The Role of Sign Phonology and Iconicity During Sign Processing: The Case of Deaf Children

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To investigate the influence of sign phonology and iconicity during sign processing in deaf children, the roles of these sign features were examined using an experimental sign–picture verification paradigm. Participants had to make decisions about sign–picture pairs, manipulated according to phonological sign features (i.e., hand shape, movement, and location) and iconic sign features (i.e., transparent depiction of meaning or not). We found that phonologically related sign pairs resulted in relatively longer response latencies and more errors whereas iconic sign pairs resulted in relatively shorter response latencies and fewer errors. The results showed that competing lexical sign candidates (neighbor signs) were activated during sign processing by deaf children. In addition, deaf children exploit the iconicity of signs during sign recognition.

The common view in many schools for deaf children is that the acquisition of sign language is essential for the deaf children’s social and academic achievements. In order to optimize sign language instructional programs, we need to gain insight into the cognitive processes present during the recognition and production of signs by school-aged deaf children. Although we have recently gained considerable knowledge about the processes that are involved in the recognition and production of signs by deaf adults (e.g., Corina & Knapp, 2006; Dye & Shih, 2006; Emmorey & Corina, 1990; Marthur & Best, 2007; Mayberry & Witcher, 2006; Thompson, Vinson, & Vigliocco, 2009), very little is known about how deaf children produce and recognize signs. In this article, we have started to explore the processes that are involved in the recognition of signs by deaf children. We examined two sign–language components, which might affect sign processing in deaf children. First, we examined the activation of sign phonology in sign recognition, in line with the involvement of phonology in spoken word recognition. Second, we examined the activation of iconicity, which is rather unique to the visual modality of signs.

In spoken word recognition studies, phonological competition has been found during word recognition. Many models of spoken and visual word recognition assume that the presentation of a spoken or written word (e.g., DOG) leads to the activation of its sublexical (phonological/orthographic) features (/d/, /o/, & /g/). These sublexical features subsequently activate words (e.g., DOG, DOLL) that match these sublexical features. Words that are activated during this process will compete for selection. The extent to which words become activated during the recognition process depends upon the amount (and position) of the overlap of the phonological/orthographic features. In other words, many spoken and written word recognition models, for example, the Cohort model of lexical access, assume that the word recognition can be viewed as a competition process in which a cohort of phonologically related words (neighbor words) competes for selection while the information of the spoken word becomes available (e.g., Gaskell & Marslen-Wilson, 2002; Zwitserlood, 1996). Thus, not only is the target word activated when accessing the meaning of a word but so also is a combination of sublexical phonological units, which activates a cohort of competing neighbor words. In this article, the study into the activation of neighbor signs can be seen as the sign variant of studies into the activation of neighbor words during spoken word recognition (e.g., Gaskell & Marslen-Wilson, 1999, 2002). Individual
signs in all sign languages are composed of cheremes, which thus constitute the sign phonological system (Corina & Sandler, 1993; Emmorey, McCullough, & Brentari, 2003; Hildebrandt & Corina, 2002; Klima & Bellugi, 1979; Thompson, Emmorey, & Gollan, 2005). The most relevant cheremes include handshape, movement, orientation, and location (Emmorey & Corina, 1990). In spoken word recognition, the activation of combinations of phonemes in a word leads to the activation of neighbor words. It may seem trivial that the recognition of signs also starts with the activation of combinations of sign phonological segments or cheremes (i.e., hand shape, movement, orientation, and location) and several competing lexical candidates (neighbor signs). However, the actual activation process has hardly been studied in online paradigms, in particular for children as they may process signs more holistically than adults.

The influence of sign phonology during sign processing has been examined in perception (e.g., Dye & Shih, 2006; Emmorey & Corina, 1990; Marthur & Best, 2007; Mayberry & Witcher, 2006, see also Emmorey, 2002) and in production (e.g., Corina & Knapp, 2006). These different studies into sublexical sign phonology activation during sign processing have convincingly demonstrated that the recognition of signs by deaf adults is also driven by the activation of its sublexical elements, even though signs are seemingly organized less sequentially than spoken and written words. Several sign priming studies (e.g., Dye & Shih, 2006; Marthur & Best, 2007; Mayberry & Witcher, 2006) and a gating study (Emmorey & Corina, 1990) showed that the activation of sign phonology and competing lexical sign candidates (sign neighbors) play an important role in lexical access to signs in deaf adults. In the priming studies cited above, a prime and a target that shared sign phonology (cherology) overlap were presented. Priming effects were found, which showed that the signers initially identified lexical sign neighbors. In the gating study, the same conclusion could be drawn while using a different paradigm. The process of lexical access and sign identification through time was examined by using a gating procedure, whereby participants are asked to guess the meaning of a sign. The signs were presented repeatedly and increased in length each time (33 ms). Similar to the priming studies and consistent with the Cohort model of lexical access, the conclusion could be drawn that a cohort of potential sign neighbors, which shared phonological parameters, was activated. One question that has remained unanswered thus far, however, is whether sign processing of deaf children also involves the activation of a cohort of competing sign neighbors. As far as we know, no studies of online sign processing were carried out with deaf children to examine if deaf children process signs as units without sublexical activation (more holistically) or as a combination of sublexical units, and consequently activating a cohort of competing neighbor signs.

