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Effects of language modality on word segmentation: An experimental study of phonological factors in a sign language*

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This paper analyzes the word-segmentation strategies used in signed and spoken languages. The claim is that there is a strong "modality effect" in the word segmentation strategies used in these two types of languages. The experimental results show that both signers and non-signers use place of articulation and movement more heavily than handshape to make word segmentation judgments; however, signers are more sensitive to handshape than nonsigners are for making such judgments. This work shows that there are strategies for segmenting visual language input that are different from those used in segmenting auditory language input, regardless of language exposure. From the experimental evidence presented here and from the work on word segmentation in spoken language, one can conclude that viewers *use a word-sized unit itself to segment strings into words, which is argued to be due in large part to the visual/gestural nature of sign languages. In contrast,* listeners *depend most heavily on the syllable in their word segmentation strategies, which is argued to be due the auditory/vocal nature of spoken languages. This work can at least partially explain the variation in the well-formedness constraints on found in signed and spoken languages, which capitalize on this modality effect.*

1. Introduction

From the structural point of view, sign languages are more like each other than they are like the surrounding spoken languages in their locale, and they constitute a distinct typological class among languages with respect to phonology and morphology in a number of ways (van der Hulst 2000, Brentari 2002). An important question is how much of this similarity is due to modality effects – i.e., the fact that sign languages use the hands, face and body to produce visible signals while spoken languages use the vocal tract to produce audible signals – rather than to the relatively short period that sign languages have existed. One can address the impact of modality on language structure in a number of ways. One way is to do cross-linguistic work on as many sign languages as possible, both on comparatively younger and older sign languages, and to study these languages from as many different genetic sources as possible. This type of work is underway in a variety of forms, asking a range of questions about general typological features (Zeshan 2000), morphological characteristics (Mathur 2001; Aronoff et al. 2003), and sign language genesis (Senghas 1995; Kegl, Senghas and Coppola 1999). Studying the time course of language acquisition in signed and spoken languages has also been a way to uncover modality effects or lack thereof (Meier 1990; Pettito and Marentette 1991). Another way to approach this question is in the laboratory, by constructing psycholinguistic experiments that illuminate modality issues. This approach has been used by Singleton, Morford, and Goldin-Meadow (1993), Supalla (1990), Emmorey (2001 and references therein), to name a few. Finally, from the perspective of theory, there is a body of work that has investigated where modality effects might be responsible for the structures that represent signed and spoken languages at the level of phonology (e.g., Stokoe 1960; Liddell and Johnson 1989; Sandler 1989; Brentari 1998), syntax (e.g., Padden 1983; Lillo-Martin 1991; Neidle et al., 2000) and morphology (e.g., Supalla 1982; Mathur 2001; Liddell 2003). In this chapter, the focus is on the modality question and its relation to phonology – particularly, its effect on word segmentation. The analysis utilizes what has been discovered about phonology in sign languages over the last 40 years to examine the phonological well-formedness constraints in signed and spoken languages. These phonological constraints established for American Sign Language (ASL) are used to construct an experimental task that will help disambiguate the effects of language exposure (in this case, exposure to ASL or English) from modality effects.

This chapter is organized as follows. First, the rational for studying word segmentation in sign languages is given and predictions made for the outcome of the empirical study. In Section 1.1, the use of cue conflict as a design for studying word segmentation is motivated, and in Section 1.2 enough information is provided about the structure of signed words so that the properties under investigation will be well understood. Second, the empirical study is presented and the results discussed. Finally the broader implications of the findings are discussed, especially as they bear upon discussions of word segmentation in the literature on spoken languages.

