CHAPTER 43

The psycholinguistics of signed and spoken languages: how biology affects processing

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Linguistic research over the last few decades has revealed substantial similarities between the structure of signed and spoken languages (for reviews see Emmorey, 2002; Sandler and Lillo-Martin, 2006). These similarities provide a strong basis for cross-modality comparisons, and also bring to light linguistic universals that hold for *all* human languages. In addition, however, biology-based distinctions between sign and speech are important, and can be exploited to discover how the input–output systems of language impact online language processing and affect the neurocognitive underpinnings of language comprehension and production. For example, do the distinct perceptual and productive systems of signed and spoken languages exert differing constraints on the nature of linguistic processing? Recent investigations have suggested that the modality in which a language is expressed can impact the psychological mechanisms required to decode and produce the linguistic signal. This chapter explores what aspects of language processing appear to be universal to all human languages and what aspects are affected by the particular characteristics of audition vs. vision, or by the differing constraints on manual versus oral articulation.

Sign language processing is appropriately compared to speech processing, rather than to reading, because unlike written text, which can be characterized as "visual language," sign language consists of dynamic and constantly changing forms rather than static symbols. Further, neither sign language nor spoken language comes pre-segmented into words and sentences for the perceiver. The production of writing, although performed by the hand, differs substantially from sign language production because writing derives its structure from a separate system (the orthography of a spoken language). In contrast to written language, sign and speech are both primary language systems, acquired during infancy and early childhood without formal instruction.

43.1 Sign perception and visual processing

Although non-signers may interpret the visual signed signal simply as a collection of rapid hand and arm motions, signers quickly extract complex meaning from the incoming visual signal. Similarly, speakers extract meaning from a rapidly changing acoustic stream, if they know the language. Listeners and viewers are able to automatically parse an incoming auditory or visual linguistic signal by virtue of stored internal representations. Speech perception involves segmentation of speech sounds into phonemic units. For signed languages, a first question is whether signs actually exhibit sublexical linguistic structure that could be used by a parser to segment visual signed input. Is it possible to have a phonology that is not based on sound?

43.1.1 Phonology in a language without sound

Several decades of linguistic research has shown that signed languages, like spoken languages, have a level of structure in which meaningless elements are combined in rule-governed ways to create meaningful forms (e.g. Stokoe, 1960; Battison, 1978; Sandler, 1986; Brentari, 1998). For spoken languages, these elements are oral gestures that create sounds. For signed languages, manual and facial gestural units are combined to create distinct signs. The discovery that sign languages exhibit phonological structure was groundbreaking because it demonstrated that signs are not holistic pantomimes lacking internal organization. Furthermore, this discovery showed that human languages universally develop a level of meaningless linguistic structure and a system that organizes this structure.

Briefly, signs are composed of three basic phonological parameters: hand configuration, location (place of articulation), and movement. Orientation of the hand/arm is another contrasting parameter, but many theories represent orientation as a sub-component of hand configuration or movement, rather than as a basic phonological element. Figure 43.1 provides illustrations of minimal pairs from LIS (*Lingua Italiana dei Segni*, Italian Sign Language). The top part of the figure illustrates two LIS signs that differ only in hand configuration. Not all sign languages share the same hand configuration inventory. For example, the "t" hand configuration in American Sign Language (the thumb is inserted between the index and middle fingers of a fist) is not found in European sign languages. Chinese Sign Language contains a hand configuration formed with an open hand with all fingers extended except for the ring finger, which is bent—this hand configuration does not occur in American Sign Language (ASL). In addition, signs can differ according to where they are made on the body or face. Figure 43.1B illustrates two LIS signs that differ only their place of articulation, and these different locations do not add meaning to the signs. Signs can also differ minimally in orientation, as illustrated in Figure 43.1C. Finally, movement is another contrasting category that distinguishes minimally between signs, as shown in Figure 43.1D.

In addition to segment-like units, syllables have also been argued to exist in signed languages (Brentari, 1998; Corina and Sandler, 1993; Wilbur, 1993). The syllable is a unit of structure that is below the level of the word but above the level of the segment, and is required to explain phonological form and patterning within a word. Although sign phonologists disagree about precisely how sign syllables should be characterized, there is general agreement that a sign syllable must contain a movement of some type. In ASL, several phonological constraints have been identified that must refer to the syllable. For example, only certain movement sequences are allowed in bisyllabic (two-movement) signs: circle + straight movements are permitted, but straight + circle movements are not (Uyechi, 1994). Although a straight + circle movement sequence is ill-formed as a single sign, it is well-formed when it occurs in a phrase. Thus, the constraint on movement sequences needs to refer to a level smaller than the word (the constraint does not hold across word boundaries), but larger than the segment. Within Sandler's (1986) Hand Tier model, signed segments consist of Movements and Locations, somewhat akin to Vowels and Consonants.

However, syllables in signed language differ from syllables in spoken language because there is little evidence for internal structure within the signed syllable. Spoken syllables can be divided into onsets (usually, the first consonant or consonant cluster) and rhymes (the vowel and final consonants). Such internal structure does not appear to be present for sign syllables, although some linguists have argued for weight distinctions, i.e. "heavy" vs. "light" syllables, based on differences in movement types. Because of the lack of internal structure, there do not appear to be processes such as resyllabification in sign languages (e.g. a segment from one syllable becomes part of another syllable). These facts are important, given the emphasis that speech production models place on syllabification as a separate processing stage (e.g. Levelt et al., 1999).

Syllabification processes and/or the use of a syllabary may be specific to phonological encoding for speech production. The syllable likely serves as an organizational unit for speech, providing a structural frame for multisegmental words. For example, MacNeilage (1998) argues that the oscillation of the mandible creates a frame around which syllable production can be organized. Meier (2000; 2002) points out that signing differs dramatically from speaking because signing does not involve a single, predominant oscillator, akin to the mandible. Rather, signs can have movement that is restricted to just about any joint of the arm. Thus, sign production

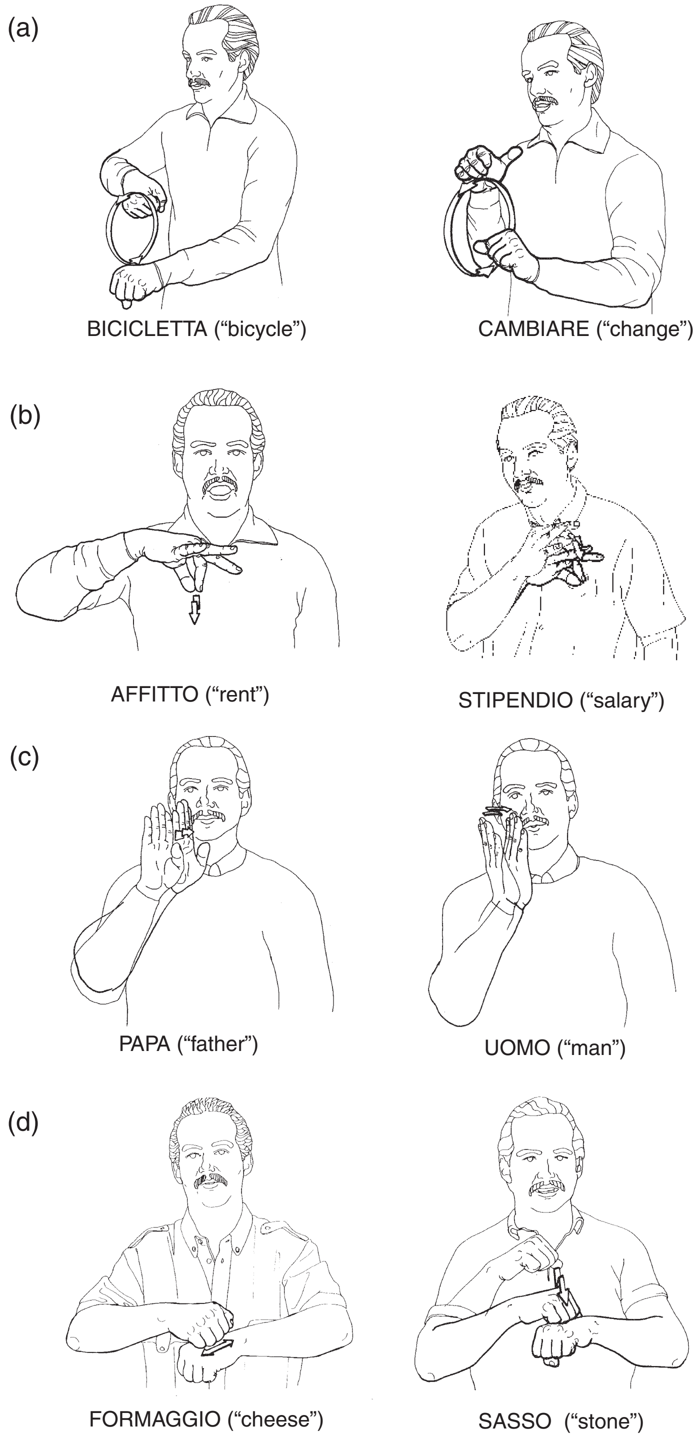

Figure 43.1 Examples of minimal pairs in Lingua Italiana dei Signi, LIS (Italian Sign Language) (A) signs that contrast in hand configuration; (B) signs that contrast in place of articulation (location); (C) signs that contrast in orientation; (D) signs that contrast in movement. Illustrations from V. Volterra (ed.), *La lingua italiana dei segni*. Bologna: Il Mulino, 1987 (new edn 2004) Copyright © Virginia Volterra and Elena Radutzky. Reprinted with permission.

may not be constrained to fit within a frame imposed by a single articulator. Further, multisegmental signs (e.g. signs with more than three segments) are relatively rare, regardless of how signed segments are defined (see Brentari, 1998). In contrast, syllabification processes for speech production may serve a critical framing function for words, which can contain many segments.