In addition to sign phonology, iconicity might play an essential role in sign processing. In the literature, the term iconicity has been explained in various ways. Iconicity is referred to as the mapping between the meaning of a sign and its form; the level of transparency or translucency (see also in a review by Luftig, 1983). Like sign phonology, the role of iconicity has not been studied intensively in online paradigms. Also similar to studies of sign phonology, the majority of the online studies of iconicity have been conducted with deaf adults instead of deaf children (e.g., Emmorey et al., 2004; Thompson et al., 2009).

In spoken languages, onomatopoeias are classic examples of iconicity (e.g., Luftig, 1983; Thompson, Vinson, & Vigliocco, 2009). For spoken language, words such as cuckoo (onomatopoeia) provide the meaning in the sound of the words. In contrast to spoken languages, the associations between the form of the lexical item and the meaning of the lexical item are frequently more transparent in signed languages (Emmorey, 2002; van der Kooij, 2002). The sign for house, for example, is transparent in Sign Language of The Netherlands (SLN; Figure 1).

The form of the iconic sign for house reflects a roof of a house, providing a direct link between form and meaning. One could argue that iconic properties may provide signers with valuable cues on the meaning of the sign, which can facilitate the sign recognition process. If iconic properties would make a sign more related to the imagistic properties of a particular sign, one might expect that these signs are easier to process than signs with a weaker or no relation to the imagistic properties of a sign. Imagistic properties refer to
imagining or conceiving the movement (motor imagery) and the shape of an object (visual imagery), without performing the movement or seeing the object. When a sign is iconic, it is easier to imagine the movement and to imagine the shape of an object compared with when a sign is not iconic.

We would like to mention two different sign recognition studies, which examined effects of iconicity in a picture–sign matching task. One interesting recent online study with deaf adults showed the importance of iconicity in sign processing (Thompson et al., 2009). The results in this study showed that a close mapping between meaning and form (iconicity) can facilitate lexical retrieval in an online picture–sign matching task. Deaf adults were faster to respond when the iconic component in a sign was made salient in the corresponding picture, compared with pairs in which pictures did not show the iconic component of the corresponding sign. This online study provided evidence for the automatic use of iconicity during sign recognition. However, a separate study showed no effects of iconicity in deaf adult patients with brain lesions in a picture–sign matching task, matching single signs (nouns) to one of five pictures (Atkinson, Marshall, Woll, & Thacker, 2005).

Different types of studies were implemented to examine the role of iconicity. Some of these studies were aimed at sign acquisition, sign memory, sign production, or sign judgments, as opposed to sign recognition. Klima and Bellugi (1979) and Meier (2002) provided examples of slips of the hand, which disrupted the iconicity of signs. They also performed a short-term memory study, showing that signs were memorized in terms of their lexical structure instead of iconic qualities. During the production of a sign verb by deaf adults, moreover, iconicity does not appear to differentially activate the neural system underlying the production of lexical items (Emmorey et al., 2004). However, Vigliocco, Vinson, Woolfe, Dye, and Woll (2005) showed that language processing by deaf signers involved a strong focus on iconicity. They showed that imagery and language are not separate cognitive modules. In signed languages, there seems to be a lot of “cross-talk” between language and imagery, more so than generally seen in spoken languages, resulting from this link between imagery and iconicity. When asked to judge which two out of three signs were most closely related for meaning, deaf adults were more affected by imagery components of the related signs than hearing people, which seems to indicate that the iconicity of signs causes deaf people to pay large attention to imagery components (Vigliocco et al., 2005).

A number of studies on iconicity have been conducted in children instead of adults (e.g., Markman & Justice, 2004; Meier, 2002; Namy, Campbell, & Tomasello, 2004; Tolar, Lederberg, Gokhale, & Tomasello, 2007). Importantly, Tolar et al. (2007) found a gradual developing ability of hearing children to recognize the meaning of iconic signs in preschool years. Markman and Justice (2004) examined the influence of iconicity on the ability to describe the function of object by children. Namy et al. (2004) studied the changing role of iconicity in gestures in hearing children. These different studies provided evidence for a beneficial role of iconicity in language acquisition. On the other hand, several acquisition studies suggest that iconicity may not play a large role for deaf children (e.g., Emmorey, 2002; Meier, 2002; Morford, 1996; Orlansky & Bonvillian, 1984). None of these different studies examined the exploitation of iconicity during online sign recognition.

In sum, ambiguous results were found for the role of iconicity in sign acquisition of children and in sign processing of adults. Online studies of the automatic use of iconicity during sign recognition in deaf children are exceptional. Thompson et al. (2009) examined the online use of iconicity during sign recognition in deaf adults, using a similar online task as presented in this article. This article focuses on the activation of sign phonology and iconicity during the online

![Figure 1](Example of an iconic sign (the sign for house).)