1.1. Background on Word Segmentation

Word segmentation is the competency that allows language users to break up a string of an uninterrupted language signal into shorter, more manageable pieces that are subjected to further analysis; it helps us identify word breaks (Mattys and Jusczyk 2001). We have all experienced watching a sign language or listening to a spoken language in an unfamiliar language setting, and having the sensation that the signal is continuous, without breaks; this is the lack of the ability to segment the string into words. Word segmentation differs from lexical access, which is the competency that allows us to identify a word with a particular meaning, because it is not necessary to know the meaning of the word-sized units to segment the string; it is sufficient to recognize where the words begin and end. Babies are able to this well before they have a lexicon, between 6–9 months of age (Mattys and Jusczyk 2001).

Individuals segment words by utilizing phonetic properties, such as pause length, and by the phonological properties of individual languages. In spoken languages, this might be the allophonic variation that appears in different parts of the word. For example, in English, it includes the ability to recognize that if one hears an aspirated /t/ ([t^h]), it must be the beginning of a word (Jusczyk, Hohne and Bauman 1999). In a sign language, it might be the ability to recognize that two handshapes, such as the W-handshape and the H-handshape in ASL, do not appear in a single word, and hence there must be a word break between them (Friedman, 1977, Mandel 1981). The study of word segmentation is important because it is a key component in acquiring a language, and because this skill seems to involve both an innate competence and an acquired skill. To what extent is it a part of our innate abilities (i.e., competence) and to what extent is it tied to exposure to properties of a particular language or a particular type of language (i.e., performance)? Is it a general type of learning that could apply, for example, to both strings of linguistic units or strings of music, or is it a special type of language learning? And most relevant for the study reported here, how much of word segmentation depends on language modality – i.e., whether it is produced by the hands and body in space or by the vocal tract?

An experimental design using cue conflict has been useful in studying word segmentation effects in spoken languages in order to determine their strength and importance with respect to one other in making such judgments; it allows a ranking of strategies to emerge from most resilient to least resilient (Cutler et al 1986, Jusczyk et al. 1993; Suomi et al 1997; Vroomen et al 1998; Houston, et al 2000). In spoken languages, for example, word stress might be put into conflict with allophonic behavior in English or with vowel harmony in Finnish, in order to determine which of these aspects of the phonology is more important for listeners. In the next section, the properties that will be put into conflict in the sign language experiment are explained. This technique will be employed here to investigate questions of word segmentation in a sign language. In particular, we want to know if adults without exposure to a sign language have a systematic strategy for segmenting signed strings, and if they do, whether it is the same as or different from the word segmentation strategies used by signers. We will address whether non-signing individuals are equipped to do this purely on the basis of intuitions about how a signal produced by the hands, arms, face and body might do this. We will examine the experimental results to determine the degree to which users of spoken languages rely on learned, spoken language strategies to segment signed strings. In the experiment reported on here, one group of participants consists of individuals who do not know a sign language. To insure that the signers and non-signers are being presented the same task, nonsense words must be used, rather than actual signs, because having lexical access to the signs would give signers an advantage.

One of the questions concerning the differences in word segmentation judgments between signers and non-signers is the extent to which each group is able to use the different types of simultaneous information in the signed signal. Both signed and spoken languages have paradigmatic (simultaneous) information and syntagmatic (sequential) information used in creating contrast between words, but it has been argued that sign languages make more extensive use of simultaneous information in their phonology while spoken languages make more extensive use of sequential information (Brentari 2002; Meier 2002). It would, therefore, be plausible to expect that signers might be more sensitive to simultaneous information in making word segmentation judgments.

1.2. Sign Language Phonological Structure

There is general consensus that there are five basic phonological parameters (or feature classes) of sign language phonology: handshape, place of articulation, movement, non-manual behaviors, and orientation. We will not directly test orientation or non-manual behavior in the experiment (although we control these factors to prevent experimental confounds), so we will not discuss them at length here. Our experiment will place handshape, place of articulation, and movement parameters in conflict with one another to assess the strength and importance of each for signers and non-signers in making word segmentation judgments. In general, we predict that exposure to the language-particular phonology of ASL will affect word segmentation judgments in signers, but not non-signers. Some useful information about these three parameters of ASL phonology is explained in the following paragraphs.