In sum, the linguistic evidence indicates that sign languages exhibit a level of sublexical structure that is encoded during sign production and that could be used to parse an incoming visual linguistic signal. A next question is whether signers make use of such internal representations when perceiving signs. Evidence suggesting that they do comes from studies of categorical perception in American Sign Language.

43.1.2 Categorical perception in sign language

Just as hearing speakers become auditorily tuned to perceive the sound contrasts of their native language, ASL signers appear to become visually tuned to perceive manual contrasts in American Sign Language. Two studies have now found evidence of categorical perception for phonologically distinctive hand configurations in ASL (Emmorey et al., 2003; Baker et al., 2005). "Categorical perception" refers to the finding that stimuli are perceived categorically rather than continually, despite continuous variation in form. Evidence for categorical perception is found (1) when perceivers partition continuous stimuli into relatively discrete categories and (2) when discrimination performance is better across a category boundary than within a category. For these categorical perception experiments, deaf signers and hearing non-signers were presented with hand configuration continua that consisted of two handshape endpoints with nine intermediate variants. These continua were either generated via a computer morphing program (Emmorey et al., 2003) or from a live signer (Baker et al., 2005). In addition, Emmorey et al. (2003) investigated categorical perception for place of articulation continua. For all experiments, participants performed a discrimination task in which they made same/different judgements for pairs or triplets of images from a continuum, and an identification task in which each stimulus was categorized with respect to the endpoints of the continuum (the discrimination task always preceded the categorization task).

Deaf ASL signers and hearing English speakers (non-signers) demonstrated similar category boundaries for both hand configuration and place of articulation (Emmorey et al., 2003; Baker et al., 2005). This result is consistent with previous studies which found that deaf and hearing participants exhibit similar perceptual groupings and confusability matrices for hand configuration and for place of articulation (Lane et al., 1976; Poizner and Lane, 1978). Thus, these ASL categories may have a perceptual as well as a linguistic basis. However, only deaf signers exhibited evidence of categorical perception, and only for distinctive hand configurations. Only deaf signers were sensitive to hand configuration category boundaries in the discrimination task, performing significantly better across category boundaries than within a hand configuration category (Emmorey et al., 2003; Baker et al., 2005).

Interestingly, neither group exhibited categorical perception effects for place of articulation (Emmorey et al., 2003). Lack of a categorical perception effect for place of articulation may be due to more variable category boundaries. In speech, categorical perception is modulated by the nature of the articulation of speech sounds. For example, categorical perception is often weak or not present for vowels, perhaps because of the more continuous nature of their articulation compared to stop consonants (Fry et al., 1962). The same may be true for place of articulation in sign language. For example, the location of signs can be displaced within a major body region in casual signing (Brentari, 1998) or completely displaced to the side during whispering. Category boundaries for place of articulation appear to be much less stable than for hand configuration. Categorical perception may only occur when articulations are relatively discrete for both sign and speech.

The fact that only deaf signers exhibited categorical perception for ASL hand configurations indicates that linguistic experience is what drives these effects. However, categorical perception effects are weaker for sign than for speech. Deaf signers' discrimination ability within hand configuration categories was better than the near-chance discrimination ability reported within stop consonant categories for speech (e.g. Liberman et al., 1957). Nonetheless, the sign language results resemble discrimination functions observed for categorical perception in other visual domains, such as faces or facial expressions (e.g. Beale and Keil, 1995; de Gelder et al., 1997). Discrimination accuracy within visual categories tends to be relatively high; generally, participants perform with about 70–85 per cent mean accuracy rates within categories. The difference in the strength of categorical perception effects between speech and sign may arise from psychophysical differences between audition and vision.

In sum, deaf signers appear to develop special abilities for perceiving aspects of sign language that are similar to the abilities that speakers develop for perceiving speech. These findings suggest that categorical perception emerges naturally as part of language processing, regardless of language modality. In addition, the results indicate that phonological information is utilized during the perception of moving nonsense signs (Baker et al., 2005) and when viewing still images of signs (Emmorey et al., 2003). Further research is needed to discover what parsing procedures might be used to identify sign boundaries, and whether categorical perception processes might play a role in segmenting the signing stream.

43.2 Processing universals and modality effects in the mental lexicon

Many models of spoken word recognition hypothesize that an acoustic-phonetic representation is sequentially mapped onto lexical entries, and lexical candidates which match this initial representation are activated (e.g. Marslen-Wilson, 1987; McClelland and Elman, 1986; Goldinger et al., 1989). As more of a word is heard, activation levels of lexical entries which do not match the incoming acoustic signal decrease. The sequential matching process continues until only one candidate remains which is consistent with the sensory input. At this point, word recognition can occur. This process is clearly conditioned by the serial nature of speech perception. Since signed languages are less dependent upon serial linguistic distinctions, visual lexical access and sign recognition may differ from spoken language. To investigate this possibility, Grosjean (1981) and Emmorey and Corina (1990) used a gating technique to track the process of lexical access and sign identification through time.

43.2.1 The time course of sign vs. word recognition

In sign language gating tasks, a sign is presented repeatedly, and the length of each presentation is increased by a constant amount (e.g. one videoframe or 33 msec). After each presentation, participants report what they think the sign is and how confident they are. Results from such studies show that ASL signers produce initial responses which share the place of articulation, orientation, and hand configuration of the target sign but differ in movement (Grosjean, 1981; Emmorey and Corina, 1990). The movement of the sign is identified last, and coincides with lexical recognition. This pattern of responses suggests that, similarly to the speech signal, the visual input for sign activates a cohort of potential lexical candidates that share some initial phonological features. This set of candidates narrows as more visual information is presented—until a single sign candidate remains. Clark and Grosjean (1982) showed further that sentential context did not affect this basic pattern of lexical recognition, although it reduced the time to identify a target sign by about 10 per cent.

However, unlike spoken word recognition, sign recognition appears to involve a two- stage process of recognition in which one group of phonological features (hand configuration, orientation, and place of articulation) initially identifies a lexical cohort, and then identification of phonological movement leads directly to sign identification. Such a direct correlation between identification of a phonological element and lexical identification does not occur with English and may not occur for any spoken language. That is, there seems to be no phonological feature or structure, the identification of which leads directly to word recognition. Movement is the most temporally influenced phonological property of sign, and more time is required to resolve it. For speech, almost all phonological components have a strong temporal component, and there does not appear to be a single feature that listeners must wait to resolve in order to identify a word.

Furthermore, both Grosjean (1981) and Emmorey and Corina (1990) found that signs were identified surprisingly rapidly. Although signs tend to be much longer than words, only 35 per cent of a sign had to be seen before the sign was identified (Emmorey and Corina, 1990). This is significantly faster than word recognition for English. Grosjean (1980) found that approximately 83 per cent of a word had to be heard before the word could be identified. There are at least two reasons why signs may be identified earlier than spoken words. First, the nature of the visual signal for sign provides a large amount of phonological information very early and simultaneously. The early availability of this phonological information can dramatically narrow the set of lexical candidates for the incoming stimulus. Second, the phonotactics and morphotactics of a visual language such as ASL may be different from those of spoken languages. In English, many words begin with similar sequences, and listeners can be led down a garden path if a shorter word is embedded at the onset of a longer word—for example, "pan" in "pantomime." This phenomenon does not commonly occur in ASL. Furthermore, sign initial cohorts seem to be much more limited by phonotactic structure. Unlike English, in which many initial strings have large cohorts (e.g. the strings [kan], [mæn], and [skr] are all shared by thirty or more words), ASL has few signs which share an initial phonological shape (i.e. the same hand configuration and place of articulation). This phonotactic structure limits the size of the initial cohort in ASL. The more constrained phonotactics and the early and simultaneous availability of phonological information may conspire to produce numerically and proportionally faster identification times for ASL signs.

In sum, lexical access and word recognition are generally quite similar for spoken and signed languages. For both language types, lexical access involves a sequential mapping process between an incoming linguistic signal and stored lexical representations. For signed languages, this appears to be a two-stage process in which one set of phonological elements are initially accessed and then identification of movement leads to sign recognition. Finally, the phonotactics of ASL (and possibly other signed languages) leads to proportionally faster recognition times for signs than for words.

43.2.2 The organization of a sign-based lexicon: evidence from tip-of-the-fingers

A tip-of-the-tongue (TOT) experience refers to the state in which a speaker is temporarily unable to retrieve a word from memory, while being sure that he or she knows the word (see Brown, 1991; Schwartz, 1999 for reviews). Often, speakers are able to retrieve the first letter and sometimes the number of syllables, which provides evidence for the organization of spoken language lexicons. The existence and nature of TOTs in spoken languages suggest that independent processing stages provide access to word meanings and word forms (e.g. Dell et al., 1997; Garrett, 1975; Levelt et al., 1999). However, for signed languages, the division between semantic and phonological form has been questioned because they exhibit a high degree of iconicity. For example, Stokoe (1991) proposes a theory of "semantic phonology" in which representations of a sign's form can be derived from aspects of its semantics. Semantic phonology eliminates form/meaning distinctions and rejects duality of patterning for signed languages (Armstrong et al., 1995). Under such a model, a "tip-of-the-fingers" experience should not occur for signers because there is no clear division between semantics and phonology.

