DEAFNESS & EDUCATION INTERNATIONAL, Vol. 0 No. 0, Month, 2014, 1–19

Training Literacy Skills through Sign Language

Mary Rudner, Josefine Andin and Jerker Rönnberg

Linnaeus Centre HEAD, Swedish Institute for Disability Research, Department of Behavioural Studies and Learning, Linköping University, Sweden

Mikael Heimann

Swedish Institute for Disability Research, Department of Behavioural Studies and Learning, Linköping University, Sweden

Anders Hermansson

Swedish Institute for Disability Research, Department of Behavioural Studies and Learning, Linköping University, Sweden and Psychiatric Clinic Höglandet Hospital Eksjö/Nässjö, Sweden

Keith Nelson

Pennsylvania State University, USA

Tomas Tjus

University of Gothenburg, Sweden

The literacy skills of deaf children generally lag behind those of their hearing peers. The mechanisms of reading in deaf individuals are only just beginning to be unraveled but it seems that native language skills play an important role. In this study 12 deaf pupils (six in grades 1–2 and six in grades 4–6) at a Swedish state primary school for deaf and hard of hearing children were trained on the connection between Swedish Sign Language and written Swedish using a pilot sign language version of the literacy training software program Omega-is. Literacy skills improved substantially across the 20 days of the study. These literacy gains may have rested upon the specific software-based intervention, upon regular classroom activities, or upon a combination of these factors. Omega-is-d, and similar software utilizing sign

© W. S. Maney & Son Ltd 2014
MORE OpenChoice articles are open access and distributed under
the terms of the Creative Commons Attribution License 3.0
DOI 10.1179/1557069X14Y.0000000037

language as a component, targets an important mechanism supporting reading development in deaf children and could play an important role in bilingual education refinements.

KEYWORDS deafness, sign language, training, working memory, decoding, language comprehension, literacy

The ability to read gives us access to the universe of knowledge and fantasy contained in books and magazines. This ability may be particularly important for those who have restricted access to conversation, due either to social isolation or functional impairment. However, these individuals may have difficulty learning to read (Bonvillian *et al.*, 1973; Marschark *et al.*, 2012; Moores, 2013). Reading requires decoding and language comprehension (Haenggi & Perfetti, 1992; Just & Carpenter, 1992; Hulme & Snowling, 2014). Decoding involves mapping the printed words on a page onto the expressions of a primary language while language comprehension involves understanding those expressions. For most people, the primary language is spoken and decoding involves connecting speech sounds to printed words in the written equivalent, for example linking the sounds of spoken English to the orthography of written English. Deaf children have limited access to spoken language, and according to some sources, these limits persist for many even when they use hearing aids and cochlear implants (CIs) (Kral & Sharma, 2012; Holmström, 2013). This makes it more difficult for them to learn the correspondence between speech sounds and printed letters (Wass *et al.*, 2010). Deaf children growing up with sign language have a different problem to tackle. Because sign language has no written form they have to learn to read in a second language which does not map directly onto their primary language either at the word or sentence level. Thus, it is apparent that deafness changes the nature of decoding. Whether it changes the problem of language comprehension is less obvious. However, although many deaf children have difficulty learning to read, some do conquer literacy (Prinz & Strong, 1998; Goldin-Meadow & Mayberry, 2001; Miller & Clark, 2011).

Growing awareness of the full linguistic status of sign language through the 1970s led to the introduction of bilingual education for deaf children in the 1980s (Mayer, 2009). In 1981, the Swedish parliament recognized the existence of sign language and the right of deaf people to be educated in their own language (Svartholm, 2010). Two years later, a new special school curriculum was introduced enshrining the legal right of deaf people to two languages. Since then, deaf people in Sweden are entitled to education in their first language, that is, Swedish Sign Language (SSL). It is the responsibility of special schools for persons with deafness in Sweden to promote bilingualism, that is the ability to understand sign language and read Swedish as well as being able to express thoughts and ideas in both sign language and writing. This means that deaf children may receive an education based on sign language rather than speech with Swedish being taught as a second language (Schönström, 2010).

Cochlear implantation of deaf children began in Sweden in 1990 and today upwards of 90% of Swedish children born deaf receive one, or more commonly two, CIs (Anmyr *et al.*, 2012). Parents of children with CIs often choose mainstream education for their children (Archbold & Mayer, 2012). This has led to a renewed emphasis on the development of spoken language in deaf children and an increased focus on phonological processes in the development of literacy (Mayer, 2009; Wass *et al.*, 2010) coupled with an awareness of the special needs of this special population of deaf children (Archbold & Mayer, 2012; Holmström, 2013). Thus, the numbers of children in Swedish deaf schools is dwindling (Svartholm, 2010). At the same time, there are higher proportions of children with learning difficulties relating to factors other than hearing impairment and children with immigrant backgrounds as well as late starters than in mainstream schools (Svartholm, 2010). These factors have fundamentally changed the educational landscape for deaf learners (Mayer & Leigh, 2010). It remains important to understand how literacy skills are acquired by those deaf children for whom sign language is the primary mode of communication in school.

In children with normal hearing, decoding is underpinned by phonological awareness, verbal memory, and verbal processing speed (Wagner & Torgesen, 1987; Hulme & Snowling, 2014). In this group, phonological awareness refers to the ability to detect and manipulate the phonemes that constitute the sounds of words. However, it is a matter of debate whether phonological awareness in this sense underpins successful decoding in deaf children (Kyle & Harris, 2010) and empirical evidence is scant (Wass, *et al.*, 2010; Mayberry *et al.*, 2011). Signed languages have their own internal structure or phonology (Emmorey, 2002), which rather than being based on sound is based on the shape, movement, location, and orientation of the signing hands. Thus, sign language phonology is described in terms of its articulatory features and for a sign language user, phonological awareness is about detecting and manipulating these articulatory features. So, if decoding involves phonological awareness, does that awareness have to relate to the phonemes of the spoken equivalent of the written language to be decoded, or is it sufficient to understand the internal structure of one's own native sign language? If the former is the case, deaf children learning to read should be trained to understand the patterning of speech phonology (c.f. Nakeva von Mentzer *et al.*, 2013) but if the latter is the case they might better spend time getting to understand the structure of their own native language, sign language.

