.5, range 0.0–6.0). Finally, one participant used SSL and another spoken language (age of first exposure to SSL and Swedish was 11.7 years). All participants used SSL in school. Seven of the participants were born abroad, one in an expatriate family; age at which residence in Sweden commenced ranged from 2.2 to 10.6 years, based on five available parental reports. None of the participants born elsewhere originated from the same country. The primary languages spoken in the participants' homes were SSL (n = 4), a mixture of SSL and Swedish (n = 4) or a spoken language from Africa (n = 1), Central Asia (n = 1), Central Europe (n = 1), and the Middle East (n = 1).

NVIQ was screened using Raven's Colored Progressive Matrices (Raven & Raven, 1994); twelve participants were above the 5th percentile and one was one point below (raw score M = 25.2, SD = 5.88). All participants and their parents provided informed consent.

3.1.2. Procedure

The procedure in study 2 was generally similar to study 1. Participants were tested individually at their schools by a fluent signer. However, here tests were arranged in two blocks because we anticipated that participants might find difficulty with some of the tasks and require more frequent breaks than the participants in study 1. Test order within each block was as follows: (1) Motor speed; Cognitive speed; Digit decision; Letter decision; C-PhAT-SSL; C-PhAT-Swed; Working memory; (2) Wordchains; Lexical decision. Breaks were taken when needed between blocks or between tests, and test order was sometimes adapted to meet the needs of the participant. The test administrators made sure that the participants understood each task before testing took place. Participants practiced on all tasks before administration. Phonological processing subtest of NEPSY was not administered to this group. Instead, SSL comprehension was tested using an adaptation of the British Sign Language receptive skills test (Herman, Holmes, & Woll, 1999). After a vocabulary check, the participant was presented with 40 videos of SSL sentences and had to judge which picture out of three or four alternatives best represented the meaning of each sentence. One point was awarded for each correct response and the dependent measure was the total number of correct answers. The test was administered by trained native SSL users.

3.1.3. Data analysis

One participant did not perform the motor speed task due to a technical error and another one misunderstood the cognitive speed task (the same participant did however manage more advanced tasks, like the C-PhAT-SSL). A missing completely at random mechanism (MCAR) was assumed and, thus, pairwise exclusion was used (Enders, 2010).

Otherwise, data was analyzed in the same way as in study 1. Shapiro–Wilks test statistics indicated that one measure (Motor speed) had non-normal distribution; results were therefore analyzed both non-parametrically and parametrically. No differences were found in the pattern of results between approaches, and thus only the results of the parametric analyses are reported. All statistical computations were conducted using IBM SPSS Statistics (Version 22.0).

3.2. Results

3.2.1. Descriptive statistics

Descriptive statistics are presented in Table 2. Performance on C-PhAT-SSL was better than chance, that is, group d' average differed significantly from zero, $t(12) = 3.03$ $p = .010$; on C-PhAT-Swed, however, it did not, $t(12) = 1.81$, $p = .096$, and thus performance on C-PhAT-Swed could not be said to be above chance. Participants were no less successful on correctly rejecting pairs from the RL category ($M = 1.9$, $SD = 2.1$) than from the NS category ($M = 1.9$, $SD = 2.0$) in the C-PhAT-SSL, $t(12) = 0.22$, $p = .83$; hence, there was no evidence of spoken language interference effects. Performance did not differ between boys and girls on either version of the C-PhAT. Accuracy was high on the test of cognitive speed ($M = 90\%$, $SD = 14\%$) and digit and letter decision ($M = 88\%$, $SD = 8\%$). Thus, we had no reason to suspect that the format of the C-PhAT was too difficult, or that participants were unable to identify the letters and digits included in the task.

There was no difference between participants in study 1 and study 2 in word reading skills: Wordchains, $t(47) = 0.73$, $p = .471$, or lexical decision, $t(47) = 0.24$, $p = .808$. As in study 1, participants performed within ± 2 SD of the norms for hearing children in Grade 1 (Hogrefe Psykologiförlaget, 2010) on Wordchains, confirming that they were all at an early stage of reading. There was no difference in NVIQ, $t(47) = 0.10$, $p = .919$, or working memory, $t(47) = 0.96$, $p = .34$, between participants in studies 1 and 2.