Thompson et al. (2005) investigated whether a "tip-of-the-fingers" (TOFs) experience occur for ASL signers and whether TOFs are similar to TOTs. Thonmpson et al. (2005) conducted a small diary study and also experimentally elicited TOFs by asking signers to translate English words (e.g. what is the sign for "Moscow"?). Thompson et al. (2005) found that ASL signers reported having TOF experiences in which they could retrieve detailed semantic information, but had little or no access to the sign form. TOFs were similar to TOTs in that the majority involved proper names, and participants sometimes had partial access to phonological form (e.g. recalling the hand configuration and location of a sign, but not its movement). Although some TOF phonological parameters were iconic, there was no relationship between degree of iconicity for a particular parameter and access to it during a TOF. This separation between semantic and phonological retrieval provides evidence against semantic phonology (Stokoe, 1991), and indicates that independent processing stages provide access to lexical meanings and lexical forms for both sign and speech.

In addition, lexical access during sign production parallels access during sign perception. That is, during a TOF participants were equally likely to recall hand configuration, location, and orientation, which constitute the onset of a sign, and least likely to recall movement, which unfolds over time. These results parallel the gating studies of sign perception, indicating that phonological onsets are privileged for both signed and spoken languages.

Perhaps the most remarkable aspect of the TOFs for signs was participants' frequent recall of as many as three out of the four phonological parameters. This qualitative aspect of TOFs has further implications for models of signed language production, and distinguishes TOFs from TOTs. TOFs appear to be qualitatively quite different from TOTs with respect to the amount of phonological information that is retrieved simultaneously. However, recall of three phonological parameters did not result in more TOF resolutions compared to when fewer or no parameters were recalled. Thus, signs appear to be stored as a set of phonological attributes where retrieval of one or more attributes does not result in immediate access to the full phonological representation. TOFs therefore can occur when any one parameter is insufficiently activated.

In sum, the existence of a tip-of-the-fingers phenomenon for sign language argues for a two-stage model of lexical access and a division between semantic and phonological representations. The nature of recall for TOFs was analogous to TOTs in that partial phonological information (most frequently from word onsets) was sometimes retrieved. However, lexical TOFs differed from TOTs in the amount of information simultaneously available. The results of the Thompson et al. (2005) study suggest that the ASL mental lexicon is not organized by a single phonological parameter (e.g. hand configuration) that guides retrieval. Rather, sign production appears to parallel sign perception, such that when in a TOF, signers are least likely to retrieve the movement of the target sign. More generally, the findings argue for a language universal processing pattern in which onsets have a special status, regardless of language modality.

43.2.3 The preference for non-concatenative morphology: a processing explanation

Signed languages differ from spoken languages in the type of combinatorial processes that most often create morphologically complex words. Specifically, signed languages show a marked preference for non-concatenative (simultaneous) morphological processes, in contrast to the preference for linear affixation exhibited by spoken languages. Examples of typical simultaneous morphological processes are given in Figure 43.2 from British Sign Language (BSL). In Figure 43.2A,

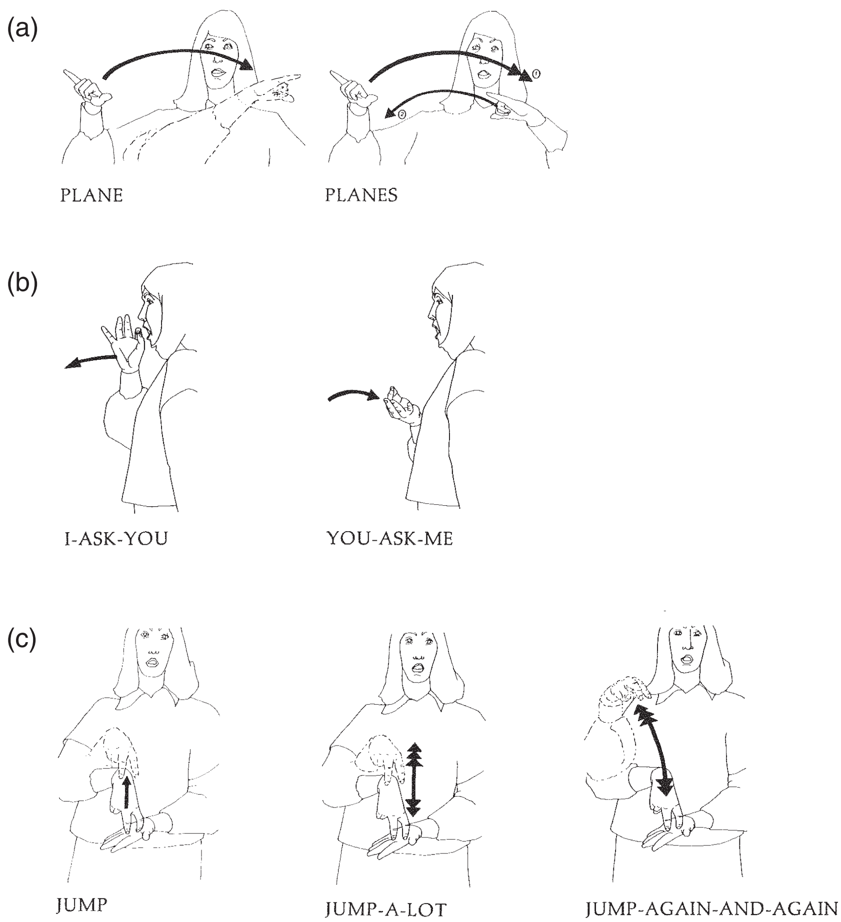

Figure 43.2 Examples of non-concatenative (simultaneous) morphology in British Sign Language (BSL) From Kyle and Woll (1985). Reprinted with permission.

a second hand is added to indicate plural. In Figure 43.2B, the direction of movement of the verb indicates subject and object arguments, and in Figure 43.2C, aspectual information is indicated by the type of the movement superimposed on the verb stem.

Linear affixation has been documented in signed languages. For example, ASL contains a few suffixes: the multiple suffix (Wilbur, 1987), the agentive suffix -ER, and a negative suffix ZERO (Aronoff et al., 2005). Aronoff et al. (2005) also describe a derivational prefix in Israeli Sign language. However, the majority of morphological processes in signed languages appear to be simultaneous. In fact, Bergman (1982) claims that Swedish Sign Language has neither suffixation nor prefixation, but exhibits several types of reduplication and other non-concatenative morphological process. Similarly, Sutton-Spence and Woll (1999) describe only non-concatenative morphological processes for British Sign Language, with the exception of compounding. Thus far, the data from numerous signed languages indicates that linear affixation is rare and that simultaneous expression of a stem and its morphological markings is the preferred linguistic encoding.

In contrast, for spoken languages, simultaneous affixation (e.g. template morphology, infixation, reduplication) is relatively rare, and linear affixation is the preferred linguistic encoding for morphological processes. Cutler et al. (1985) argue that processing constraints underlie the rarity of morphological processes which alter the phonological integrity of the base form (e.g. infixation which inserts an affix into the middle of a word). Languages avoid processes that disrupt the structural integrity of linguistic units. Hall (1992) also argues that the rarity of non-concatenative (simultaneous) morphology is due to the processing complexity associated with discontinuous elements in general (e.g. center embedding or verbs with particles). Concatenative morphology requires much less computational complexity because of the straightforward mapping between the surface form of a word and its underlying representation (Anderson, 1992). Given these arguments, why do signed languages prefer non-concatenative morphology, and does it pose the same processing challenges that it does for spoken languages?

First, signed languages appear to favor non-concatenative morphology because the visual modality affords parallel processing. Vision can easily encode spatially distinct information in parallel (unlike audition), and as we have noted, the hand configuration, place of articulation, and orientation of signs are perceived nearly simultaneously. Second, the capacity for short-term memory is limited by articulation rate (Baddeley, 1986), and signs take longer than words to articulate (Bellugi and Fischer, 1972). Universal constraints on short-term memory capacity and a slower articulation rate may induce sign languages to disfavor linear affixation. Third, unlike the non-concatenative processes of infixation and circumfixation, the morphological processes of signed languages do not *interrupt* the base form and do not involve discontinuous affixes. As can be seen in the examples in Figure 43.2, in no case is the base form of the BSL sign actually interrupted by the morphological marking. Discontinuous circumfixation is not the correct analysis for these forms since the morphological marking is superimposed onto the verb stem. Thus, the morphological parsing difficulties that arise from non-concatenative processes in spoken languages do not arise for signed languages.

