8

ADVANTAGES OF LEARNING A SIGNED LANGUAGE

PETER C. HAUSER AND GEO KARTHEISER

Pierre Desloges wrote in 1779, in the first book known to be published by a deaf person, that he could not understand why everyone did not learn a signed language, given all the apparent benefits of learning one.[1] At the same time, French philosopher Étienne Condillac also suggested teaching sign not only to deaf children but also to hearing children.[2] However, the cognitive advantages of learning a signed language were not documented until the late twentieth century, partially because it was not until the 1960s when scholars began to accept that signed languages are natural languages. It all started when William Stokoe, a Gallaudet University English professor, noticed that there were grammatical patterns appearing in the gestures of American Sign Language (ASL) that were similar to those of spoken languages.[3] Since then, scholars have studied different signed languages around the world and determined that they in fact have all the characteristics of natural languages. The linguistic features of natural languages, such as phonology, morphology, and syntax, are found in signed languages.[4]

The research of Laura-Ann Petitto, an educational neuroscientist and the science director of the National Science Foundation's Science of Learning Center on Visual Language and Visual Learning (VL2) at Gallaudet University, and her colleagues has shown that exposure to language, whether it be spoken or signed, activates the classic language-oriented brain tissue in hearing babies.[5] Petitto and others have also found that deaf and hearing babies raised in signing households achieve developmental language milestones at the same age-appropriate times that hearing children achieve spoken-language milestones.[6] Deaf babies learn their first signs around the same time that other babies learn their first spoken words. The first two-word sentences also appear in signed and spoken languages at the same developmental stage. The brain has the ability to learn languages regardless of the modality used, visual or auditory, which means learning to sign or speak is really about learning a language.

Cognitive neuroscientists such as Daphne Bavelier, along with her colleagues, used neuroimaging technology (fMRI) to compare ASL and English processing in deaf and hearing native adult signers.[7] They found that the classic area in the left

hemisphere of the brain that is typically used for processing spoken language is also used for processing sign language. This suggests that the areas of the brain responsible for language process language independent of the modality (spoken or signed) of the language. They also found that processing of ASL involves some of the right hemisphere as well. Follow-up studies by Aaron Newman and colleagues revealed that specific areas in the right hemisphere of the brain are used for processing inflectional morphology, narratives, and prosody in ASL, some of which are the same areas used in spoken languages and some of which are not.[8] Older studies on deaf signers with right-hemisphere strokes also illustrated that the right hemisphere involves the use of spatial syntax and classifier constructs in signed languages.[9]

Some of the surface aspects of signed languages require visuospatial processing. As a result, signed languages utilize some parts of the brain, particularly in the right hemisphere, that are not exercised (or at least not to the same extent) by spoken languages. Learning a signed language, therefore, has some linguistic and nonlinguistic cognitive gains that are recognized here as "sign gains." Sign gains are overlooked in many research studies and are often "misinterpreted" as a hearing-status effect. When scientists compare deaf signers with hearing nonsigners and discover differences between the two groups, it is not clear whether the differences are due to hearing status or signing skills (or a combination of both). To truly identify sign gains, studies must find that both deaf signers and hearing signers perform better than deaf and hearing nonsigners on a specific cognitive skill.

There have been some studies on the impact of sign-language competency since the 1980s. Experimental studies on the cognitive functioning in signers' brains have shown that signers perform better in some areas of face, memory, and motion processing. Each of these gains is discussed in depth here with a description of the studies that show its effects. Although the focus is placed on particularly the advantages for all people, regardless of hearing status, there are some advantages that are specific to deaf children and adults. These specific advantages are discussed in the last part of the chapter, along with the implications of Sign Gain in research and practice.

Face-Processing Advantages

A person who is not familiar with signed languages might think that signs are made with the hands and arms only. The face plays an important role in the production of sign-language utterances, including phonological, morphological, lexical, syntactical, and prosodic features. To interpret appropriate linguistic information from the face, signers must be able to rapidly identify many different features and expressions during language comprehension. Eye-tracking studies have found that fluent signers focus on the face when engaged in a conversation or perceiving signed language instead of following the hands.[10] A number of studies since the

1980s have investigated whether signers have some superior face-processing skills because of their frequent attention to and processing of facial features.