3.2.2. Reliability estimates

Due to exclusion of the three participants with additional disabilities, who also performed these tasks, assignment of lists (1 or 2) between C-PhAT-SSL and C-PhAT-Swed was unbalanced. Cronbach's alpha on the C-PhAT-SSL was .86 ($n = 8$) for List 1 and .69 ($n = 5$) for List 2, which indicates at least marginally acceptable levels (i.e., $>.70$; Schmitt, 1995). Internal consistency for C-PhAT-Swed was not calculated since group performance was at chance level, which in itself is a sign of low reliability.

3.2.3. Correlations

C-PhAT correlations are presented in Table 3. Performance on the C-PhAT-SSL was significantly associated with scores on both tests of word reading: Wordchains, $r(13) = .66$, $p = .013$, and lexical decision, $r(13) = .63$, $p = .021$, but not with cognitive speed or working memory. Scores on the C-PhAT-Swed, on the other hand, were strongly associated with working memory, $r(13) = .60$, $p = .032$, and cognitive speed, $r(12) = -.68$, $p = .016$ (see scatterplots in Fig. 2). However, although coefficients were relatively large, correlations with word reading did not reach significance.

The correlation between the two versions of C-PhAT was not significant, $r(13) = .53$, $p = .06$. Age was correlated both with C-PhAT-SSL, $r(13) = .58$, $p = .038$, and C-PhAT-Swed, $r(13) = .56$, $p = .049$, but not SSL comprehension, $r(12) = .22$, $p = .47$. Associations between NVIQ and C-PhAT-SSL, $r(13) = .34$, $p = .26$, and C-PhAT-Swed, $r(13) = .31$, $p = .31$, were not statistically significant. However, the correlation between NVIQ and SSL comprehension was, $r(12) = .66$, $p = .020$.

3.3. Discussion

This is the first study where PA in both signed and spoken language modalities and the relations to word reading are investigated in a group of DHH children; moreover, using the same set of materials designed for cross-modal testing. Given the small, heterogeneous sample and the explorative nature of this work, all results should be interpreted with caution. However, our results show in line with our prediction, that the performance of children attending Swedish state special schools for DHH pupils on C-PhAT-SSL is associated with word reading using two different methods of assessment. Importantly there was no indication that C-PhAT-SSL performance was associated with SSL comprehension, cognitive speed or working memory, suggesting that it was not simply tapping into general linguistic or cognitive processing abilities. Reliability estimates indicate that C-PhAT-SSL provides reliable results and thus may be good candidate for testing sign language PA in future studies. It is quick and easy to administer and a clinical version could be developed quite easily. One limitation of the present study is that we did not test whether the participants knew the Swedish and SSL labels of the C-PhAT stimuli, which is a prerequisite for correct task performance. Future C-PhAT studies should include a production task. Notwithstanding, the current results and those of earlier studies (e.g., Morford et al., 2014, 2011) lend support to the notion that sign language skills support reading development in DHH children (Chamberlain & Mayberry, 2000; Hoffmeister & Caldwell-Harris, 2014).

Similar associations between sign language PA and word reading have been reported from a North American context (McQuarrie & Abbott, 2013). Thus, one important contribution of the present study is to generalize earlier results to a European context. Associations between cognitive skills and sign language PA have not, to our knowledge, been investigated in earlier studies. Thus, the lack of such an association is a second important contribution of the present study.

