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Prosodic and segmental aspects of nonword repetition in 4- to 6-year-old children who are deaf and hard of hearing compared to controls with normal hearing

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ABSTRACT

Children who are deaf or hard of hearing (DHH) are at an increased risk of speech and language deficits. Nonword repetition (NWR) is a potential predictor of problems with phonology, grammar and lexicon in DHH children. The aim of the present study was to examine repetition of prosodic features and segments in nonwords by DHH children compared to children with normal hearing (NH) and to relate NWR performance to measures of language ability and background variables. In this cross-sectional study, 14 Swedish-speaking children with mild–profound sensorineural hearing loss, aged 4–6 years, and 29 age-matched controls with NH and typical language development participated. The DHH children used cochlear implants (CI), hearing aids or a combination of both. The assessment materials included a prosodically controlled NWR task, as well as tests of phonological production, expressive grammar and receptive vocabulary. The DHH children performed below the children with NH on the repetition of tonal word accents, stress patterns, vowels and consonants, with consonants being hardest, and tonal word accents easiest, to repeat. NWR performance was also correlated with language ability, and to hearing level, in the DHH children. Both prosodic and segmental features of nonwords are problematic for Swedish-speaking DHH children compared to children with NH, but performance on tonal word accent repetition is comparably high. NWR may have potential as a clinically useful tool for identification of children who are in need of speech and language intervention.

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Introduction

Language deficits in children who are deaf and hard of hearing

Today, many children who are deaf and hard of hearing (DHH) due to a sensorineural hearing loss gain earlier access to spoken language, thanks to universal newborn hearing screening, and early fitting of hearing aids (HA) and/or cochlear implants (CI) (Kral, Kronenberger, Pisoni, & O'Donoghue, 2016; Niparko et al., 2010). Despite technological advancements, any type and degree of hearing loss increases the risk of deficits with the development of cognition and language compared to children with normal hearing (NH)

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(Moeller, Tomblin, Yoshinaga-Itano, Connor, & Jerger, 2007; Wake, Hughes, Poulakis, Collins, & Rickards, 2004). The cause of language deficits is multifactorial, and it is not possible to predict individual development based solely on simple clinical tests of hearing, cognition or language (Lederberg, Schick, & Spencer, 2013).

Language deficits in children with mild-to-moderate hearing loss often persist into adolescence, with possibly as much as half of the population displaying weak language performance between the ages of 11 and 15 (Delage & Tuller, 2007). Several studies have also found a large variability in speech and language performance in children with hearing loss, which is heterogeneous regarding many different aspects (Briscoe, Bishop, & Norbury, 2001; Gilbertson & Kamhi, 1995; Halliday, Tuomainen, & Rosen, 2017; Hansson, Sahlen, & Maki-Torkko, 2007; Niparko et al., 2010). Some children achieve age-appropriate levels, while others may display severe problems. The prevalence of impaired language is, however, considerably higher than in children with NH (Tuller & Delage, 2014). However, concurrent hearing loss and language deficits do not necessarily imply causality (Schwartz, 2009), and in line with prevalence figures for specific language impairment (SLI), it can be assumed that about 7% of children with hearing loss have language problems that are independent of their hearing ability (Tomblin et al., 1997).

A range of background variables are associated with speech and language outcomes in children with CI or HA. Early implantation or HA fitting, high nonverbal intelligence and more years of parental/maternal education hves been found to benefit both parent-reported and tested receptive and expressive language outcomes, including phonological production, grammar and vocabulary, in children with CI or HA (Cupples et al., 2017; Geers, Moog, Biedenstein, Brenner, & Hayes, 2009). Further, low maternal education has been identified as a risk factor for impaired language in children with mild-to-moderate hearing loss using HA (Halliday et al., 2017).

In the present study, one potential indicator of language deficits, *nonword repetition (NWR)*, was examined in children aged 4–6 years, who use CI and/or HA due to sensorineural hearing loss. Despite technological advancements, not all aspects of the sound signal can be conveyed by the CI/HA. Limitations in processing of temporal fine-structure have greater effects on the perception of segmental compared to prosodic information (Moore, 2008). However, both CI and HA users typically have reduced ability to perceive fundamental frequency and amplitude (Moore, 2003, 2007), both of which provide important cues to prosody. Results from previous studies suggest that stress in nonwords is more accurately repeated than segments by Swedish-speaking DHH children (Ibertsson, Willstedt-Svensson, Radeborg, & Sahlén, 2008; Nakeva von Mentzer et al., 2015). It is not clear, however, if this extends to the prosodic feature tonal word accent. Therefore, repetition of stress and tonal word accent as well as consonants and vowels were investigated in the present study.

Nonword repetition

Nonwords can be described as words without meaning (Gathercole, 2006). In a NWR task, the child hears an audio-recorded or orally presented nonword and is asked to repeat it back immediately. The usefulness, and popularity, of NWR in clinical research likely stems from the fact that it has been able to discriminate typical from atypical language development in children (for a review, see Graf Estes, Evans, & Else-Quest, 2007). NWR has been suggested as a marker of SLI (Bishop, North, & Donlan, 1996). However, it might be more accurate to view NWR as an indicator of poor language ability in general (Reilly et al., 2014).

The question of exactly what NWR measures is still up for debate. Gathercole and Baddeley (1989) and Gathercole, Willis, Baddeley, and Emslie (1994) proposed NWR as a relatively pure measure of phonological working memory. However, accurate NWR also depends on long-term lexical knowledge (Gathercole, 2006) and phonological processing skills (Bowey, 2006; Snowling, Chiat, & Hulme, 1991). The fact that NWR gauges several underlying skills means that the properties of the nonwords impact repetition performance (Gathercole, 1995). Repetition accuracy decreases with increasing nonword length (Gathercole & Baddeley, 1990), low resemblance to real words (Munson, Kurtz, & Windsor, 2005) and high phonological complexity, e.g. presence of consonant clusters (Gallon, Harris, & van der Lely, 2007). Thus, results on NWR tasks will depend on how the nonwords are constructed, as well as on which properties are examined.

Analyses of what role prosodic features may play in NWR are comparably rare, but there are studies that have found effects of features relating to both stress and tone. English-speaking children and adults demonstrate higher repetition accuracy when strings of syllables are presented in a natural prosodic pattern, compared to when the same syllables are presented in isolation as a list (Archibald & Gathercole, 2007; Archibald, Gathercole, & Joanisse, 2009). In contrast, Japanese-speaking children appear to achieve higher repetition performance when there is a short pause in-between morae (Yuzawa, Saito, Gathercole, Yuzawa, & Sekiguchi, 2011). Regarding the influence of stress and prosodic position within nonwords, omissions of unstressed syllables have been found to be more frequent in positions before compared to after the stress in children speaking Swedish, English and Italian (Chiat & Roy, 2007; Dispaldro, 2014; Roy & Chiat, 2004; Sundström, Lyxell, & Samuelsson, 2018). Tone has not been extensively studied in the context of NWR, although there are some indications that repetition in Japanese- or Swedish-speaking children is facilitated more by some tonal features than others, e.g. high pitch accent in Japanese (Yuzawa & Saito, 2006), or tonal word accent 2 in Swedish (Sundström, Samuelsson, & Lyxell, 2014).

