The acquisition of sign language: the impact of phonetic complexity on phonology

Wolfgang Mann, Chloe R. Marshall, Kathryn Mason, and Gary Morgan

Deafness, Cognition and Language Research Centre, University College London &

Department of Language and Communication Science, City University London

Key words: sign language development; sign phonology; sign phonetics; language processing

Running head: Nonsense sign repetition

Corresponding author:

Dr. Wolfgang Mann

Department of Language and Communication Science

City University

Northampton Square

London EC1V 0HB

Email: wolfgang.mann.1@city.ac.uk

Abstract

Research into the effect of phonetic complexity on phonological acquisition has a long history in spoken languages. This paper considers the effect of phonetics on phonological development in a signed language. We report on an experiment in which non-word-repetition methodology was adapted so as to examine in a systematic way how phonetic complexity in two phonological parameters of signed languages – handshape and movement – affects the perception and articulation of signs. 91 Deaf children aged 3-11 years acquiring British Sign Language (BSL), and 46 hearing non-signers aged 6-11, were tested. For Deaf children, repetition accuracy improved with age, correlated with wider BSL abilities, and was lowest for signs that were phonetically complex. Repetition accuracy was correlated with fine motor skills for the youngest children. Despite their lower repetition accuracy, the hearing group were similarly affected by phonetic complexity, suggesting that common visual and motoric factors are at play when processing linguistic information in the visuo-gestural modality.

Introduction

Deaf people around the world have created visual ways of talking to each other. Through many generations of users coming together in schools and associations for Deaf[1] people, languages such as American, British and Nicaraguan Sign Language have been created (Woll, 2003; Senghas, Kita, & Özyürek, 2004). Not until the mid-twentieth century, however, did linguists demonstrate that signed languages obey linguistic principles in a way that separates them from mere pantomime and gesture (Klima & Bellugi, 1979; Stokoe, 1960). This work revealed that signed and spoken languages share basic linguistic properties, despite the radical modality differences in reception and expression. Furthermore, children who are exposed to signed languages from birth show remarkable parallels in onset, rate and patterns of development compared to children learning spoken languages: first signs and early sign combinations appear at a similar time to first words and early word combinations, and syntax is also mastered along a similar timescale (Petitto et al, 2001; Chamberlain, Morford, & Mayberry, 2000; Morgan & Woll, 2002; Schick, Marschark, & Spencer, 2005).

Nevertheless, modality does shape how linguistic structure is expressed (Meier, Cormier, & Quinto-Pozos, 2002; Sandler & Lillo-Martin, 2006), and this is particularly true for phonology, where the effects of phonetics are most keenly felt (Sandler & Lillo-Martin, 2006). Research into the effect of phonetic complexity, both perceptual and articulatory, on phonology and on phonological acquisition has a long history in spoken languages (e.g. Jakobson, 1941; Stampe, 1973), and has returned to the fore with the advent of Optimality Theory and its emphasis on markedness[2] (McCarthy, 2004).

[1] Following the conventions of the sign language literature, we use Deaf with an uppercase (D) to refer to members of the community that use BSL. We use deaf with a lowercase (d) only when discussing the effects of hearing loss.

[2] Marked structures are those that are less common cross-linguistically, and such structures tend to be acquired later by children (Jakobson, 1941). As a first approximation, marked phonological structures tend to be more complex than unmarked, notwithstanding disagreements over exactly how complexity is best measured (Gierut, 2007).

The purpose of the present study is to investigate the impact of phonetic complexity on children's ability to carry out a phonological task – the repetition of nonsense signs. We tested two groups: Deaf children who are acquiring British Sign Language (BSL) as a first language (aged 3-11 years), and hearing children with no experience of signing (aged 6-11 years). This method gives us the opportunity to investigate two things: (1) the systematic manipulation of phonetic (i.e. visual and motoric) complexity in two phonological parameters - handshape and movement - enables us to investigate how phonetic complexity impacts on children's accuracy in perceiving and articulating nonsense signs and how this changes during development, and (2) the comparison of children who regularly use sign language (Deaf children) to children with no experience of sign language (hearing children) enables us to determine whether the effects of sign language phonetics are universal, and to what extent sign language processing is affected by language experience and language-specific phonological knowledge.

In the remainder of this introduction, we first discuss the acquisition of phonology and the relationship between phonetics and phonology in children who are acquiring a spoken language. We then provide a background to sign language phonology, concentrating on the parameters 'handshape' and 'movement', as they are the focus of our experimental work. We go on to discuss children's acquisition of sign language phonology, and then introduce the methodology that we adjust for use in our study: non-word repetition. Finally, we outline our hypotheses and predictions.

The acquisition of spoken language phonology and the relationship between phonetics and phonology

There have been many studies detailing phonological development in hearing children (e.g. Smith, 1973; Locke, 1983; Vihman, 1995; Bernhardt & Stemberger, 1998). Children's first phonological forms can be strikingly different to the standard forms used by adults. For example, young English-speaking children frequently reduce consonant clusters to single consonants (e.g. *frog* → [fɔg]), and substitute phonemes (e.g. *fish* → [fɪs]). These errors are generally fairly systematic and predictable, and result in simplified forms: a singleton consonant is less complex than a cluster, and the /ʃ/ in *fish* has been replaced by the earlier acquired phoneme /s/. Prosodic structure is also simplified in early child language, for example, by the deletion of unfooted syllables (Demuth, 1996)

Taken together, the afore-mentioned examples can be characterised as the substitution of complex or ‘marked’ phonological structures by simple, ‘unmarked’, structures. There is a long tradition of seeing phonological markedness as having its grounding in phonetics (e.g. Stampe, 1973), a view that has had a resurgence with the popularity of constraint-based models of phonology (see Hayes & Steriade, 2004; McCarthy, 2004). For example, clusters are considered marked relative to singleton consonants because of their perceptual and articulatory complexity. Likewise, because children are acquiring language at a time when their vocal tract is undergoing considerable physiological development, articulatory pressures influence children’s simplification errors.

Several recent studies have attempted to explore this relationship between phonology and articulation in some detail. Kirk (2008) investigated substitution errors in English-speaking children’s clusters, whereby the cluster is retained but its segmental content is altered, e.g *ducks* → [dʌts] and *swing* → [fwɪŋ]. The children were aged 1;5 to 2;7. She found that the majority of substitution errors resulted in clusters where both consonants shared place of articulation (i.e. one of the consonants had undergone assimilation, as in the aforementioned examples). After considering various alternative hypotheses, Kirk argued that children produced such forms because they are articulatorily simpler.

Inkelas and Rose (2008) produced a detailed case study of a child (“E”) aged 1;0 to 2;2 whose speech was characterised by two phonological processes, velar fronting (whereby /k/ and /g/ are realised as [t] and [d]) and lateral gliding (whereby /l/ is realised as [j]). Both processes only took place word-initially or in the onsets of strong syllables, with examples of velar fronting including *cup* → [tʰʌp], *again* → [əˈdɪn] and *conductor* → [tʌnˈdʌktə]. Inkelas and Rose argued that the greater gestural magnitude of prosodically strong onsets in English interacted with the anatomy of the child’s vocal tract (specifically, children have tongues that are relatively large for their mouth, and palates that are relatively short, compared to adults) so that E produced coronals rather than velars in these positions. E then extended this pattern to lateral gliding, which developed later and showed similar prosodic conditioning, even though its existence had less direct articulatory motivation. This account - the phonologization of a phonetically-motivated effect - therefore appeals to an interplay between phonology and phonetics in explaining phonological errors.

The existence of so-called ‘chain shifts’ in child speech reveals that not only articulatory, but also perceptual pressures, lead to phonological errors. A common pattern in child speech is for /*θ*/ to be replaced by [*f*] but for /*s*/ to be produced as [*θ*]; for example, /*θɪn*/ and /*fɪn*/ are both pronounced as [*fɪn*], but /*sɪn*/ is pronounced as [*θɪn*]. The fact that the child is able to produce [*θɪn*] suggests that the /*θɪn*/ ~ [*fɪn*] error is a perceptual one; indeed, even adults perceptually confuse /*θ*/ and /*f*/ (see discussion of chain shifts in Dinnsen & Barlow, 1998).

All of the above work has been carried out on children who are acquiring a spoken language. We know that children learn signed and spoken languages in very similar ways, and so we would expect phonological markedness and phonetic complexity to also play a role in the acquisition of signed languages. In the next section we explore what phonological markedness and phonetic complexity in the signed language modality can be defined, and how they impact on phonological acquisition.

Sign language phonology

As in spoken languages, signed languages systematically organize meaningless phonological units into meaningful ones (Stokoe, 1960; Brentari, 1998). However, modality differences make the phonologies of signed and spoken languages appear quite different. Signs are formed through the combination of several different sources of information articulated on the body of the signer. The three main phonological parameters discussed in the literature are: handshape (the configuration of the hand), movement (how the sign is articulated) and location (where the sign is articulated). Furthermore, phonological parameters are expressed simultaneously in a sign. For example, in the British Sign Language (BSL) sign NAME (see first sign in Figure 1), the signer forms the handshape at the same time she moves it to the forehead location, and she maintains this handshape throughout the sign.