One way to test face processing is to determine whether signers have a better ability to recognize faces than nonsigners. Studies began this investigation using the Benton Test of Facial Recognition.[11] It was a multiple-choice test in which each page (item) had a picture of a person at the top; at the bottom, the same person appeared along with other people. The person at the top was shown in a lighting condition, angle, or both that were different from the depiction at the bottom. The test taker had to identify where the person at the top of the page appeared again at the bottom of the page. Ursula Bellugi and her colleagues from the Salk Institute for Biological Studies found that deaf children between the ages of six and nine performed better on the Benton Test than their hearing age-peers who did not know sign.[12] However, it remained unclear whether the advantage was due to sign-language competency or hearing status.

In 1992, Jeffrey Bettger's doctoral dissertation investigated whether deaf signers' enhanced performance on the Benton Test was due to sign competency.[13] He found that hearing signers performed as well as deaf signers on the Benton Test, and both groups performed better than hearing nonsigners. In a follow-up study, Ila Paranis and colleagues found that deaf nonsigners did not perform as well as hearing and deaf signers on the Benton Test.[14] Bettger and his colleagues further investigated whether signers' advanced performance on the Benton Test was specifically related to face processing or whether signers were better at processing objects in general. The Benton Test was then given to deaf signers and hearing nonsigners with the faces flipped upside down. The participants had to find the upside-down face on the top of the page among a sample of upside-down faces depicted on the lower half of the page. Signers and nonsigners performed similarly in this condition; Bettger and colleagues concluded that the impact of signed-language competency on the mechanism of discrimination is limited to faces, not objects, in their upright, everyday position.[15]

Although the Benton Test was developed to measure face recognition, a sign-language neurolinguist, Karen Emmorey, claimed that it is actually a visual-discrimination test.[16] Emmorey pointed out that the test did not require the participants to exercise any of their memory skills, which would have been involved in any task requiring recognition. Instead, it required participants to discriminate between faces, as they had to single out the target face among a group of other faces. Stephen McCullough, a deaf neuroscientist, worked with Emmorey to investigate whether signers actually have better face-recognition skills. They used the Warrington Recognition Memory Test for Faces to answer their question. In that test, participants were asked to view fifty faces and mark each as either "pleasant" or "unpleasant" so that participants would not realize they had to memorize the faces. At random intervals, the participants would be asked to recall which face they last saw. Deaf signers and hearing nonsigners performed equally

well, suggesting that the demanding nature of signed language for gathering linguistic information from the face affects not facial recognition but attention to facial features.[17]

Now it was clear that signers attend to facial detail better than nonsigners, but it remained unclear whether sign-language competency had a positive impact on the processing of the local features (eyes, nose, or mouth) or global features (whole face, head, neck) of the face. To investigate this, McCullough and Emmorey gave the Mooney Faces Closure Test to signers and nonsigners. Participants had to categorize pictures of human faces that were highly contrasted (so that the local facial features became unrecognizable, leaving only global features detectable) into groups based on age (young, old) or gender (male, female).[18] Signers and nonsigners did not perform differently on this task, suggesting that the discriminating advantages of facial processing in sign language most likely are limited to specifically local facial features.

McCullough and Emmorey were keen to investigate which local facial feature was most salient to signers when it came to discrimination.[19] They gave a group of deaf signers and hearing nonsigners a test in which they were presented with a target face for a few seconds and then were given two faces to choose from as a response to the target face. The two faces were identical to the target faces with one exception: one of the local facial features (nose, eyes, or mouth) of one of the two faces had been replaced with a new feature. With one of the two faces slightly altered, the participants had to report which of the two shown faces matched the target face. Hearing and deaf signers excelled in performance when the eyes were changed; they had higher accuracy than nonsigners. Only the deaf signers had greater accuracy with the mouth feature. All groups did not differ in accuracy when the nose was altered.

Naomi Goldstein and Robert Feldman speculated that since signed language extracts linguistic information from the face, it could impact the ability to recognize emotional facial expressions as well. To put their hypothesis to a test, hearing signers and nonsigners were asked to watch a videotape of people expressing spontaneous emotions and then to identify facial expressions with emotional labels (happy, sad, angry, and so on). All participants performed equally well at recognizing happy faces, but signers were better at recognizing two specific facial expressions: disgusted and angry.[20] Elaborating upon the study on facial-expression recognition, Goldstein, James Sexton, and Feldman produced an experiment that tested hearing signers' and nonsigners' ability to express emotions through the face.[21] The participants were filmed producing different facial expressions that were eventually shown to untrained judges. The judges, who had no knowledge of ASL, were able to correctly identify the emotional facial expressions produced by hearing signers better than those produced by hearing nonsigners.