Handshape is the particular form the hand assumes when producing a sign; there are approximately 40–45 distinctive handshapes in ASL, specified by approximately 13 distinctive features (Brentari 1998). Fingers are divided into those that move or have physical contact with a place of articulation, called the *selected fingers*, and those that do not, the *non-selected fingers*. The selected fingers have features of *joint configuration, quantity* and *point of reference*. Quantity and point of reference express the number of fingers and where on the hand they are located (the 1-handshape and the V-handshape in APPLE, and NERVE differ in quantity: Figure 1), while the 1-handshape and the I-handshape, made with the single pinkie finger (Figure 2), differ in point of reference. Joint configuration of the selected fingers specifies the joints of the fingers that are [flexed] or extended when articulating a specific handshape. The handshapes in CANDY and APPLE differ in joint configuration (Figure 1). When the fingers are extended, this is not expressed in the representation because, based on its phonological behavior and appropriate use of underspecification theory (Archangeli, 1984), 'extended' is the default specification, for joints in ASL (Brentari 1998: 162).

Figure 1. CANDY – 1st position and 2nd position (left); APPLE – 1st and 2nd position (middle); NERVE – 1st position and 2nd position (right).

Handshapes have been divided into marked and unmarked sets (Battison 1978), based on the selected fingers and the joints that are involved (Figure 2). The unmarked set uses either all of the fingers in a range of joint configurations (i.e., B, A, S, C, O, 5) or solely the extended index finger (i.e., 1); the marked handshapes use either other fingers – e.g., I (i.e., the pinkie finger), H (i.e., the index and middle fingers), W (i.e., the index and middle fingers), or other joint configurations of the fingers, such as the X-handshape that occurs in APPLE (Figure 1). The handshape in APPLE is considered marked with respect to joint configuration, since it has the 1-handshape, but it is bent at the interphalangeal joint. NERVE (Figure 1) is marked both because it has marked selected fingers (the index and middle finger) and because it is bent.

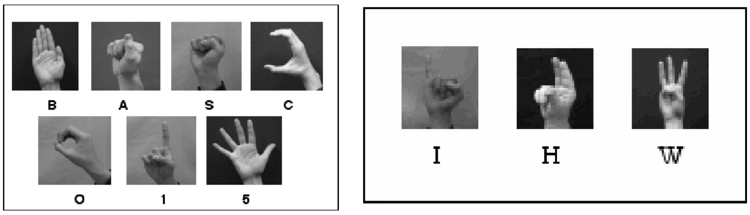

Figure 2. Unmarked ASL handshapes (left), and three marked handshapes (right).

Handshape will be manipulated in the experimental design by being divided into marked and unmarked groups. This is a fundamental distinction because even signs with two handshapes typically include one or both unmarked handshape(s), such as occurs in the following lexicalized compounds: FACE^STRONG=RESEMBLANCE (handshapes: 1→S), MIND^DROP=FAINT (handshapes:1→5), WATER^RISE=FLOOD (handshapes: W→5).[1] Handshapes in monomorphemic forms may change allophonically in aperture ([open]←→[closed]; see DESTROY, Figure 3), but not in selected fingers (Friedman 1977, Mandel 1981). These allophonic handshape sequences have been argued to be tied to segmental units (Sandler 1986; Liddell and Johnson 1989; Perlmutter 1992; Brentari 1998). The handshape aperture change itself is also discussed further below, because this dynamic change is classified as a movement (specifically, a local movement) within the phonology.