//Insert Figure 1about here//

By combining parameters in different ways, signed languages exhibit minimal pairs similar to those in spoken languages (e.g. *cap/gap*; *bus/but*): there are pairs of signs that share all their parameters but one. For example, the sign NAME forms a minimal pair with AFTERNOON (see second sign in figure 1): the two signs are identical with regard to their handshapes and movements involved but differ in their location (forehead and chin respectively).

In this paper we focus on markedness in just two parameters - handshape and movement, and we describe these next.

Handshape

In several different areas of research handshape has been identified as the most difficult parameter to acquire and process. Children who learn to sign late have difficulties mastering this aspect of signing (Singleton, Morford, & Goldin-Meadow, 1993), handshape comes up as consistently different when comparing gesture and sign (Schembri, 2005) and in studies of sign perception in gesturers and signers, handshape stands out as difficult for nonsigners (Brentari 2006).

Different handshapes vary with respect to their phonetic complexity. Handshapes are formed from different configurations (e.g. open, closed, curved) of specific parts of the hand (fingers, thumb and wrist). Some handshapes are more difficult to articulate than others, due to constraints on the anatomy and physiology of the different fingers and their joints (Ann, 1996). For example, only the thumb, index and little fingers have independent extensor muscles which allow them to be more easily extended than the middle and ring fingers in one-finger handshapes (i.e. handshapes where just one finger is extended and the other fingers are closed; Ann, 1996).

The articulators in signed languages are obviously very different to those in spoken languages. Yet just as spoken languages have distinctive features which are the phonological correlates of phonetic dimensions and which form a web of dependencies – “feature geometry”, so signed languages are proposed to have features and feature geometries. Handshapes with the simplest phonological structure have the fewest number of selected features and therefore the simplest feature geometry (Brentari, 1998). They are also unmarked.

Complexity and markedness affect how frequently different handshapes are used within and across languages. Simple, unmarked, handshapes are more frequent in the lexicon than complex, marked, handshapes (Sutton-Spence & Woll, 1999). Four unmarked handshapes have been proposed for BSL: ‘G’[3] (fist with index finger extended), ‘5’ (with all five digits extended and spread), ‘B’ (fingers extended and together), and ‘A’ (fist), which together count for 50% of signs (Sutton-Spence & Woll, 1999)[4]. For example, the ‘G’ handshape occurs in hundreds of BSL signs and also plays a major role as a person classifier, in pronominal reference and finger spelling (Brien, 1992). In contrast, the ‘Y’ handshape, formed with an extension of the thumb and little finger, is used much less frequently, being listed in only ten lexical signs in the BSL Dictionary (Brien, 1992). Furthermore, marked handshapes are less frequent cross-linguistically than unmarked ones (Ann, 1996).

Movement

The second phonological parameter that we consider in this study is movement. Signs can differ in their path of primary movement. For example, they may contain a straight or curved movement. Alternatively, signs may not have any path movement at all, but a hand-internal movement instead,

[3] The convention is for handshapes to be named after the letters they represent in the American Sign Language alphabet or counting system.
[4] These handshapes occur in American Sign Language, where they are also considered unmarked, e.g. by Brentari (1998) (who uses the term ‘1’ handshape instead of the ‘G’ handshape).

such as finger flicking or wiggling. More phonetically complex than single movements are clusters of movements, whereby an internal movement is produced simultaneously with a path movement. An example is the BSL sign FIRE (noun), which consists of an up-and-down movement of both hands while, at the same time, the fingers move back and forth (wiggle). In an abstract sense this complex cluster of movements resembles groups of sounds in spoken words where phonemic units are expressed in sequential clusters e.g. **'spl**ash'. But additionally in signs like FIRE the two movement components are packed together so that they show partial or total overlap (Brentari, 1998; Crasborn, 2001).

Acquisition of sign language phonology

Research into the development of sign language phonology is hindered by us having only partial linguistic descriptions of some signed languages, and far fewer studies of acquisition in those languages. Despite this, several studies have shown similarities in the development of sign phonology to previously documented cases in the spoken language literature (Boyes-Braem, 1990; Clibbens & Harris, 1993; Karnopp, 2002; Meier, 2005; Morgan, 2006). In particular, phonetic complexity and phonological markedness affect phonological acquisition in signed languages as in spoken languages, with young children simplifying phonological forms and mastering complex target forms only gradually.

The first handshapes acquired by young Deaf children are unmarked ones (Boyes-Braem, 1990; McIntire, 1977; Siedlecki & Bonvillian, 1997). Marked handshapes are acquired later, with some still developing in children after 5 years of age (Boyes-Braem, 1990; McIntire, 1977; Siedlecki & Bonvillian, 1997). During acquisition Deaf children have been documented to substitute unmarked handshapes for complex ones. For example, the sign COW produced with a marked 'Y' hand in the adult input might be repeated by the child with an unmarked '5' hand. This observation has been compared with phoneme substitution in hearing children (Meier, 2005; Morgan; 2006; Morgan, Barrett-Jones, & Stoneham, 2007).

Underlying the reported phonological simplification data from sign acquisition studies are the effects of phonetic complexity – both motoric and visual – driving that simplification process. Unmarked handshapes are easier to articulate and to distinguish from other handshapes, while marked handshapes are harder to produce and to perceive (Conlin, Mirus, Mauk, & Meier, 2000; Siedlecki & Bonvillian, 1993). Young children often misarticulate signs and replace marked handshapes with unmarked ones, but in doing so retain some of the visual similarity between the target and the child handshape (Marentette & Mayberry, 2000; Morgan et al, 2007). Handshapes, because of their fine phonetic detail, also require most attention in perceiving phonological contrasts. Children find handshape perception the most demanding part of sign comprehension (Hamilton, 1986). Consequently, children aged 1-3 years tend to make fewer errors with regard to the movement component of the sign than with handshapes.

However, gross and fine motor development influences the types of movements the child produces (Meier, 2005). The most demanding aspect of a sign's movement in this latter respect is the correct articulation of internal movements e.g. finger flicks, wiggles, pinches and repeated finger bends. Furthermore, children will sometimes simplify complex clusters of movements. For example, they may delete one of the movements, producing FIRE either without the hand internal movement or with a wiggle of the fingers but without the up and down path movements (Morgan et al, 2007). This process has been likened to consonant cluster reduction in spoken language (Morgan, 2006).

The third phonological parameter concerns the location at which a sign is produced. Location represents by far the simplest part of the sign for Deaf children to acquire and several studies report early mastery of this component with very few errors after 3 years of age (Cheek, Cormier, Repp, & Meier, 2001; Meier, 2005; Morgan, 2006). For this reason we do not focus on the location component in the present study. In contrast, the handshape, movement and hand-internal components of the sign continue to develop beyond 3 years of age, but it is not clear at what age they are mastered and whether they cause difficulties with phonological processing.

Until now, our understanding of the first steps in sign language acquisition has come from single case studies or studies of small numbers of Deaf children. There have been few descriptions of sign phonology development of older children. The creation of a nonsense sign repetition test, where Deaf children repeat novel signs, allows us to experimentally manipulate the phonetic complexity of phonological representations and collect data from a large number of Deaf children over a wide age range (3-11 years). It allows us to look at the interaction between complexity of handshape and complexity of movement in a way that is very difficult to accomplish using spontaneous data. It also allows us to confirm whether results from previous small-scale studies, showing that path movement is mastered earlier than handshape and internal movement, generalise to a larger group of children, and to investigate whether handshape and internal movement continue to cause difficulties during the processing of phonological material. By comparing non-word repetition abilities with scores on a test of BSL comprehension we can compare Deaf children's developing phonological abilities with their general language skills. Finally, because the task can be carried out as a gesture-copying task by hearing children with no phonological knowledge of BSL (or indeed any other sign language), we can investigate how phonetic complexity contributes to accuracy in handshape and movement repetition.

Our experimental design allows us to determine whether the effects of sign language phonetics are universal, and to what extent sign language processing is affected by (lack of) language experience and by language-specific phonological knowledge. Hence we can examine the relationship between phonetics and phonology in a way that would not be possible in spoken language – hearing children could be tested on non-word repetition in another spoken language, but they would presumably bring the phonology of their first language to bear on the task, whereas when tested in a different modality they are unable to do so.

Non-word repetition as a tool for investigating phonological processing

Our method is based on non-word repetition tasks that are widely used in studies of spoken language acquisition (Dollaghan & Campbell, 1998; Gallon, Harris, & van der Lely, 2007; Gathercole

& Baddeley, 1990; Kirk & Demuth, 2006; Roy & Chiat, 2004). The participant is required to listen to a set of non-words and repeat each one immediately after hearing it. This task recruits perceptual and production skills, as well as the ability to encode a phonological representation for storage in phonological working memory and to retrieve it from there (Gathercole, 2006). Because the child has never encountered these forms before, the task taps into the child's productive phonology, unconfounded by stored lexical knowledge[5]. Although the task might appear abstract, it is ecologically valid. Non-word repetition abilities are linked to word-learning abilities (Gathercole, 2006) and to language development more generally. For instance, children with Specific Language Impairment (SLI) and dyslexia are poor at repeating non-words (Dollaghan & Campbell, 1998; Gallon, Harris, & van der Lely, 2007; Gathercole & Baddeley, 1990).