438 Journal of Deaf Studies and Deaf Education 14:4 Fall 2009
recognition of individual signs of SLN in deaf children who are in deaf education settings.

The Present Study: Sign Processing of Deaf Children

In order to determine if iconicity and sign phonology in SLN are exploited during lexical access to signs by deaf elementary school-aged children, we used a Sign–Picture Verification Task. For sign phonology, extended sign phonology overlap between SLN signs (i.e., sign neighbors) is expected to create an interference effect for sign–picture verification. Responses to sign–picture pairs for which the two signs share underlying sign phonology (sign neighbors) are expected to be slower and less accurate than responses to pairs for which the two signs do not share underlying sign phonology, resulting from the competition between the activated set of candidates. The correct response in the sign phonology condition would be “no” to these items, but because the sign is activated by the preceding phonological neighbor, it is harder to say “no”. Once the lexical sign is activated, sign phonology (sublexical sign) also becomes activated: that is, movement, hand shape, location, and orientation. These sublexical sign phonological features subsequently activate a set of sign candidates that match these sublexical features. Sign recognition can be viewed as a competition process in which a cohort of phonologically related signs (neighbor signs) competes for selection while the information of the sign becomes available. For example, the sign for DOG would activate the correct sign DOG, but also the sign candidate CHAIR, amongst other sign candidates. Signs for DOG and CHAIR are sign neighbors in SLN, but do not share the same hand shape (see Figure 2). The expected interference effect would occur as a result of competing lexical items with overlapping combinations of sublexical sign phonological features.

For iconicity, the close association between the form of a sign and its meaning is expected to produce a facilitation effect in the Sign–Picture Verification Task. Responses to items with strongly iconic signs are expected to be faster and more accurate than responses to items with weakly iconic signs. The correct response in the iconicity condition is “yes.” It is expected that is even easier to say “yes” to the strongly iconic items than to the weakly iconic signs, given that aspects of the form provide an advantage for recognition. It becomes easier to imagine the object or action that is being referred to, which maps closely to the contents in the corresponding picture.

Description of the Instrument Design

Initially, two tasks were implemented to select stimulus material for the design of the Sign–Picture Verification Task. The first task was necessary prior to the target investigation in order to find sign pairs with a strong sign phonological relation. The second task was necessary to confirm that the signs in the target experiment were indeed iconic. In the first instrument design task, the Phonology Similarity Judgment Task, signs were judged for sign phonology similarity. In the second instrument design task, the Iconicity Judgment Task, signs were judged for their level of iconicity. They are each described here.

Phonology Similarity Judgment Task

Method. Participants. Three deaf and six hearing bilingual adults participated in this task. The three deaf adults and three of the six hearing adults were employed as teachers of SLN. Three hearing participants participated in the final year of SLN teacher training, a college for SLN teacher and SLN interpreter training in The Netherlands.

Materials and procedure. The Phonology Similarity Judgment Task consisted of a selection of 121 sign pairs with different degrees of sign formational parameter overlap (overlap in location, movement, and/or
hand shape). This task is different from a parameter classification system, in which a distinction is made between complete parameter overlap and no parameter overlap. In a parameter classification system, two signs can have overlap for hand shape (H), movement (M), and location (L) or overlap at combinations of these three parameters (H–M, H–L, M–L, or M–L–H). However, such an approach is rather restricted. In fact, when one parameter is distinctive between two signs, the difference is somewhere along the line of a minor difference and a highly distinctive difference. For example, two signs can have an identical movement (e.g., both signs containing a straight line) or a highly distinctive movement (e.g., one sign containing a zigzag movement and the other sign containing a circular movement). However, two signs can also have very similar but distinctive movements (e.g., one sign containing a straight line and the other sign containing a slight arch, which is similar to a straight line). At present, one important question is how to deal with sign pairs that show similar but no identical parameters. Another issue relates to the differential importance for the occurrence of different hand shapes, different locations, different orientations, and different movements. For example, signs at typical locations or with very specific hand shapes may play a different role when compared with signs in neutral signing space. For these reasons, we used similarity judgments instead of the robust yes-or-no parameter overlap classification system.

Dutch translation equivalents of the sign pairs were unrelated with respect to orthography, phonology, and meaning. The signs were presented on a computer screen. Participants were asked to judge, as rapidly as possible on a 1–7 point rating scale, the extent to which two consecutively presented signs were similar in form. Items were presented randomly, varying with regard to the degree of sign phonology overlap. Based on the results of the similarity judgments, 24 pairs with a large degree of overlap according to the judgments by the seven participants were selected for the Sign–Picture Verification Task.

Iconicity Judgment Task

Method. Participants. Thirty-one hearing elementary school-aged children from Grades 4, 5, and 6, aged 10–12 years, participated in this task. All children attended an elementary school in The Netherlands. None of these children were familiar with SLN.