Finally, evidence for signed languages' aversion to linear affixation comes from Supalla's (1991) finding that when the linear morphology of a spoken language is transferred to the visual modality, deaf children exposed to this artificial language do not acquire the system and in fact, alter it to create simultaneous (spatial) morphological encoding. In the United States, Manually Coded English (MCE) is the cover term for sign systems developed in the 1970s to represent the morphology and syntax of English, such as Signing Exact English or SEE (Gustason et al., 1980). MCE was invented by educators (many fluent in ASL) as a means to make English accessible to deaf children. The basic vocabulary of MCE borrows heavily from the lexicon of ASL, but its inflectional morphology is strictly sequential and based on English morphology. For example, to express "He asked her," the MCE sign HE is made at the forehead with an "E" hand configuration, the ASL sign REQUEST is produced (with no spatial inflection), then the MCE suffix -ED is produced, followed by the MCE sign HER made at the chin with an "R" hand configuration (see Figure 43.3). To express "He asked her" in ASL (or in BSL), the verb ASK is directed from the location in signing space associated with the subject (the referent of "he") to the location of the object (the referent of "her") (see Figure 43.3B). Tense is not expressed morphologically in ASL. Further, pronouns in signed languages are generally directed toward locations in signing space to convey co-reference.

Supalla (1991) found that children exposed only to Manually Coded English modify the inflectional morphology of verbs and pronouns

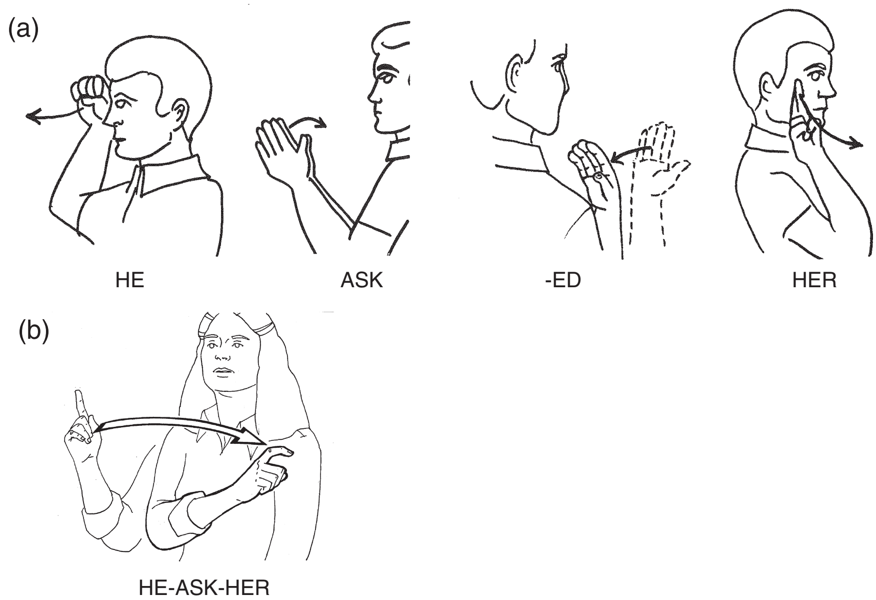

Figure 43.3 Examples of Manually Coded English (MCE) and ASL. (A) the MCE sentence 'He asked her'; (B) the equivalent sentence in ASL. The MCE signs are reprinted from Gustason et al. (1972). Reprinted with permission. ASL illustration copyright ©Ursula Bellugi, The Salk Institute.

to take advantage of the visual modality. That is, these children produce spatial non-linear modifications to base verbs in order to mark verb arguments, despite the fact that they were exposed only to linguistic input that produced these distinctions linearly. The children's spatial morphological creations were idiosyncratic, but they were systematic within a child and similar to the grammatical morphology found in signed languages of the world. Stack (1999) also found that Jamie, a young child exposed only to MCE, failed to acquire the non-spatial pronouns and linear inflections of MCE; rather, she created a pronominal system that utilized space and innovated non-linear morphology to express linguistic notions such as plurality (by reduplication), reciprocal aspect (the second hand mirrors the first), and lexical arguments (indicated by the beginning and endpoints of a verb). These results suggest that not only does the visual modality easily afford non-linear affixation, but visual processing may actually demand it.

43.3 **Comprehension and discourse: the unique role of space for signed languages**

The comprehension of sign language discourse depends upon interpreting the meaning of locations in signing space. For example, for many (if not most) signed languages, discourse referents are associated with locations in signing space, and pronominal signs and "agreeing" verbs (like ASK in Figure 43.3B) can be directed toward those locations to refer back to the associated referents. In addition, signing space is used to convey information about spatial relationships among objects. In this case, signing space serves both a topographic and a referential function (Emmorey et al., 1995). Several psycholinguistic studies have explored how ASL signers understand and maintain the associations between referents and spatial locations, and whether the same processing mechanisms hold for spoken and signed languages. These studies are briefly summarized below.

43.3.1 **Understanding spatial coreference**

To understand a sentence containing a pronoun, a perceiver must correctly assign an antecedent to the pronoun, which for languages like ASL involves interpreting the direction of the pronoun (where the pointing sign is directed) and recalling the referent associated with the targeted location. Emmorey et al. (1991) used the probe recognition methodology to investigate whether ASL pronouns re-activate their antecedents, as has been found with spoken language pronouns (e.g. Corbett and Chang, 1983; Gernsbacher, 1989). In the Emmorey et al. (1991) study, deaf participants viewed videotaped ASL sentences with and without pronouns and responded to probe signs presented after the pronoun. Participants had to decide whether the probe sign occurred in the sentence, and probe signs were either antecedent or non-antecedent nouns. Response times to antecedent nouns were faster than to non-antecedent nouns, and response times to antecedent nouns were faster when a pronoun was present in the sentence. Furthermore, Emmorey (1997) found that ASL pronouns suppress activation of non-antecedents, when the appropriate baseline condition is used. These results indicate that ASL pronouns activate their antecedents and suppress non-antecedents in memory, just as has been found for spoken languages (Gernsbacher, 1989).

In addition, ASL agreeing verbs license phonologically null pronouns. In clauses with agreeing verbs, subjects and objects appear as null elements that do not have an overt lexical form. Null pronouns are permitted to occur because of the morphological marking of agreeing verbs (see Figure 43.2B for an example of a BSL agreeing verb and Figure 43.3B for an ASL example). Using the same probe recognition methodology, Emmorey and Lillo-Martin (1995) found that null pronouns that were licensed by ASL agreeing verbs activate their antecedents to the same extent as overt pronouns. Again, these results parallel what has been found for spoken languages (e.g. Bever and McElree, 1988; Fodor, 1989) and suggest that the psycholinguistic mechanisms involved in anaphora resolution are universal and not dependent upon language modality.

Finally, Emmorey and Falgier (2004) investigated the unique case of "locus doubling," in which a single referent is associated with two distinct spatial locations (van Hoek, 1992). Emmorey and Falgier (2004) asked whether an ASL pronoun activates both its antecedent referent and the location associated with that referent. In this experiment, participants were presented with an introductory discourse that associated a referent (e.g. MOTHER) with two distinct locations (e.g. $\text{STORE}_{\text{left}}$, $\text{KITCHEN}_{\text{right}}$), and a continuation sentence followed that either contained a pronoun referring to the referent in one location or contained no anaphora (the control sentence). Deaf participants made lexical decisions to probe signs presented during the continuation sentences, and the probe signs were either the referent of the pronoun, the referent-location determined by the pronoun, or the most recently mentioned location (not referenced by the pronoun). The results indicated that response times to referent nouns were faster in the pronoun than in the no-pronoun control condition and that response times to the location signs did not differ across conditions. Thus, the spatial nature of coreference in ASL does not alter the processing mechanism underlying the online interpretation of pronouns. Pronouns activate only referent nouns, not spatial location nouns associated with the referent.

In sum, results from a series of sign language comprehension experiments indicate that the processing mechanisms used to resolve and interpret coreference relations do not differ cross-linguistically or cross-modally. Pronouns, whether spatialized pointing signs, spoken words, or null elements licensed by verb morphology, activate antecedents and suppress non-antecedents in memory, thereby improving the accessibility of coreferent nominals within the discourse (Gernsbacher, 1989). Language modality does not appear to affect co-reference resolution processes, despite great differences in the surface form of spoken and signed pronominal systems.

43.3.2 Understanding spatial descriptions

Most spoken languages encode spatial relations with prepositions or locative affixes. There is a grammatical element or phrase that denotes the spatial relation between a figure and ground object, e.g. the English spatial preposition *on* indicates support and contact, as in *The cup is on the table*. The prepositional phrase *on the table* defines a spatial region in terms of a ground object (the table), and the figure (the cup) is located in that region (Talmy, 2000). Spatial relations can also be expressed by compound phrases such as *to the left* or *in back of*. Both simple and compound prepositions constitute a closed class set of grammatical forms for English. In contrast, signed languages convey spatial information using classifier constructions in which spatial relations are expressed by where the hands are placed in signing space or with respect to the body (e.g. Supalla, 1982; Engberg-Pedersen, 1993). For example to indicate 'The cup is on the table,' an ASL signer would place a C classifier handshape (a curved handshape referring to the cup) on top of a B classifier handshape (a flat hand referring to the table). There is no grammatical element specifying the figure–ground relation; rather, there is a schematic and isomorphic mapping between the location of the hands in signing space and the location of the objects described (Emmorey and Herzig, 2003). This spatialized form has important ramifications for the nature of addressee vs. speaker perspective within spatial descriptions and for how these descriptions are understood.