Some light can be shed on this issue by studying the role of phonological awareness in learning to read languages that display different levels of consistency in grapheme-to-phoneme mapping. Georgiou *et al.* (2012) found that for English-speaking children's phonological awareness in kindergarten was associated with grade 2 reading fluency in their native language, but that for Greek- and Finnish-speaking children, no such association was found. In the English language, there is a relatively low level of consistency in grapheme-to-phoneme mapping whereas in both Greek and Finnish there is a one-to-one mapping. The finding of the study by Georgiou *et al.* (2012) suggests that phonological awareness becomes more important when the consistency in grapheme-to-phoneme mappings decreases and decoding becomes harder. The corollary of this is that phonological awareness should be even more important for deaf children learning to read than for hearing children. However, it does not tell us whether for best reading results, phonological awareness should be related to the learner's native language or the language of literacy, where these differ.

It has been suggested that the basic linguistic abilities that allow for successful first language reading have similar impact on the acquisition of reading skills in a second language (Sparks & Ganschow, 1993; Cummins, 2012). In particular, first language phonological awareness predicts second language reading abilities (Kahn-Horwitz *et al.*, 2005). This implies that for deaf native sign language users, knowledge of the structure of sign language may facilitate the process of learning to read. Indeed, Strong and Prinz (1997) showed that deaf children with better skills in American Sign Language (ASL) also had better literacy skills, irrespective of age and general intelligence. They drew the conclusion that 'Deaf children's learning of English appears to benefit from the acquisition of even a moderate fluency in ASL'. Recently, it has been shown that reading comprehension in deaf adults is related to sign language grammar skills (Cormier *et al.*, 2012; Rudner *et al.*, 2012) and that when deaf adults read they activate sign translations of the written words (Morford *et al.*, 2011). Further, a Swedish study examining the language proficiency of school-aged deaf pupils from a bilingual perspective showed a positive correlation between Swedish skills and SSL skills (Schönström, 2010). This was interpreted as indicating that a well-developed sign language is important for deaf individuals to learn any written language as a second language. Thus, a bilingual approach to deaf reading may be fruitful (Piñar *et al.*, 2011).

Positive effects on reading abilities in poor readers (Gustafson *et al.*, 2011; Helland *et al.*, 2011) and children with autism and cerebral palsy (Heimann *et al.*, 1995; Nelson *et al.*, 1997; Tjus *et al.*, 1998, 2004) have been achieved as a result of intervention using Omega-is (Omega-Interactive Sentences; Heimann *et al.*, 2004) or its software forerunners. Omega-is is a computerized literacy training program that focuses on language abilities. It applies a cognitive strategy including both word- and sentence-level processing of written language. By clicking on text buttons with words or phrases, the user can rapidly create their own sentences such as 'The lion chases the swan'. Then the user hears the sentence being read by a prerecorded voice and finally the meaning of sentence is illustrated by an animation. Thus, the program offers hearing children close correspondence between text, speech, and animations, providing familiarization with the links between these modalities.

Training with Omega-is builds on cognitive abilities including working memory storage and processing (Nelson *et al.*, 2012). Temporary storage capacity is needed to hold words in mind while a sentence is being constructed or comprehended. In addition, executive functions are needed to process the content of working memory and carry out multiple steps in comparisons of structures, abstraction of new structures, and encoding new structures into long-term memory (Best *et al.*, 2011). Thus, age-appropriate cognitive skills are likely to support the learning processing.

In this study, we developed and evaluated a pilot version of Omega-is (Omega-is-d1) aimed specifically at deaf children learning to read in a classroom environment where SSL is the primary mode of communication. Similar work with prior versions of software programs that closely linked text, sign language, and animations documented literacy gains by moderately to profoundly deaf children in the US and in Belgium (Prinz & Nelson, 1985; Nelson *et al.*, 1989, 1991; Prinz *et al.*, 1993).

The assumption underlying this study is that successful development of sign language-related skills in deaf children can lead to a good basis for learning to read a second, speech-based language. The purpose of this study was to determine whether the literacy skills of deaf children who are sign language users can be enhanced by use of a computerized training program that focuses on the relationship between signed language and speech-based written language.

Method

Participants

Twelve pupils (five girls) at a Swedish state primary school for deaf and hard of hearing children took part in the study. They were selected by their teachers as beginning readers whom it was thought would benefit from sign-language-based literacy training with Omega-is-d1. The average age was 9:6 years ranging from 7:2 to 12:6 years. Six of the pupils attended grades 1–2 (age 7:2–8:9 years) and six attended grades 4–6 (age 10:3–12:6 years). Seven pupils had CIs. Of these seven, two also had a hearing aid and another two had hearing aids only. Apart from having a hearing impairment, five of the participants also had a neuropsychiatric diagnosis. These diagnoses included autism spectrum diagnosis and attention deficit/hyperactivity disorder according to Diagnostic and Statistical Manual of Mental Disorders, 4th Edition, Text Revision (APA, 2000). SSL was the primary means of communication for five participants. Other primary modes of communication were home sign as well as both European and non-European oral and signed languages. This heterogeneity is typical of the population of children attending schools for deaf children in Sweden (Svartholm, 2010) and internationally (Mayer & Leigh, 2010).

The participants were randomized by class into two groups, that is, there were equal numbers of pupils from grades 1–2 and grades 4–6 in each group. The pattern of testing and training differed for the two groups. For demographic

TABLE 1

DEMOGRAPHIC DETAILS OF THE TWO GROUPS

	Group 1 (n = 6)	Group 2 (n = 6)
Mean age (SD)	9:7 (1:11)	9:4 (2:1)
Female	2	3
CI and/or HA	4	5
Neuropsychiatric diagnosis	2	3
SSL primary language	2	3

information by group see Table 1. Both the children and their parents gave informed consent and the study was approved by the regional ethics committee.