The ability to perceive and use prosody enables segmentation of the speech stream and subsequent detection of important elements (Arbisi-Kelm & Beckman, 2009). As such, prosody facilitates the acquisition of lexical, grammatical and phonological units, a process referred to as prosodic bootstrapping (Jusczyk, 1997; Morgan & Demuth, 1996). Thus, taking prosodic features into account in tasks that may be indicative of more general linguistic competence in children with hearing loss, such as NWR (Nittrouer, Caldwell-Tarr, Sansom, Twersky, & Lowenstein, 2014), may yield both theoretically and clinically relevant information.

Nonword repetition in children who are deaf and hard of hearing

Both prosodic and segmental aspects of NWR have been found to correlate with measures of language and cognition in 8- to 9-year-old CI users. Carter, Dillon, and Pisoni (2002) found that both the ability to repeat word length and stress placement in nonwords were related to word recognition, language comprehension, speech intelligibility, short-term memory and perceptual goodness ratings. Dillon, Cleary, Pisoni, and Carter (2004) found the same relations between these measures and segment repetition in children with CI aged 8–9 years. NWR at age 8–10 years has also been found to be a strong predictor of language performance at 16–18 years of age, in children with CI (Casserly & Pisoni, 2013).

Swedish-speaking DHH children using CI or HA, and children with NH and language impairment, were compared regarding NWR by Ibertsson et al. (2008). The 5- to 9-year-old children with CI and HA displayed a relatively low ability to correctly repeat consonants, as well as the number of syllables and stress patterns of nonwords, compared to age-matched children with NH. However, both syllable number and stress were easier to repeat compared to consonants, suggesting a difference between repetition of prosodic and segmental nonwords features. Further, children with CI were less successful in the NWR task compared to the children with mild-to-moderate hearing loss using HA (Ibertsson et al., 2008).

Nakeva von Mentzer and colleagues (2015) also compared Swedish-speaking children using CI (mean age of 6.5 years) to an age-matched group of children with NH on prosodic and segmental measures of NWR. The children with CI performed at a lower level compared to the children with NH on both repetition of consonants and vowels, and repetition of stress patterns. The children with CI did, however, achieve different levels of performance for each NWR outcome measure; stress (about 80% correct) was repeated more accurately compared to vowels (69%), which in turn were easier to repeat than consonants (53%). Similar results have been reported for English-speaking 8- and 9-year-old children with CI in two studies by Carter et al. (2002) and Dillon et al. (2004), who found that repetition of stress placement (64% correct) and number of syllables (61%) was more accurate than repetition of consonants (39%). This suggests that information about the prosodic envelope is relatively well preserved in children with CI, while details about the segments, especially in consonants, are lost to a higher extent.

With regard to preservation of stress patterns, both Swedish- and English-speaking children with CI omit unstressed syllables more frequently than NH children (Carter et al., 2002; Nakeva von Mentzer et al., 2015). Further, there appears to be an effect of prosodic position on syllable omissions. Nakeva von Mentzer et al. (2015) found that unstressed syllables were omitted twice as often when they occurred before the stress, outside of the trochaic foot, compared to post-stressed positions within the nonwords (Nakeva von Mentzer et al., 2015). Similarly, the findings of Carter et al. (2002) suggested that fewer syllable omissions occurred in nonwords with initial stress, compared to non-initial stress. In line with the metrical hypothesis (Gerken, 1991, 1994), these findings may suggest that children with CI are better at perceiving nonwords that conform to the more frequent rhythmical pattern of their ambient language, which in Swedish or English could be argued to be trochaic.

In summary, NWR is challenging for DHH children using CI or HA, although prosodic features of nonwords are typically less challenging than segments. Previous findings indicate that stress is problematic, but repetition of lexical tones, such as the Swedish tonal word accents, has not been included in previous studies. As nonwords are often modelled after the real words of a specific language, it is reasonable to assume that there are cross-linguistic differences concerning how challenging certain prosodic and segmental properties are. For example, the stress patterns of nonwords constructed in accordance with a language that has fixed stress are presumably easier to repeat than nonwords following a language with variable stress. In the present study, a NWR task that enables analyses of the prosodic features tonal word accent and stress, as well as consonants and vowels, was used.

Swedish lexical phonology

Central Swedish has 18 vowels, often described as short and long variants of nine vowel phonemes, and 18 consonant phonemes, most of which have long and short allophones. Quantity is complementary in stressed syllables, with lengthening of either the vowel or the consonant (Riad, 2014). Children have typically acquired all phonemes except the consonants/r/,/ɕ/, and/ɧ/before six years of age (Nettelbladt, 2007).

With regard to lexical prosody, Swedish has varying stress placement and a system with two distinct lexical tones, so-called tonal word accents. With regard to stress, simplex words receive one primary stress, while compounds, which are common in Swedish, receive both primary and secondary stress (Riad, 2014). The predominant stress pattern is trochaic, e.g. with a stressed syllable followed by an unstressed syllable within a two-syllable foot (Bruce, 2012), and this is the pattern preferred by young children (Nettelbladt, 2007).

The tonal word accents are commonly referred to as 1 or 2 (or sometimes acute or grave). Tonal word accent 1 constitutes a low tone on the stressed syllable, with a following rise. Tonal word accent 2 is instead characterised by a high tone followed by a fall on the stressed syllable (Bruce, 2012). Simplex words have either accent 1 or accent 2, while compounds typically have accent 2. Assignment of tonal word accent 2 requires an unstressed syllable after the stressed, tone bearing, syllable, while tonal word accent 1 does not have this limitation (Bruce, 2012). In many words, the tonal word accent can be predicted by morphological properties. As an example, the monosyllabic stem *sitt–* combined with the present tense suffix *–er* yields the tonal word accent 1 word *sítter* 'sits', while the combination with the infinitive suffix *–a* results in the tonal word accent 2 word *sìtta* 'to sit'. Accent 2 has been found to develop before accent 1 in children (Peters & Strömqvist, 1996), and language appropriate contrastive use of the tonal word accents is achieved after about 4 years of age (Plunkett & Strömqvist, 1992).