Figure 43.4A provides a simple example of an ASL spatial description. An English translation of this example would be "I entered the room. There was a table to the left." In this type of narrative, the spatial description is from the point of view of the speaker (for simplicity and clarity, "speaker" will be used to refer to the person who is signing.) The addressee, if facing the speaker, must perform a mental transformation of signing space. For example, in Figure 43.4A, the speaker indicates that the table is to the left by articulating the appropriate classifier sign on his left in signing space. Because the addressee is facing the speaker, the location of the classifier form representing the table is actually on the right for the addressee. There is a mismatch between the location of the table in the room being described (the table is on the left as seen from the entrance) and what the addressee actually observes in signing space (the classifier handshape referring to the table is produced to the addressee's right). In this case, the addressee must perform what amounts to a 180° mental rotation to correctly comprehend the description.

Although spatial scenes are most commonly described from the speaker's point of view (as in Figure 43.4A), it is possible to indicate a different viewpoint. ASL has a marked sign that can be glossed as YOU-ENTER, which indicates that the scene should be understood as signed from the addressee's viewpoint (see Figure 43.4B). When this sign is used, the signing space in which the room is described is, in effect, rotated 180° so that the addressee is "at the entrance" of the room. In this case, the addressee does not need to mentally transform locations within signing space. However, ASL descriptions using YOU-ENTER are quite unusual and rarely found in natural discourse. Furthermore, Emmorey et al. (1998)

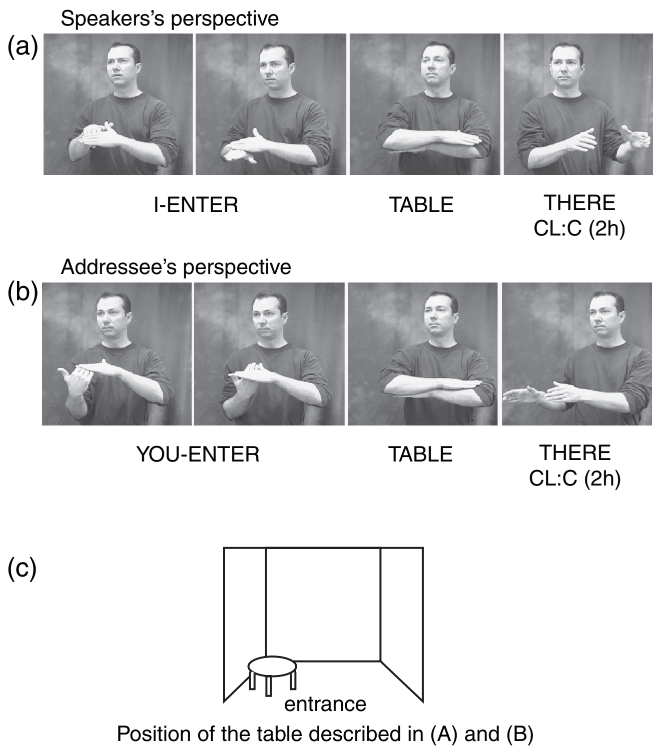

Figure 43.4 Illustration of ASL descriptions of the location of a table within a room, described from (A) the speaker's perspective or (B) the addressee's perspective. Signers exhibit better comprehension for room descriptions presented from the speaker's perspective, despite the mental transformation that this description entails. Reprinted from Emmorey (2002), with permission.

found that ASL signers comprehended spatial descriptions much better when they were produced from the speaker's point of view compared to the addressee's viewpoint. In that study, signers viewed a videotape of a room and then a signed description and were asked to judge whether the room and the description matched. When the room was described from the addressee's perspective (using YOU-ENTER), the description spatially matched the room layout shown on the videotape, but when signed from the speaker's perspective (using I-ENTER), the description was the reverse of the layout on the videotape (a simplified example is shown in Figure 43.4). Emmorey et al. (1998) found that ASL signers were more accurate when presented with descriptions from the speaker's perspective, despite the mental transformation that these descriptions entailed.

One might consider this situation analogous to that for English speakers who must understand the terms *left* and *right* with respect to the speaker's point of view (as in *on my left*). The crucial difference, however, is that these relations are encoded spatially in ASL, rather than lexically. The distinction becomes particularly clear in situations where the speaker and the addressee are both in the environment, observing the same scene. In this situation, English speakers most often adopt their addressee's point of view, for example giving directions such as, *Pick the one on your right*, or *It's in front of you*, rather than *Pick the one on my left* or *It's farthest from me* (Schober, 1993; Mainwaring et al., 1996). However, when jointly viewing an environment, ASL signers do not adopt their addressee's point of view but use "shared space" (Emmorey and Tversky, 2002). Signing space is shared in the sense that it maps to the physically observed space and to both the speaker's and addressee's view of the physical space. In such situations, there is no true speaker vs. addressee perspective and no mental transformation is required by the addressee. Furthermore, spatial descriptions of jointly viewed environments are not altered by the location of an addressee. That is, in these situations, ASL signers do not need to take into account where their addressee is located, unlike English speakers, who tend to adopt their addressee's viewpoint (Emmorey and Tversky, 2002). These differences between languages derive from the fact that signers use the actual space in front of them to represent observed physical space.

In sum, the spatialization of linguistic expression in ASL affects the nature of language comprehension by requiring an addressee to perform a mental transformation of the linguistic space under certain conditions. Specifically, for descriptions of non-present environments, an addressee must mentally transform the locations within a speaker's signing space in order to correctly understand the left/right arrangements of objects with respect to the speaker's viewpoint. For speech, spatial information is encoded in an acoustic signal, which bears no resemblance to the spatial scene described. An English speaker describing the room in Figure 43.4 might say either *You enter the room, and a table is to your left* or *I enter the room, and a table is to my left*. Neither description requires any sort of mental transformation on the part of the addressee because the relevant information is encoded in speech rather than in space. However, when English speakers and addressees discuss a jointly viewed scene, an addressee may need to perform a type of mental transformation if the speaker describes a spatial location from his or her viewpoint. Again, this situation differs for ASL signers because the speaker's signing space maps to the observed physical space and to the addressee's view of that space. Signing space is *shared*, and no mental transformation is required by the addressee. When shared space is used, speakers and addressees can refer to the same locations in signing space, regardless of the position of the addressee. Thus, the interface between language and visual perception (how we talk about what we see) has an added dimension for signers (they also see what they talk about). That is, signers see (rather than hear) spatial descriptions, and there is a schematic isomorphism between aspects of the linguistic signal (the location of the hands in signing space) and aspects of the spatial scene described (the location of objects in the described space). Signers must integrate a visually observed linguistic signal with a visually observed environment or a visual image of the described environment.

43.4 **Speaking vs. signing**

Currently, very little is known about the psycholinguistic mechanisms that translate thoughts into linguistic expression for signers, and it is unclear whether models of speech production can simply be appropriated for sign language. According to most production models, successful speech involves (1) the selection of a word that is semantically and syntactically appropriate, (2) retrieval of the word's phonological properties, (3) rapid syllabification of the word in context, and (4) articulatory preparation of the associated gestures (see Levelt, 1999 for review).

Sign production is likely to involve these components as well, although evidence for syllabification processes is weak (see above). In this section, I discuss aspects of sign production that are unique to the visual-manual modality and review some provocative parallels and contrasts between the nature of speech and sign production.

43.4.1 Lexical selection and phonological encoding during sign production

Evidence for the time course of lexical selection and phonological encoding for speech production comes from the picture–word interference task (Schriefers et al., 1990). In this task, subjects are presented with a picture that they must name, and a distractor name is presented either prior to, at the same time, or after the presentation of the picture. Subjects are told to ignore the distractor item, which they find difficult to do. If a semantically related word (e.g. *goat* for a picture of a sheep) is presented at the same time or slightly (100–400 msec) before the presentation of the picture, subjects are much slower to name the picture. That is, semantic inhibition occurs, and speakers are slow to produce the name of the object. In contrast, if a phonologically related word (e.g. *sheet* for a picture of a sheep) is presented at the same time or shortly (100–400 msec) after presentation of the picture, subjects are quicker to name the picture. That is, phonological facilitation occurs, and speakers are faster at producing the object name. Evidence for early phonological facilitation has been mixed (e.g. Starreveld, 2000; Schriefers et al., 1990), but the general pattern of results suggests that activation of semantic information occurs early in lexical retrieval, while phonological encoding occurs simultaneously with or subsequent to lexical selection.

Recently, Corina and Knapp (forthcoming) investigated lexical selection processes for ASL using a picture–sign interference task. Deaf participants were asked to sign the name of a picture, and response time was measured from the time of picture presentation to when the participant's hands moved from a rest position, breaking an infrared beam. Superimposed on the picture was an image of a signer producing a sign that was either phonologically or semantically related to the picture, e.g. MATCH–cigarette (a semantically related sign–picture pair) or ORANGE–ice cream (a phonologically related sign–picture pair—the signs ORANGE and ICE-CREAM are both made with an S handshape at the mouth). Both the distractor sign and the picture were clearly visible because the overlaid image of the signer was semi-transparent (but still quite recognizable). Corina and Knapp (forthcoming) found that, like speakers, signers exhibited semantic interference when they had to name a picture that was preceded by a semantically related sign (-130 msec "SOA" – the time between the onset of the picture and the onset of the superimposed distractor sign). Semantic interference was not found with zero or later SOAs. Thus, as for speech, sign production involves the early retrieval of lexical semantic information, and sign production can be disrupted (slowed) by the prior activation of a semantically related sign.