In spoken language research, two manipulations of non-word items have been carried out: the quantity of phonological material, achieved by manipulating the number of syllables (Gathercole & Baddeley, 1990; Dollaghan & Campbell, 1998), and the nature of that phonological material, achieved by manipulating the segmental content, syllabic complexity and/or metrical structure of that material (de Bree, 2007; Gallon, Harris, & van der Lely, 2007; Kirk & Demuth, 2006; Marshall & van der Lely, 2009; Roy & Chiat, 2004). There is evidence that both the quantity of phonological material and the nature of the phonological representation to be encoded impact on accuracy in this task – participants are less accurate as length and complexity increase, and this is the case for children with typical and atypical language development. Furthermore, the methodology allows the investigation of how different aspects of the phonological representation might interact when stimulus length is controlled, for example how word position and stress interact to affect consonant cluster accuracy (Marshall & van der Lely, 2009).

[5] The degree to which this statement is true depends on how word-like the stimuli are. Although non-words are by definition not stored in the lexicon phonotactic probability is an important predictor of how accurately children will repeat them (see Coady & Evans, 2008, for a review).

In the present study we have adapted the non-word repetition methodology for BSL. While it is not possible to manipulate the length of a sign, as most signs are only one syllable long (Brentari, 1998), nonsense signs can be manipulated with regards to their phonetic complexity along two phonological parameters – handshape and movement – in ways which we have described earlier. Using this methodology, we can investigate the perception, short term retention and articulation of novel phonological forms, in both Deaf and hearing children. This enables us to compare performance on the nonsense sign repetition task across age ranges and levels of phonetic complexity.

Hypotheses and predictions

Our hypotheses and predictions are as follows:

Hypothesis 1: Phonetic complexity has an impact on nonsense sign repetition accuracy.

Prediction: Deaf participants will repeat phonetically simple nonsense signs more accurately than complex nonsense signs, and show most difficulties with nonsense signs that contain complex handshapes *and* movement clusters. Handshape complexity will affect the accuracy of handshape repetition, and that deletion of a movement from a movement cluster will be more likely if one of the handshapes is complex.

Hypothesis 2: Handshape and internal movement are mastered later than path movement, and therefore Deaf children will make more errors on handshape and internal movement than on path movement.

Prediction: Although the number of errors made on all phonological parameters will decrease with age, difficulties with repeating handshape and internal movement will persist longer than difficulties with path movement.

Hypothesis 3: Phonological abilities develop in concert with other linguistic abilities. Consequently, repetition accuracy taps into other linguistic components of BSL ability (as has been found for spoken language, see Gathercole, 2006, for a review).

Prediction: Accuracy on the repetition task will correlate with Deaf children's BSL comprehension ability, even when age is accounted for.

Hypothesis 4: Phonological abilities develop in concert with the development of fine motor skills, i.e. children's ability to master the articulatory phonetics of signs. Children with more advanced fine motor skills have better phonetic skills and therefore better phonology.

Prediction: Accuracy on the repetition task will correlate with Deaf children's fine motor skills, even when age is accounted for.

Hypothesis 5: Hearing, non-signing children approach the task as a gesture-copying task, without the advantage of having any phonological knowledge of signs, but are still affected by the same phonetic aspects of nonsense signs as Deaf children. In other words, they are able to approximate the nonsense signs they see despite having never experienced sign language before, and therefore having no phonological system in that modality: their repetitions represent the phonetic element of the task.

Prediction: Hearing children will perform overall significantly below their Deaf peers but will make the same relative proportions of phonetically-driven complexity errors across conditions.

For ease of exposition, we divide the study into three parts. Part I presents the nonsense sign repetition test and the data for the 91 Deaf participants. Part II investigates the relationship between the Deaf children's nonsense sign repetition accuracy and their wider BSL skills and fine motor skills. Part III presents the data for the 46 hearing participants with no experience of BSL who undertook the nonsense sign repetition test, and compares their data with those of the Deaf children.

Part I. Nonsense sign repetition test: Deaf children

Methods

Sample

A total of 91 congenitally Deaf children (60 boys/31 girls) participated in the experiment, and were divided into three age groups labelled according to mean age: Group 4: 3-5 years old (N = 26, mean = 4;11, range = 3;4-5;11), Group 7: 6-8 years old (N = 26 mean = 7;4, range = 6;0-8;10) and Group 10: 9-11 years old (N = 38 mean = 10;3, range = 9;0-11;9). They were recruited through schools for the Deaf in the UK. The children were either born into BSL-using Deaf families (N=14) or had very early exposure to BSL at nursery school, and subsequent typical language development as measured using the BSL Receptive Skills test (Herman et al, 1999).[6] Furthermore, we selected children with no diagnosed special educational need additional to deafness and normal non verbal cognitive development, as reported by the school educational psychologist and/or speech and language therapist. All parents received letters asking permission to have their child participate in the project and to be recorded by a video camera while completing the tasks. Only children who agreed to participate and whose parents gave consent were included.

Nonsense sign stimuli

Test items consisted of nonsense signs that were phonotactically possible but meaningless in BSL. To make sure that none of the items existed in BSL, three native signers (two Deaf and one hearing) rated possible similarity to existing signs in BSL. Any flagged items were deleted and replaced with an alternative. All the stimuli were produced by a Deaf fluent signer, sitting against a blue screen facing a digital camera. The signer practiced each item several times in order to produce it with normal fluency. All items were presented to participants as 10 x 14 inch images on a laptop computer with a 15 inch screen.

Design

We manipulated the phonetic complexity of two phonological parameters: handshape and movement. Using a 2 x 2 design, different phonetic complexity levels were generated for each parameter, as shown in Table 1:

//Insert Table 1 about here//

[6] This test assesses the comprehension of selected aspects of BSL morphology and syntax (negation, plurals, verb morphology and the distinction between nouns and verbs) in a picture-pointing paradigm. There is an initial vocabulary check for the signs that are used in the test, to avoid the possibility of the child making errors because of unfamiliarity with individual lexical items.

Items contained handshapes that were either simple or complex. We classed ‘B’, ‘5’, ‘G’ and ‘A’, which are the four unmarked handshapes of BSL (Sutton-Spence & Woll, 1999), as ‘simple’. All other handshapes (which were selected from the inventory of BSL handshapes (Sutton-Spence & Woll, 1999), and which are marked), were classed as ‘complex’. We classed one movement – either internal movement (IM) or path movement (PM) – as ‘simple’ and two movements (IM plus PM) as ‘complex’, balancing across conditions for different types of path movement (e.g., straight, arc) and different types of internal movement (e.g., opening, closing, wiggling). We also controlled for phonological properties that were not experimentally manipulated, such as one-handedness versus two-handedness. Examples of nonsense signs are presented in Figures 2 and 3.

//Insert figures 2 and 3 about here//

Procedure

Each participant was tested individually by a fluent BSL signer in a quiet room at the school in a single session which took between 15-20 minutes. A motor skills task (bead-threading) was administered before the nonsense sign repetition task. At the beginning of the repetition task, participants were given pre-recorded instructions in child-friendly BSL by a Deaf native-signing adult, explaining to them that they were to be presented with a number of novel signs and had to copy each sign as accurately as possible once the computer screen turned dark. These instructions were followed by three practice items during which participants could ask questions, if necessary.

Once the child began the task, the experimenter gave encouragement where appropriate. Each stimulus item was presented just once, and the order in which the items appeared was randomized across participants. Items were presented in sets of 10 with a ‘smiley’ face between each item. After each set, there was a short break during which participants were shown a cartoon for approximately 60 seconds. The children reported that they found the test fun to complete.

Scoring

Responses were scored as to whether the overall response was correct, and according to whether errors were made on the phonological parameters that we manipulated (handshape, path movement and internal movement), following the scheme developed during the pilot version of this test (Marshall, Denmark, & Morgan, 2006). Furthermore we coded whether one of the movements in a movement cluster was deleted.

All scores were coded separately by two hearing experimenters (the first and third authors), both of whom are fluent signers. They then compared their scores and resolved any discrepancies. In addition, fifteen participants were randomly selected and coded by a third coder, who was a Deaf native signer. Inter-rater agreement was high (85% for overall score, 88% for handshape, 87% for path movement, 83% for internal movement, and 96% for deleted movement in movement clusters).

Results

We report the results as follows. The first analysis concerns how Deaf children's accuracy in repeating nonsense signs is affected by complexity of handshape and movement. The second analysis concerns how Deaf children's errors in repeating handshapes, path movements and hand-internal movements change with age.

Repetition accuracy and phonetic complexity

We analyzed participants' performance according to how accurately they repeated nonsense signs with different levels of phonetic complexity (see table 2).