Study aims

NWR has potential as a clinically useful tool for predicting language ability in children with hearing loss, irrespectively of hearing technology (CI and/or HA). Since NWR measures several underlying skills, detailed investigations of repetition performance and how it relates to language, cognition, hearing and background factors are motivated. Prosodic features of nonwords, such as stress and tone, have not been as extensively studied as the repetition of segments. Further, it is largely unclear how the ability to repeat of prosodic nonword features is related to language abilities or background variables associated with cognition, socio-economic status and hearing. The aims of the present study were (1) to examine repetition of prosodic features and segments in nonwords by 4- to 6-year-old DHH children, compared to age-matched controls with NH, and (2) to explore possible relations of repetition of tonal word accent and stress, as well as segments, to measures of language ability, nonverbal cognitive ability, maternal education and hearing level.

Method

Participants

Two groups of children participated in the study. The DHH group consisted of 14 children (3 boys) aged 48–80 months (*M* = 60.3, *SD* 9.8) with bilateral sensorineural hearing loss, using either bilateral conventional HA (nine children), bilateral CI (three children) or with a combination of both (two children). All children with bilateral CI were sequentially implanted. The children had no identified additional disabilities besides the hearing loss. Recruitment was made through audiology clinics at two major university hospitals in central Sweden. The children's degree of hearing loss prior to implantation or HA fitting, measured as the average better ear hearing level by their regular audiologists, ranged from mild to profound (Clark, 1981). Cause of hearing loss was inner ear malformation for one child, suspected but not confirmed congenital cytomegalovirus infection for one child, and unknown reasons for 12 of the children. The caregivers of all children reported that the HA and/or CI were used full time. The children used spoken Swedish as their first language, and they were raised in hearing, Swedish-speaking families. All children attended preschool integrated in a mainstream educational setting. Hearing background information is provided in Table 1. Screening with the Nordic Orofacial Test-Screening (Bakke, Bergendal, McAllister, Sjögreen, & Åsten, 2007) indicated that all children had orofacial function within normal limits.

The age-matched control group comprised 29 children (11 boys) with NH, aged 49–80 months (*M* = 61.3, *SD* 8.2). To be eligible for inclusion in the study, the controls

Table 1. Hearing background of the DHH children (*n* = 14).

Child	Unaided PTA dB BEHL	Age at testing	Age 1st CI implantation	Age activation 1st CI	Age 2nd CI	Age 1st HA fitting	Time since 1st CI/HA
Bilateral CI							
01	85.0	68.2	9.6	10.2	29.7	3.2	58.0/65.0
02	103.0	48.5	20.5	21.3	32.5	16.0	27.2/32.5
03	102.0	48.4	15.0	15.9	22.7	3.0	32.5/45.4
Mean	97.0	55.0	15.0	15.8	28.3	7.4	39.2/47.6
Bimodal CI+HA							
04	57.5	79.5	56.4	58.0	–	4.9	21.5/74.6
05	55.0	57.6	49.2	50.1	–	38.2	7.5/19.4
Mean	56.3	68.6	52.8	54.1		21.6	14.5/47.0
Bilateral HA							
06	46.0	64.0	–	–	–	55.9	8.1
07	42.5	55.8	–	–	–	18.9	36.9
08	64.5	58.7	–	–	–	49.3	9.4
09	25.0	73.2	–	–	–	40.4	22.8
10	30.0	50.0	–	–	–	29.0	20.9
11	50.0	64.0	–	–	–	37.8	26.2
12	55.0	48.3	–	–	–	4.1	44.2
13	47.5	68.4	–	–	–	3.9	64.4
14	52.5	59.3	–	–	–	12.4	47.0
Mean	45.9	60.2				28.0	31.1
Md CI	102.0	48.5	15.0	15.9	30.7	3.2	32.5
Md HA	47.5	59.3				29.0	26.2

Notes: Ages are reported in months. DHH = deaf and hard of hearing; PTA dB BEHL = pure tone average better ear hearing level in decibels; CI = cochlear implant; HA = hearing aid; *Md* = median value.

should be monolingual Swedish-speaking children, with no diagnosed disorders of cognition or language. Further, they should have NH, with no history of hearing loss, as reported by their caregivers. All children spoke a regional variant of Swedish similar to that of the DHH children. Controls were mainly recruited through preschools and in two cases through personal contacts.

Comparisons between groups for the background factors age, maternal education and nonverbal cognitive ability revealed no difference in age. However, the duration of maternal education was significantly longer in the NH group ($M = 16.0$, $SD = 2.3$) compared to the DHH group ($M = 14.0$, $SD = 2.1$); $U = 109.00$, $z = 2.469$, $p = 0.013$, $r = 0.38$. Nonverbal cognitive ability scores were also slightly higher for the children with NH ($M = 25.8$, $SD = 3.7$) than for the children with DHH ($M = 22.9$, $SD = 4.3$); $U = 125.00$, $z = 2.043$, $p = 0.041$, $r = 0.31$.

Procedure

Ethical permission for the study was obtained from the Regional Ethical Review Board in Linköping (Dnr 2013/92-31), and all caregivers gave their written consent to participation. Tests were administered in one or two sessions, and suitable breaks were taken. The total testing duration was 1.5–2 hours. The data collection took place either in a hospital setting or at the children's home, according to the participants' preferences. The order of the tests was randomised for each participant prior to testing using the RAND function in Microsoft Excel.

Measures

Nonword repetition

The NWR task comprised 25 pre-recorded nonwords ranging from one to five syllables in length. The prosodic features of the items varied so that all possible combinations of stress patterns and tonal word accents in Swedish were included for each length condition. Some of the nonwords were adopted from Sahlén, Reuterskiöld-Wagner, Nettelbladt, and Radeborg (1999). There were 15 nonwords with tonal word accent 1, and 10 nonwords with tonal word accent 2. The uneven number of nonwords in each tonal word accent condition is due to the fact that Swedish words with primary stress on the last syllable can only have tonal word accent 1. Consequently, there was only one nonword with this stress placement in each length condition (one to five syllables). Another result of this was that there were nonwords, all with tonal word accent 1, where a trochaic (stressed–unstressed) stress pattern could not occur. All other nonwords contained a trochaic foot. A more detailed description of the NWR task can be found in the Appendix.

The nonwords were presented in randomised order in free field at approximately 70 dB SPL. All child responses were audiorecorded and transcribed phonetically by the first author. Percentages of correctly repeated tonal word accents, stress patterns, phonemes (PPC), consonants (PCC) and vowels (PVC) were calculated in Microsoft Excel. Nonwords that the children did not attempt to repeat were excluded. Ten percent of the recordings from the repetition task were transcribed by an experienced speech-language pathologist (author 4) to assess inter-rater reliability. The formula used was the number of agreements divided by the total number of agreements + disagreements. Agreement was 97.4% for both tonal word accents and stress, and agreement for consonants and vowels combined was 90.3%.