Overall, there are clear advantages of learning a signed language in relation to face processing. Signers fixate on the face during sign-language discourse and

develop enhanced skills in discriminating eye features and, for deaf signers, mouth features. This specialized attention to facial features has enabled signers to perform better than nonsigners on the Benton Test whether they are deaf or hearing, children or adult, and native or nonnative signers. These enhanced face-processing abilities are a gain obtained through learning a signed language, hence an example of a Sign Gain.

Memory-Processing Advantages

Memory is involved in language processing. A person coming up with a sentence has to remember what he or she wants to say, the words to use, and the situation in which the sentence will be shared. Similarly, a person listening to someone talking needs to remember what was said and to build a mental "image" or story (requiring short-term memory) about what is being told. In the case of signed-language utterances, there are often spatial markers in the signer's space or environment that are a part of the story. There are visual aspects of utterances constructed in signed language, so visual memory is involved in comprehension. Sometimes signers talk about something from their own perspectives, thus forcing the listeners to mentally "rotate" the information (requiring visual working memory) so that they "get" the signer's perspective. Cognitive experiments that have investigated memory advantages of sign-language competency have shown that signers, compared to nonsigners, perform better on tasks that involve spatial memory, visual working memory, and image generation. Signed-language processing "exercises" these cognitive functions and makes them "stronger" to a point where these cognitive functions are improved even when processing nonlinguistic information.

Spatial memory is a specific type of visual short-term memory, and it is used when one imagines spatial images in short-term memory. Spatial images are simple representations of how objects are arranged in space, whereas visual images carry information in regard to what the object looks like. An example of a spatial image is imagining the layout of your bedroom, visualizing where each piece of furniture is set in relation to the others (regardless of what the furniture looks like). Spatial images are created frequently in signed-language utterances. Signers use their signing space to represent spatial images or to show spatial relations between objects. In other words, using and understanding a sign language "exercises" an individual's spatial memory frequently. Signed language's strong relation to spatial images prompted researchers to investigate whether signers have better spatial memory than nonsigners.

The Corsi Blocks Task is used in experiments to measure individuals' spatial-memory span. An individual's spatial span represents how many different spatial objects or locations an individual can hold in short-term memory at once. The task involves a board with blocks glued on in a random order. The experimenter taps a sequence of blocks, and the participant has to repeat the tapping sequence. The number of blocks involved in the tapping sequences increases through the test.

The number of blocks a participant can remember before failing is considered his or her spatial span.

An elementary school in Italy taught hearing children Lingua dei Segni Italiana (Italian Sign Language) as a part of their regular curriculum. A team of researchers compared hearing children from that school who had studied signed language for a year with hearing children from the same school who had no sign-language knowledge. They found that the children with one year of signed-language training had significantly greater spatial spans.[22] In another study, it was found that deaf children in India who did not know signed language did not have a longer spatial span than hearing nonsigners.[23] Taken together, these studies suggest that learning a signed language enriches an individual's spatial memory.

Visual working memory is used when one holds visual information (that one is attending to at the moment) in short-term memory and does something (work) with that visual information (such as mentally move it around, take it apart, or manipulate it). The visual information in the short-term memory may be spatial (involving an object in space) or the visualization of a two-dimensional or three-dimensional object. One way to test visual working memory is to give a test called mental rotation. A complex three-dimensional shape is shown to the test taker; then the same shape is rotated into a different position and shown to the test taker along with a few other shapes that do not match the original shape. The test taker has to mentally rotate the original shape to figure out which choice matches the original shape even though it is in a different position, perspective, or orientation.

A deaf researcher, David McKee, was the first to give the mental-rotation test to deaf and hearing participants in research for his doctoral dissertation.[24] The participants were shown three rotated shapes and were asked to choose which two of the three shapes were the same. McKee's study showed that deaf signers performed the mental-rotation task better than hearing nonsigners. Karyn Talbot and Richard Haude wanted to know whether the level of sign-language competency had an impact on visual working memory. They administered the mental-rotation test to hearing signers with one year or less experience in signing and to hearing signers with six years or more experience in signing. Hearing signers with more sign experience were found to perform better on the mental-rotation task than hearing signers with less experience.[25] To further illustrate that sign-language competency alone supplements visual working memory, Charlene Chamberlain and Rachel Mayberry found that deaf nonsigners perform equally well on the mental-rotation task as hearing nonsigners.[26]

The idea that signers perform better on visual-working-memory tasks was similarly found in a study conducted in Japan. Nobuo Masataka found that when the letter *p* was traced on deaf children's bodies, they were more likely to identify the correct letter than their hearing nonsigning peers.[27] The hearing nonsigning children tested in Masataka's experiment were three times more likely to make a

mirror-reversed error (such as *d* for *b*). It was also discovered in this study that the breadth of sign vocabulary had a corresponding effect on the likelihood of accurately transforming what was being written on the deaf children's bodies.