//Insert table 2 about here//

A 4 (condition: 0, 1a, 1b, 2) x 3 (group) ANOVA, with total number of correct responses as the dependent variable, was performed to examine the effect of phonetic complexity on repetition accuracy. Results revealed significant effects of condition, $F(3, 264) = 9.027$, $p < 0.001$, and group, $F(2, 88) = 25.516$, $p < 0.001$, but no interaction between the two, $F(6, 264) < 1$. On post hoc testing (with Bonferroni correction) it was found that Group 4 repeated nonsense signs less accurately than Groups 7 and 10, $p = 0.003$ and $p < 0.001$, respectively, and that Group 7 was less accurate than Group

10, $p = 0.004$. To further explore the main effect of condition, a series of t-tests was performed to compare accuracy for each pair-wise combination of conditions (see Table 3). Accuracy was significantly lower for the most phonetically complex items (level 2) compared to all other conditions (i.e., 0, 1a, 1b). Therefore, Deaf participants across all groups have most difficulty repeating those items that are phonetically the most complex.

//Insert Table 3 about here//

Having shown that the most complex nonsense signs are the hardest to repeat accurately, we now investigate why this might be the case. First we compared the proportion of handshape errors for conditions with complex versus simple handshapes (complexity levels 0 and 1a, versus levels 1b and 2), as shown in Table 4. A 2 (handshape: complex, simple) x 3 (group) ANOVA revealed no interaction between handshape and group, $F(2, 88) < 1$, but a significant main effect of handshape: accuracy was significantly lower for nonsense signs containing a complex handshape than for nonsense signs with a simple handshape, $F(1,88) = 14.384$, $p < 0.001$.

//Insert Table 4 about here//

Next, we investigated whether movement of a movement cluster was more likely to be deleted if the nonsense sign contained a complex handshape. We compared the proportion of deleted movements in conditions 1a (simple handshape) and 2 (complex handshape) (see table 5). A 2 (condition: 1a, 2) x 3 (group) ANOVA revealed a significant main effect of condition, $F(1,88) = 60.767$, $p < 0.001$, but also an interaction between condition and group, $F(2,88) = 8.825$, $p < 0.001$. Exploring this interaction by performing paired samples t-tests within each participant group revealed that each group deleted significantly more movements when the sign contained a complex handshape than when the sign contained a simple handshape: Group 4, $t(25) = -6.918$, $p < 0.001$, Group 7, $t(26) = -2.897$, $p = 0.008$, Group 10, $t(37) = -3.472$, $p = 0.001$. One-way ANOVAs within each condition revealed a significant effect of group within both condition 1a, $F(2,90) = 5.369$, $p = 0.006$, and condition 2, $F(2,90) = 19.820$, $p < 0.001$. Post-hoc testing (Bonferroni-corrected) within condition 1a showed significant differences between Groups 4 and 7 ($p = 0.049$) and Groups 4 and 10 ($p = 0.006$), but not between Groups 7 and 10 ($p = 1$). Similarly, within condition 1 there were significant differences between Groups 4 and 7 ($p < 0.001$) and Groups 7 and 10 ($p < 0.001$), but not between Groups 7 and 10 ($p = 1$).

//Insert table 5 about here//

In summary, Deaf participants across all groups had most difficulty repeating those items that are phonetically the most complex. Further analysis sheds light on why repetition accuracy is lowest for the most complex nonsense signs. Handshape complexity affects repetition accuracy in two ways. Firstly, complex handshapes are more likely than simple handshapes to be substituted. Secondly, a movement is more likely to be deleted from a movement cluster if the nonsense sign contains a complex handshape.

Nonsense sign repetition errors and phonological parameters

We analyzed participants' performance according to how many errors they made on the different phonological parameters (see table 6).

//Insert table 6 about here//

A 3 (parameter: handshape, path movement, internal movement) x 3 (group) by subjects ANOVA, with errors on each parameter as the dependent variable, revealed main effects of parameter and group. There also was a significant interaction between phonological parameter and group, $F(4,176) = 2.750$, $p = 0.030$. To explore this interaction further, we conducted a series of paired sample t-tests within each of the three participant groups (see table 7). All groups showed the same pattern of significant differences between accuracy on handshape and path movement ($p < 0.001$ for all groups) and between internal movement and path movement ($p < 0.001$ for all groups), but no differences between handshape and internal movement ($p = 0.516$ (Group 4); $p = 0.922$ (Group 7); $p = 0.251$ (Group 10).

//Insert Table 7 about here//

We then carried out a set of one-way ANOVAs within each parameter. Each ANOVA revealed significant group differences at $p < 0.001$: for handshape, $F(2,90) = 17.836$, for path movement, $F(2, 90) = 25.198$, and for internal movement, $F(2,90) = 19.445$. However, post hoc testing (Bonferroni-corrected) revealed slightly different group patterns. For handshape, all groups differed from one another (Groups 4 and 7, $p = 0.037$; Groups 7 and 10, $p = 0.006$, Groups 4 and 10, $p < 0.001$). For path movement, there were significant differences between Groups 4 and 7 ($p < 0.001$) and Groups 4 and 10 ($p < 0.001$), but no significant difference between Groups 7 and 10 ($p = 0.236$). For internal movement, there were significant differences between Groups 4 and 10 ($p < 0.001$) and 7 and 10 ($p = 0.001$) respectively, but the difference between Groups 4 and 7 failed to reach significance ($p = 0.064$).

In summary, all three groups of Deaf children made fewest errors on path movement and most errors on handshape and internal movement, with no advantage for internal movement over handshape. However, the findings from the one-way ANOVA analyses suggest some developmental differences between the phonological parameters: there is steady improvement for repetition accuracy of handshape and internal movement, but path movement is acquired most easily and thereby shows only limited improvement in older age groups.

Part II. Relationship between nonsense sign repetition accuracy, fine motor control and wider BSL skills.

Participants

Participants were the same Deaf children who participated in Part 1.

Methods

Participants completed a timed bead-threading task (White et al, 2006), where they were asked to thread 15 large beads onto a string as quickly as possible. The task was performed twice and the faster completion time recorded.

We collected Deaf participants' scores on the BSL Receptive Skills Test, a standardised test of BSL comprehension (Herman et al, 1999). This test had been administered by the schools within 6 months of our testing session.

Results

Speed of threading in 90 participants correlated significantly with nonsense sign repetition accuracy, even when age was partialed out, r(87) = -0.319, p = 0.002[7]. One child refused to do the bead-threading task. Examining the relationship between motor skills and repetition accuracy by age group, we found that for Group 4, r = -0.698, p < 0.001, Group 7 r = -0.341, p = 0.088. Group 10 r = 0.048, p = 0.772. Thus, motor skills were closely related to nonsense sign repetition accuracy only in the youngest Deaf children.

Data from the BSL Receptive Skills Test were provided for 65 Deaf participants (m= 100.49, SD=16.10 for Standardized Scores). The remaining participants had not been administered this test by the school. Overall repetition accuracy, with age partialed out, correlated significantly with scores on the BSL Receptive Skills Test, r(62) = 0.278, p = 0.026. Because of the incompleteness of the data set, we did not run the correlation within each group.

Part III. Nonsense sign repetition test: hearing children

Participants

Prior to the main study, we piloted the nonsense sign repetition test on 4 hearing children, aged 3-5 years, who had no knowledge of BSL, but it proved too difficult for them[8]. As a result, 46 older hearing children (26 boys/ 20 girls), aged 6;0 – 11;10, were recruited and divided into two age groups,

[7] The correlation here is negative because the score for the motor skills task is measured in seconds – lower scores represent faster bead threading, and hence better fine motor skills.

[8] This already shows a difference between the Deaf and hearing children, as the hearing children couldn't do the task at the younger ages whereas the Deaf children could.

again labelled according to mean age: Hearing Group 7: 6-8 years (N = 23, mean = 7;1, range = 6;0-8;9) and Hearing Group 10: 9-11 years (N = 23, mean = 10;6, range = 9;1-11;10). Participants were recruited from three local schools. They had no prior experience of signing, were randomly selected by teachers, and had normal language and non-verbal cognitive development as reported by their teachers.

Methods

Hearing participants completed the same nonsense sign repetition test as the Deaf children. They received their instructions in English, translated from the BSL instructions video. In addition to the nonsense repetition task, they completed the bead-threading task.

Results

Before reporting the results from our analysis for this participant group, which was the same as for the Deaf children in Part 1, we begin with a comparison of overall levels of performance between the hearing children and the two Deaf groups whom they match in age. In addition, we examine some qualitative differences between the types of errors that Deaf and hearing children make.

Comparing Deaf and hearing children's overall scores

The accuracy data are set out in Table 2. We used a one-way ANOVA to compare the overall performance between the two hearing groups and the two older Deaf groups (Hearing 7, Hearing 10, Deaf 7, Deaf 10). There was, not surprisingly, a significant effect of group, $F(3,110) = 32.341$, $p < 0.001$. Post hoc testing (Bonferroni-corrected) revealed that the Hearing 7 group performed significantly worse than all other groups (compared to Hearing 10, $p = 0.028$, compared to Deaf 7 and 10, $p < 0.001$ for each). The Deaf 10 group performed significantly better than all other groups, $p < 0.001$ for each comparison. There was no significant difference between the Hearing 10 and Deaf 7 groups. Overall, therefore, the hearing children perform significantly less accurately than Deaf children of the same age.