Place of articulation has distinctive regions of the *body* – head, torso, arm, and the non-dominant hand (also called H2, to distinguish it from the dominant signing hand, or H1) – as well as the three dimensional planes (e.g., the *horizontal plane*, the *vertical plane*, and the *midsagittal plane*; see Figure 3). In monomorphemic signs, while there may be allophonic changes within a distinctive region, there is typically just one distinctive place of articulation, (Sandler 1987). For example, in DESTROY (Figure 3), the two hands move allophonically from the ipsilateral to the contralateral sides of the horizontal plane and back again, but the region remains the horizontal plane throughout the sign's production. Other examples are signs such as DEAF, MEMBER, NAVY, all of which have a change in allophonic places of articulation within a region, but do not change distinctive place of articulation from one region to another. In polymorphemic forms, however, such as the lexicalized compounds mentioned above (MIND^DROP=FAINT, WATER^RISE =FLOOD, FACE^STRONG=RESEMBLANCE), there may be two distinctive places of articulation. In the present experimental design, the number of distinctive places of articulation is manipulated. Items contain either 1 or 2 distinctive places of articulation. Changes in place of articulation, like those of handshape, have been argued to be tied to segmental units (Sandler 1987, Brentari 1998).

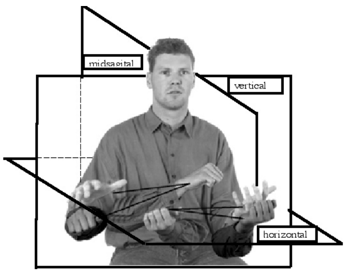

Figure 3. The ASL sign DESTROY, and the three dimensional planes utilized for places of articulation (those not on the body) are superimposed on the figure.

The Movement parameter is divided into path and local movements (Brentari 1998). Path movements are articulated by the elbow or shoulder; local movements are articulated by the wrist or hand. All movements may also have a shape (circle, straight, and arc). All of the signs in Figure 1 have a local movement, namely an orientation change, specifically [supination] of the wrist. The sign DESTROY has a sequence of two, straight path movements, the second of which is a complex movement. The second movement of DESTROY has, simultaneously, both a [straight] path movement and a change from an [open] to [closed] variant of the 5-handshape, which is a local movement (Figure 3).

Movements have been argued to be the "vowels" in ASL phonology (Liddell 1984) and also the syllable nuclei of the signed word, based on the way that they behave in the phonology (Brentari 1990a, Perlmutter, 1992). For example, all well-formed signs must have a movement, just as virtually all words have a syllable nucleus, and the notion of sonority can be calculated based on the size and excursion of movements of joints (Corina 1990; Brentari 1990a, 1998; Sandler 1993), analogous to the way that sonority in spoken languages can be calculated based on the size and excursion of mandibular movements (MacNeilage and Davis 1993; MacNeilage 1998). APPLE, NERVE, and CANDY have one syllable; DESTROY has two syllables. While most signs are monosyllabic, there are also a number of monomorphemic words, such as DESTROY (also REMOVE, GOVERNMENT, MONOPOLIZE, APPOINTMENT, LOCK) that are disyllabic. See Brentari (1998: 47) for a discussion of these forms. Moreover, lexicalized compounds, such as those mentioned earlier, are also often disyllabic. Repetitions of movement and a combination of circle+straight movement are permissible; other movement combinations are not permissible in a single disyllabic sign, and no ASL sign has more than two syllables (Uyechi 1996). The experimental design manipulated the number of movements (one vs. two) and the quality of the changes in 2-movement forms; the stimuli include permissible monosyllabic items, permissible disyllabic items, and non-permissible disyllabic items. The distinctive and allophonic properties of the three parameters, and the ways that they were manipulated in the empirical study are given in Table 1.

Table 1. The distinctive and allophonic properties of handshape (HS), place of articulation (POA), and movement (M).