Language abilities

Receptive vocabulary was assessed with a Swedish adaption of the Peabody Picture Vocabulary Test, Third Edition (Dunn & Dunn, 1997), in which the examiner says a word, and the child answers by pointing to one out of four pictures. Due to the lack of relevant norms for Swedish-speaking children, only raw scores are used in the present study. The maximum score is 204.

Expressive grammar assessment was made with Gramba (Hansson & Nettelbladt, 2004). The test targets verb morphology, noun morphology and syntax. Production is elicited through sentence completion or continuation. The maximum total score is 44 points, divided between the three subtests verb morphology (15 p), noun morphology (19 p) and syntax (10 p).

Phonological production was examined with the short version of the Phoneme test (Hellqvist, 1995). The child names 72 pictures of everyday objects and activities. The test targets words with Swedish speech sounds and consonant clusters in different word positions. The intended targets include 32 one-syllable words, 32 two-syllable words, 7 three-syllable words and 1 five-syllable word. Stress patterns vary, but penultimate stress is the most frequent in the words that have more than one syllable. There are 45 words with tonal word accent 1, and 27 with tonal word accent 2. All responses were accepted, even when they differed lexically from the words originally intended in the test, for example, *klänning* 'dress' instead of *kjol* 'skirt'. The children's productions were audiorecorded and transcribed phonetically by the first author. Words that the children did not attempt to say were excluded from the analyses. The test is normally used for qualitative assessments of phonology, and there is no scoring procedure. For the purpose of the present study, percentages of correctly produced consonants, vowels, stress patterns, and tonal word accents were calculated based on phonetic transcriptions.

Nonverbal cognitive ability

Assessment of nonverbal cognitive ability was done with the block design subtest of the Wechsler Preschool and Primary Scale of Intelligence, Third Edition (Wechsler, 2005). In this test, the child is tasked with replicating patterns of blocks with increasing difficulty, within a limited amount of time. There are 20 model patterns, out of which the first 12 are built by the examiner, while the last 8 are shown in pictures. The maximum total score is 40.

Statistical analyses

Mann–Whitney U test was used for between-group comparisons, as sample sizes were small, with unequal variances in the groups. For within-group analyses, Wilcoxon's signed rank test was used when two conditions were compared, and Friedman's analysis of variance was used for comparisons between more than two conditions. Kendall's tau was computed for the correlational analyses. To account for multiple comparisons, the false discovery rate was controlled using the Benjamini–Hochberg procedure (Benjamini & Hochberg, 1995).

Results

NWR and language abilities in DHH children compared to children with NH

The first aim of the present study was to examine repetition of tonal word accent, stress and segments, in DHH children, and to compare their performance to that of age-matched controls with NH. In the following, group comparisons of NWR, as well as language measures, will be presented first, followed by within-group analyses of NWR performance.

NWR

Figure 1 shows the overall NWR results for all children. The DHH children performed significantly below the children with NH on NWR tonal word accents; $U = 59.50$, $z = 3.778$, $p < 0.001$, $r = 0.58$, stress; $U = 52.00$, $z = 3.932$, $p < 0.001$, $r = 0.60$, PCC; $U = 62.00$, $z = 3.655$, $p < 0.001$, $r = 0.56$, and PVC; $U = 57.50$, $z = 3.771$, $p < 0.001$, $r = 0.58$. Between 71% and 79% of the DHH children scored at least 1 SD below the mean of the controls with NH. In order to examine if the difference between the groups was dependent on nonword length, accuracy scores for segments (PPC), stress and tonal word accent were compared in each length condition (two, three, four and five syllables). The DHH children performed below the children with NH in all conditions of segment and stress repetition. For tonal word accent repetition, no group difference was found in two-syllable nonwords. NWR results for each of the length conditions are described in Table 2.

Language abilities

Language outcome measures for each group, together with group comparisons, are shown in Table 3. Phonological production on the Phoneme test (Hellqvist, 1995), measured as the percentages of correctly produced tonal word accents, stress patterns, consonants and vowels, was significantly lower in the DHH children, with the exception of tonal word accents. About half to two thirds of the children in the DHH group scored more than 1 SD below the mean of the controls with NH on stress, consonants and vowels, while only two children (14%) scored below 1 SD on tonal word accent production. Both these children had bilateral CI and were among the youngest in the sample (48 months). However, children's phonological production during this picture naming task was generally quite good in the DHH group, with the exception of consonants, which were 74% accurate.

Concerning expressive grammar, the DHH children were overall significantly below the controls with NH, and only two children (14%) achieved total scores above −1 SD. But breaking the results up into the respective subtests – verb morphology, noun morphology and syntax – revealed a picture in which morphological production appeared considerably more vulnerable than syntax in the DHH group. On both verb and noun morphology, the DHH children scored significantly below the children with NH, and over 70% were below the −1 SD mark. For syntax, on the other hand, no group difference was found, and 79% of the DHH children scored within or above 1 SD of the mean for the controls.

