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Deaf signers use phonology to do arithmetic

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ABSTRACT

Deaf students generally lag several years behind hearing peers in arithmetic, but little is known about the mechanisms behind this. In the present study we investigated how phonological skills interact with arithmetic. Eighteen deaf signers and eighteen hearing non-signers took part in an experiment that manipulated arithmetic and phonological knowledge in the language modalities of sign and speech. Independent tests of alphabetical and native language phonological skills were also administered. There was no difference in performance between groups on subtraction, but hearing non-signers performed better than deaf signers on multiplication. For the deaf signers but not the hearing non-signers, multiplicative reasoning was associated with both alphabetical and phonological skills. This indicates that deaf signing adults rely on language processes to solve multiplication tasks, possibly because automatization of multiplication is less well established in deaf adults.

1. Introduction

Deaf students generally lag several years behind hearing peers in arithmetic (e.g. Traxler, 2000), a delay that has been shown to occur even before formal schooling starts (Kritzer, 2009) and persist throughout adulthood (Bull et al., 2011). However, there are no differences in general cognitive ability that can explain this. Recent work has demonstrated a link between sign language skills and reading ability in deaf signers (Mayberry, del Giudice, & Lieberman, 2011; Rudner et al., 2012) indicating that native language skills may support academic achievement in general. In this study we investigate the relation between phonology and arithmetic.

Whereas phonological skill refers to the ability to process the sublexical structure of language, arithmetic skill refers to the ability to combine numbers. Simple arithmetic refers to operations of addition, subtraction, multiplication and division with smaller values of numbers. Generally, the same components of arithmetical processing cause problems for both hearing and deaf students (Norell, 1998), but there are several areas in which differences between the groups can be seen. Hearing non-signers perform better than deaf signers on relational statements, including expressions such as *less than*, *more than* and *four times as many as* (Kelly, Lang, Mousley, & Davis, 2003; Serrano Pau, 1995), arithmetic word problems that require reading a text in which the arithmetic problem is stated (Hyde, Zevenbergen, & Power, 2003), fractions (Titus, 1995) and multiplicative reasoning (Nunes et al., 2009). On the other hand, deaf children outperform hearing children on problems that involve spatial arrays of figures (Zarfaty, Nunes, & Bryant, 2004). Simple arithmetic is related to linguistic ability in the form of phonological skills, at least for hearing individuals (De Smedt, Taylor, Archibald, & Ansari, 2010). Many of the mathematical domains that are identified as problematic for deaf individuals are related to linguistic abilities, and relational statements as well as arithmetic word problems are related to reading skills (Serrano Pau, 1995). It is possible that the use of phonological abilities in simple arithmetic processing differs between deaf and hearing persons. If so, this might help explain the performance differences in simple arithmetic between the two groups. The overall aim of this study is to investigate the relations between simple arithmetic and first language phonological skills in adult deaf signers and hearing non-signers.

1.1. Sign language phonology

Development of phonological skills is closely related to access to language during childhood, irrespective of whether that language is speech or sign based (Mayberry & Lock, 2003). Sign languages are visual, natural and fully fledged languages with their own vocabulary and grammar used in deaf communities (for a review see Emmorey, 2002). Sign languages are produced manually and perceived visually, in contrast to spoken languages which are produced orally and perceived audio-acoustically. Otherwise, sign languages are fully comparable to spoken languages and can be described using the same linguistic terms as spoken languages, which means that sign languages possess phonology, morphology, syntax and prosody (Emmorey, 2002; Klima & Bellugi, 1976; Sandler & Lillo-Martin, 2006). Although sign languages are not representations of either spoken or written language, sign languages make use of manual alphabets (fingerspelling) to represent letters and

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orthography when producing e.g. place names or proper names. In Swedish Sign Language (SSL) there is a substantial overlap between the phonologies of the manual alphabet, manual numerals and word signs, particularly as regards handshape, although the manual alphabet and manual numerals display less movement and diversity of location compared to word signs (Bergman, 2012). Sign languages differ considerably in regard to the extent to which fingerspelling is used. For example, in American sign language (ASL) fingerspelling is used extensively and constitutes up to 35% of signed discourse, whereas in Italian Sign Language (LIS) fingerspelling is used very sparsely (Morere & Roberts, 2012; Padden & Gunsauls, 2003). SSL, which is in focus in the present study, has a one-handed manual alphabet and resembles ASL in its extensive use of fingerspelled words and signs (Padden & Gunsauls, 2003). In SSL, fingerspelling can be used for proper names and foreign words, to describe how a word is spelled and to fill lexical gaps. Furthermore, fingerspelling is used in 'fingerspelled signs', which are loan words from Swedish that have been incorporated in the SSL vocabulary (Bergman & Wikström, 1981). SSL fingerspelled signs may comprise either all the letters of the Swedish word or only its consonants, demonstrating just how morphologically different they are from word signs. Sometimes the fingerspelled sign does not have the same function in SSL as the original word has in Swedish, e.g. a loan word that is a noun in Swedish can be a verb in SSL. Despite morphological differences, these fingerspelled signs are used as regular lexical signs and can be inflected in the same way as other lexical signs in SSL. Because fingerspelled signs are extensively used in SSL, native deaf children encounter fingerspelling explicitly and the manual alphabet implicitly early in their language development, probably many years before their hearing peers start to bother about letters (Bergman, 2012). In the present study we focus on the phonological feature of handshape where the overlap of the manual alphabet, manual numerals and sign words is at its greatest.