	HS	POA	M
distinctive properties	selected fingers and joint configurations	body regions and dimensional planes	shapes: arc, circle, straight
allophonic properties	aperture changes	areas within a given region	repetitions
properties manipulated in the experiment	1. combinations of marked and unmarked HSs 2. changes permissible within a word and those occurring only across a word boundary	1. number of distinctive regions (1 vs. 2)	1. combinations of path and local movement 2. mono- and disyllabic forms

An important generalization can be stated regarding all three parameters discussed here. Namely, within a word, allophonic changes in handshape, place of articulation, and movement are permitted, but a change from one distinctive handshape, place of articulation, or movement to another is not permitted, except in special cases, such as compounds. Even in compounds, there is a tendency toward unmarked combinations of handshapes and permissible combinations of movements. It is predicted that the phonological structure of ASL will influence the word segmentation judgments of signers, but not of non-signers.

1.3. Modality Effects

Modality effects are defined here as the predispositions in signed and spoken languages to organize linguistic material in a manner that capitalizes on the relative strengths of the particular phonetic systems involved. A fundamental assumption employed in this work is that signed and spoken languages use different organizational strategies to present phonological information. These differences affect not only the substance of individual features and feature classes (e.g., the difference between having a [nasal] feature on vowels vs. a [circle] feature on movements), but also our intuitions about where word breaks might be found. For example, concerning the use of sequential (syntagmatic) vs. simultaneous (paradigmatic) organization in the two types of languages, Meier (2002) and Brentari (2002) have argued that factors such as the following allow sign languages to transmit more simultaneous information in the linguistic signal at a given moment in time: (i) the relatively fast speed of light vs. the relatively slow speed of sound (Bregman 1990), and (ii) the differences in so-called ‘tone fusion,’ which is the relatively short time needed between two auditory signals in order to perceive them as discrete, versus ‘flicker fusion,’ which is the relatively long time needed between two visual signals in order to perceive them as discrete (Chase and Jenner 1993).

The primary motivation of the experiment is to investigate whether the different organizational patterns to which speakers or signers are exposed affect word segmentation judgments a different language modality. Are we, regardless of language experience, capable of using the patterns of organization in a different modality effectively without prior experience? In the following sections two examples of modality differences in the phonology of signed and spoken languages are explained, and their potential relationship to the following empirical study is spelled out.

1.3.1. The segment in signed and spoken languages

It has been argued in that one modality difference between signed and spoken languages is the relative importance of segments (van der Hulst 2000, Brentari 2002, Channon 2002a, 2002b). With respect to the prominence of phonological units in a features geometry, the position of the segment – understood here as timing unit – is fundamentally different in signed and spoken languages. The difference can be stated as follows: In a spoken language hierarchy of units, segments are autonomous from features, dominate features, and can create minimal contrast (i.e., segments >> features). In a sign language hierarchy of phonological units, feature information predicts and dominates segmental units (i.e., features >> segments). This can be seen in the use (or lack of use) of segmental orders to create new words, and in the unit upon which minimal pairs are based. Both phenomena are described below.[2]

Regarding segment order, the degree of variability in order and content of segments in spoken words is greater than in signed words. 'Teen' and 'neat' are different, unrelated words in English, using the same phonological segments in different orders. In ASL, this type of contrast is severely limited (Channon 2002a, 2002b). Except in the case of compounds, the order of handshapes in a sign is largely predictable; the only handshape that can precede or follow a [closed] handshape is its [open] variant and the only place of articulation that can precede or follow a specified place is an allophonic place within that region. Most counter-examples to this generalization – i.e., pairs of signs, similar to 'neat'/'teen' with contrasting order in ASL are signs with the opposite meaning, such as CATCH (Hs1→Hs2) vs. THROW (Hs2→Hs1); IMPROVE (POA1→POA2) vs. GET-WORSE (POA2→POA1), showing that segment order might have a morphological rather than a phonological use. Since changes in handshape and place of articulation are argued to be segmental properties, as discussed earlier, by manipulating these parameters in the experiment, we will be able to determine the effects of the segment in making word segmentation judgments in our groups.