Repetition accuracy and phonetic complexity

A 4 (condition: 0, 1a, 1b, 2) x 2 (group) ANOVA revealed a significant effect of complexity, $F(3,132) = 8.278$, $p < 0.001$, and a significant effect of group, $F(1,44) = 15.831$, $p < 0.001$, but no interaction between group and complexity, $F(3,132) = 1.047$, $p = 0.374$. A series of t-tests comparing each pair-wise set of conditions revealed that, as for the Deaf children, accuracy was significantly lower for the most complex condition (condition 2) compared to the other three (see Table 3). However for hearing children, there was an additional significant difference between conditions 0 and 1a, indicating that within nonsense signs with simple handshapes, the presence of a movement cluster caused significantly more difficulties than just a single movement.

As was the case for the Deaf children, the hearing children made significantly more errors on complex compared to simple handshapes (see Table 4). A 2 (handshape: complex, simple) x 2 (group) ANOVA revealed a main effect of handshape, $F(1,44) = 31.243$, $p < 0.001$, but no interaction between handshape and group, $F(2, 88) < 1$.

Like the Deaf children, hearing children deleted one of the movements in a movement cluster significantly more often if the nonsense sign contained a complex handshape (see Table 5). A 2 (condition: 1a, 2) x 2 (group) ANOVA revealed a significant main effect of condition, $F(1,44) = 7.089$, $p = 0.011$, but no interaction between condition and group, $F(1,44) < 1$.

Finally, hearing participants' nonsense sign repetition accuracy did not correlate with their performance on the motor skills task when age was partialed out, $r(43) = -0.176$, $p = 0.248$, which was what we also found for the Deaf children at this age. An independent samples t-test revealed no differences in bead threading times between the Deaf (mean = 84.72s) and hearing (mean = 88.76s) groups, $t(108) = -0.470$, $p = 0.639$.

Repetition errors and phonological parameters

The hearing children's error data are set out in Table 6. A 3 (parameter: handshape, path movement, internal movement) x 2 (group) ANOVA on errors scores revealed a main effect of parameter, $F(2,88) = 98.798$, $p < 0.001$, and of group, $F(1,44) = 15.371$, $p<0.001$, with no interaction between error type and group. A series of pair-wise t-tests showed that children made fewer errors on path movement compared to handshape and internal movement, but that there was no significant difference in errors between handshape and internal movement (see Table 7).

Qualitative differences in errors between the Deaf and Hearing groups

On the whole, the Deaf children were more accurate than hearing children at repeating nonsense signs. However, as we were analysing the data, we became puzzled by a few items for which this pattern did not hold, i.e. items on which the hearing groups performed, unexpectedly, more accurately than the Deaf groups. One such item is shown in figure 4. This nonsense sign has a movement that starts at the ipsilateral side (i.e. the same side as the hand that makes the movement) and crosses to the contralateral side. 43% of Deaf children (but only 20% of hearing children) reversed the direction of this movement, starting on the contralateral side. In other words, almost half the Deaf children changed the nonsense sign so that it started on the contralateral side. The fact that the hearing children were more accurate suggests that there is nothing about the movement *per se* that is difficult, so this is not a phonetic difficulty. Instead, it appears that Deaf children were using their knowledge of the lexicon, and the phonological generalisations that can be drawn across signs contained within it. Most BSL signs with movement across the body start on contralateral side, in contrast to this particular nonsense sign item. Such signs include MORNING, ARMY, KENYA and DOCTOR at the chest, PRIEST at the neck, LIE at the chin and HOT at the head. Very few signs start on the ipsilateral side and then move across – a rare example is CLEVER, located at the forehead. We had inadvertently created a nonsense stimulus that was not consistent with Deaf children's phonological knowledge.

//Insert figure 4 about here//

Another such item is shown in figure 5. Here, 79% of deaf children changed the orientation of the hand when they produced the nonsense sign, whereas only 58% of the hearing children did. The Deaf children changed the orientation of the hand so that it resembled the real sign I-ASK-YOU. In other words, it appears that they were lexicalising the nonsense sign, something that has been reported for hearing children attempting non-word repetition tasks (e.g. Marshall, Harris, & van der Lely, 2003) and for Deaf adults in a sign-spotting task (Orfanidou, Adam, McQueen, & Morgan, 2009). Here we had included a nonsense sign which was so close to a real sign that it caused confusion for the Deaf children.

//Insert figure 5 about here//

Discussion

The purpose of our study was to explore the impact of phonetic complexity on phonology in Deaf children who are acquiring British Sign Language (BSL) as a first language, by systematically manipulating how handshape and movement complexity affect the repetition of nonsense signs. Comparing Deaf children to children with no experience of sign language (hearing children) allowed us to determine whether the effects of sign language phonetics are universal, and to what extent sign language processing is affected by (lack of) language experience and language-specific phonological knowledge. In the general study of language development researchers are interested in how children's wider language skills, and their motor and perceptual abilities, come to bear in their processing of new phonological forms. Thus the present study contributes to the wider study of how characteristics of the input and the learner's knowledge come together in language processing.

From the outset we proposed a number of hypotheses. We hypothesised that phonetic complexity has an impact on repetition accuracy, and predicted that Deaf children would repeat phonetically simple nonsense signs more accurately than phonetically complex ones, with nonsense signs containing complex handshapes and movement clusters being the most difficult of all. This turned out to be the case: repetition accuracy was lowest for the most phonetically complex items. However, nonsense signs with either a complex handshape or a movement cluster were overall not repeated less accurately than nonsense signs containing a simple handshape and a single movement. We also had hypotheses about the precise way in which phonetic complexity acts to affect repetition accuracy. We predicted that handshape complexity would affect the accuracy of movement repetition, and that deletion of a movement from a movement cluster would be more likely if one of the handshapes was complex. As expected, we observed more errors in nonsense signs with complex handshapes and more deletions of movements in nonsense signs with movement clusters if the nonsense sign had a complex handshape.

Furthermore, we hypothesised that handshape and internal movement are mastered later than path movement, and therefore predicted that Deaf children's difficulties with handshape and internal movement would persist for longer than difficulties with path movement. This is, indeed, what we found, and our findings on a large group of children support previous fine-grained work on smaller groups of children and case studies (Marentette & Mayberry, 2000; Morgan et al, 2007; Meier et al, 2008). We show that handshape and internal movement continue to cause difficulties in sign language processing until at least the age of 10 or 11.

Our finding that children have difficulties in processing handshape, and small changes in handshape form through internal movements, concurs with a wide range of previous studies (Brentari 2006; Schembri, 2005; Singleton, Morford, & Goldin-Meadow, 1993). Why this is the case is perhaps linked both to the bigger phonological repertoire for handshape that exists compared with other sign parameters (Orfanidou et al, 2009), as well as the added motoric difficulty in articulating the small articulators involved in forming handshapes.

Following findings in the spoken language literature of a robust relationship between phonology and wider language skills (e.g. de Bree, 2007; Dollaghan & Campbell, 1998; Gathercole, 2006), we hypothesised that such a relationship also exists for signed languages. We predicted that children with better BSL grammar, as measured by a comprehension task, would have better phonological skills. This turned out to be the case, even when age was partialed out of the correlation. These results suggest that non-word repetition accuracy and language skills are related whatever the modality of that language, and support the suggestion that nonsense sign repetition could be a useful diagnostic tool for SLI in sign languages just as non-word repetition is in spoken languages (Mann & Marshall, under revision; Marshall et al, 2006). In non-word repetition tests, the repetition accuracy of children with language impairments decreases as phonological complexity increases (Gallon, Harris, & van der Lely, 2007), and we predict that this will also be the case for signing children with language impairments, such that even signs with one movement cluster or complex handshape will be harder to repeat than the most simple signs.

We also predicted that children with better fine motor control, as measured by a timed bead threading task, would have better phonetic skills and therefore better phonological skills. As our results showed, motor skills correlated significantly with phonological skills only in the youngest children: for children aged 6 and above, this relationship no longer held, suggesting that articulatory constraints are important for young children's signing but become less important as they get older. Bonvillian, Orlansky, & Novack (1983) made the surprising claim that while hearing children's speech and motor development are related, Deaf children's sign language skills are independent of their motor development. The results from our study suggest otherwise for children up until the age of 5. However, as the older Deaf children (aged 6 and over) in our study were past the major landmarks for fine and gross motor development (Sheridan, 1997), it is not surprising that they were less influenced by the motoric complexity of signs. On the other hand, it could be that our task was not sensitive enough to detect differences in fine motor development in older children.

That phonetic complexity still drives children's errors, even when motor skills are good, is consistent with phonological markedness being grounded not just in articulatory complexity, but also in perceptual complexity, as has been argued for both sign languages (Meier, 2005) and spoken languages (Hayes & Steriade, 2004). Hamilton (1986) tested a large group of Deaf children ages 6-9 years on their ability to match a sign to a corresponding static image of the same sign in a picture. Minimal pair pictures were used, made up of the target sign and an alternative, which differed only on one of the hand shape, movement or location parameters. Children made significantly more errors with items that differed only on handshape than with those which diverged on either movement or location. In fluent signing, hand shapes are far less visually salient than the bigger arm movements that accompany them, and signers can perceive movement and location information in peripheral vision, but not handshapes (Wilcox, 1992). There is more recent evidence that adult signers continue to substitute unmarked handshapes for marked handshapes in a visual processing task (Orfanidou et al, 2009). Sutton-Spence and Woll (1999) argue that the four unmarked handshapes of BSL – ‘B’ (a simple flat surface), ‘5’ (the most extended and spread), ‘A’ (maximally compact) and ‘G’ (a narrow linear form) – are also the most geometrically contrastive.