However, the evidence for phonological facilitation was not as clear-cut. No significant phonological effects were observed at any of the SOAs used in the experiment (-130, 0, +130 msec), and an examination of the number of shared phonological parameters also revealed no significant facilitation effects from distractor signs that shared one, two, or three phonological parameters with the target sign (the picture name). There was no evidence of increased facilitation with increased phonological overlap. However, further post hoc analyses indicated that distractor signs which shared movement and location with the target sign produced significant facilitation effects at all SOAs, while signs which shared handshape and location or handshape and movement did not.

The fact that phonological facilitation was only observed when sign pairs shared movement and location supports phonological models that treat hand configuration as an autonomous element and movement and location as segmental units that could frame sign production (e.g. Sandler, 1986; Corina, 1993). In addition, phonological facilitation based on shared movement and location for sign production is consistent with results from a perceptual similarity judgment study. Hildebrandt and Corina (2002) found that native ASL signers rated non-signs that shared movement and location as highly similar, and essentially ignored handshape similarity. It is possible that movement and location form a syllabic unit that is perceptually salient and that can be primed during sign production.

In sum, the picture–sign interference results of Corina and Knapp (forthcoming) indicate that semantic inhibition occurs only at an early SOA (−130msec), while phonological facilitation (based on shared movement and location) occurs at both early and late SOAs. This pattern of results mirrors what has been found for spoken languages, and suggests that lexical selection precedes phonological encoding for sign, as it does for speech (note, however, that the data do not rule out cascaded activation of phonological representations during lexical selection).

43.4.2 Slips of the hand

In her well-known 1971 paper "The non-anomalous nature of anomalous utterances," Victoria Fromkin demonstrated that slips of the tongue (speech errors) were not random mistakes in speaking, but revealed something about speech planning and the nature of the mental representation of phonology. She argued that speech errors provide evidence for the underlying units of speech production: "despite the semi-continuous nature of the speech signal, there are discrete units at some level of *performance* which can be substituted, omitted, transposed, or added" (Fromkin, 1971: 217; emphasis in the original). Errors of sign production provide similar evidence for the status of the major phonological parameters as discrete units involved in sign production.

Sign error corpora collected for ASL by Newkirk et al. (1980) and for Deutsche Gebärdensprache (DGS; German Sign Language) by Hohenberger et al. (2002) document exchange, preservation, and anticipation errors which involve hand configuration, place of articulation, or movement (see also Leuniger et al., 2004). Figure 43.5 provides an example of a hand configuration anticipation error in DGS. The signer planned to sign SEINE ELTERN ('his parents'), and incorrectly produced SEINE with a Y handshape instead of a B handshape. The Y hand configuration of the sign ELTERN was anticipated and substituted for the intended B hand configuration of SEINE.

The existence of such errors suggests that these phonological parameters constitute units in the production of signed utterances. As noted above, many models of sign language phonology treat hand configuration as a separate autosegment, much as tone is represented for spoken languages. The speech error data from tone languages suggests that tones are independent units that can participate in exchange, anticipation, or perseveration errors (Gandour, 1977)—just as we find for hand configuration in sign language. Unlike tone, however, hand configuration errors are much more common than errors involving other phonological parameters (Newkirk et al., 1980; Hohenberger et al., 2002). Speech errors involving tone do not appear to be more frequent than errors involving consonants or vowels (Wen, 2000). One possible explanation for the frequency of hand configuration errors is that hand configuration is the most complex phonological parameter (Brentari, 1998; Sandler and Lillo-Martin, 2006). The feature geometry required to represent hand configuration requires several hierarchical nodes and more features than are needed to specify the movement or location of a sign. This complexity may render hand configuration more vulnerable to error during sign production.

The fact that movement exchange errors occur (Klima and Bellugi, 1979) argues for a phonological representation in which movement is represented as a separate unit, rather than deriving from articulation constraints, as was proposed by Uyechi (1995). The data also support the analysis of place of articulation as a

Figure 43.5 Illustration of the intended phrase SEINE ELTERN ('his parents') and a slip of the hand in Deutsche Gebärdensprache (German Sign Language) In the slip, the Y hand configuration of ELTERN is anticipated and substituted for the intended B hand configuration of SEINE. From Hohenberger et al. (2002). Reprinted with permission.

high-level unit within the representation of a sign, rather than as a phonetic feature(s) associated with a segment slot (as place of articulation is often represented for consonants). This argument derives from evidence indicating that phonetic features do not operate as units in speech production and rarely participate in speech errors (see Roelofs, 1999). Thus, since place of articulation in sign participates in exchange and other types of errors, it suggests that this parameter is a unit rather than a feature for the purposes of sign production.

Both the ASL and DGS error corpora contained very few sign exchange errors, e.g. LIKE, MAYBE TASTE instead of TASTE, MAYBE LIKE ('Taste it, and maybe you'll like it'; Klima and Bellugi, 1979). Word exchanges are argued to take place at a separate stage of sentence planning (Garrett, 1975; Levelt, 1989). Hohenberger et al. (2002) report that only 1 per cent of errors were sign exchanges, compared to 15 per cent word exchange errors found in the Frankfurt corpus of spoken German errors. In addition, Hohenberger et al. (2002) did not find evidence for morpheme stranding errors, and no stranding errors were reported by Newkirk et al. (1980). A morpheme stranding error in English would be *That's why they sell the cheaps drink* for the intended *That's why they sell the drinks cheap* (Garrett, 1988). In this example, the *-s* suffix is "stranded" or left behind when the two words exchange. The fact that stranding errors do not occur in sign languages is likely due to the rarity of sign exchange errors and to the fact that morphological processes are non-concatenative rather than affixal. Stranding errors may only occur when morphemes are arranged linearly, rather than articulated simultaneously.

Finally, Hohenberger et al. (2002) found that sign errors were repaired much faster than speech errors. The locus of repairs for speakers is most often after the word (Levelt, 1983), but for DGS signers the error was preferentially caught somewhere within the sign, i.e. before the signer finished articulating the sign containing the error. For DGS, 57 per cent of repairs were made within the word; in contrast, only 27 per cent of the error repairs of Dutch speakers occurred within the word (from Levelt, 1983). Hohenberger et al. hypothesize that the longer articulation time for signs allows for earlier detection of sign errors compared to speech errors. Early repair of errors also explains the lack of sign exchange errors, because the slip is detected before the second exchanged sign is produced.

In sum, data from slips of the hand provide evidence for phonological encoding during sign production. Signs are not produced as gestural wholes without internal structure. As with speech, phonological elements in sign language can be anticipated, perseverated, and exchanged during production. Sign and speech appear to differ with respect to the speed of error detection and the nature of word and morpheme level errors. The slower rate of sign articulation leads to earlier error repairs for signers and to fewer exchange errors. The linear affixation processes found in most spoken languages lead to morpheme stranding errors that are not observed for sign languages.

43.4.3 Sign monitoring

Levelt (1983, 1989) proposes that speakers monitor their internal speech and can intercept errors before they are overtly uttered—he terms this "prearticulatory editing." It is reasonable to hypothesize that signers also have such an internal monitor. Working-memory experiments with ASL provide evidence for a non-overt articulatory-based system of sign rehearsal that is used during short-term memory tasks (Wilson and Emmorey, 1997; 1998). This rehearsal system appears to be equivalent to subvocal rehearsal for speech, and provides evidence for a type of inner signing. Like speakers, signers may be able monitor this internal signing, catching errors before they are actually articulated. In fact, Hohenberger et al. (2002) report that a small proportion of sign errors (8 per cent) are detected *prior to* articulation of the intended (target) sign. For example, an incorrect hand configuration can be produced and corrected during the movement transition to the target sign. In addition, signers produce the signed equivalent of *um* (a 5 handshape with wiggling fingers), which indicates they are having production difficulty (Emmorey, 2002). Signers also sometimes stop signing and shake their head, suggesting that they have detected an error prior to articulation. These data support the existence of an internal monitor for sign production. Whether this monitor operates on a phonological or a phonetic (articulatory) representation is currently under investigation in my laboratory.

Sometimes errors or inappropriate words do nonetheless slip through, and speakers also monitor their overt speech and can catch errors by listening to their own voice. Herein lies a potentially interesting difference between sign and speech. Speakers hear their voices, but signers do not look at their hands and cannot see their own faces. Facial expressions convey critical grammatical information for signed languages (e.g. Zeshan, 2004). When speakers are prevented from hearing their own voices (e.g. by wearing headphones emitting loud white noise) or when speakers silently mouth words, they are less likely to detect speech errors compared to when they can hear themselves speak (Lackner and Tuller, 1979; Postma and Noordanus, 1996). These results suggest that speakers rely to some extent on auditory feedback to detect errors in production. Levelt (1989) proposes that the perceptual monitor for overt speech operates via the language user's speech-understanding system. However, this cannot be the entire story for sign language monitoring, because the sign-understanding system operates on the basis of visual input, which is unavailable or distorted for self-signed input. Signers cannot see their own grammatical facial expressions, the view of their own hands falls in the far periphery of vision, and they have a "backward" view of their hands. Thus, it is problematic to simply adopt the same processing system which parses visual input when comprehending another's signing in order also to parse the visual input from one's own signing. It is possible that the nature of the perceptual loop for sign monitoring is quite different from that for speech monitoring. My colleagues and I are currently investigating this hypothesis by examining how differences in visual feedback impact sign language production.