Study design

In view of the relatively small number of pupils that we were able to recruit to the study and to maximize experimental power, we employed a crossover design in which participants acted as their own controls. All participants were tested on three separate occasions, T1, T2, and T3 at 2-week intervals. On all three occasions tests of reading skills, sign language comprehension, and cognitive skills were administered. The tests of reading skills included tests of decoding at character, word. and sentence level, and tests of reading comprehension. The same tests of reading skills and sign language comprehension were used on each of the three occasions in order to chart development of these skills over the 4-week period of the study. Each of the cognitive skills, non-verbal intelligence, working memory, and executive function was tested on one occasion only at one of the three testing occasions (see Table 2). All testing took place in a room at the school designed for psychological testing.

Between T1 and T2 Group 1 trained for 10 days using Omega-is-d1 while Group 2 pursued regular school work. Between T2 and T3 Group 2 trained for 10 days using Omega-is-d1 while Group 1 returned to regular school work.

Omega-is-d1

Omega-is is a computer program that has proved effective in supporting children in their reading development (Heimann *et al.*, 2004). It builds on the pedagogical model Multimedia, Interaction and Recasting (Heimann *et al.*, 2004). According to this model, the development of literacy skills can be enhanced by encouraging the use of parallel patterns of information in several different modalities. Another aspect of Multimedia, Interaction and Recasting is that training can be customized with the support of a teacher to facilitate learning through discussion and reflection about what is happening in the program. The notion of dynamic systems is used as a framework to both guide design of the teacher/software/child interactions and to interpret gains in literacy and language made by children with a range of learning needs (Nelson, 1998, 2006; Nelson *et al.*, 2001; Nelson & Arkenberg, 2008).

Omega-is includes two different types of training exercises, Construction and Testing. In Construction exercises, the user practices constructing sentences by serially selecting words, using a pointing device such as a computer mouse, from lists displayed on the computer screen. As each word is selected, it is read aloud by a pre-recorded voice. When sufficient words have been selected to form a sentence, the whole sentence is read aloud. Sentences may be conventional such as 'The lion chases the swan' or unconventional such as the 'Swan chases the lion'. This gives the user the opportunity to use language creatively. Finally, the meaning of sentence is illustrated by an animation to reinforce the semantics of the user's creation. In the Construction exercises, the user can select words in the wrong order and still create a Swedish sentence. The program simply arranges the selected words in the right order to create a sentence and a correct sentence is presented.

In testing exercises the user practices finding the right sequence of words to form a sentence that semantically matches a particular animation. Omega-is in standard versions uses printed and spoken material at word and sentence level as well as animations of sentences. Both types of exercises are available at six levels ranging from single words to complete stories.

In this study we developed Omega-is-d1, a pilot version of Omega-is for use by deaf beginning readers. We built on the overall theoretical notion of Multimedia, Interaction and Recasting (Heimann *et al.*, 2004). The principles of Multimedia and Interaction were enhanced for the participant group by adding a new language modality, sign language, to meet the learning needs of the participants, while retaining the original printed material and replaced the animations with videos of SSL, modelled by a deaf native user of SSL. We turned off the sound so that there would be no auditory stimulation for those participants who had residual hearing and used amplification. Practical limitations did not allow us to implement Recasting. However, Omega-is-d1 only included the first three exercise levels (single words, two-word sentences, and three-word sentences) which, although they could certainly be subject to Recasting, offer less scope for this principle than longer sentences and complete stories. These levels were selected because we deemed them most appropriate for the deaf children who were beginning readers that were targeted in this pilot study.

In the testing exercises in Omega-is-d1, signed sentences are presented and the task of the user is to select listed words in the right order to create a Swedish sentence that corresponds to the signed sentence. Feedback is given to the user to indicate whether or not the right words were selected. Training time is logged.

Participants trained in Omega-is-d1 at their own computer, using a personal USB-memory-card with their own copy of the program. The participants' class teachers were instructed in the use of Omega-is-d1 by the research team. Instructions were given in SSL (two of the participating teachers were deaf) and orally. Written instructions were also provided. The class teachers made sure all the participants understood the training program and could use it independently. They also answered any questions the participants had related to training with Omega-is-d1. Further, class teachers facilitated home training for those participants who so desired during the 10-day training period. When data collection was complete, the teachers were debriefed.

Participants were encouraged to train with the software in individual sessions as much as possible during the 10-day training period. This included classroom training and training at home. Unlike prior studies with versions of Omega-is software, no trained adult sat by the child during their computer sessions to facilitate learning through Recasting, that is, discussion and reflection about what is happening in the program. Due to pressure on teacher time, it was impossible to provide resources for this throughout training.

All training was logged. This included training in the classroom and training at home. The average logged time spent on training was 3 hours 49 minutes. The minimum time logged was 49 minutes and the maximum logged time was 8 hours 51 minutes. A technical error led to data loss for one participant and so the average training time was based on logs for 11 of the participants. The actual training time for the participant for whom data were lost was estimated to be in excess of one hour.

Literacy skills

Reading comprehension

The Woodcock Passage Comprehension test from the Woodcock Reading Mastery Test–Revised uses a 'cloze' procedure that requires the child to orally provide a single missing word, denoted by an underlined space in a sentence, to assess their ability to understand short passages consisting of one or two short sentences that are read silently (Woodcock, 1998). A Swedish translation of this test was used in this study (Olson *et al.*, 2011). In the standard test procedure, the missing word is reproduced orally. In this study, participants signed their responses either in SSL or using the Swedish manual alphabet. Points were given for each correct word and grammatical form and the maximum possible score was 68. Testing stopped after six incorrect responses.