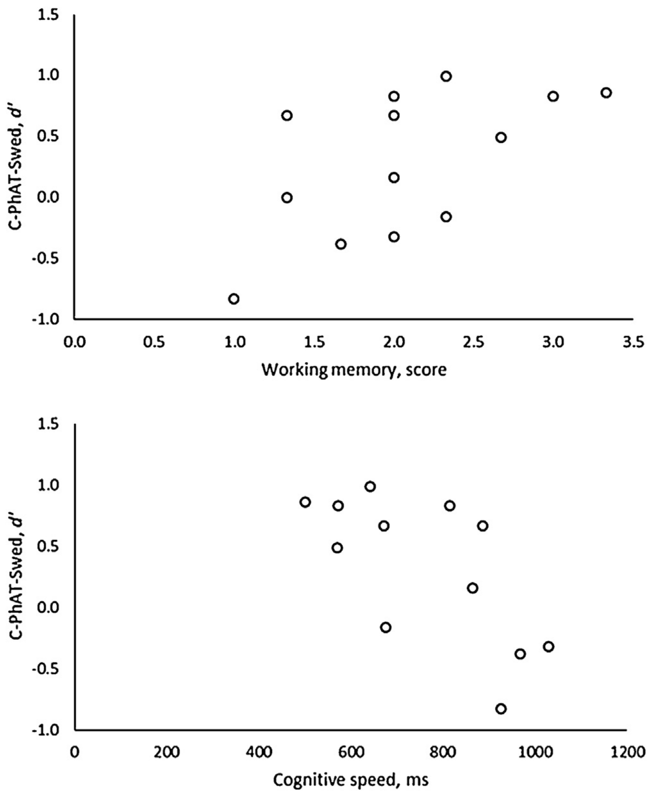


Fig. 2. Associations between C-PhAT-Swed and working memory (upper panel) and cognitive speed (lower panel) for deaf and hard-of-hearing children in study 2.

C-PhAT-Swed performance at group level was no better than chance for the participants in study 2. However, the correlational pattern supported by the scatterplots shown in Fig. 2 indicated strong associations with cognitive skills. Although these associations should be interpreted cautiously due the small sample size and heterogeneity of the group as well as chance performance on the C-PhAT-Swed task, they do suggest that only some of the participants were able to access and manipulate speech-based phonological representations in the manner required to solve the task, and that this was contingent on the maintenance and processing abilities represented by good working memory capacity. Such an interpretation is in line with findings suggesting the working memory capacity supports performance on challenging language tasks (Carpenter, Miyake, & Just, 1995) and recent findings showing that cognitive skills distinguish between better and poorer DHH readers (Daza, Phillips-Silver, Ruiz-Cuadra, del, & López-López, 2014). It also supports the Ease of Language Understanding model (ELU, Rönnberg et al., 2013) which states that when lexical access cannot be achieved rapidly and automatically due to adverse processing conditions, explicit cognitive processes are brought into play to solve the mismatch between input and existing representations in long-term memory. The way in which cognitive skills support the development of, and access to, speech-based phonology in DHH children is an interesting topic for future studies.

Because performance on C-PhAT-Swed was unreliable and did not correlate significantly with word reading, the present results do not lend support to the theoretical position claiming that DHH children use spoken language phonological codes to learn to read (e.g., Paul & Lee, 2010), at least not in written word identification. The DHH individuals in the present study are representatives of a heterogeneous population (Svartholm, 2010), and although some DHH individuals can successfully use spoken language skills to learn to read, others do not (Miller & Clark, 2011; see Colin, Leybaert, Ecalle, & Magnan, 2013, for another view on this).

According to the model of reading development in deaf individuals proposed by Hoffmeister and Caldwell-Harris (2014), one important early step is mapping printed words to sign equivalents; similar ideas have also been mooted by Crume (2013) and Haptonstall-Nykaza and Schick (2007). If DHH children learn to read words by mapping their visual forms to lexicalized signs in long-term memory (cf., Hoffmeister & Caldwell-Harris, 2014), the association between sign language PA and word reading in the present study may indicate that if a DHH child is good at retrieving and analyzing sign representations, the same child is also good at connecting manual and orthographic forms. In this context, it is important to bear in mind that C-PhAT-SSL taps into the subset of SSL handshapes specifically linked to orthography as employed by the Swedish Manual Systems. However, the association might also indicate that sign language PA helps differentiate between different orthographic forms. Anecdotally, it has been reported that DHH children have particular difficulties differentiating between similar orthographic forms (e.g., warm and worm), and thus often assign the same meaning to similar forms (Hoffmeister & Caldwell-Harris, 2014). This is interesting in light of recent experimental evidence, showing that orthographic preview supports lexical access in both skilled and less skilled deaf readers (Bélanger, Baum, & Mayberry, 2012; Bélanger, Mayberry, & Rayner, 2013). It may be the case that deaf individuals access semantics directly from orthography, avoiding a phonological route. However, Navarrete, Caccaro, Pavani, Mahon, and Peressotti (2015) reported results that suggest that deaf signers bypass semantics when accessing sign lexicon from written words. To further dissect what role sign language skills play in reading, the timing of reading related phenomena in DHH individuals needs to be established; for example, via electrophysiological recordings or eye tracking (Leinenger, 2014).