Materials and procedure. In the Iconicity Judgment Task, 24 strongly iconic signs and 24 arbitrary signs were presented on a computer screen. The iconic properties of the signs resembled form features of the referred objects (e.g., signs for MOUNTAIN [berg], MOON [maan], and HOUSE [huis] were including strongly iconic properties, whereas signs for CHAIR [stoel], MEAT [vlees], CLOCK [klok] did not include any strong iconic properties). One second after the sign offset, four words appeared on the screen simultaneously. The participants were to determine which of the four words belonged to the presented SLN sign. The participants used a computer mouse to respond. Both response times and accuracy measures were recorded.

Results. Accuracy rates were computed separately for each participant for both test conditions. The expectation was that if the iconic signs were indeed iconic, the meaning of those signs could be derived more easily than for arbitrary signs for nonsigners. This was confirmed by the hearing children. A significant effect was obtained for iconicity. ($t = 4.76, p < .001$: Strong iconicity condition, $MS = 76.34\%$; Weak iconicity condition, $MS = 44.13\%$).

Experiment: Sign–Picture Verification Task

Method. Participants. The participants in this article were 40 bilingual deaf children ranging in age from 8.1–12.2 years ($M = 10.6$ years; standard deviation $[SD] = 1.8$). The participants were divided into two age groups. The younger participants were between 8.1 and 10.3 years ($n = 20, M = 9.7$ years; $SD = 0.7$, around Grades 3 and 4; Note 1: In the schools for the deaf in The Netherlands, age ranges within one group can sometimes be larger than those in one group in mainstream elementary education) and the older participants were between 10.4 and 12.2 years ($n = 20, M = 11.0$ years; $SD = 0.7$ years, around Grades 5 and 6). The children attended one of three schools for deaf education in The Netherlands. All of the schools provided bilingual deaf education with a curriculum that consisted of a combination of
SLN and Dutch (including Sign Supported Dutch [SSD]). In SSD, Dutch word order is used with the support of signs. The children had been taught Sign Language of The Netherlands from the age of 4 years at school. Prior to the age of 4 years, many of the children had already attended preschool for deaf children and thus interacted with preschool teachers who used sign language.

**Stimuli.** In the Sign–Picture Verification Task, 192 sign–picture pairs were presented: 50% of the sign–picture pairs were matches and thus required a “yes” response whereas 50% of the pairs were mismatches and thus required a “no” response. The sign videos were part of the standard SLN lexicon. The videos were created by the Dutch Centre for Sign Language and presented on the left side of a computer screen. The pictures originated from Leesladder (Reading Ladder; Irausquin & Mommers, 2001), which is a computer program for children with reading disabilities. The pictures were colored 6 × 6 cm line drawings representing nouns and presented on the right side of the computer screen. The experimental stimuli were created with the aid of two instrument design studies: the Phonology Similarity Judgment Task and the Iconicity Judgment Task. The stimulus items were distributed across four experimental conditions reflecting the strengths of two factors: iconicity (Condition 1: Strong iconicity, match items; Condition 2: Weak iconicity, match items; see Figure 3) and sign phonology (Condition 3: Strong phonological relation, mismatch items; Condition 4: Weak phonological relation, mismatch items; see Figure 4). In addition, filler items were added.

In the second instrument design study, the Iconicity Judgment Task, we demonstrated that hearing children without any knowledge of sign language recognized the meaning of the strong iconic signs (Condition 1, match items) significantly better than the meaning of the weak iconic signs (Condition 2, match items), showing that the meanings of the signs were recognizable as a result of the form of the sign. Each of the four conditions contained 24 unique sign–picture combinations (Table 1).

In Conditions 1 and 2 (iconicity), the pictures, and therefore the unique pairs were repeated once, adding up to 48 items in Condition 1 and 48 items in Condition 2 (96 pairs referring to the same concept; e.g., sign for horse and a picture of a horse). The rationale behind the repetition of unique items in Conditions 1 and 2 was based on the design for Conditions 3 and 4, which also involved repetition of pictures. Conditions 3 and 4 (sign phonology, mismatch items) involved 24 pairs referring to different concepts (e.g., the sign for dog and a picture of a chair). Condition 4 was constructed by recombining the signs and pictures from the related condition (i.e., Condition 3) in such a manner that unrelated pairs were formed (Note 2: In other words, Condition 4 consisted of the same set of signs and pictures as Condition 3 but combined in a sign phonologically unrelated manner. In Condition 3, e.g., the Dutch sign for DOG was combined with a picture of a CHAIR (sign phonology related); similarly, the Dutch sign for SOCK was combined with a picture of a BLANKET (sign phonology related). In Condition 4, sign phonologically unrelated pairs were created via the combination of the sign for DOG with
The experimental test consisted of four sets of stimuli initially preceded by a separate practice set, which included 10 items. The practice set contained items that were different from the experimental sets. Each of the four experimental sets consisted of 12 pairs from Condition 1 (Strong iconicity, match), 12 pairs from Condition 2 (Weak iconicity, match) to make up 24 “yes responses” per set, 6 pairs from Condition 3 (Strong phonological relation, mismatch), 6 pairs from Condition 4 (Weak phonological relation, mismatch), and 12 filler items to make up 24 “no responses” per set, adding up to 48 unique pairs per set. At the start of each stimulus set, four new practice items were shown.