In order to assess the relative level of reading comprehension of participants in this study compared to the population of beginning reader pupils in Swedish schools, we obtained Swedish comparison data from the International Longitudinal Twin Study (ILTS) of early reading development (Olson *et al.*, 2011). These data show scores on the Woodcock test of reading comprehension of 14.0 (SD 8.0, $N = 252$) in grade 1; 22.3 (SD 6.3; $N = 164$) in grade 2, and 34.8 (SD 6.8, $N = 64$) in grade 4.

Decoding

The reading chains test measures decoding ability (Jacobson, 2001). Reading chains consists of a number of subtests: character chains, word chains, and sentence chains. For all subtests, the task is to separate chains of characters using a pen stroke according to a particular instruction. For character chains, uppercase letters, lowercase letters, and numbers should be separated. For word chains, words should be separated and for sentence chains, sentences. There are different versions of word chains for grades 1–2 and 4–6; for grades 1–2 there are three words in each chain and for grades 4–6 there are four words. In grades 1–2, word chains only are recommended, while in grades 4–6 all three subtests are recommended. Thus, in this study all 12 participants performed the appropriate versions of the word chains subtest while only the six participants in grades 4–6 performed the character and sentence chain tests. Two minutes are given to complete each subtest and participants are instructed to work as quickly and yet as accurately as they can. One point is awarded for each correctly completed character and word chain. For sentence chains, one point is awarded for each correctly separated sentence.

Using the reading chains manual (Jacobson, 2001), points for word chains were converted to stanine using the table (total) for grade 4 (the lowest grade for which a conversion table was available).

Teacher assessment of reading skills

The class teachers were asked to assess the participants' reading skills on a scale of 1–10, where 1 represented poor skills and 10 represented good skills.

Sign language skills

Sign language comprehension

There are at present no standardized tests of comprehension of SSL. In order to test the participants' ability to comprehend SSL in this study we made a SSL adaptation of the Test for Reception of Grammar, Version 2 (TROG-2; Bishop, 2009). This standardized test is originally designed to measure receptive grammatical understanding. In this test the experimenter reads a passage aloud and the participant is shown a set of four pictures from which he or she is instructed to select the one that best fits the passage. Thus, each set of four pictures includes one target and three distractors that are closely related but not identical to the target and as such constitute lexical or grammatical lures. The test has 20 blocks, each with four test passages. For the SSL version, the original sentences were translated from Swedish to SSL by an accredited professional SSL interpreter in collaboration with a teacher of deaf children. The test was administered in SSL. This adapted version of TROG-2, referred to as TROG-2-SSL was administered in accordance with the standard procedure for TROG-2. One point was given for each correct block. Testing stopped either when no correct answers were given for two blocks in a row or when no points were awarded for five blocks in a row.

Teacher assessment of sign language skills

The class teachers were asked to assess the participants' skills in SSL on a scale of 1–10, where 1 represented poor skills and 10 represented good skills.

Cognitive skills

The cognitive skills tested in this study measured non-verbal intelligence (at T2) working memory (at T3) and executive function (T1).

Raven's Coloured Progressive Matrices

Raven's Coloured Progressive Matrices (Raven's CPM) measures nonverbal general intelligence (Raven *et al.*, 1994). The test includes 36 trials arranged in three subtests of increasing difficulty. Each trial involves choosing the best of six options to complete a pattern. One point is awarded for each correct trial. There are no Swedish norms available for Raven's CPM. In this study we applied norms for the Federal Republic of Germany. These norms were chosen because the education system in Germany is similar to that in Sweden. These norms were used to determine percentiles and age equivalents.

Letter span

The letter span task measures the short-term storage and processing capacity that characterizes working memory. While forward letter span emphasizes the storage component, backward letter span puts relative emphasis on the processing component as it requires reversal at recall of the order of items encoded in memory. Letter span tasks were chosen in preference to the more commonly used digit span tasks. This is because the digit span task has consistently been shown to put deaf people at a disadvantage (Rudner *et al.*, 2009) and it has thus been suggested that its use in educational testing may be inappropriate (Boutla *et al.*, 2004; Andin *et al.*, 2013). Furthermore, performance on the same version of the letter span task as used in the present study has been shown to be similar for matched groups of deaf signers and hearing non-signers (Andin *et al.*, 2013). The test was administered on an ASUS laptop with presentation software DMDX (version 4.0.4.4). Each version (forward and backward) comprised 16 trials in which letters were displayed serially for one second each in sequences of increasing length (from two to nine letters) in two different versions for each sequence length. The letters used in this task where R, S, X, L, M, Q, G, H, J, which are phonologically dissimilar in both Swedish and the Swedish manual alphabet. They are monosyllables in Swedish and have no movement in the Swedish manual alphabet. The participants were instructed to respond after each sequence by using a set of nine keys (numpad) each labelled with one of the letters. For the forward letter span task they were instructed to press the sequence of keys that correctly represented to the sequence displayed and for the backward version of the task they were instructed to reverse the sequence. The score is the individual span size which is the length of the longest completely correctly reproduced sequence at which at least one correct sequence has been reproduced at all preceding sequence lengths.

Simon task

The Simon task measures executive functioning relating to inhibition (Simon & Rudell, 1967). The test was administered on an ASUS laptop with presentation software DMDX (version 4.0.4.4). In each of 16 trials, a red or blue rectangle was randomly displayed an equal number of times either at the right or left side of the screen. The participant was instructed to respond as quickly and accurately as possible by pressing a key to the right of the computer keyboard when the rectangle was red and to the left when it was blue. The score for each participant was the average reaction time for incongruent trials (when the correct response key was on the opposite side to the stimulus) minus the average reaction time for congruent trials (response key on same side as stimulus).

Results

Mean test scores and standard deviation for T1, T2, and T3 are shown in Table 2.