It should be considered whether the observed association between sign language PA and word reading in the present study is driven by other skills associated with the C-PhAT-SSL. In particular, since the task depends on familiarity with the handshapes of letters and digits, fingerspelling ability and manual numeral skill might have affected the results. It has been suggested that fingerspelling can be used as a manual-phonological bridge between words and the sign lexicon (Crume, 2013; Haptonstall-Nykaza & Schick, 2007; for a review, see Tucci, Trussell, & Easterbrooks, 2014). For example, Haptonstall-Nykaza and Schick (2007) showed that fingerspelling written words in addition to translating them into corresponding signs was a more effective strategy for DHH children to learn the meaning of written words, than just translating them. Future work should investigate whether fingerspelling ability, manual numeral skill and sign language PA contribute separately to reading development in DHH children.

Another aspect worth considering, is that it might be of particular importance that the C-PhAT-SSL involved judgment of handshapes and not of other visual-manual phonological parameters. Handshape processing has been shown to play a role in late stages of lexical retrieval (Gutiérrez, Müller et al., 2012) which involves discarding activated candidates, while other parameters, like location, seem to lead to activation of lexical candidates (Baus et al., 2014; Gutiérrez, Müller et al., 2012). This implies that different manual-visual parameters may be involved in partly separate processes when DHH individuals read words or texts; possibly, analysis of handshapes serves a function that is of particular importance for DHH children's reading.

Rapid identification of the meaning of written words is one of the strongest predictors of text comprehension in early reading development, both for hearing (Garcia & Cain, 2013; Ripoll Salceda et al., 2014) and DHH children (Marschark & Wauters, 2008). Hence, at a practical level, it is critical to identify means by which DHH children can efficiently extract the meaning of written words. Interventions aimed at improving sign language PA may prove effective for supporting the development of word reading skills in DHH children, as spoken language PA training has proven to be in hearing children (Bus & van IJzendoorn, 1999; National Institute for Literacy, 2008). Experimental evidence of efficacy of literacy training in DHH subjects is scarce (for a review, see Tucci et al., 2014; also see Rudner et al., 2015, for an example); hence, there is a strong need for intervention studies in the future.

C-PhAT performance improves with age in study 2, where the age range was wide, but not observed in study 1 where age range was restricted. Typically, PA increases with age (McQuarrie & Abbott, 2013; Scarborough, Ehri, Olson, & Fowler, 1998) but as the sample in study 2 was selected on the basis of reading skill, age is not a proxy for normal development in this particular sample where exposure to both SSL and Swedish was delayed. Tentatively, however, we suggest that good C-PhAT-SSL performance in the older individuals in this sample, especially those with delayed exposure to Swedish, may predict a potential to develop more age-appropriate reading skills given time and appropriate support (cf., Ferjan Ramirez et al., 2014). Future studies should investigate C-PhAT-SSL performance and its association with reading skills longitudinally. Ceiling performance on C-PhAT is likely to be achieved when phonological representations are well established and then the response time measures generated by the test can be used as a more sensitive dependent variable.

The superior performance of hearing participants, compared to the DHH children, on the C-PhAT-Swed suggest that the task is sensitive to language experience. Future work should investigate whether this generalizes to C-PhAT-SSL by testing samples with varying levels of language experience (e.g., native versus non-native signers). As a further step to assess the validity of the task, it should be explored whether task performance is related to reading disabilities. For example, children with dyslexia should show weaker C-PhAT performance than controls (cf., Melby-Lervåg et al., 2012).

4. Conclusions

The present work introduces a new set of materials for cross-modal assessment of PA (C-PhAT) and validates it for Swedish PA. Further, it shows that the Swedish Sign Language version of C-PhAT (C-PhAT-SSL) can be successfully performed by DHH children who are at an early stage of reading development and who attend Swedish schools for DHH children and that it predicts word reading ability in these children. However, the DHH children did not perform successfully on the Swedish version of C-PhAT (C-PhAT-Swed). Their scores on this version of the task correlated significantly with cognitive skills but not with word reading. This pattern of results provides preliminary evidence that DHH children who are more aware of the phonology of the sign language they use habitually are better at reading words in the ambient spoken language. This finding is in line with previous findings demonstrating a functional connection across language modalities but needs to be interpreted cautiously considering the small and heterogeneous sample of DHH children in the present work. Previous results showing an association between spoken language PA and word reading in DHH children may be confounded by individual differences in cognitive skills.

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