The unit upon which minimal pairs are based also shows a lack of reliance on the segment. Minimal pairs in ASL involve the unit of the entire word, rather than the syllable or the segmental unit.[3] For example, in ASL, the surface difference between the signs CANDY and APPLE (Figure 1) is based on the presence vs. absence of a [flexed] feature located at the joints structure – APPLE has a joints structure, given in bold in Figure 4a, and CANDY has none. CANDY has no specification for joints because the index finger is extended, which is the default setting for joints (Brentari 1998:107).

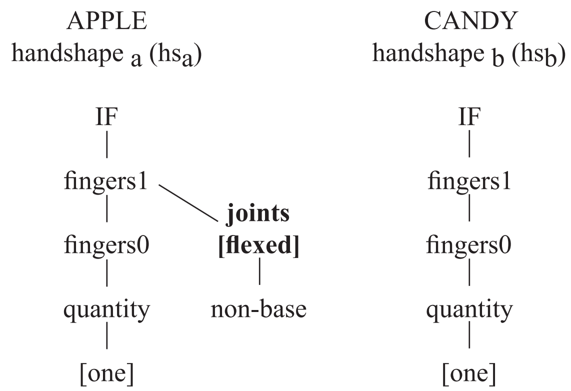

Figure 4. Representations of APPLE (left) and CANDY (right) in the Prosodic Model (Brentari, 1998), showing the placement of the branch structure responsible for creating a minimal pair in bold.

In the Prosodic Model, the concept of a consonant is taken to be the combination of handshape and place of articulation specified for the sign; these are the *inherent features* (IF) of the sign. This idea was first proposed in Chinchor (1978), but it was developed within a contemporary framework of feature geometry and autosegmental phonology in Brentari (1998). In Figure 4, only the handshape information is given, because it is the only structure relevant to this particular contrast. In the Prosodic Model representation, the joints structure spans the entire word domain – in this case, a monosyllabic word domain – not the segmental domain as expected in a spoken language (e.g., the initial consonant in [tin] 'teen' and [din] 'Dean'). In previous work on sign language phonology, a model more similar to that of spoken languages was used. Consider the representation in Figure 5a, which is a representation in the Hold-Movement model of sign language phonology (Liddell 1984; Liddell and Johnson 1989). In this model, periods of stasis were considered the consonantal units of ASL. A sign such as APPLE or CANDY would have three segments (stasis-movement-stasis), and the difference in handshape would be expressed on all three segments. Since the "joints/no joints" distinction is expressed on each of the three segments (hs_s represents the handshape in APPLE with the finger joints flexed, and hs_b represents the handshape in CANDY with the finger joints not flexed) these two forms cannot therefore be considered a minimal pair in the Hold-Movement model. In contrast, in Figure 5b, the handshapes (and their features) of CANDY and APPLE are represented only once in the representation. The important point here is that in the Hold-Movement representation, it is not possible to call APPLE and CANDY a minimal pair in ASL, yet this is a contrast accepted as such by native signers. There is only one specification for handshape in the representations in Figure 5b, which allows these to be called a minimal pair.

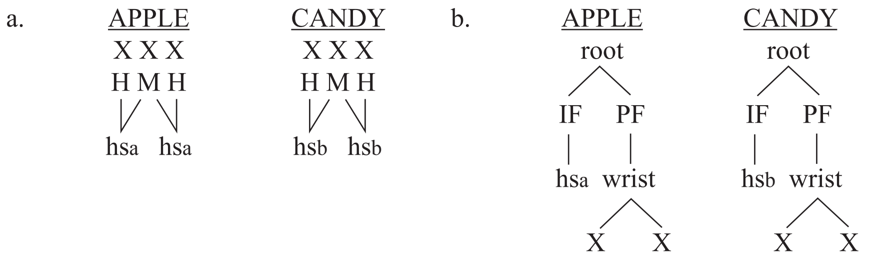

Figure 5. a. The Hold-Movement Model (Liddell and Johnson, 1989) and
b. the Prosodic Model (Brentari, 1998) representations of APPLE and CANDY, with hsa and hsb substituted for the complete representations of their respective handshapes