Effect of computerized sign language-based literacy training

To determine whether literacy improved over the course of the training period, a repeated measures analysis of variance (ANOVA) was computed on a composite literacy score. The composite score incorporated all available literacy scores for both younger and older children: it was created by averaging across the *z*-scores of Woodcock and Word chains for all participants as well as across Character chains and Sentence chains for the older participants. The ANOVA included the within group factor testing occasion (T1, T2, T3) and the between group factor training group. There was a main effect of testing occasion ($F(2,20) = 6.42$, $MSE = 0.03$, $P = 0.007$, partial $\eta^2 = 0.39$). This large effect size reveals a substantial and highly significant improvement in performance between T1 and T3. For composite literacy scores, there was no main effect of group ($F(1,10) = 0.2.24$, MSE = 1.77, $P = 0.17$) and no significant interaction ($F(2,20) = 0.24$, $P = 0.79$). Thus, it is indeterminate whether literacy gains may have rested upon the specific software-based intervention, upon regular classroom activities, or upon a combination of these factors.

To determine whether the sign language comprehension skills were enhanced by training, a repeated measures ANOVA was performed on TROG-2-SSL scores. There was a non-significant tendency towards improvement in performance across time ($F(2,20) = 2.84$, $MSE = 4.6$, $P = 0.08$). However, there was no interaction with group ($F(2,20) = 1.39$, $P = 0.27$). Thus, the tendency to improvement in sign language skills over time could not be specifically attributed to training with Omega-is-d1.

Levels of performance relative to norms

The levels of performance of the participants in this study were compared to those of typically developing children.

TABLE 2

PERFORMANCE BY GROUP AND TESTING OCCASION ON EACH OF THE TESTS OF READING, SIGN LANGUAGE AND COGNITIVE SKILL

	Group 1									Group 2								
	T1			T2			T3			T1			T2			T3		
	n	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD
Literacy skills																		
Woodcock	6	3.67	2.42	6	2.83	1.94	6	2.67	1.97	6	8.17	10.01	6	9.00	12.07	6	8.83	12.35
Character chains*	3	8.67	3.06	3	12.67	5.03	3	16.33	4.04	3	19.33	2.89	3	23.00	4.58	3	24.00	1.73
Word chains	6	4.00	2.28	6	5.50	3.27	6	5.00	2.90	6	8.17	8.04	6	10.50	9.89	6	10.67	8.87
Sentence chains*	3	0.33	0.58	3	1.00	1.73	3	1.00	1.73	3	12.67	15.53	3	14.67	17.47	3	18.33	25.93
SSL skills																		
TROG-2-SSL	6	5.33	4.08	6	5.00	3.52	6	7.00	5.06	6	6.00	3.85	6	8.50	5.32	6	8.50	6.47
Cognitive skills																		
Simon (ms)	6	132.01	125.45							6	170.09	108.65						
Ravens CPM				6	24.00	6.45							6	27.17	5.67			
Letter span fd							6	2.17	1.17							6	3.50	1.87
Letter span bd							5	2.40	0.55							4	3.25	2.36

*Grades 4–6 only.

Literacy skills

Reading comprehension – Woodcock

Grade scores for Swedish children from the ILTS (Olson *et al.*, 2011) were used as comparison scores. At T1 one participant in group 2 performed within one standard deviation of ILTS grade score while all other participants scored <2 SD below ILTS grade score. Thus, 11 of the 12 participants had reading comprehension scores that were below that of their typically developing peers.

Decoding – word chains

When the word chain scores (reported in Table 2) were converted to stanine, we found that at T1 ten of the participants had a stanine of 1, one of the participants had a stanine of 3 and another had a stanine of 6. In other words, only two of the twelve participants performed within the normal range.

Decoding – character chains

When character chain scores were converted to stanine, we found that at T1 three of the six participants in grades 4–6 who performed this test had a stanine of 1. Among the remaining three, one had a stanine of 3 and two had a stanine of 4. Thus, three out of six participants performed within the normal range on this test.

Decoding – sentence chains

At T1, one of the participants had a stanine of 6 while the other five had a stanine of 1. Thus, only one of six participants performed within the normal range on this test.

In summary, the participants showed a generally low level of reading-related skills compared to typically developing peers, except on the character chain test which measures word decoding in the form of visuo-motor speed with no demand on reading comprehension (Jacobson, 2001). This suggests that although reading skill was low, the fundamental level of decoding was in place for three of the six participants in grades 4–6.

Cognitive skills

Performance on the cognitive tests by group is shown in Table 2. Three of the participants chose not to perform the backward span task. The average digit span scores of group 2 were within one standard deviation of the score reported by Gathercole and Pickering (2000) for 6- and 7-year-old children and those of group 1 were within two standard deviations.

On Raven's CPM ten out of twelve participants performed above the 25th percentile norm for their age. Eight participants performed above the 50th percentile and three above the 75th percentile. Of the remaining two participants, one performed above the 10th percentile and the other above the 5th percentile. Thus, all twelve participants in this study performed within the normal range on Raven's CPM.

Teacher assessments

The mean teacher rating for reading was $M = 4.3$ (SD = 2.8) in group 1 and $M = 5.0$ (SD = 3.1) in group 2. There was no difference in assessed reading skills between groups ($t(10) = 0.39$, $P = 0.70$). The mean teacher rating for SSL was $M = 3.8$ (SD = 1.0) in group 1 and $M = 5.7$ (SD = 3.1) in group 2. Assessed SSL skills were significantly different between groups ($t(10) = 2.36$, $P = 0.04$).

Discussion

The purpose of this study was to determine whether literacy skills could be enhanced by training with Omega-is-d1.

Although literacy skills were generally low we showed that they improved substantially and significantly over the course of training and did so for both training groups. Cognitive skills were in the normal range providing a basis for learning. However, in the absence of group x time interaction effects, it is unclear whether the improvement in literacy skills over time was caused by the specific literacy software intervention. Instead, the children's advances in literacy may have rested upon the specific software-based intervention, upon regular classroom activities, or upon a combination of these factors.