43.5 **Summary and conclusions**

Psycholinguistic studies of sign language have revealed (and continue to reveal) significant insights into the nature of human language processing. Linguistic and psycholinguistic evidence has established that all human languages have a level of meaningless sublexical structure which must be assembled during language production and which is exploited during language perception. Both signers and speakers exhibit categorical perception effects for distinctive phonological categories in their language, and both combine phonological units prior to articulation, as evidenced by slips of the tongue and hand. Signs, like words, are not holistic gestures without internal structure. Furthermore, the fact that signs are generally more iconic than words does not lead to a lack of separation between the representation of meaning and the representation of form. Signers experience a tip-of-the-fingers state (analogous to the tip-of-the- tongue state) in which semantic information is retrieved, while access to the form of the sign is somehow blocked. The study of signed languages has identified universal properties of language processing and exposed aspects of language processing that are impacted by the biology of the language processing system.

Specifically, biology has an impact of the speed of linguistic articulation: the tongue is quicker than the hands. Biology also affects language perception: the auditory system is particularly adept at processing rapid, temporal sequences, while the visual system can easily process shape and location information presented simultaneously within the visual field. These biological differences exert specific effects on language processing and linguistic structure.

With respect to lexical processing, language modality affects the time course of word recognition and the nature of morphological parsing. Words take proportionally longer to recognize than signs. More of a word must be heard before it can be recognized, probably owing to the phonotactics of speech (many words share an initial cohort), the fact that words tend to contain more segments than signs, and the fact that word onsets may be less informative than sign onsets. In addition, it has been argued that spoken languages avoid non-concatenative morphological processes such as reduplication and circumfixation because such processes have a high processing cost (e.g. the stem is disrupted and difficult to identify). Thus, spoken languages prefer linear affixation. In contrast, the biology of signed languages favors non-concatenative morphology because movement "affixes" can be superimposed onto a sign stem without disrupting lexical recognition. Further, linear affixation results in processing costs for signed languages because affixes increase articulation time, thus increasing demands on working memory. In fact, when the linear affixation processes are transferred to the visual-gestural modality via Manually Coded English, children fail to acquire the linear morphology and often create simultaneous morphological processes that are not observed in their input.

The modality of signed languages affords the use of signing space to convey linguistic distinctions. Signed languages tend to use signing space for co-reference functions and to convey topographic information about spatial relationships. Despite large differences in the form of signed and spoken pronouns, psycholinguistic studies indicate that the same mechanisms underlie coreference processing, namely, activation of pronominal antecedents and suppression of non-antecedents in memory. In contrast, the use of space to convey spatial information leads to some modality-specific effects on language comprehension. For example, ASL signers make use of "shared space" when describing jointly observed scenes, which does not require a particular viewer perspective. In contrast, English speakers must adopt a spatial perspective (*It's on my left* or *It's on your right*). When comprehending descriptions of non-present spatial scenes, viewers of ASL must perform a mental transformation of signing space. English speakers are not faced with such spatial computations. Thus, although co-reference processing appears to be largely unaffected by the spatialization of linguistic form, the processing mechanisims required to comprehend and produce spatial descriptions are clearly affected by the visual-spatial modality.

In conclusion, signed languages provide a unique tool for investigating the psycholinguistic mechanisms which underlie language processing. Their study reveals both universal and biology-specific mechanisms, and clarifies the nature of constraints on spoken language processing. Future studies may reveal how the biology of language affects the nature of output monitoring, the nature of perceptual segmentation, and the interplay between language and other cognitive systems.

Acknowledgements

Preparation of this chapter was supported by grants from the National Institute on Child Health and Human Development (R01 HD13249; R01 HD047736). I thank Virginia Volterra for help with the LIS examples in Figure 43.1.

References

Anderson, S. R. (1992) *A-morphous Morphology*. Cambridge University Press, Cambridge.

Armstrong, D. F., Stokoe, W. C., and Wilcox, S. E. (1995) *Gesture and the Nature of Language*. Cambridge University Press, Cambridge.

Aronoff, M., Meir, I., and Sandler, W. (2005) The paradox of sign language morphology. *Language*, 81: 301–44.

Baddeley, A. (1986) *Working Memory*. Clarendon Press, Oxford.

Baker, S., Idsardi, W., Golinkoff, R. M., and Petitto, L. A. (2005) The perception of handshapes in American Sign Language. *Memory and Cognition*, 33: 887–904.

Battison, R. (1978) *Lexical Borrowing in American Sign Language*. Linstok Press, Silver Spring, Md.

Beale, J. M., and Keil, F. C. (1995) Categorical effects in the perception of faces. *Cognition,* 57: 217–239.

Bellugi, U., and Fischer, S. (1972) A comparison of sign language and spoken language, *Cognition*, 1: 173–200.

Bergman, B. (1982) *Forskning om Teckenspråk* [Research on sign language]. Stockholm University.

Bever, T., and McElree, B. (1988) Empty categories access their antecedents during comprehension. *Linguistic Inquiry*, 19, 35–43.

Brentari, D. (1998) *A Prosodic Model of Sign Language Phonology*. MIT Press, Cambridge, Mass.

Brown, A. (1991) A review of the tip-of-the-tongue experience. *Psychological Bulletin,* 109: 204–223.

Clark, L., and Grosjean, F. (1982) Sign recognition processes in American Sign Language: the effect of context. *Language and Speech*, 25: 325–340.

Corbett, A., and Chang, F. (1983) Pronoun disambiguation: accessing potential antecedents. *Memory and Cognition*, 11: 283–294.

Corina, D. P. (1993) To branch or not to branch: underspecifications in ASL handshape contours. In G. Coulter (ed.), *Phonetics and Phonology: Current Issues in ASL Phonology*, pp. 63–96. Academic Press, New York.

Corina, D. P. and Knapp, H. (forthcoming) Lexical retrieval in American Sign Language production. In L. M. Goldstein, D. H. Whalen, and C. T. Best (eds.), *Papers in Laboratory Phonology 8: Varieties of Phonological Competence*. Mouton de Gruyter, Berlin.

Corina, D. P., and Sandler, W. (1993) On the nature of phonological structure in sign language. *Phonology,* 10: 165 – 207.

Cutler, A., Hawkins, J., and Gilligan, G. (1985) The suffixing preference: a processing explanation. *Linguistics, 23:* 723–758.

de Gelder, B., Teunisse, J-P., and Benson, P. J. (1997) Categorical perception of facial expressions: categories and their internal structure. *Cognition and Emotion,* 11: 1–22.

Dell, G. S., Schwartz, M. F., Martin, N., Saffran, E. M., and Gagnon, D. A. (1997) Lexical access in aphasic and nonaphasic speakers. *Psychological Review*, 104: 801–838.

Emmorey, K. (1997) Non-antecedent suppression in American Sign Language. *Language and Cognitive Processes*, 12: 103–112.

Emmorey, K. (2002) *Language, Cognition, and the Brain: Insights from Sign Language Research*. Erlbaum, Mahwah, NJ.

Emmorey, K., and Corina, D. (1990) Lexical recognition in sign language: effects of phonetic structure and morphology. *Perceptual and Motor Skills*, 71: 1227–1252.

Emmorey, K., Corina, D., and Bellugi, U. (1995) Differential processing of topographic and referential functions of space. In K. Emmorey and J. Reilly (eds) *Language, Gesture, and Space*, pp. 43–62. Erlbaum, Hillsdale, NJ.

Emmorey, K., and Falgier, B. (2004) Conceptual locations and pronominal reference in American Sign Language. *Journal of Psycholinguistic Research*, 33: 321–331.

Emmorey, K., and Herzig, M. (2003) Categorical versus gradient properties of classifier constructions in ASL. In K. Emmorey (ed) *Perspectives on Classifier Constructions in Signed Languages*, pp. 222–46, Erlbaum, Mahwah, NJ.

Emmorey, K., Klima, E. S., and Hickok, G. (1998) Mental rotation within linguistic and nonlinguistic domains in users of American Sign Language. *Cognition*, 68: 221–246.

Emmorey, K. and Lillo-Martin, D. (1995) Processing spatial anaphora: referent reactivation with overt and null pronouns in American Sign Language. *Language and Cognitive Processes*, 10: 631–664.

Emmorey, K., McCullough, S., and Brentari, D. (2003) Categorical perception in American Sign Language. *Language and Cognitive Processes*, 18: 21–45.

Emmorey, K., Norman, F., and O'Grady, L. (1991) The activation of spatial antecedents from overt pronouns in American Sign Language. *Language and Cognitive Processes*, 6: 207–228.

Emmorey, K., and Tversky, B. (2002) Spatial perspective choice in ASL. *Sign Language and Linguistics*, 5: 3–25.

Engberg-Pedersen, E. (1993) *Space in Danish Sign Language: The Semantics and Morphosyntax of the Use of Space in a Visual Language.* Signum, Hamburg.

Fodor, J. (1989) Empty categories in sentence processing. *Language and Cognitive Processes*, 4: 155–209.