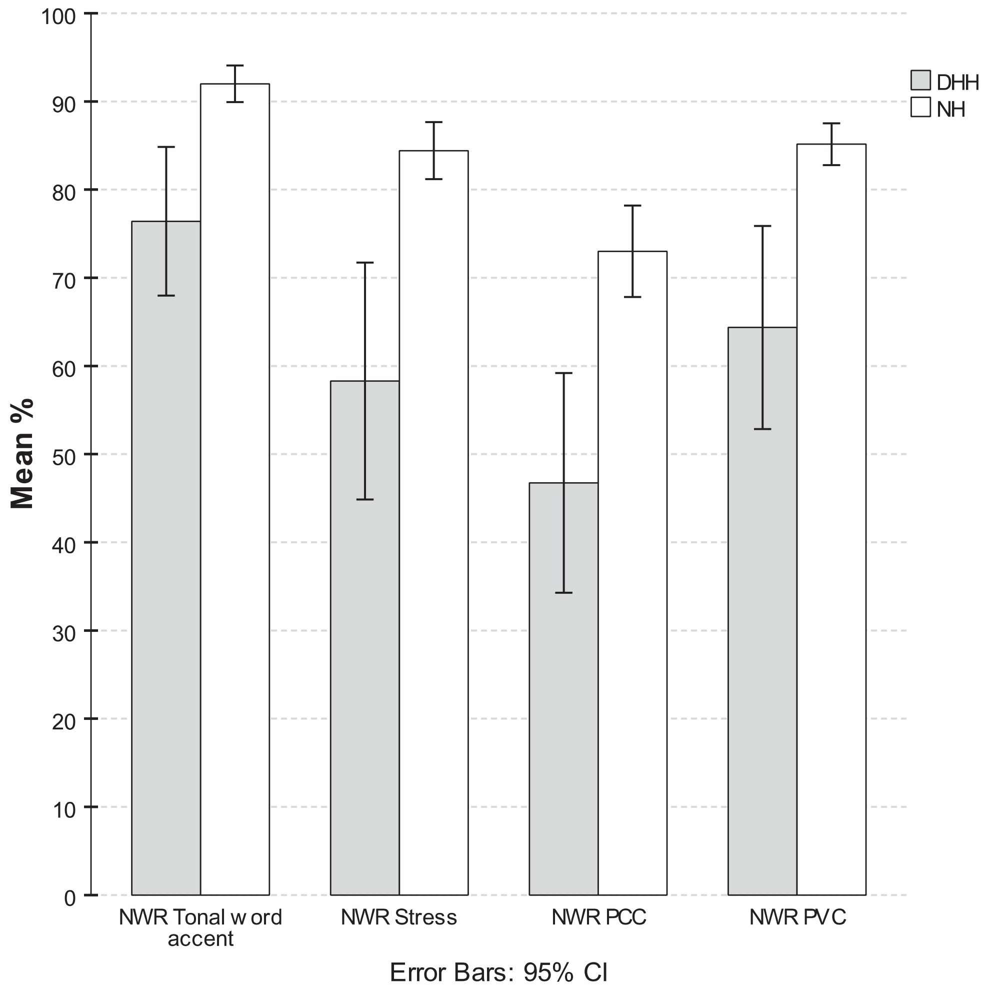

Figure 1. Mean percentages for tonal word accents, stress, consonants (PCC) and vowels (PVC) in nonword repetition (NWR) in deaf and hard of hearing (DHH) and normal hearing (NH) children.

Within-group analyses of NWR

Tonal word accent

Differences between the two tonal word accent conditions (tonal word accent 1 or 2) concerning repetition of the tonal word accents themselves, as well as repetition of stress, consonants and vowels, are described in Table 4. Starting with the DHH children, the results indicated that tonal word accent 1 was easier to repeat than tonal word accent 2. The majority of errors were judged to be substitutions of one tonal word accent for the other, and not a lack of tonal word accent altogether. No difference was found between nonwords with tonal word accent 1 and nonwords with tonal word accent 2 regarding the repetition of stress, consonants or vowels. Tonal word accent repetition performance was near ceiling in the children with NH, and no difference between tonal word accents 1 and 2 was found. Stress pattern and consonant repetition did not differ between the tonal word

Table 2. Performance in percent (mean, SD) on the NWR task in DHH and NH children.

	DHH (n = 14)		NH (n = 29)					
	M	SD	M	SD	U	z	p	r
NWR tonal word accent								
Total	76.4	14.6	92.0	5.5	59.50	3.778	<0.001	0.58
Two syllables	86.3	16.5	90.8	19.7	166.00	1.221	0.244	0.18
Three syllables	78.8	26.5	93.8	10.8	130.00	2.206	0.034	0.34
Four syllables	74.8	20.6	95.1	7.9	65.00	3.906	<.001	0.60
Five syllables	69.4	19.7	87.8	10.9	87.00	3.079	0.002	0.47
NWR stress								
Total	58.3	23.3	84.4	8.5	52.00	3.932	<0.001	0.60
Two syllables	82.1	19.0	96.6	13.6	118.50	3.092	0.003	0.47
Three syllables	57.9	27.2	84.1	14.5	82.00	3.298	0.001	0.50
Four syllables	58.6	31.7	85.7	14.3	96.50	2.850	0.004	0.43
Five syllables	47.2	29.9	77.6	14.8	76.00	3.344	<0.001	0.51
NWR PPC								
Total	54.4	20.8	78.3	10.2	58.50	3.745	<0.001	0.57
Two syllables	56.7	21.6	88.2	10.8	38.00	4.318	<0.001	0.66
Three syllables	58.3	21.5	81.7	10.3	62.00	3.656	<0.001	0.56
Four syllables	54.5	21.8	79.2	10.3	66.00	3.551	<0.001	0.54
Five syllables	52.0	22.4	74.8	12.5	71.00	3.421	<0.001	0.52

Notes: Mann–Whitney U test was used for group comparisons; DHH = deaf and hard of hearing; NH = normal hearing; NWR = nonword repetition; PPC = percentage of phonemes correct; U = Mann–Whitney U statistic; r = effect size.

Table 3. Group performance on phonological production, expressive grammar and receptive vocabulary.

	DHH (n = 14)		NH (n = 29)						
	M	SD	M	SD	U	z	p	r	DHH < −1 SD
Phonological production									
Tonal word accent (%)	94.2	6.3	96.1	5.7	150.50	1.370	0.175	0.21	14%
Stress patterns (%)	93.9	6.9	98.2	1.9	91.00	2.932	0.003	0.45	50%
PCC	74.2	23.5	93.0	6.6	66.00	3.551	< 0.001	0.54	64%
PVC	88.0	11.0	96.3	2.7	74.50	3.332	0.001	0.51	71%
Expressive grammar									
Total score	23.1	7.6	34.2	4.8	34.00	4.387	< 0.001	0.67	86%
Verb morphology	7.6	3.2	11.7	2.4	62.00	3.675	< 0.001	0.56	71%
Noun morphology	8.1	3.6	14.6	2.4	25.50	4.625	< 0.001	0.71	86%
Syntax	7.4	2.6	7.9	1.9	184.00	0.501	0.628	0.08	21%
Receptive vocabulary	56.8	18.4	90.6	21.1	45.00	4.097	< 0.001	0.62	79%

Notes: Mann–Whitney U test was used for group comparisons. DHH = deaf and hard of hearing; NH = normal hearing; PCC = percentage of consonants correct; PVC = percentage of vowels correct; U = Mann–Whitney U statistic; r = effect size. 'DHH < −1 SD' indicates the percentage of DHH children with HI who performed more than 1 SD below the mean of the NH group.

accent conditions, while vowels were easier to repeat in nonwords with tonal word accent 2 in the NH group.

Comparisons between the length conditions showed that the repetition accuracy for tonal word accents differed significantly between nonwords of different length in the DHH children; $\chi^2(3) = 9.248$, $p = .026$. However, follow-up pairwise comparisons revealed a difference only between two-syllable and five-syllable nonwords ($p = .032$).