The small group of participants in this study recruited from a Swedish state primary school for deaf and hard of hearing children displayed the heterogeneity typical of this population (Mayer & Leigh, 2010; Svartholm, 2010) in terms of age, primary mode of communication, hearing rehabilitation, and comorbidity. Despite careful randomization by class into the two groups, behavioural performance varied across groups. This variance militated against the ability of our crossover design to detect a specific effect of the intervention.

In contrast, children using Omega-is software have made literacy gains more specifically attributable to intervention periods in studies that used longer intervention duration than the current one and that also employed trained teachers to enhance the child's engagement with the software. Improvements in reading skills as a result of training in Omega-is (Heimann *et al.*, 2004) and its forerunners have been reported in a number of prior studies across a range of cultures including children with specific reading difficulties (Gustafson *et al.*, 2011; Helland *et al.*, 2011) as well as children with autism and cerebral palsy (Heimann *et al.*, 1995, 2004; Nelson *et al.*, 1997; Tjus *et al.*, 1998, 2004). Positive results in terms of reading have also been achieved using Omega-is (Heimann *et al.*, 2004) for children with hearing impairment (Tjus *et al.*, 2004). In this study we developed a new version, Omega-is-d1, which allowed deaf children to train the association between SSL and Swedish text. Recent work has shown a link between reading skills and sign-language-related skills and the rationale behind this study was that training this link through software incorporating sign language may lead to better literacy for deaf children (Strong & Prinz, 1997; Schönström, 2010; Cormier *et al.*, 2012; Rudner *et al.*, 2012). It is likely that the present intervention approach would have been more successful if resources had been available to fully implement the concept of Multimedia, Interaction and Recasting with the support of a teacher to facilitate children's learning through discussion and reflection of what is happening in the training program and if the training period for each child had been extended.

Conclusion

The literacy skills of deaf beginning readers improved substantially over the course of the study. These improvements may have depended upon the specific software-based intervention, upon regular classroom activities where teachers also employed SSL, or upon a combination of these factors. Future interventions for deaf beginning readers including Omega-is-d and similar software utilizing sign language as a component should extend the duration of training and fully implement the concept of Multimedia, Interaction and Recasting.

Acknowledgements

The authors would like to thank Stefan Samuelsson for access to normative data from the Woodcock test of reading comprehension. We would also like to thank all the pupils who patiently took part in this study, as well as their parents and teachers. This work was supported by grant no. 2008-0846 from the Swedish Council for Working Life and Social Research held by the first author.

Disclaimer statements

Contributors

All the authors contributed to the design of the study. Hermansson collected the data. Rudner and Hermansson analysed the data. All the authors were involved in interpretation of the analyses. Rudner wrote the paper, incorporating comments provided by all the authors on earlier drafts.

Funding

Swedish Council for Working Life and Social Research.

Conflicts of interest

None.

Ethics approval

The study was approved by the regional ethics committee in Linköping, Sweden.

References

American Psychiatric Association (APA). 2000. *Diagnostic and Statistical Manual of Mental Disorders*, 4th ed., text revision. Washington, DC: American Psychiatric Association (APA).

Andin, J., Orfanidou, E., Cardin, V., Holmer, E., Capek, CM., Woll, B., Rönnberg, J. & Rudner, M. 2013. Similar Digit-based Working Memory in Deaf Signers and Hearing Non-Signers Despite Digit Span Differences. *Frontiers in Psychology*, 4:942. doi:10.3389/fpsyg.2013.00942.

Anmyr, L., Larsson, K., Olsson, M. & Freijd, A. 2012. Strengths and Difficulties in Children with Cochlear Implants—Comparing Self-Reports with Reports from Parents and Teachers. *International Journal of Pediatric Otorhinolaryngology*, 76(8):1107–12.

Archbold, S. & Mayer, C. 2012. Deaf Education: The Impact of Cochlear Implantation? *Deafness and Education International*, 14(1):2–15.

Best, J.R., Miller, P.H. & Naglieri, J.A. 2011. Relations between Executive Function and Academic Achievement from Ages 5 to 17 in a Large, Representative National Sample. *Learning and Individual Differences*, 21(4):327–36.

Bishop, D.V.M. 2009. *Test for Reception of Grammar—Version 2. TROG-2 Manual*. Stockholm: Pearson Assessment and Information AB.

Bonvillian, J.D., Charrow, V.R. & Nelson, K.E. 1973. Psycholinguistic and Educational Implications of Deafness. *Human Development*, 16(5): 321–45.

Boutla, M., Supalla, T., Newport, E.L. & Bavelier, D. 2004. Short-Term Memory Span: Insights from Sign Language. *Nature Neuroscience*, 7(9):997–1002.

Cormier, K., Schembri, A., Vinson, D. & Orfanidou, E. 2012. First Language Acquisition Differs from Second Language Acquisition in Prelingually Deaf Signers: Evidence from Sensitivity to Grammaticality Judgement in British Sign Language. *Cognition*, 124(1):50–65.

Cummins, J. 2012. The Intersection of Cognitive and Sociocultural Factors in the Development of Reading Comprehension Among Immigrant Students. *Reading and Writing*, 25(8):1973–90.

Emmorey, K. 2002. *Language, Cognition, and the Brain: Insights from Sign Language Research*. New Jersey: Lawrence Erlbaum Associates.

Gathercole, S.E. 1999. Cognitive Approaches to the Development of Short-Term Memory. *Trends in Cognitive Sciences*, 3(11):410–19.

Gathercole, S.E. & Pickering, S.J. 2000. Assessment of working memory in six- and seven-year old children. *Journal of Educational Psychology*, 92(2):377–390.

Gathercole, S.E., Pickering, S.J., Knight, C. & Stegmann, Z. 2004. Working Memory Skills and Educational Attainment: Evidence from National Curriculum Assessments at 7 and 14 Years of Age. *Applied Cognitive Psychology*, 18(1):1–16.

Georgiou, G.K., Torppa, M., Manolitsis, G., Lyytinen, H. & Parrila, R. 2012. Longitudinal Predictors of Reading and Spelling Across Languages Varying in Orthographic Consistency. *Reading & Writing*, 25:321–46.