Sign frequency measures are not yet available for SLN. Word orthography frequency measures were based on the CELEX Lexical Database (Baayen, Piepenbrock, & van Rijn, 1993). CELEX stands for Centre for Lexical Information. CELEX measures refer to a large lexical database, which can be found at an open source: www.celex.mpi.nl. Recombining the signs and pictures in Condition 3 into unrelated pairs in Condition 4 resulted in identical signs and pictures between the two conditions. As a result of recombining the same signs and pictures, the sign and picture properties in Condition 3 (Strong phonological relation, mismatch) were identical to these properties in Condition 4 (Weak phonological relation, mismatch). Given that the purpose of the study was not to compare the effects of sign phonology with the effect of iconicity, word and sign properties could be different between the two different factors sign phonology and iconicity. Instead, the purpose was to examine effects of sign phonology and to examine effects of iconicity independently for deaf children. The word translations for the signs and the words corresponding to the pictures in Condition 1 had an average of 1.59 log frequency per million, using CELEX measures, and an average frequency of 22.21 per 15,000, as observed.

Table 1  Structure of the sign-picture verification task

<table>
<thead>
<tr>
<th>Factors and conditions</th>
<th>Grades</th>
<th>Response</th>
<th>Nr items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iconicity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condition 1: Strong</td>
<td>3rd/4th grade</td>
<td>Yes</td>
<td>24 × 2</td>
</tr>
<tr>
<td>Condition 2: Weak</td>
<td>3rd/4th grade</td>
<td>Yes</td>
<td>24 × 2</td>
</tr>
<tr>
<td>Condition 1: Strong</td>
<td>5th/6th grade</td>
<td>Yes</td>
<td>identical</td>
</tr>
<tr>
<td>Condition 2: Weak</td>
<td>5th/6th grade</td>
<td>Yes</td>
<td>identical</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Subtotal 96</td>
</tr>
<tr>
<td>Sign phonology</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Condition 3: Strong</td>
<td>3rd/4th grade</td>
<td>No</td>
<td>24 × 1</td>
</tr>
<tr>
<td>Condition 4: Weak</td>
<td>3rd/4th grade</td>
<td>No</td>
<td>24 × 1</td>
</tr>
<tr>
<td>Condition 3: Strong</td>
<td>5th/6th grade</td>
<td>No</td>
<td>identical</td>
</tr>
<tr>
<td>Condition 4: Weak</td>
<td>5th/6th grade</td>
<td>No</td>
<td>identical</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Subtotal 48</td>
</tr>
<tr>
<td>Fillers</td>
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<tr>
<td>Filler condition</td>
<td>3rd/4th grade</td>
<td>No</td>
<td>48</td>
</tr>
<tr>
<td>Filler condition</td>
<td>5th/6th grade</td>
<td>No</td>
<td>identical</td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Total 196</td>
</tr>
</tbody>
</table>

Figure 4  Sign phonological relatedness. Participants were shown a videotaped sign (e.g., the sign for a dog) and a picture (e.g., of a chair). A. Condition 3: Strong phonological relation. B. Condition 4: Weak phonological relation.
for children by Schrooten and Vermeer (1994). The mean length was 4.66 letters. In Condition 2, the word translations for the signs and the words corresponding to the pictures had an average of 1.52 log frequency per million (CELEX), an average frequency of 22.79 per 15,000, as observed in the children’s corpora (Schrooten & Vermeer, 1994), and the mean length was 5.21 letters. In Conditions 3 and 4, the word translations for the signs and the words corresponding to the pictures had a combined average of 1.52 log frequency per million, using CELEX measures, and an average frequency of 18.98 per 15,000, as observed in the children’s corpora by Schrooten and Vermeer. The mean length was 5.46 letters. In the filler items, there was an average of 1.53 log frequency per million, using CELEX measures, and an average frequency of 38.84 per 15,000, as observed for children by Schrooten and Vermeer. The mean length was 4.31 letters.

**Design.** The order of presentation was constructed using a Latin Square design. Within each of the four stimulus set, the 48 pairs were presented in a random order per child.

**Apparatus.** In this experiment, a laptop, type Dell, Latitude 640, was used. The test was constructed using the commercially available software program E-Prime, version 1.0, Science Plus Group (The Netherlands; Schneider, Eschman, & Zuccolotto, 2002).