Stress

In the DHH groups, stress was less accurately repeated compared to tonal word accent; $z = -2.396$ $p = .001$, $r = 0.45$. Stress repetition was also dependent on length; $\chi^2(3) = 14.836$, $p = .002$. Stress patterns in two-syllable nonwords were easier to repeat

Table 4. Comparisons between nonwords with tonal word accent 1 and 2.

	Tonal word accent 1		Tonal word accent 2				
	M	SD	M	SD	*z*	*p*	*r*
DHH (n = 14)							
Tonal word accent	81.6	14.2	68.2	20.2	2.657	0.005	0.50
Stress	58.5	22.3	57.9	30.2	0.000	1.000	0.00
PCC	47.9	22.0	45.3	22.2	0.847	0.426	0.16
PVC	62.9	20.9	66.4	20.7	1.036	0.326	0.20
NH (n = 29)							
Tonal word accent	93.3	6.9	90.0	11.3	1.075	0.292	0.14
Stress	85.1	9.5	83.5	13.2	0.395	0.702	0.05
PCC	74.2	13.5	71.4	14.9	1.617	0.109	0.21
PVC	83.0	7.2	88.1	6.7	3.600	<0.001	0.47

Notes: Wilcoxon's signed rank test was used for within-group comparisons; DHH = deaf and hard of hearing; NH = normal hearing; NWR = nonword repetition; PPC = percentage of phonemes correct; *r* = effect size.

than in nonwords with three and five syllables (p = .041 and .003, respectively), but not compared to four-syllable ones.

In order to examine the effect of prosodic structure on stress pattern repetition, comparisons were made between stressed and unstressed syllables, as well as between prestressed and poststressed syllables. The most common stress repetition error made by the DHH children was syllable omission. A total of 11.5% of all syllables were omitted. Only 4.3% of the stressed syllables were omitted compared to 14.5% of the unstressed syllables. There was also an effect of prosodic position on unstressed syllable omission: 19.5% of the prestressed and 10.8% of the poststressed syllables were omitted, a difference that was significant; $z = 2.731$, $p = .004$, $r = 0.52$.

Segments

Comparing repetition of segments and prosodic features, consonants were significantly harder to repeat compared to both tonal word accent; $z = 3.296$, $p < .001$, $r = 0.62$, and stress; $z = 3.233$, $p < .001$, $r = 0.61$. Vowel repetition was less accurate than repetition of tonal word accent; $z = 2.731$, $p = .004$, $r = 0.52$, but in fact more accurate compared to stress; $z = 2.103$, $p = .035$, $r = 0.40$.

Correlations of NWR to language ability and hearing background

The second aim of the study was to explore possible relations between NWR, language and background variables in the DHH children. Table 5 shows the correlations between NWR and language, nonverbal cognitive ability, maternal education, age and hearing level in the DHH group. Correlations in the NH group are displayed in Table 6.

Repetition of tonal word accent, stress and segments correlated with phonological production (naming PPC), expressive grammar and receptive vocabulary in the DHH children. A significant negative correlation was also found with hearing level, indicating lower repetition scores for DHH children with more severe hearing loss. No other significant correlations were observed.

A different pattern of correlations was found in the children with NH. The only significant correlation between repetition of prosodic nonword features and language was that of stress repetition to naming PPC. In contrast, the ability to repeat segments

Table 5. Correlations of NWR to language and background variables in the DHH group.

	Correlation coefficients (τ)		
	NWR accent	NWR stress	NWR PPC
Naming PPC	0.544**	0.738**	0.739**
Grammatical production	0.520*	0.625**	0.536**
Receptive vocabulary	0.514*	0.753**	0.751**
Nonverbal cognitive ability	−0.035	0.047	0.082
Maternal education	0.234	0.247	0.255
Unaided hearing PTA	−0.492*	−0.416*	−0.464*
Age at 1st HA fitting	0.022	0.233	0.187
Duration of HA use	0.022	−0.233	−0.099
Chronological age	0.067	0.303	0.309

*$p \le .05$, **$p \le .01$. NWR = nonword repetition; DHH = deaf and hard of hearing; τ = Kendall's tau correlation coefficient; PPC = percentage of phonemes correct; PTA = pure tone average; HA = hearing aid.

Table 6. Correlations of NWR to language and background variables in the NH group.

	Correlation coefficients (τ)		
	NWR accent	NWR stress	NWR PPC
Naming PPC	0.127	0.317*	0.557**
Grammatical production	−0.044	−0.003	0.145
Receptive vocabulary	−0.128	0.118	0.419**
Nonverbal cognitive ability	0.075	0.086	0.234
Maternal education	−0.030	0.073	0.409**
Chronological age	0.071	0.130	0.261*

*$p \le .05$, **$p \le .01$. NWR = nonword repetition; NH = normal hearing; τ = Kendall's tau correlation coefficient; PPC = percentage of phonemes correct.

in nonwords was significantly correlated with both naming PPC and receptive vocabulary, as well as to maternal education and age.

In sum, the general results indicated that the DHH children performed significantly below the level of the children with NH on both prosodic and segmental measures of NWR. Repetition of segments and stress was lower in the DHH group regardless of nonword length, while there was no group difference regarding tonal word accent repetition in two-syllable nonwords. Comparisons of the various repetition measures in the DHH group showed that tonal word accent was easiest to repeat, followed by vowels, stress and consonants. Concerning the language measures, significant group differences were found for phonological production in naming of familiar words regarding consonants, vowels and stress, but not tonal word accent. The ability to correctly produce verb and noun morphology was significantly lower in the DHH children, while no difference compared to the controls with NH was found for syntax. Finally, NWR performance correlated significantly with phonological production, expressive grammar, receptive vocabulary and hearing level in the DHH group.

Discussion

The purpose of the present study was to examine repetition of tonal word accent, stress and segments in nonwords by Swedish-speaking DHH children and to relate NWR performance to language and background measures. In general, the DHH children scored below the children with NH on the NWR task. Both the prosodic features stress and tonal word accent, consonants and vowels were less successfully repeated. Performance on tonal word accent repetition was, however, high compared to the other repetition measures. Somewhat surprisingly, vowels were more accurately repeated than stress. Although the difference between stress and vowel repetition was not analysed statistically by Nakeva von Mentzer et al. (2015), the children with CI in their study achieved higher scores for repetition of syllable number and primary stress compared to vowels. Possible explanations for this difference between studies are that the children in Nakeva von Mentzer et al. (2015) all used bilateral CI and were slightly older (5–8 years), and that the NWR task used only included three- and four-syllable nonwords. Consonant repetition was lower compared to repetition of tonal word accent, stress and vowels. An advantage for stress over consonant repetition has been found previously in Swedish-speaking DHH children (Ibertsson et al., 2008; Nakeva von Mentzer et al., 2015), and the present results concerning tonal word accent repetition add to the evidence that prosodic features are easier to repeat compared to consonants. The present findings do not, however, indicate a generally better ability to repeat prosodic features in DHH children with CI or HA, as performance was higher for vowels than for stress.