Phonology can be defined as the level of linguistic structure that organizes the medium through which language is transmitted (Sandler & Lillo-Martin, 2006). Thus, for spoken languages, phonology can be described as the combination of sounds to form utterances. For signed languages, phonology refers to how components of the signs are put together with respect to handshape, orientation, location and movement (Sandler & Lillo-Martin, 2006). Signs that share at least one of these features are thus considered to be phonologically similar (Klima & Bellugi, 1976; Sandler & Lillo-Martin, 2006). In SSL this can be exemplified by the manual numeral for the digit "6" and the fingerspelled letters "B" and "Q" (Fig. 1). These three hand configurations all share the same handshape and are thus considered to be phonologically similar, despite the fact that the orientation of the hand configuration for "Q" is different from that of the two others. Despite the differences in the surface description of phonology for speech and sign, it can be described in the same terms at a theoretical level. Phonology is used in similar ways in spoken and in signed language, e.g. it is the basis of poetry (Klima & Bellugi, 1976; Sutton-Spence, 2001) and nursery rhymes (Blondel & Miller, 2001). Further, the processing of sign-based and

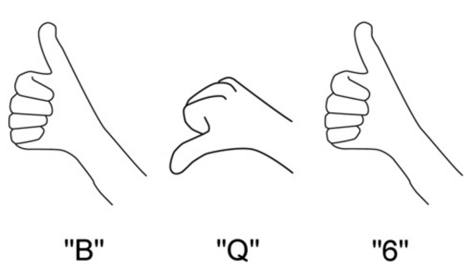

Fig. 1. Sign language phonology. Fingerspelled letters B, and Q and the manual numeral for the digit 6 share the same handshape, and Q is distinguished from the two others by a different orientation. The three signs are all phonologically similar.

speech-based phonology appears to be supported by generally similar neural networks in left hemisphere language areas (MacSweeney, Waters, Brammer, Woll, & Goswami, 2008). MacSweeney et al. (2008) used a picture-based phonological task that involved accessing either the English or British Sign Language (BSL) lexical labels of picture pairs and judging whether the English words rhymed and whether the signs shared a location. Despite the general similarity of the neural activation patterns for BSL and English in deaf and hearing signers and hearing non-signers, some differences were identified. Similarly, in a study investigating the neural correlates of processing phonology in a working memory context it was found that despite overall similarities across modalities, there were significant differences (Rudner, Karlsson, Gunnarsson, & Rönnberg, 2013). In the study by Rudner et al. (2013), phonological similarity in sign language was based on handshape. Behavioural results suggest that a closer relationship between semantics and phonology in signed compared to speech-based languages may influence the functional role of phonology in cognitive processing (Marshall, Rowley, & Atkinsson, 2013; Vigliocco, Vinson, Woolfe, Dye, & Woll, 2005). For example, during a sign-based phonological fluency task, adult deaf signers displayed particularly rich clustering of items according to both semantics and phonology (Marshall et al., 2013).

1.2. Arithmetic and language

Success in mathematics requires a wide range of abilities ranging from lower level arithmetical skills to linguistic skills, especially reading skills (Bull, Blatto-Vallee, & Fabich, 2006; Serrano Pau, 1995). Bull et al. (2006) have shown that there are no major differences between deaf and hearing adults on lower level arithmetical skills such as subitizing, magnitude processing or magnitude automatization that can explain deaf students' mathematical difficulties. However, they did find that the deaf individuals had a reduced efficiency in retrieval of magnitude information, concluding that the efficiency with which deaf individuals process numerical information, but not the numerical representations per se, differ between deaf and hearing individuals, which may influence overall performance on mathematical tasks (Bull, Marschark, & Blatto-Vallee, 2005). Further, it has been suggested that deaf individuals tend to have weaker association between concepts (Marschark, Convertino, McEvoy, & Masteller, 2004) and a tendency to rely on item-specific processing rather than relational processing (see review in Marschark, 2003) that might lead to delay in the establishment of arithmetic number representations and affect higher level arithmetical competence, such as simple arithmetic. Further, it has been shown that deaf children in Swedish schools for deaf and hard-of-hearing children often make use of a "double counting" strategy, in which both hands are used to represent different digits simultaneously, when modelling problems (Foisack, 2003). Such a strategy may be appropriate up to a point, but it does not lead to the development of the arithmetic fact based strategies that are important for learning multiplication tables and establishing automaticity. This may lead to greater reliance on phonological processing during multiplication for deaf than hearing individuals.

Simple arithmetic can be roughly divided into two separate conceptual domains; additive reasoning that include problems solved by addition and subtraction, and multiplicative reasoning that includes problems solved by multiplication and division (Nunes et al., 2009). However, newer data points to a relatively lower functional dependency between multiplication and division compared to addition and subtraction (Robinson & LeFevre, 2012; Venneri & Semenza, 2011). Multiplication has been shown to rely on speech based phonology, whereas subtraction uses a visual-analogue magnitude code (Lee & Kang, 2002). Bull et al. (2005) have shown that deaf individuals have access to the visual-analogue magnitude code, but it is probable that they have a less efficient access to speech based phonology. Further, hearing children make sense of the world around them by simultaneous coordination of auditory and visual information (Marschark, 2006). Deaf