**Procedure.** The instructions for the task were provided in SLN on a class basis provided by the teachers of the children. After group instruction, questions could be asked about the procedure. The experiment was then conducted with groups of six children in a separate, well-lightened room with two experimenters present. The distance between the children and the screen was approximately 40 cm. During instruction, the participants were informed that a fixation point would appear on the screen for 1 s, followed by an SLN sign on the left side of the screen and a picture on the right side of the screen, which appeared simultaneously with the sign onset. The video was presented once. As soon as the video was finished, the left side of the screen was blank. The stimuli disappeared after the participant responded or after a period of 10 s and the next item followed. When both the sign and picture referred to the same concept, a match response was required and the respondent had to press the “Enter” button that had a green mark on it. When the sign and picture did not refer to the same concept, a mismatch response was required and the respondent had to press the “Caps Lock” button that had a red mark on it. After the instructions were provided and understood by the participants, the practice set with 10 items was presented. After these 10 items, the Dutch word for “break” appeared on the screen, indicating the start of a self-paced break; the participants could continue by pressing one of the response buttons. After every 52 items (4 practice items plus 48 stimulus items), a self-paced break occurred again. Upon completion of the four sets of stimuli, the Dutch word for “End” appeared.

**Results.** Both response time (RT) and accuracy of responding (%) were measured (see Table 1). The RTs were measured from the onset of the stimuli and, for the RT analyses, erroneous responses and RTs that were more than 2 SD from a participant’s mean and the item mean were excluded from further analysis. For the younger participants, 1.29% of the data was excluded. For the older participants 1.46% of the data was excluded from further analysis. Participant and item analyses were performed on the data. The F values for the participant analyses will be referred to as $F_1$ and the $F$ values for the item analyses will be referred to as $F_2$. A one-way ANOVA was conducted for the item analyses on the iconicity data (i.e., on Conditions 1 and 2, match). Repeated measures ANOVAs were conducted for the participant analyses on the iconicity data (i.e., Conditions 1 and 2). Repeated measures ANOVAs were also conducted for the participant as well as the item analyses on sign phonology (i.e., Conditions 3 and 4, mismatch).

**RT data sign phonology.** Sign phonology was treated as a within-participants and within-items factor. Grade was treated as a between-participants factor and within-items factor. A significant inhibitory effect was found for Sign phonology. Pairs of items with strong phonological relations between the relevant
signs (Condition 3) were responded to more slowly than pairs of items with weak phonological relations between the relevant signs (Condition 4; \( F[1, 38] = 60.65, p < .001, \eta^2_p = .62; F[2, 23] = 16.41, p < .001, \eta^2_p = .42 \)) and a main effect for grade was also detected (\( F[1, 38] = 7.71, p < .01, \eta^2_p = .17; F[2, 23] = 107.09, p < .001, \eta^2_p = .82 \)), with the older participants responding faster than the younger participants. No interaction was found between grade and sign phonology (\( F[1, 38] = 2.95, p < .1, \eta^2_p = .07; F[2, 23] = .54, p > .05, \eta^2_p = .02 \)).

**Accuracy data sign phonology.** Sign phonology produced significant main effects on the accuracy data. The effect of sign phonology showed that more errors were made for pairs with strong phonological relations (\( F[1, 38] = 200.17, p < .001, \eta^2_p = .84; F[2, 23] = 18.49, p < .001, \eta^2_p = .45 \)). A significant effect was found for grade, but only in the item analyses (\( F[1, 38] = 1.26, p > .1, \eta^2_p = .03; F[2, 23] = 5.58, p < .05, \eta^2_p = .20 \)). No interaction was found between grade and sign phonology (\( F[1, 38] = 1.63, p > .1, \eta^2_p = .04; F[2, 23] = 2.14, p > .1, \eta^2_p = .09 \)).

**RT data iconicity.** In this analysis, iconicity was treated as a within-participants and between-items factor. A significant facilitation effect was found for iconicity (see Table 1). Strongly iconic pairs were responded to faster than weakly iconic pairs (\( F[1, 38] = 24.18, p < .001, \eta^2_p = .39; F[2, 46] = 4.48, p < .05, \eta^2_p = .09 \)). A main effect for grade was also detected (\( F[1, 38] = 6.62, p < .05, \eta^2_p = .15; F[2, 46] = 199.34, p < .001, \eta^2_p = .81 \)). The older children responded significantly faster than the younger children. No interaction was found between grade and iconicity (\( F[1, 38] = .59, p > .1, \eta^2_p = .02; F[2, 46] = 1.02, p > .1, \eta^2_p = .02 \)).

**Accuracy data iconicity.** Iconicity also produced significant main effects on the accuracy data, but no interactions with grade. The effect of iconicity showed fewer errors to be made with strongly iconic pairs than with weakly iconic pairs (\( F[1, 38] = 46.68, p < .001, \eta^2_p = .55; F[2, 46] = 11.21, p < .01, \eta^2_p = .20 \)). No main effect was found for grade (\( F[1, 38] = .09, p > .1, \eta^2_p = .00; F[2, 46] = .28, p > .1, \eta^2_p = .01 \)). No interaction was found between grade and iconicity (\( F[1, 38] = .94, p > .1, \eta^2_p = .02; F[2, 46] = 1.40, p > .1, \eta^2_p = .03 \); Table 2).