Finally, we hypothesised that hearing children would tackle nonsense sign repetition as a gesture-copying task, without the advantage of prior phonological knowledge in this modality, but would still be affected by the same difficulties in perceiving and articulating complex nonsense signs as Deaf children. We predicted that hearing children’s overall repetition accuracy would be significantly lower than that of the Deaf children, but that they would make the same proportions of phonetically driven errors. This turned out to be the case. In fact we found remarkably similar error patterns across groups. Like the Deaf children, hearing children with no experience of sign language made more errors on handshape and internal movement than on path movement, and produced more errors on items with complex handshapes plus movement clusters.

These comparisons between Deaf and hearing children reveal that sign language phonology is intimately entwined with the phonetics of the visual-gestural modality. Our results are consistent with theories of spoken language phonology which state that phonological complexity and markedness are grounded in phonetic knowledge (Chomsky & Halle, 1968; Hayes & Steriade, 2004; Stampe, 1973). The articulation and/or perception of a complex handshape or a movement cluster is generally more difficult than that of a simple handshape or a single movement, and a hand-internal movement is more difficult to articulate and/or perceive than a path movement.

Yet, three findings suggests that knowledge of sign language phonology *also* plays an important role in perceiving, storing and articulating novel signs: (1) Deaf signers can attempt this task at a younger age than hearing children with no prior knowledge of sign language, (2) Deaf signers repeat nonsense signs significantly more accurately than non-signing hearing children, despite not having better fine motor skills (at least, as measured by how quickly they can thread a string of beads), and (3) their nonsense sign repetition accuracy correlates with their wider BSL skills. These findings are consistent with claims from non-word repetition studies that long-term language knowledge supports short-term memory performance (Thorn & Gathercole, 2001). Signing Deaf children have acquired a large repertoire of handshapes and movements that they use in their everyday signs, which allows them to analyse the nonsense signs within a phonological system. All the handshapes and movements they saw in the test items were possible phonological forms in real BSL signs they might have known. Therefore they were able to use phonological knowledge when perceiving, storing, and repeating items, and were therefore more accurate than hearing children, who were presumably relying solely on visuo-spatial working memory, without any language support.

Further evidence that Deaf children's phonological knowledge does come into play during their repetition of nonsense signs is evidenced by certain items where they were *less* accurate than the hearing children, despite their higher levels of performance overall. In other words, these items seem not to be in line with Deaf children's expectations of BSL phonology despite our best efforts to design stimuli that were phonotactically possible within the rules of BSL. For example, when confronted with a nonsense sign that required ipsi- to contralateral movement across the torso, a significant proportion of Deaf children changed the direction of the movement from contra- to ipsilateral, presumably to conform to the large number of signs in their lexicons that make use of this movement. The fact that few hearing children made this error shows that ipsi- to contralateral movement is phonetically possible, but that Deaf children preferred to make a movement that fitted in with their phonological knowledge. One direction for future research would be to explore the extent of Deaf children's language-specific knowledge using a set of nonsense sign stimuli manipulated for phonological unexpectancy. Non-word repetition tests can be used to test phonotactic sequences that are unexpected or not permitted in a speaker's grammar, but this is rarely done[9]. A second direction would be to examine phonological frequency through the effects of neighbourhood density, given that this is a factor known to play a role in the repetition of spoken words and non-words (Coady & Evans, 2008). As yet there no frequency statistics are available for sign languages, but as dictionaries and corpus data become available, at least for some sign languages, the calculation of neighbourhood densities for those languages will become possible. As is the case for spoken languages, we would predict repetition accuracy to be greater for signs and nonsense signs drawn from denser neighbourhoods.

Conclusion

Using a non-sign repetition task with a large number of Deaf signing children, we have replicated smaller scale studies showing that handshape and internal movement are more difficult to acquire and process than path movement. A comparison with hearing nonsense signing children reveals that phonological complexity is grounded in the phonetics of the visuo-gestural modality, but that Deaf signing children's phonological knowledge also comes into play when they repeat nonsense signs, suggesting that biological factors and experience both underpin children's language development.

[9] A notable exception is de Bree, Wijnen, & Zonneveld (2006), who tested Dutch children on the repetition of non-words with different stress patterns, including stress patterns prohibited in Dutch.

Acknowledgements

This work was supported by the Economic and Social Research Council of Great Britain (Grant RES-620-28-6001), Deafness, Cognition and Language Research Centre (DCAL), a City University London Research Fellowship awarded to the first author, and a Leverhulme Early Career Fellowship awarded to the second author. All the authors would like to thank Cathy Green and Tanya Denmark for their help in the pilot version, Gary Cutmore for modelling the nonsense signs, and Katherine Rowley for assistance with data coding. We are very much indebted to the three anonymous reviewers and the editor of this journal, Susan Goldin-Meadow, for their insightful comments on earlier versions of this paper. Finally we would like to express our gratitude to all the children and teachers who took part in and supported this research study.

References

Ann, J. (1996). On the relation between ease of articulation and frequency of occurrence of handshapes in two languages. *Lingua*, 98, 19-41.

Bernhardt, B.H. & Stemberger, J.P. (1998). *Handbook of phonological development*. London: Academic Press.

Bonvillian, J., Orlansky, M., & Novack, L. (1983). Developmental milestones: Sign language acquisition and motor development. *Child Development*, 54, 1435-45.

Boyes Braem, P. (1990). Acquisition of the handshape in American Sign Language: A preliminary analysis. In V. Volterra & C. J. Erting (Eds.), *From gesture to language in hearing and deaf children* (pp. 107–127). Washington, DC: Gallaudet University Press.

Brentari, D. (1998). *A prosodic model of sign language phonology*. Cambridge, MA: MIT Press.

Brentari, D. (2006). Effects of language modality on word segmentation: An experimental study of phonological factors in a sign language. In L. Goldstein, D. Whalen, and C. Best (Eds.), *Papers in Laboratory Phonology VIII* (pp. 155-164). Berlin: Mouton de Gruyter.

Brien, D. (Ed.) (1992). *Dictionary of British Sign Language*. London, UK: Faber and Faber.

Chamberlain, C., Morford, J.P., & Mayberry, R.I. (Eds.) (2000). *Language acquisition by eye*. Mahwah, NJ: Erlbaum.

Cheek, A., Cormier, K., Repp, A., & Meier, R.P. (2001). Prelinguistic gesture predicts mastery and error in the production of early signs. *Language*, 77, 292–323.

Chomsky, N. & Halle, M. (1968). *The sound pattern of English*. New York: Harper and Row.

Clibbens, J. & Harris, M. (1993). The acquisition of formational parameters in British Sign Language: a case study. In D. Messer & G. Turner (Eds.), *Critical aspects of language acquisition and development* (pp 197 - 208). London: Macmillan.

Coady, J. & Evans J. (2008). Uses and interpretations of non-word repetition tasks in children with and without specific language impairments. *International Journal of Language and Communication Disorders*, 43, 1-40.

Conlin, K. E., Mirus, G. R., Mauk, C., & Meier, R. P. (2000). The acquisition of first sign place, handshape and movement. In C. Chamberlain, J. Morford, & R. Mayberry (Eds.), *Language acquisition by eye* (pp. 51–70). Mahwah, NJ: Erlbaum.

Crasborn, O. (2001). *Phonetic implementation of phonological categories in sign language of the Netherlands*. Unpublished doctoral dissertation, University of Utrecht, LOT.

de Bree, E. (2007). *Dyslexia and phonology: A study of the phonological abilities of Dutch children at-risk of dyslexia*. Unpublished doctoral dissertation, University of Utrecht, LOT.

de Bree, E., Wijnen, F. & Zonneveld, W. (2006). Word stress production of three-year-old children at risk for dyslexia. *Journal of Research in Reading*, 29, 304-317.

Demuth, K. 1996. The prosodic structure of early words. In J. Morgan & K. Demuth (eds.), *Signal to Syntax*: *Bootstrapping from Speech to Grammar in Early Acquisition.* Mahwah, N.J.: Lawrence Erlbaum Associates. pp. 171-184.

Dinnsen, D. A., & Barlow, J. A. (1998). On the characterization of a chain shift in normal and delayed phonological acquisition. *Journal of Child Language*, *25*, 61–94.

Dollaghan, C. & Campbell, T. (1998). Nonword repetition and child language impairment. *Journal of Speech, Language and Hearing Research*, 41, 1136-1146.

Gallon, N., Harris, J. & van der Lely, H. (2007). Nonsense word repetition: An investigation of phonological complexity in children with Grammatical SLI. *Clinical Linguistics and Phonetics,* 21, 435-455.

Gathercole, S. E. (2006). Nonsense word repetition and word learning: The nature of the relationship, *Applied Psycholinguistics*, 27, 513-543.