Fromkin, V. A. (1971) The non-anomalous nature of anomalous utterances. *Language*, 47: 27–52.

Fry, D. B., Abramson, A. S., Eimas, P. D., and Liberman, A. M. (1962) The identification and discrimination of synthetic vowels. *Language and Speech*, 5: 171–189.

Gandour, J. (1977) Counterfeit tones in the speech of southern Thai bidialectals. *Lingua*, 41: 125–143.

Garrett, M. (1975) The analysis of sentence production. In G. Bower (ed.), *Psychology of Learning and Motivation*, vol. 9, pp. 133–177. Academic Press, New York.

Garrett, M. (1988) Processes in language production. In F. J. Newmeyer (ed.), *Linguistics: The Cambridge Survey*, vol. 3: *Language: Psychological and Biological Aspects,* pp. 69–96. Cambridge University Press, Cambridge.

Gernsbacher, M. (1989) Mechanisms that improve referential access. *Cognition*, 32: 99–156.

Goldinger, S. D., Luce, P. A., and Pisoni, D. B. (1989) Priming lexical neighbors of spoken words: effects of competition and inhibition. *Journal of Memory and Language*, 28: 501–518.

Grosjean, F. (1980) Spoken word recognition processes and the gating paradigm. *Perception and Psychophysics*, 28: 267–283.

Grosjean, F. (1981) Sign and word recognition: a first comparison. *Sign Language Studies*, 32: 195–219.

Gustason, G., Pfetzing, D., and Zawolkow, E. (1980) *Signing Exact English*. Modern Signs Press, Los Alamitos, Calif.

Hall, C. J. (1992) *Morphology and Mind: A Unified Approach to Explanation in Linguistics*. Routledge, London.

Hildebrandt, U., and Corina D. (2002) Phonological similarity in American Sign Language. *Language and Cognitive Processes*, 17: 593–612.

Hoek, K. van (1992) Conceptual spaces and pronominal reference in American Sign Language. *Nordic Journal of Linguistics*, 15: 183–199.

Hohenberger, A., Happ, D., and Leuniger, H. (2002) Modality-dependent aspects of sign language production: evidence from slips of the hands and their repairs in German Sign Language. In R. P. Meier, K. Cormier, and D. Quinto-Pozos (eds) *Modality and Structure in Signed and Spoken Languages*, pp. 112–42, Cambridge University Press, Cambridge.

Klima, E., and Bellugi, U. (1979) *The Signs of Language.* Harvard University Press, Cambridge, Mass..

Kyle, J., and Woll, B. (1985) *Sign Language: The Study of Deaf People and Their Language*. Cambridge University Press, Cambridge.

Lackner, J. R., and Tuller, B. H. (1979) Role of efference monitoring in the detection of self-produced speech errors. In W. E. Cooper and E. C. T. Walker (eds), *Sentence Processing: Psycholinguistic Studies Presented to Merrill Garrett,* pp. 281–294. Erlbaum, Hillsdale, NJ.

Lane, H., Boyes-Braem, P., and Bellugi, U. (1976) Preliminaries to a distinctive feature analysis of American Sign Language. *Cognitive Psychology*, 8: 263–289.

Leuniger, H., Hohenberger, A., Waleschkowski, E., Menges, E., and Happ, D. (2004) The impact of modality on language production: evidence from slips of the tongue and hand. In T. Pechmann and C. Habel (eds.), *Multidisciplinary Approaches to Language Production*, pp. 219–77. Mouton de Gruyter, Berlin.

Levelt, W. J. M. (1983) Monitoring and self-repair in speech. *Cognition*, 14: 41 – 104.

Levelt, W. J. M. (1989) *Speaking: From Intention to Articulation.* MIT Press, Cambridge, Mass.

Levelt, W. J. M. (1999) Models of word production. *Trends in Cognitive Sciences*, 3: 223–232.

Levelt, W. J. M., Roelofs, A., and Meyer, A. S. (1999) A theory of lexical access in speech production. *Behavioral and Brain Sciences*, 22: 1–75.

Liberman, A. M., Harris, K. S., Hoffman, H. S., and Griffith, B. C. (1957) The discrimination of speech sounds within and across phoneme boundaries. *Journal of Experimental Psychology*, 54: 358–368.

MacNeilage, P. (1998) The frame/content theory of evolution of speech production. *Behavioral and Brain Sciences*, 21: 499–546.

Mainwaring, S., Tversky, B., and Schiano, D. (1996) Perspective choice in spatial descriptions. IRC Technical Report, 1996–06. Interval Research Corporation, Palo Alto, Calif.

Marslen-Wilson, W. (1987) Functional parallelism in spoken word recognition. *Cognition*, 25: 71–102.

McClelland, J. L., and Elman, J. (1986) The TRACE model of speech perception. *Cognitive Psychology*, 18: 1–86.

Meier, R. P. (2000) Shared motoric factors in the acquisition of sign and speech. In K. Emmorey and H. Lane (eds.), *The Signs of Language Revisited: An Anthology to Honor Ursula Bellugi and Edward Klima*, pp. 333–57, Erlbaum, Mahwah, NJ.

Meier, R. P. (2002) Why different, why the same? Explaining effects and non-effects of modality upon linguistic structure in sign and speech. In R. P. Meier, K. Cormier, and D. Quinto-Pozos (eds.), *Modality and Structure in Signed and Spoken Languages*, pp. 1–26, Cambridge University Press, Cambridge.

Newkirk, D., Klima, E., Pedersen, C. C., and Bellugi, U. (1980) Linguistic evidence from slips of the hand. In V. Fromkin (ed.), *Errors in Linguistic Performance: Slips of the Tongue, Ear, Pen, and Hand*, pp. 165–198. Academic Press, New York.

Poizner, H., and Lane, H. (1978) Discrimination of location in American Sign Language. In P. Siple (e.d), *Understanding Language through Sign Language Research*, pp. 271–87. Academic Press, New York.

Postma, A., and Noordanus, C. (1996) Production and detection of speech errors in silent, mouthed, noise-masked, and normal auditory feedback speech. *Language and Speech*, 39: 375–392.

Roelofs, A. (1999) Phonological segments and features as planning units in speech production. *Language and Cognitive Processes*, 14: 173–200.

Sandler, W. (1986) The spreading hand autosegment of American Sign Language. *Sign Language Studies*, 50: 1–28.

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

Schober, M. F. (1993) Spatial perspective-taking in conversation. *Cognition*, 47: 1–24.

Schriefers, H., Meyer, A., and Levelt, W. J. M. (1990) Exploring the time course of lexical access in speech production: picture-word interference studies. *Journal of Memory and Language*, 29: 86–102.

Schwartz, B.L. (1999) Sparkling at the end of the tongue: the etiology of tip-of-the-tongue phenomenology. *Psychonomic Bulletin and Review*, 6: 379–393.

Stack, K. M. (1999) Innovation by a child acquiring Signing Exact English II. Doctoral dissertation, University of California at Los Angeles.

Starreveld, 2000) On the interpretation of onsets of auditory context effects in word production. *Journal of Memory and Language*, 42: 497–525.

Stokoe, W. (1960) Sign language structure: an outline of the visual communication systems of the American Deaf. *Studies in Linguistics, Occasional Papers 8*, available from Linstok Press, Silver Spring, Md.

Stokoe, W. (1991) Semantic phonology. *Sign Language Studies*, 71: 107–114.

Supalla, S. (1991) Manually coded English: the modality question in signed language development. In P. Siple and S. D. Fischer (eds.), *Theoretical Issues in Sign Language Research,* pp. 85–109, University of Chicago Press, Chicago.

Supalla, T. (1982) Structure and acquisition of verbs of motion and location in American Sign Language. Ph.D. dissertation, University of California, San Diego.

Sutton-Spence, R., and Woll, B.(1999) *The Linguistics of British Sign Language: An Introduction*. Cambridge University Press, Cambridge.

Talmy, L. (2000) *Toward a Cognitive Semantics*, vol. 1: *Concept Structuring Systems*. MIT press, Cambridge, Mass.

Thompson, R., Emmorey, K., and Gollan, T. (2005) Tip-of-the-fingers experiences by ASL signers: insights into the organization of a sign-based lexicon. *Psychological Science*, 16: 856–860.

Uyechi, L. (1995) *The Geometry of Visual Phonology*. CSLI Publications, Stanford, Calif.

Wen, I.P. (2000) Mandarin phonology: evidence from speech errors. Doctoral dissertation, State University of New York, Buffalo.

Wilbur, R. B. (1987) *American Sign Language: Linguistic and Applied Dimensions*, 2nd edn. College Hill, Boston, Mass.

Wilbur, R. B. (1993) Syllables and segments: hold the movements and move the holds! In G. Coulter (ed.), *Phonetics and Phonology: Current Issues in ASL Phonology*, pp. 135–68. Academic Press, San Diego, Calif.

Wilson, M., and Emmorey, K. (1997) A visual-spatial "phonological loop" in working memory: evidence from American Sign Language. *Memory and Cognition*, 25: 313–320.

Wilson, M., and Emmorey, K. (1998) A "word length effect" for sign language: further evidence on the role of language in structuring working memory. *Memory and Cognition*, 26(3), 584–590.

Zeshan, U. (2004) Head, hand, and face: negative constructions in sign languages. *Linguistic Typology*, 8: 1–57.