**Conclusion.** The experimental factors sign phonology and iconicity produced significant effects. The expected inhibition effect for sign phonology suggests that the presentation of a sign results in the activation of competing sign neighbors. The expected iconicity effect suggests that the children exploit the iconicity of signs during sign recognition.

**General Discussion**

**Sign Processing for Deaf Children**

The main question of this article is whether the recognition processes of signs are the same for adults and deaf children. Past studies on sign phonology showed that deaf adults activate sign neighbors during sign processing. No studies on sign phonology were performed with deaf children. Studies on iconicity in adults as well as in children showed mixed results with one recent online study showing that deaf adults activate iconicity during sign recognition.

The results in the present online study suggest that the involvement of sign phonology and iconicity in sign recognition processes found in some studies of deaf adults is also applicable to deaf children. First, this article showed that deaf children clearly do not activate the presented sign only when accessing the meaning of a sign, but rather process signs as

<table>
<thead>
<tr>
<th>Factors and conditions</th>
<th>Grade</th>
<th>Reaction times</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sign phonology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condition 1: Strong</td>
<td>3rd/4th grade</td>
<td>1871 (455)</td>
<td>.92 (.05)</td>
</tr>
<tr>
<td>Condition 2: Weak</td>
<td>3rd/4th grade</td>
<td>1959 (367)</td>
<td>.83 (.09)</td>
</tr>
<tr>
<td>Condition 1: Strong</td>
<td>5th/6th grade</td>
<td>1542 (378)</td>
<td>.93 (.06)</td>
</tr>
<tr>
<td>Condition 2: Weak</td>
<td>5th/6th grade</td>
<td>1680 (384)</td>
<td>.81 (.11)</td>
</tr>
<tr>
<td>Iconicity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condition 1: Strong</td>
<td>3rd/4th grade</td>
<td>2437 (419)</td>
<td>.72 (.12)</td>
</tr>
<tr>
<td>Condition 4: Weak</td>
<td>3rd/4th grade</td>
<td>2178 (409)</td>
<td>.94 (.05)</td>
</tr>
<tr>
<td>Condition 3: Strong</td>
<td>5th/6th grade</td>
<td>2054 (376)</td>
<td>.68 (.14)</td>
</tr>
<tr>
<td>Condition 4: Weak</td>
<td>5th/6th grade</td>
<td>1887 (375)</td>
<td>.93 (.08)</td>
</tr>
</tbody>
</table>
a combination of sublexical units, and consequently, they activate a cohort of competing neighbor signs. When the sign phonology of two signs partly overlapped, inhibition occurred; that is, because neighbor signs were apparently activated during the verification task, participants were slower and less accurate in responding. The phonological activation of signs demonstrated in this experiment is in agreement with the findings of recent research on the sign processing of deaf adults (e.g., Dye & Shih, 2006). Second, when the sign to be processed was highly iconic (i.e., the meaning of the sign resembled the form to a considerable extent), facilitation was found to occur; that is, strongly iconic signs produced faster and more accurate responding than weakly iconic signs. Thus, the iconicity effect in this experiment is in agreement with some findings of sign processing of deaf adults (e.g., Thompson et al., 2009).

In summary, the process involved in sign recognition in deaf children, based on our results, is as follows: When a lexical sign (e.g., DOG) is processed, sign phonology (sublexical sign) also becomes activated: that is, movement, hand shape, location, and orientation. The correct combination of the four sublexical sign phonemes is activated, leading to the accompanying lexical sign (e.g., DOG, see Figure 4), but also combinations whereby only part of these sublexical sign phonemes are activated (e.g., leading to CHAIR, see Figure 4). Thus, not only is the target sign activated when accessing the meaning of a sign but also are combinations of sublexical phonological units, and they activate a cohort of competing neighbor signs. In addition to the correct combination of sign phonemes, several other combinations of (partly overlapping) sign phonemes are therefore also activated, together with the competing neighbor signs (e.g., CHAIR). Both at the lexical sign level and at the sublexical sign level, iconic features are expected to affect the relation between form and semantics.