The present study is, to the best of our knowledge, the first to investigate tonal word accent repetition in DHH children. Although scores for tonal word accent repetition were higher than for repetition of stress patterns, vowels and consonants, performance was lower compared to the age-matched controls with NH. The exception was repetition of the shortest, two-syllable, nonwords, for which no group difference was found. This could indicate that DHH and NH children have a similar ability to store and process tonal word-level information when phonological working memory demands and phonological complexity are low. The relative strength in tonal word accent use was also reflected in the results of the naming task; tonal word accent scores were high and did not differ between the DHH and NH children.

The DHH children repeated tonal word accent 1 more accurately than tonal word accent 2. This finding is intriguing considering that tonal word accent 2 is generally acquired first by typically developing NH children, and may have slightly higher perceptual saliency (Peters & Strömqvist, 1996). Since differences in acoustic or perceptual salience appear to be unlikely explanations for the higher tonal word accent 1 accuracy, more linguistically oriented approaches might be needed. Riad (2014) proposes that, in simplex words, tonal word accent 2 is specified as part of the lexical representation, while tonal word accent 1 is assigned by default when there is no specification for tonal word accent 2. Hence, it could be the case that DHH children to some extent default to the use of tonal word accent 1 in NWR because there are no lexical representations. The finding that the difference in accuracy between tonal word accent 1 and 2 in the DHH group was not found in the NH group could indicate that tonal word accent development follows a different pattern in DHH children, or that it is delayed. Future studies of tonal word accent repetition should include children of different ages to answer questions about the developmental trajectory in NH and DHH children.

While the analysis of repetition of the tonal word accents per se demonstrated an advantage for tonal word accent 1 in the DHH group, the tonal word accents do not appear to have provided different conditions for repetition of other nonword features. Repetition accuracy for stress, vowels and consonants was more or less equal in nonwords with tonal word accent 1 and 2, with no significant differences. This suggests that problems perceiving or producing the correct tonal word accent can exist independently of the ability to use stress or segments in the same nonword. The results further suggested that the NH children repeated vowels more easily in nonwords with tonal word accent 2. It is possible that the relationship between tonal word accent and other nonword features develops differently in DHH and NH children. Future research should examine changes over time, preferably using longitudinal study designs.

Tonal word accents are used to focus information together with stress, which is of course an important function in communication. However, the vast majority of tonal word accent errors made by the DHH children were substitutions of one tonal word accent for the other, and not absence of a distinct tonal pattern. The Swedish tonal word accent system is also intimately linked to morphology; the two tonal word accents signal different suffixes and thereby grammatical functions for both nouns and verbs (Riad, 2014). The implications of tonal word accent difficulties for language acquisition are largely unknown, but the present findings may warrant more detailed investigations into the nature of a potential association between problems with tonal word accents and grammatical deficits.

Stress patterns were on average incorrectly repeated in more than 40% of the nonwords by the DHH children, compared to just over 15% for the controls with NH. This indicates a large quantitative difference in the ability to perceive and reproduce rhythmic linguistic properties of speech. However, binary scoring of stress repetition (right/wrong) does not give any information about the types of errors made. Consistent with findings from previous studies (Carter et al., 2002; Nakeva von Mentzer et al., 2015), the most frequent stress error in the DHH children was omissions of unstressed syllables. Unstressed syllables have shorter duration and less acoustic energy compared to stressed syllables, making them more prone to omission (Svirsky, Stallings, Lento, Ying, & Leonard, 2002). There was also an effect of position within the nonwords on syllable omission; unstressed syllables were twice as likely to be omitted if they occurred before the trochaic foot, compared to unstressed syllables within or after the trochaic foot. A similar trochaic bias effect in Swedish-speaking DHH children with CI has been proposed by Nakeva von Mentzer et al. (2015). This effect of prosodic position was not found in the NH group in the present study. However, it has previously been established in younger children with NH and typical language development, as predicted by the metrical hypothesis (Gerken, 1991, 1994). Thus, it is possible that the development of the ability to perceive and produce unstressed syllables in DHH children follows a typical trajectory, but that it is delayed.

Accurate repetition of longer nonwords is assumed to require sufficient phonological working memory capacity, mainly evidenced by the finding that longer nonwords are harder to repeat than short ones (Gathercole & Baddeley, 1990). For the DHH children in the present study, there was no clear linear relation between increased nonword length and decreased repetition accuracy. This could indicate that the maximum phonological working memory capacity is reached already when nonwords are two syllables long. The lack of a significant effect of length on PPC in the DHH group indicates that consonants and vowels in longer nonwords were not harder to repeat compared to short ones. It should be noted, however, that repetition performance for both tonal word accent and stress was highest in the shortest nonwords. Successful repetition has been shown to be dependent on, for example, sensitivity to phonological structure and efficient encoding of phonological information (Bowey, 2006). Limitation in such skills, rather than in phonological store capacity per se, may better explain the NWR difficulties exhibited by the DHH children in the present study.

The second aim of the present study was to explore potential relationships of NWR to language and background measures. Overall, the DHH children who were more successful on NWR also displayed higher language ability, as indicated by the positive correlation between NWR and language. Similar results have previously been found for older children using CI or HA (Carter et al., 2002; Dillon et al., 2004; Ibertsson et al., 2008; Nittrouer et al., 2014). However, the present findings reveal nothing about causality or directions of potential relationships between NWR and phonological production, expressive grammar or receptive vocabulary. Further, the results provide little guidance to what specific aspects of language ability could potentially be predicted by NWR. The finding that hearing level was negatively correlated with repetition performance may indicate that the quality of auditory stimulation prior to HA fitting or cochlear implantation is important for NWR, together with a shorter period of auditory deprivation (Torkildsen, Arciuli, Haukedal, & Wie, 2018).