Goldin-Meadow, S. & Mayberry, R.I. 2001. How Do Profoundly Deaf Children Learn to Read? *Learning Disabilities Research & Practice*, 16:222–29. doi:10.1111/0938-8982.00022.

Gustafson, S., Fälth, L., Svensson, I., Tjus, T. & Heimann, M. 2011. Effects of Three Interventions on the Reading Skills of Children with Reading Disabilities in Grade 2. *Journal of Learning Disabilities*, 44(2):123–35.

Haenggi, D. & Perfetti, C.A. 1992. Individual Differences in Reprocessing of Text. *Journal of Educational Psychology*, 84(2):182–92.

Heimann, M., Nelson, K.E., Tjus, T. & Gillberg, C. 1995. Increasing Reading and Communication Skills in Children with Autism Through. An Interactive Multimedia Computer Program. *Journal of Autism and Developmental Disorders*, 25:459–80.

Heimann, M., Lundälv, M., Tjus, T. & Nelson, K.E. 2004. *Omega-Interactive Sentences, a Multimedia Software for Language Exploration and Play*. Göteborg: Topic Data & Språkbehandling Hb (http://www.omega-is.com).

Helland, T., Tjus, T., Hovden, M., Ofte, S. & Heimann, M. 2011. Effects of Bottom-Up and Top-Down Intervention Principles in Emergent Literacy in Children at Risk of Developmental Dyslexia: A Longitudinal Study. *Journal of Learning Disabilities*, 44:105–22.

Holmström, I. 2013. *Learning by Hearing? Technological Framings for Participation*. Doctoral dissertation, Örebro Studies in Education, 42.

Hulme, C. & Snowling, M.J. 2014. The Interface between Spoken and Written Language: Developmental Disorders. *Philosophical Transactions of the Royal Society B*, 369: 20120395. http://dx.doi.org/10.1098/rstb.2012.0395.

Jacobson, C. 2001. *Läskedjor. Manual*. Stockholm: Hogrefe Psykologiförlaget AB.

Just, M.A. & Carpenter, P.A. 1992. A Capacity Theory of Comprehension—Individual Differences in Working Memory. *Psychology Review*, 99:122–49. doi:10.1037/0033-295X.99.1.122.

Kahn-Horwitz, J., Shimron, J. & Sparks, R.L. 2005. Predicting Foreign Language Reading Achievement in Elementary School Students. *Reading and Writing*, 18(6):pp. 527–58.

Kral, A. & Sharma, A. 2012. Developmental Neuroplasticity after Cochlear Implantation. *Trends in Neurosciences*, 35(2):111–22.

Kyle, F.E. & Harris, M. 2010. Predictors of Reading Development in Deaf Children: A 3-Year Longitudinal Study. *Journal of Experimental Child Psychology*, 107:229–43.

Marschark, M., Sarchet, T., Convertino, C.M., Borgna, G., Morrison, C. & Remelt, S. 2012. Print Exposure, Reading Habits, and Reading Achievement among Deaf and Hearing College Students. *Journal of Deaf Studies and Deaf Education*, 17(1):61–74.

Mayberry, R.I, del Giudice, A.A. & Lieberman, A.M. 2011. Reading Achievement in Relation to Phonological Coding and Awareness in Deaf Readers: A Meta-analysis. *Journal of Deaf Studies and Deaf Education*, 16(2):164–88.

Mayer, C. 2009. Issues in Second Language Literacy Education with Learners Who are Deaf. *International Journal of Bilingual Education and Bilingualism*, 12(3):325–34.

Mayer, C. & Leigh, G. 2010. The Changing Context for Sign Bilingual Education Programs: Issues in Language and the Development of Literacy. *International Journal of Bilingual Education and Bilingualism*, 13(2):175–86.

Miller, P. & Clark, M.D. 2011. Phonemic Awareness is Not Necessary to Become a Skilled Deaf Reader. *Journal of Developmental and Physical Disabilities*, 23(5):459–76.

Moores, D.F. 2013. One Size Does not Fit All: Individualized Instruction in a Standardized Educational System. *American Annals of the Deaf*, 158(1):pp. 98–103.

Morford, J.P., Wilkinson, E., Villwock, A., Piñar, P. & Kroll, J.F. 2011. When Deaf Signers read English: Do Written Words Activate their Sign Translations? *Cognition*, 118(2):286–92.

Nakeva von Mentzer, C., Lyxell, B., Sahlén, B., Wass, M., Lindgren, M., Ors, M., Kallioinen, P. & Uhlén, I. 2013. Computer-Assisted Training of Phoneme–Grapheme Correspondence for Children who are Deaf and Hard of Hearing: Effects on Phonological Processing Skills. *International Journal of Pediatric Otorhinolaryngology*, 77(12):2049–57.

Nelson, K.E. 1998. Toward a Differentiatied Account of Facilitators of Literacy Development and ASL in Deaf Children. *Topics in Language Disorders*, 18:73–88.

Nelson, K.E. 2006. A Dynamic Tricky Mix Theoretical Perspective on Educational Interventions to Support the Acquisition of L1 and L2 Spoken Languages, Sign Languages, Text, and Art. *Studies in Language Sciences*, 5:91–102.

Nelson, K.E. & Arkenberg, M.E. 2008. Setting the Stage: Developmental Cognitive and Interactional Underpinnings of Language and Reading from a Dynamic Systems Perspective. In: M. Mody & E.R. Silliman eds. *Language Impairment and Reading Disability: Interactions among Brain, Behavior, and Experience*. New York: Guilford.

Nelson, K.E., Prinz, P.M. & Dalke, D. 1989. Transitions from Sign Language to Text Via an Inteactive Microcomputer System. In: B. Woll & J. Kyle (eds.), *Deaf children's development*. Cambridge: Cambridge University Press. pp. 77–94.