Building an image of the story or information being told in signed language is an important part of processing signed language. To test the impact of signed language on image generation, Emmorey, Stephen Kosslyn, and Ursula Bellugi developed a task in which deaf and hearing participants were shown a matrix of solid and empty cells, with the solid cells forming an uppercase letter. The participants were asked to remember what the uppercase letters looked like and the cells they covered when positioned into the matrices. The participants were then shown a lowercase letter and a matrix of squares with an *X* in one of its cells. The participants were asked to verify as quickly as possible whether the uppercase form of the letter (for example, if *g* was shown, then participants were to imagine *G*) previously covered the space where the *X* now was. The participants were given multiple trials with ten different letters. The study found that deaf and hearing signers performed equally on accuracy when compared with hearing nonsigners, but both deaf and hearing signers were able to respond faster than hearing nonsigners.[28] Emmorey theorized that signers' superior performance on mental-rotation tasks might be partially due to their faster image generation along with enhanced skills in reversal transformations and longer spatial span rather than the ability to rotate images faster.[29]

Motion-Processing Advantages

The movements of signs represent significant aspects of sign-language phonology (comparable to vowels in spoken language). When movements of signs are recognized, along with the other sign phonology features, the sign itself is then identified. Variations in movement also have narrative and prosodic components in sign-language processing. The subtle differences in the movement patterns of signed languages change the meaning of what is being expressed. Given that sign-language processing involves attention to movements, some researchers have questioned whether signers have enhanced ability to categorize subtle differences in motion.

Howard Poizner investigated motion perception in deaf signers and hearing nonsigners. He developed a video with a signer who was affixed with lights on the head, shoulders, joints of the arm, and the index fingertips and who created hand movements containing sign-language linguistic information in a pitch-black room. The video was then shown to deaf signers and hearing nonsigners, and they were asked to identify which two of the three shown movements were most similar. Deaf signers were more sensitive to certain movements in this task than hearing nonsigners, suggesting that sign-language experience might lead to enhancements in motion perception and categorization.[30]

To see whether this was an effect unique and limited to the properties of ASL,

Poizner, Angela Fok, and Bellugi repeated the study with a new population, Chinese Sign Language (CSL) signers and hearing nonsigners. The results of this study showed that CSL users were more sensitive to movement than nonsigners, just as ASL users were, but the types of movement that they were able to uniquely respond to were different. ASL signers were sensitive to the difference between straight and arc movements, whereas CSL signers were sensitive to the difference between straight and circular movements.[31] In other words, sign-language competency does not give individuals enhanced abilities to perceive motions in general, but it gives them enhanced abilities to perceive motions that are linguistically significant to a specific sign language. This is not necessarily true with another signed language, however, as sign languages around the world have some different phonological features, including movements.

Edward Klima and colleagues wanted to investigate whether signed language can alter the way the human brain categorizes movement even when it does not carry linguistic information.[32] They conducted an experiment in which fake Chinese characters were displayed in the air using a light pointer in the dark. The characters were shown to a group of deaf and nonhearing Americans who did not know Chinese. The participants were asked to re-create the characters they saw, and results showed that deaf signers were better at segmenting the strokes in their re-creation of shown characters. Specifically, they were more likely to eliminate the transitional movements, or the motions connecting one segment to the next, in their reproduction. The researchers claimed that this skill was most likely contributed by the nature of ASL to demand discrimination of signs from the transitional movements in between while comprehending what is being said. Taken together, these studies show that learning a sign language enhances an individual's ability to detect and categorize motions. There are more studies to date that could be further investigated for the effect of signed-language and/or hearing status. For example, in 2012, David Corina and Michael Grosvald found in a study that Deaf native signers were about one hundred milliseconds faster at recognizing nonlinguistic gestures (such as stroking the chin) than hearing nonsigners.[33]

Deaf-Education Advantages

Hearing parents from a growing number of countries are purchasing baby-sign materials developed for hearing infants, toddlers, and children. Not only young hearing children are learning signed languages; a rapidly growing number of hearing adolescents and young adults are taking signed-language courses. In the United States, the Modern Language Association found that ASL is the fourth-most-taught language in colleges and universities.[34] However, paradoxically, the parents of deaf children are often discouraged from teaching their children how to sign. They believe that if a deaf child learns a signed language, the child will not be able to learn how to speak or to live independently in what they see as an

auditory-oriented world. This belief is perhaps reasonable, because most parents never met a deaf individual before their deaf children were born.