The DHH children performed lower than the controls on most of the language measures, and the vast majority fell below the −1 SD mark. There were, however, two notable exceptions. The first was tonal word accent production in the Phoneme test (Hellqvist, 1995), where the children produced familiar words. No statistical group difference was found for this measure. The fact that the words produced were known to the children, and that they seldom were longer than two syllables, might have contributed to the high performance in the DHH group. Tonal word accents as part of existing lexical representations may have been quite stable for the DHH children, while the processing of tonal word accents in unknown word forms, i.e. nonwords, was less successful. This could indicate that tonal word accents are harder to perceive for DHH children, and that more exposure to a novel word is needed before a reliable long-term representation can be formed. However, production of tonal variations spanning over several segments and syllables appears to be a relative strength for DHH children, as indicated by the high performance on tonal word accent repetition compared to stress, consonants, and vowels. The lower detail of the spectral structure of the acoustic signal, especially temporal fine structure (Moore, 2008), can be assumed to lead to lower quality of phonological representations in DHH children using CI or HA. It can also be assumed that short phonetic elements are affected more than those with longer duration (Svirsky et al., 2002). Although variations in fundamental frequency is the main acoustic correlate of tonal word accents (Bruce, 2012), they also have comparably long duration compared to segments and syllables carrying stress, and might for this reason be easier to perceive and produce for DHH individuals. The two DHH children who performed below −1 SD on tonal word accent production in the Phoneme test both listened through bilateral CI, and were among the youngest in the sample. The CI technology only permits limited perception of fundamental frequency, while the perception of duration is less constrained (Moore, 2003). Difficulties with fundamental frequency perception can partly be compensated for by increased reliance on durational cues (Hegarty & Faulkner, 2013), but maybe not efficiently enough for some children with bilateral CI.

The second exception was the syntax subtest of Gramba (Hansson & Nettelbladt, 2004), where the DHH children performed comparably higher. No statistical difference between the DHH and NH groups was found. The noun and verb morphology parts of the grammar test are dependent on correct production of the consonants and unstressed syllables that constitute grammatical morphemes, such as possessive –s or past tense suffixes. This discrepancy between morphological and syntactic ability could be expected based on the fact that syntax does not demand detailed phonetic accuracy to the same degree as morphological or segmental elements, and as such are easier to use for DHH children (Nittrouer, Lowenstein, & Holloman, 2016). In the light of the correlations found between NWR and grammar in the present study, it would be interesting to study the grammatical ability of Swedish-speaking DHH children in more detail, and to further examine if problems with grammar could be predicted by NWR performance.

Large variation in speech and language functioning can be expected in DHH children (Niparko et al., 2010). In the present study, higher variability in the DHH group compared to the NH group was evident for all repetition measures, as well as for production of stress, consonants and vowels in the Phoneme Test. This suggests particularly large individual variation in the ability to perform tasks with high demands on accurate analysis of phonological elements with comparably low perceptual saliency, as well as expressive phonological skills.

There was a large heterogeneity within the group of DHH children, which is common in the population. First, the children used either HA and/or CI. Second, there was a considerable variation regarding their unaided hearing level and age at CI or fitting of HA. Severity of hearing loss ranged from mild to profound, with users of both HA and/or CI, and large differences in age at 1st HA fitting and/or cochlear implantation, and duration of hearing technology use. The correlational analyses did not indicate any relation of hearing background factors to NWR or language abilities, with the exception of hearing level. Speech and language outcomes are typically influenced by the severity, age of onset and duration of the hearing loss, and cognitive factors (Kral et al., 2016). The failure to find significant correlations between hearing background and language in the present study was likely influenced by the large variability as well as by the limited sample size. Finally, nonverbal cognitive ability and maternal education were lower in the DHH group than in the NH group. Both these variables influence language development in DDH children using CI or HA (Cupples et al., 2017; Geers et al., 2009; Halliday et al., 2017). It could be argued that the DHH children in the present study was at a disadvantage relative to the NH children, and that the group differences found for NWR and language partly reflect differences in, for example, general learning ability or language stimulation in their home environment.

Conclusion

The DHH children participating in the present study performed below the children in the control group with NH on most aspects of NWR. The results corroborate the findings of previous studies that repetition of consonants, vowels and stress is problematic for children with mild-to-severe hearing loss using HA and/or CI. It was also found that repetition of tonal word accent, i.e. tonal variations spanning over several syllables, is difficult, but not to the same extent as for the other nonword features. In fact, the ability to perceive and produce tonal word accents in short nonwords may be more or less equal in DHH and NH children. The present findings also showed that the DHH children repeated vowels more accurately than stress patterns, suggesting that prosodic features are not necessarily easier to perceive and use than segments. Further, there were significant correlations between repetition of prosodic as well as segmental nonword features, and phonological production, grammar, vocabulary and unaided hearing level. This could possibly indicate that NWR has potential as a useful clinical tool for identifying DHH individuals who, regardless of hearing technology, need speech and language training. Further, the finding that repetition of prosodic nonword features was challenging for the DHH children, and that repetition of these features was correlated with language ability, could imply that intervention targeting phonology, grammar and lexico-semantics could benefit from awareness and explicit teaching of prosodic features. However, the present results need replicating with larger samples, more closely matched for nonverbal cognitive ability and maternal education.

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Declaration of interest

The authors report no declarations of interest.

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Appendix. Features of the nonwords in the repetition task

No. of syllables	Stress pattern	Tonal word accent	Nonword	Transcription
1	S	1	jab	jɑ́ːb
2	WS	1	ifum	ɪfʉ̟́ːm
2	SW	1	datri	dɑ́ːtrɪ
2	SW	2	mirve	mɪ̀rvɛ
3	WWS	1	revuell	rɛvɵɛ́l
3	WSW	1	kratuckel	kratɵ́kɛl
3	SWW	1	kasimum	kɑ́ːsɪmɵm
3	WSW	2	pelamna	pɛlàmna
3	SWW	2	höntpule	hø̀ntpʉ̟ːlɛ
4	WWWS	1	gettenimflär	gɛtɛnɪɱflæ̌ːr
4	WSWW	1	hydoria	hʏdóːrɪa
4	WWSW	1	dralabelli	dralabɛ́lɪ
4	SWWW	1	knamtigavass	knámtɪgavas
4	SWWW	2	attefnuvi	àtɛfnʉ̟ːvɪ
4	WWSW	2	tibbefime	tɪbɛfìːmɛ
4	WSWW	2	ganolmulte	ganùːlmɵltɛ
5	WWWSW	1	larittobånis	larɪtɔbóːnɪs
5	SWWWW	1	delletammesar	dɛ́lɛtamɛsar
5	WSWWW	1	älymigerta	ɛlýːmɪgɛʈa
5	WWSWW	1	tissodario	tɪsʊdɑ́ːrɪʊ
5	WWWWS	1	amitrosokil	amɪtrʊsʊkíːl
5	WWSWW	2	berkatylpana	bærkatỳːlpɑːna
5	SWWWW	2	igotteklunna	ìːgɔtɛklɵna
5	WSWWW	2	filattsjolare	fɪlàtɧoːlarɛ
5	WWWSW	2	bamperinuffa	bampɛrɪnɵ̀fa

Notes: Some of the nonwords have been adopted from Sahlén et al. (1999). S = strong, stressed syllable; W = weak, unstressed syllable.