Gathercole, S. E. & Baddeley, A. D. (1990). Phonological memory deficits in language disordered children: is there a causal connection? *Journal of Memory and Language*, 29, 336-360.

Gierut, J. A. (2007). Phonological complexity and language learnability. *American Journal of Speech-Language Pathology*, 16, 1–12.

Hamilton, H. (1986). Perception of sign features by deaf children. *Sign Language Studies*, 50, 73–77.

Hayes, B. & Steriade, D. (2004). Introduction: the phonetic bases of phonological markedness. In Hayes, B., Kirchner, R. M., & Steriade, D. (Eds.), *Phonetically based phonology* (pp.1-33). Cambridge, UK: Cambridge University Press.

Herman, R., Holmes, S., & Woll, B. (1999). *Assessing British Sign Language Development: Receptive Skills Test.* Forest Bookshop. Gloucestershire, UK.

Inkelas, S. and Rose, Y. (2008). Positional neutralization: A case study from child language. *Language*, 83, 707-736.

Jakobson, R. (1941). *Kindersprache, Aphasie und ellgemeine Lautgesetze*. Translation: A. R. Keiler, Child Language, Aphasia and Phonological Universals. The Hague: Mouton, 1968.

Karnopp, L. B. (2002). Phonology acquisition in Brazilian Sign Language. In G. Morgan & B. Woll (Eds.), *Directions in sign language acquisition* (pp. 29–43). Amsterdam: John Benjamins.

Kirk, C. (2008). Substitution errors in the production of word-initial and word-final consonant clusters. *Journal of Speech, Language and Hearing Research*, 51, 35-48.

Kirk, C. & Demuth, K. (2006). Accounting for variability in 2-year olds' production of coda consonants. *Language Learning and Development,* 2, 97-118.

Klima, E.S. & Bellugi, U. (1979). *The Signs of Language*. Harvard University Press: Cambridge.

Locke, J.L. (1983*). Phonological Acquisition and Change*. Academic Press, New York.

Mann, W. & Marshall, C. R. (accepted subject to revision). Building an Assessment Use Argument for sign language: the BSL Nonsense Sign Repetition Test. *International Journal of Bilingual Education and Bilingualism*.

Marentette, P. F. & Mayberry, R. I. (2000). Principles for an emerging phonological system: A case study of early ASL acquisition. In C. Chamberlain, J. Morford, & R. Mayberry (Eds.), *Language acquisition by eye* (pp. 71-90). Mahwah, NJ: Erlbaum.

Marshall, C. R., Denmark, T. & Morgan, G. (2006). Investigating the underlying causes of SLI: A nonsense sign repetition test in British Sign Language. *Advances in Speech-Language Pathology,* 8, 347-355.

Marshall, C. R., Harris, J., & van der Lely, H. K. J. (2003). The nature of phonological representations in children with Grammatical-Specific Language Impairment (G-SLI). In Hall, D., Markopoulos, T., Salamoura, A., & Skoufaki, S. (Eds.), *Proceedings of the University of Cambridge First Postgraduate Conference in Language Research* (pp. 511-517). Cambridge, UK: Cambridge Institute of Language Research.

Marshall, C. R. & van der Lely, H. K. J. (2009). Effects of word position and stress on onset cluster production: Evidence from typical development, SLI and dyslexia. *Language*, 85, 39-57.

McCarthy, J. J. (Ed.) (2004). *Optimality Theory in Phonology: A Reader*. Malden, MA: Blackwell.

McIntire, M. (1977). The acquisition of American Sign Language hand configurations. *Sign Language Studies*, 16, 247–266.

Meier, R. P. (2005). The forms of early signs: Explaining signing children's articulatory development. In B. Schick, M. Marschark, & P. Spencer (Eds.), *Advances in the sign-language development of deaf and hard-of-hearing children* (pp. 202–230). Oxford: Oxford University Press.

Meier, R. P., Cormier, K., & Quinto-Pozos, D. (Eds.) (2002). *Modality and Structure in Signed and Spoken Languages*. Cambridge: Cambridge University Press.

Meier, R. P., Mauk, C., Cheek, A., & Moreland, C. (2008). The form of children's early signs: Iconic or motoric determinants? *Language Learning and Development*, 4, 63-98.

Morgan, G. (2006). Children are just lingual: The development of phonology in British Sign Language (BSL). *Lingua*, 116(10), 1507-1523.

Morgan, G., Barrett-Jones, S., & Stoneham, H. (2007). The first signs of language: phonological development in British Sign Language. *Applied Psycholinguistics*, 28, 3-22.

Morgan, G. & Woll, B. (Eds.) (2002). *Directions in sign language acquisition - Trends in Language Acquisition Research*. Amsterdam: Benjamins.

Orfanidou, E., Adam, R. McQueen, J., & Morgan, G. (2009). Making sense of nonsense in British Sign Language (BSL): The contribution of different phonological parameters to sign recognition. *Journal of Memory and Cognition.* 37, 302-315.

Petitto, L. A., Katerelos, M., Levy, B., Gauna, K., Tétrault, K., & Ferraro, V. (2001). Bilingual signed and spoken language acquisition from birth: Implications for mechanisms underlying bilingual language acquisition*.* *Journal of Child Language*, 28, 1-44.

Roy, P. & Chiat, S. (2004). A prosodically controlled word and nonword repetition task for 2- to 4-year-olds: evidence from typically developing children. *Journal of Speech, Language and Hearing Research*, 47, 223-234.

Sandler, W. & Lillo-Martin, D. (2006). *Sign Language and Linguistic Universals*. Cambridge, UK: Cambridge University Press.

Schembri, A. (2005). Comparing action gestures and classifier verbs of motion: Evidence from Australian Sign Language, Taiwan Sign Language, and nonsigners' gestures without speech. *Journal of Deaf Studies and Deaf Education*, 10, 272-290.

Schick, B., Marschark, M., & Spencer, P. (Eds.) (2005). *Advances in the sign language development of deaf children*. Oxford, UK: Oxford University Press.

Senghas, A., Kita, S., & Özyürek, A. (2004). Children creating core properties of language: evidence from an emerging sign language in Nicaragua. *Science*, 305, 1779-1782.

Sheridan, M. (1997). *From birth to five years: Children's developmental progress*. London: Routledge.

Siedlecki, T., & Bonvillian, J. D. (1993). Location, handshape and movement: Young children's acquisition of the formational aspects of American Sign Language. *Sign Language Studies,* 78, 31–52.

Siedlecki, T. & Bonvillian, J. D. (1997). Young children's acquisition of the handshape aspect of American Sign Language signs: Parental report findings. *Applied Psycholinguistics* 18, 17-39.

Singleton, J., Morford, J., & Goldin-Meadow, S. (1993). Once is not enough: Standards of well-formedness in manual communication created over three different time spans. *Language*, 69, 683-715.

Smith, N. V. (1973). *The acquisition of phonology*. Cambridge: Cambridge University Press.

Stampe, D. (1973). *A dissertation on natural phonology*. PhD dissertation, University of Chicago. Distributed by Indiana University Linguistics Club, Bloomington.

Stokoe, W.C. (1960). Sign language structure: an outline of the visual communication system of the American Deaf. *Studies in Linguistics: Occasional Paper 8*. University of Buffalo.

Sutton-Spence, R. & Woll, B. (1999). *The linguistics of British Sign Language: An introduction*. Cambridge: Cambridge University Press.

Thorn, A. & Gathercole, S. E. (2001). Language differences in verbal short term memory do not necessarily originate in the process of subvocal rehearsal. *Psychonomic Bulletin and Review*, 8, 357-365.

Vihman, M. (1995). *Phonological Development: Origins of Language in the Child*. Oxford: Blackwell.

White, S., Milne, E., Rosen, S., Hansen, P. C., Swettenham, J., Frith, U., & Ramus, F. (2006). The role of sensorimotor impairments in dyslexia: A multiple case study of dyslexic children. *Developmental Science*, 9, 237-255.

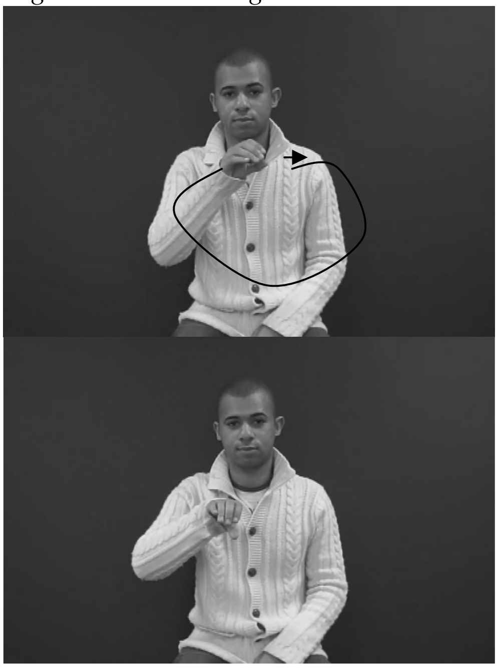
Wilcox, S. (1992). *The phonetics of fingerspelling - Studies in speech pathology and clinical Linguistics*. Amsterdam, Philadelphia: Benjamins.