Ioulia Kovelman, Stephanie Baker, and Petitto's brain research demonstrated that learning a second language does not interfere with the development of the first language, regardless of whether the language is signed or spoken.[35] As a matter of fact, there are additional benefits of learning a signed language that are unique to deaf individuals. Bencie Woll, the director of the Centre on Deafness, Cognition, and Language at University College London, conducted a study on deaf two-year-olds born to hearing parents who were in an early-intervention program that provided sign instruction. Woll found the opposite of what many people have assumed: deaf and hard-of-hearing children who signed more often actually have more spoken vocabulary than those who signed less often. That result includes even children with moderate levels of hearing.[36] The discovery means that both deaf and hard-of-hearing children who learn both speech and sign have a greater vocabulary than if they learned just one language, which in turn allows them to express themselves better. Similarly, in a study in Iran, deaf children with cochlear implants who were exposed to sign language early in life were found to have better speech perception and production than deaf children with cochlear implants who did not know how to sign.[37]

Studies in the United States have shown that learning ASL supports deaf individuals' reading development.[38] Other research has shown that fluency in a signed language facilitates deaf readers' word recognition.[39] A recent study reviewed experiments on deaf readers and found that language competency is the greatest predictor of reading processing.[40] Studies in the United States and the United Kingdom have shown that even teaching a signed language to hearing children helps these children's reading development.[41]

Signed language is important for the development of deaf children's higher cognitive functions and social cognitive skills.[42] This can be illustrated in, for example, "theory of mind" (ToM) research. ToM involves the ability to understand things from a different person's perspective and is often measured by the "false-belief task." Imagine an experiment with a researcher, a boy, and a girl in a room. The researcher has the children watch her put an apple under a box. The researcher then asks the boy to wait outside of the room. After the boy leaves, the researcher removes the apple and places it on the floor. The researcher asks the girl where she thinks the boy who is outside the room thinks the apple is now. The correct answer should be "still under the box." That would illustrate that the girl has a ToM; she is able to think about how the other child thinks. The ability to think about how others may be thinking is an important skill for social interaction and learning.

Research in the United States has shown that deaf children who learned a signed language early in life have ToM development that is the same as that of hearing children. However, deaf young children who have not learned a signed

language or have delayed signed-language development have ToM skills that are comparable to those of hearing children with autism.[43] Research has also shown that hearing parents who sign well have deaf children with better ToM skills compared to deaf children of parents who do not sign.[44] A study in the United Kingdom has found that deaf children with hearing siblings who can sign British Sign Language have better ToM than those with siblings who cannot sign.[45]

In November 2012, the World Federation of the Deaf and the European Union of the Deaf hosted a conference on endangered signed languages in Ål, Norway. There is a worldwide concern that sign languages are becoming endangered. As a growing number of deaf children around the world receive cochlear implants, parents are often told by medical professionals that there is no need for their children to learn a signed language, and some are told even that teaching their children a signed language could interfere with their learning. For example, in Denmark, deaf children are not taught a signed language anymore, because the government assumes that cochlear implants provide deaf children full access to language. Danish Sign Language, because it is not being passed to the younger generation, therefore is at risk of becoming an extinct language in the near future.

Cochlear implants can provide deaf children an awareness of sounds around them and some assistance in learning to hear and speak, but it is not a "cure," as their language development is often delayed.[46] Deaf children with cochlear implants are still deaf children, and their education would be enhanced if they learned how to sign, as suggested by the Iran study mentioned earlier. Studies have found that the earlier the exposure to sign language, the better.[47] If a child does not learn a sign language early in life, the critical window of opportunity slowly closes, and the severity of the consequences on the child's future academic success and psychosocial well-being appears to increase as time passes.[48] The myth that learning sign language is harmful has to end. The deaf community, allies, and scholars need to work collaboratively to share research on Sign Gain to parents, professionals, and policy makers.