Nelson, K.E., Prinz, P.M., Prinz, E.A. & Dalke, D. 1991. Processes for Text and Language Acquisition in the Context of Microcomputer-Videodisc Instruction for Deaf and Multihandicapped Deaf Children. In:

D.S. Martin, ed. *Advances in Cognition, Education, and Deafness*. Washington, DC: Gaullaudet University Press. pp. 162–69.

Nelson, K.E., Heimann, M. & Tjus, T. 1997. Theoretical and Applied Insights from Multimedia Facilitation of Communication Skills in Children with Autism, Deaf Children, and Children with Other Disabilities. In: L.B. Adamson & M.A. Romski, eds. *Communication and Language Acquisition: Discoveries from Atypical Development*. Baltimore, MD: Paul Brookes Publishers, pp. 295–325.

Nelson, K.E., Welsh, J., Camarata, S., Heimann, M. & Tjus, T. 2001. A Rare Event Transactional Model of Tricky Mix Conditions Contributing to Language Acquisition and Varied Communicative Delays. In: K.E. Nelson, A. Koc & C. Johnson, eds. *Children's Language, volume 11*. Hillsdale, NJ: Erlbaum.

Nelson, K.E., Barlieb, A., Khan, K., Vance Trup, E.M., Heimann, M., Tjus, T., Rudner, M. & Ronnberg, J. 2012. Working Memory, Processing Speed, and Executive Memory Contributions to Computer-Assisted Second Language Learning. *Contemporary Educational Technology*, 3(3):184–200.

Olson, R.K., Keenan, J.M., Byrne, B., Samuelsson, S., Coventry, W.L., Corley, R., Wadsworth, S.J., Willcutt, E.G., DeFries, J.C., Pennington, B.F. & Huslander, J. 2011. Genetic and Environmental Influences on Vocabulary and Reading Development. *Scientific Studies of Reading*, 15(1):26–46.

Piñar, P., Dussias, P.E. & Morford, J.P. 2011. Deaf Readers as Bilinguals: An Examination of Deaf Readers' Print Comprehension in Light of Current Advances in Bilingualism and Second Language Processing. *Linguistics and Language Compass*, 5(10):691–704.

Prinz, P.M. & Nelson, K.E. 1985. Alligator Eats Cookie: Acquisition of Writing and Reading Skills by Deaf Children using the Microcomputer. *Applied Psycholinguistics*, 6:283–306.

Prinz, P.M. & Strong, M. 1998. ASL Proficiency and English Literacy within a Bilingual Deaf Education Model of Instruction. *Topics in Language Disorders*, 18(4):47–60.

Prinz, P.M., Nelson, K.E., Loncke, F., Geysels, G. & Willems, C. 1993. A Multimodality and Multimedia Approach to Language, Discourse, and Literacy Development. In: F. Coninx & B.A.G. Elsendoorn, eds. *Advanced Technology for the Handicapped: Interactive Learning Technology for the Deaf*. Berlin: Springer-Verlag.

Raven, J.C. & Raven, J. 1994. *Raven's Coloured Progressive Matrices*. Stockholm: Psykologiförlaget.

Rudner, M., Andin, J. & Rönnberg, J. 2009. Working Memory, Deafness and Sign Language. *Scandinavian Journal of Psychology*, 50:495–505.

Rudner, M., Orfanidou, E., Cardin, V., Capek, C., Woll, B. & Rönnberg, J. 2012. Reading Ability in Adult Deaf Native Signers is Positively Associated with their Ability to Judge the Grammatically of their Native Sign Language. Neurobiology of Language Conference in San Sebastian, October 25–27, 2012.

Schönström, K. 2010. *Bilingualism in School-Aged Deaf Pupils: Processability in Swedish and Narrative Structure in Swedish and Swedish Sign Language*. Doctoral thesis, Department of Linguistics, Stockholm University. Available at: <http://urn.kb.se/resolve?urn=urn:nbn:se:su:diva-39917>.

Simon, J. & Rudell, A.P. 1967. Auditory S-R Compatibility: The Effect of an Irrelevant Cue on Information Processing. *Journal of Applied Psychology*, 51(3):300–4.

Sparks, R.L. & Ganschow, L. 1993. Searching for the Cognitive Locus of Foreign Language Learning Difficulties: Linking Native and Foreign Language Learning. *Modern Language Journal*, 77:289–302.

Strong, M. & Prinz, P.M. 1997. A Study of the Relationship between American Sign Language and English Literacy. *Journal of Deaf Studies & Deaf Education*, 2(1):37–46.

Svartholm, K. 2010. Bilingual Education for Deaf Children in Sweden. *International journal of bilingual education and bilingualism*, 13(2):159–74.

Tjus, T., Heimann, M. & Nelson, K.E. 1998. Gains in Literacy through the use of a Specially Developed Multimedia Computer Strategy: Positive Findings from Thirteen Children with Autism. *Autism*, 2:139–56.

Tjus, T., Heimann, M. & Nelson, K.E. 2004. Reading Acquisition by Implementing a Multimedia Intervention Strategy for fifty Children with Autism or other Learning and Communication Disabilities. *Journal of Cognitive and Behavioral Psychotherapies*, 2:203–22.

Wagner, R.K. & Torgesen, J.K. 1987. The Nature of Phonological Processing and its Causal Role in Acquisition of Reading Skills. *Psychological Bulletin*, 101(2):192–12.

Wass, M., Lyxell, B., Sahlén, B., Asker-Árnason, L., Ibertsson, T., Mäki-Torkko, E., Hällgren, M. & Larsby, B. 2010. Reading Strategies and Cognitive Skills in Children with Cochlear Implants. *Acta Neuropsychologica*, 8(2):142–80.

Woodcock, R.W. 1998. *Woodcock Reading Mastery Test—Revised/Normative Update*. Circle Pines, MN: American Guidance Service.

Notes on contributor

Correspondence to: Mary Rudner, Swedish Institute for Disability Research, Linköping University, Sweden. Email: mary.rudner@liu.se