Woll, B. (2003). Modality, Universality and the Similarities among Sign Languages: an Historical Perspective, in A. Baker, B. van den Bogaerde, & O. Crasborn (Eds.), *Cross-linguistic perspectives in sign language research. Selected papers from TISLR 2000* (pp. 17-30). Hamburg: Signum Press.

Figures:

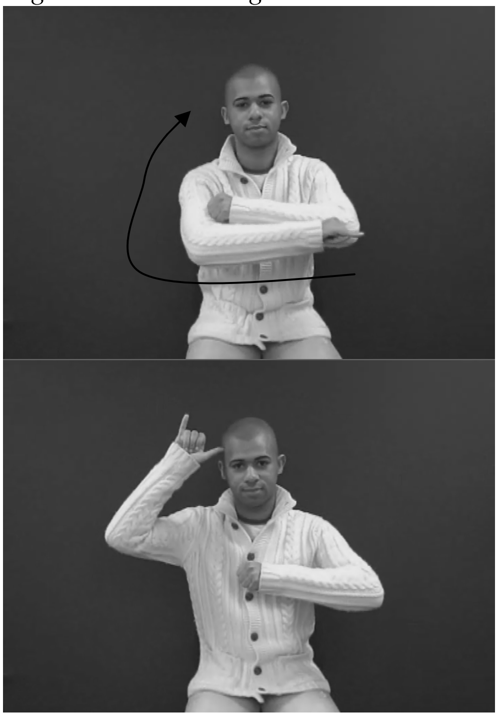
Figure 1: Example for a minimal pair: NAME vs. AFTERNOON

Figure 2: Level 0 sign



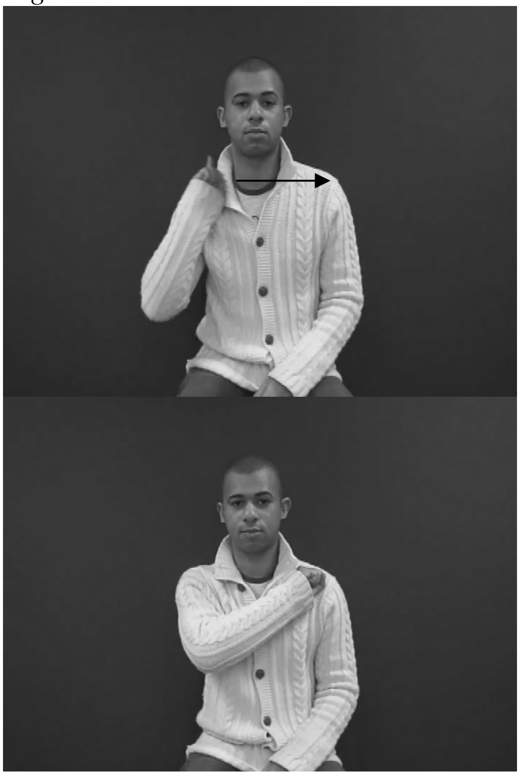
The starting and the end point of the sign are depicted. This nonsense sign has a circular movement.

Figure 3: Level 2 sign



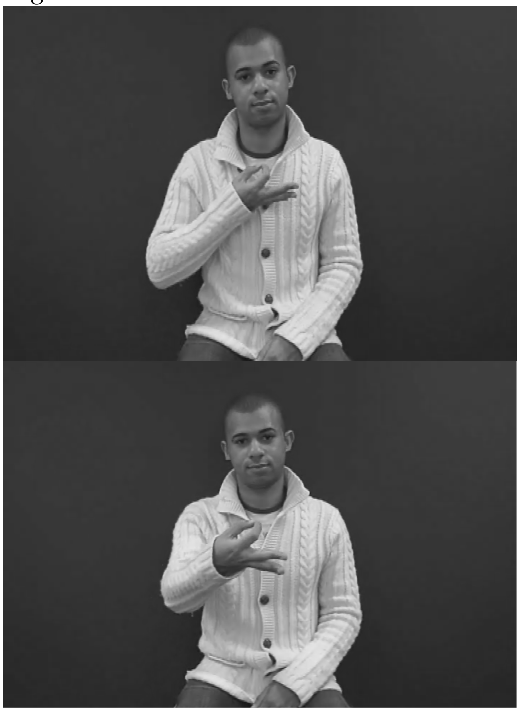
The starting and the end point of the sign are depicted. This nonsense sign has an arc path movement.

Figure 4



The starting and the end point of the sign are depicted. This nonsense sign has a straight path movement.

Figure 5



The starting and the end point of the sign are depicted. This nonsense sign has a straight path movement away from the body.

Tables

Table 1: Levels of phonetic complexity for the nonsense sign repetition task

		Handshape: simple	Handshape: complex
Movement	single movement	Level 0 (10 items): Path movement *or* hand-internal movement	Level 1b (10 items): Path movement *or* hand-internal movement
	movement cluster	Level 1a (10 items): Path movement + hand-internal movement	Level 2 (10 items): Path movement + hand-internal movement

Table 2: Nonsense sign repetition accuracy scores (expressed as mean % correct, SD) by phonetic complexity level across groups

		Deaf Children			Hearing Children	
Group	Level of Complexity	Correct (%)	SD	Group	Correct (%)	SD
4 (N=26)	0	33	26			
	1a	32	21			
	1b	35	19			
	2	26	16			
	Total	**32**	**16**			
7 (N=27)	0	42	25	7 (N=23)	31	10
	1a	48	21		27	22
	1b	51	24		25	16
	2	36	18		18	11
	Total	**44**	**16**	**Total**	**25**	**10**
10 (N=38)	0	62	21	10 (N=23)	46	19
	1a	60	18		34	14
	1b	65	22		42	18
	2	53	20		28	14
	Total	**60**	**16**	**Total**	**37**	**10**

Level of Phonetic Complexity 0: simple handshape, 1 type of movement
Level of Phonetic Complexity 1a: simple handshape, 2 types of movement
Level of Phonetic Complexity 1b: complex handshape, 1 type of movement
Level of Phonetic Complexity 2: complex handshape, 2 types of movement

Table 3: Comparison of mean accuracy scores across phonetic complexity level

	Deaf Children			Hearing Children		
Complexity level	df	t	p	df	t	p
0, 1a	90	-0.196	0.845	45	2.582	0.013
0, 1b	90	-1.760	0.082	45	1.681	0.099
0, 2	90	3.785	<0.001	45	5.038	<0.001
1a, 1b	90	-1.522	0.131	45	-0.969	0.337
1a, 2	90	3.869	<0.001	45	2.612	0.012
1b, 2	90	5.680	<0.001	45	3.314	0.002

Level of Phonetic Complexity 0: simple handshape, 1 type of movement
Level of Phonetic Complexity 1a: simple handshape, 2 types of movement
Level of Phonetic Complexity 1b: complex handshape, 1 type of movement
Level of Phonetic Complexity 2: complex handshape, 2 types of movement

Table 4: Analysis of whether handshape errors are more likely for nonsense signs with complex or simple handshapes: % handshape errors across groups

	Deaf Children					Hearing Children			
	Simple		Complex			Simple		Complex	
Group	Mean Errors (%)	SD	Mean Errors (%)	SD	Group	Mean Errors (%)	SD	Mean Errors (%)	SD
4	42	22	50	17					
7	31	17	40	19	7	37	14	53	16
10	22	14	26	14	10	25	12	37	14

Table 5: Analysis of whether deletion of a movement in a movement cluster is more likely when the nonsense sign contains a complex handshape: % movement deletion

	Deaf Children					Hearing Children			
	Simple		Complex			Simple		Complex	
Group	Mean Errors (%)	SD	Mean Errors (%)	SD	Group	Mean Errors (%)	SD	Mean Errors (%)	SD
4	8	8	16	9					
7	4	5	7	5	7	11	9	14	8
10	3	5	6	6	10	4	5	8	5

Table 6: Error scores (expressed as mean % incorrect, SD) by phonological parameter for each group

		Deaf Children			Hearing Children	
Group	Error Type	Total Errors (%)	SD	Group	Total Errors (%)	SD
4	Handshape	46	16			
(N=26)	Path Movement	28	14			
	Internal Movement	45	15			
7	Handshape	36	16	7	52	12
(N=27)	Path Movement	14	11	(N=23)	26	16
	Internal Movement	36	15		50	13
10	Handshape	24	12	10	39	10
(N=38)	Path Movement	9	6	(N=23)	18	7
	Internal Movement	23	13		37	13

Table 7: Pair-wise comparisons within each group for error scores on each parameter

	Deaf Children			Hearing Children		
Complexity level	df	t	p	df	t	p
Group 4						
HS-PM	25	6.475	<0.001			
HS-IM	25	0.658	0.516			
PM-IM	25	-6.062	<0.001			
Group 7				Groups 7&10		
HS-PM	26	12.583	<0.001	45	12.007	<0.001
HS-IM	26	0.99	0.922	45	1.349	0.184
PM-IM	26	-10.836	<0.001	45	11.672	<0.001
Group 10						
HS-PM	37	9.843	<0.001			
HS-IM	37	1.166	0.251			
PM-IM	37	-9.103	<0.001			

HS = Handshape
PM = Path movement
IM = Internal movement