The results show a similar lexical access process to what has frequently been found in spoken word recognition; sublexical units and neighbor signs become active during lexical access to a sign. Now we have confirmed that deaf children do indeed activate sign neighbors based on shared underlying sign phonological features during sign processing, it would be interesting to study whether the same phonological features are used as for adult signers. The results also suggest that sign iconicity is exploited in the sign recognition of deaf elementary school-aged children, similar to findings with deaf adults (Thompson et al., 2009). It is difficult to decide what aspects provide most nonarbitrary mapping between form and meaning. Iconicity in individual signs can be seen in hand shapes, in movements, in locations, and in combinations of these parameters. In some cases, an entire object can be represented in a sign. The Dutch sign for “ball,” for example, refers to the round shape of the ball. In other cases, only part of an object is referred to, for example, in the Dutch sign for “cat,” where the whiskers of the cat constitute the sign for cat. The hand shape for the sign cat shows extended fingers, which resemble the whiskers. Moreover, the location resembles the place of the whiskers (above the mouth). Possibly, the level of nonarbitrary mapping is not necessarily larger when the sign resembles an entire object or action as opposed to part of an object or action. Some iconic features are expected to be more salient than others. As Pietrandrea (2002) stated, signs that have body location as an iconic feature seem to be carrying more semantic information than iconic signs made into neutral space. The same may be true for different kinds of movement. The iconic meaning of certain movements may be more salient than other movements. If a movement is iconic and specific, such as zigzag, the level of iconicity may be larger than for a sign that has an iconic movement of a less specific movement, such as a straight line. We expect that frequency of occurrence of specific iconic movements, locations, and hand shapes may be related to the level of salience. Moreover, sign properties can be iconic to some people, but not to others. For example, some Dutch signs are iconic to older people but not to many younger people, for example, the signs for “milk” (resembling the procedure of milking a cow manually) and for “coffee” (resembling the procedure of grinding coffee beans manually). Thus far, it is unknown at which level the activation of iconicity can be found. The relative contribution of iconicity and sign phonology may need to be examined in order to gain insight into the levels where iconicity and sign phonology come into play during sign recognition. If
the effects of iconicity and sign phonology are additive in a sign processing task, iconicity and sign phonology are unlikely to be activated at the same level. However, if the effects are interactive, iconicity and sign phonology may be activated at the same level. It seems evident that additional research is needed to pinpoint the different degrees and different types of iconicity. In addition, further research is needed to examine the iconicity effects of different degrees and types of iconicity during sign recognition and the level where iconicity activation occurs in the sign recognition process.

Directions for Future Research

As we already mentioned in the description of the Phonology Similarity Judgment Task, the approach of merely deciding whether a certain parameter, for example, hand shape or movement, is identical between two signs may need some reconsideration. When one parameter is distinctive between two signs, the difference is somewhere along the line of minor difference and a highly distinctive difference. The current general approach is to regard all degrees of differences on a parameter as similar (i.e., the two signs are distinctive or not). A grading system may be helpful in order to gain further insight into the cognitive processes. Such a system would also be supportive when working toward a model of sign perception. Similar to spoken languages processing, for which different models were designed such as TRACE model, Cohort model, and a distributed model (see Gaskell & Marslen-Wilson, 1997 for details on these models), signed language processing should ideally also be modeled. From spoken language research, it is known that neighborhood size and frequency are some of the affecting components for spoken word recognition. The same is likely to be true for sign processing. For signed languages, it is therefore important to continue sign processing research to get neighborhood size and frequency information available, whereby sign neighbors should become defined and sign corpora could grow to serve further research.

In this article, iconicity has been studied for the processing of individual signs and, moreover, for concrete signs only. This, evidently, implies that a restricted set of signs and restricted aspects of iconicity were tested in this article. The question of whether and how iconic features affect processing of other types of signs and signs in discourse remains unanswered. Supplementary studies are therefore needed to gain further insight into the beneficial effects of iconicity on sign recognition of deaf children and whether the present results extend to different types of signs.

Thus far, iconicity and sign phonology research have been isolated fields of research. In future work, it may prove beneficial to attempt to find the connection between these two essential components during sign processing. It is possible that iconicity affects sign recognition because of the interplay between semantics and sign phonology. Moreover, the level of imageability could affect the iconicity facilitation effect. In word recognition studies, words with a larger degree of imageability are expected to be easier to process than words with a lesser degree of imageability (van Hell & de Groot, 1998). If iconic parts of a sign make a sign more related to the imagistic properties of a particular sign, one might expect those signs to be easier to process than signs with a weaker or no relation to the imagistic properties of a sign. Perhaps the level of iconicity could be regarded in terms of level of imageability, whereby strong iconic features make the movements or objects that are being referred to easier to image. In the attempt to find the connection between sign phonology and iconicity, it is important to be aware that sign phonology activation refers to sublexical activation, whereas the activation of iconicity often refers to information about the lexical item (although iconicity can be seen on one sublexical component as well, e.g., the hand shape only, and the iconic information often refers to only a part of the lexical item, e.g., the Dutch sign for cat refers to the cat’s whiskers only). We used the term activation for both types of information, given that activation does occur. More research is needed to tackle the question what the activation of both sign components involves and how they interact.

Finally, the relation between language and meaningful human actions has been studied for spoken languages recently. Processing of spoken languages is increasingly approached within the framework of “embodied cognition,” whereby the comprehension of
language is seen as inherently related to meaningful human actions within an environment (Glenberg & Kashak, 2002). Future research into the role of iconicity and sign phonology could perhaps be implemented within the framework of “embodied cognition.”

References


Received February 11, 2008; revisions received June 9, 2009; accepted June 14, 2009.