Conclusion

Pierre Desloges's observation more than two centuries ago seems correct: it is puzzling that so many people do not know a signed language, given all the apparent advantages it imparts. Learning to sign benefits hearing people in the sense that it strengthens certain higher-order cognitive functions in a way not possible without knowing sign language. Signers have enhanced abilities to discriminate among people's facial features, particularly the features critical to processing linguistic information in signed language: the eyes and the mouth. Signers have greater spatial spans, generate images in their memories faster, are more skilled at rotating images in their minds, and have better discrimination between some motions than nonsigners. These are only examples; there are other areas of cognitive processing in which signers have advantages.

Sign Gain is an advantageous slice of Deaf Gain that is applicable to both deaf and hearing people. There are also cognitive gains for being deaf that are independent from sign-language skills.[49] In studies supporting this conclusion, deaf signers and nonsigners performed better than hearing signers and nonsigners; hence, the gain is related to hearing status, not signing skills. When people discuss Deaf Gain, they might be referring to Deaf Gain or to Sign Gain without specifying which. Nevertheless, we believe that Deaf Gain involves sign gains and that Sign Gain is an advantage that hearing individuals share with deaf individuals.

The recognition of Sign Gain is important. As we have mentioned, sign languages are becoming endangered in some countries. Some deaf children are not being taught a signed language because of the fear that they might have disadvantages. This fear is having a negative impact on many deaf children's social, emotional, and cognitive development. Parents, educators, and medical professionals need to be aware of sign gains to prevent their children's risk of having developmental delays. In fact, all parents, regardless of whether they have deaf children, should be aware of Sign Gain, because learning a sign language is a great brain exercise.

Notes

1. P. Desloges, *Observations d'un sourd et muet: Sur un cours elementaire d'education des sourds et muets, publié en 1779 par M. l'Abbé Deschamps* (Amsterdam: Morin, 1779).
2. É. Condillac, cited in D. Blackburn, J. Bonvillian, and R. Ashby, "Manual Communication as an Alternative Mode of Language Instruction for Children with Severe Reading Disabilities," *Language, Speech and Hearing Services in Schools* 15 (1984): 22–31.
3. W.C. Stokoe, "Sign Language Structure: An Outline of the Visual Communication Systems of the American Deaf," *Journal of Deaf Studies and Deaf Education* 10 (2005): 3–37.
4. For review, see R. P. Meier, K. Cormier, and D. G. Quinto-Pozos, *Modality and Structure in Signed and Spoken Languages* (Cambridge: Cambridge University Press, 2002), 480; and K. Emmorey, *Language, Cognition, and the Brain: Insights from Sign Language Research* (Mahwah, N.J.: Erlbaum, 2002).
5. L.-A. Petitto et al., "Speech-Like Cerebral Activity in Profoundly Deaf People Processing Signed Languages: Implications for the Neural Basis of Human Language," *Proceedings of the National Academy of Science* 97 (2000): 13961–66.
6. Ibid.; and L. A. Petitto, "On the Autonomy of Language and Gesture: Evidence from the Acquisition of Personal Pronouns in American Sign," *Cognition* 27 (1987): 1–52.
7. D. Bavelier et al., "Hemispheric Specialization for English and American Sign Language: Left Invariance, Right Variability," *Neuroreport* 9 (1998): 1537–42.
8. A. J. Newman et al., "Prosodic and Narrative Processing in American Sign Language: An fMRI Study," *NeuroImage* 52, no. 2 (2010): 669–76; A. J. Newman et al., "Dissociating Neural Subsystems for Grammar by Contrasting Word Order and Inflection," *Proceedings of the National Academy of Science* 107, no. 16 (2010): 7539–44.
9. D.P. Corina, "The Processing of Sign Language: Evidence from Aphasia," in *Handbook of Neurology*, ed. H. Whitaker and B. Stemmer (San Diego: Academic Press, 1998), 313–29.
10. D. Agrafiotis et al., "Perceptually Optimized Sign Language Video Coding Based on Eye Tracking Analysis," *Electronic Letters* 39 (2003): 1703–5; K. Emmorey, R. Thompson, and R. Colvin, "Eye Gaze during Comprehension of American Sign Language by Native and Beginning Signers," *Journal of Deaf Studies and Deaf Education* 14 (2009): 237–43; L. J. Muir