1.3.2. The syllable in signed and spoken languages

The syllable has been demonstrated through experimental evidence to be a fundamental unit in word segmentation in spoken languages (Jusczyk et al. 1993, Jusczyk, Hohne and Bauman 1999; Mattys and Jusczyk, 2001). In adults, there is evidence that when properties such as vowel harmony, which are expressed at the word-level, are put into conflict with stress, the syllabic cue of stress is more heavily relied upon (Suomi et al 1997; Vroomen et al. 1998). Moreover, words in most spoken languages have binary metrical feet, where feet often are defined in terms of syllables (Halle and Vergnaud 1987; Hayes 1995). All of these factors indicate that there is at least a statistical preference for words to be longer than one syllable in spoken languages, and that spoken word segmentation relies more heavily on syllabic than segmental or word-level properties.

This contrasts with the relatively low use of the syllable in sign languages. The majority of ASL monomorphemic signs are one syllable (93%, based on the Stokoe et al.,1965, dictionary). However, within the 7% of disyllabic lexical items, there are four types (Brentari, 1998: 186): (i) those that repeat the movement in some form, with no change in handshape (e.g., CHILDREN, COUGH, MILITARY, LEATHER); (ii) those that repeat the movement in some form, with an allophonic change in handshape on one movement only (e.g., DESTROY, EXPENSIVE, NOTE-DOWN); (iii) those with two distinctive movements, with an allophonic change in handshape (e.g., GOVERNMENT, REMOVE, JUMP); and (iv) those that repeat the movement in some form with a contrastive change in handshape (e.g., BACKGROUND, SOCIAL-WORK, NOTRE-DAME). As argued in Brentari (1990, 1998) and Perlmutter (1992) the syllable is the unit that best captures the co-ordination of the timing of handshape with movement in such forms. For example, a handshape change such as the one in DESTROY is co-extensive with an individual movement; it does not extend throughout an entire disyllabic sign. By manipulating this set of disyllabic forms in ASL in an empirical study, word-domain effects can be disambiguated from syllable effects in order to determine if the strong reliance on syllables by users of spoken languages (in speech) carries over into their word segmentation judgments of signs, and to see if signers employ the syllable in their own word segmentation judgments.

2. Experimental Method

As we have explained above, ASL utilizes the unit of the word in capturing minimal pairs and in the distribution of distinctive handshapes, movements and places of articulation. ASL also utilizes the syllable to organize the timing of handshape changes across a single movement, but the number of monomorphemic disyllabic forms is rather small with respect to the lexicon as a whole. The segment is used relatively little in ASL, as we have seen in the previous section. In spoken languages, the syllable has been shown to be the unit most heavily relied upon in making word segmentation judgments, but segmental information, such as allophonic distribution, and word-level effects, such as vowel harmony, play a role as well.

The hypotheses of the experiment are formulated in order to investigate differences in language experience and language modality, and the role of phonological units in word segmentation judgments. First, we hypothesize that sign experience will not play a dominant role in word segmentation judgments. That is, although experience with spoken languages predisposes speakers to use the syllable or segment to make word segmentation judgments in spoken languages, we expected both speakers and signers to use word level information for word segmentation judgments in a sign language. Thus, a modality effect was expected, whereby nonsigners (speakers) adapt to the new language modality by shifting to a word-level segmentation approach. Second, we nonetheless expected experience to affect phonological contributions to word segmentation. Specifically, we hypothesized that signers would utilize more simultaneous phonological cues than nonsigners. We also expected language-particular phonological constraints (distribution of sequences of handshapes, places of articulation, and movements) to affect word segmentation by signers but not by nonsigners.

2.1. Participants

Two groups of participants were employed in this study: 13 Deaf native ASL signers (18–50 years), and 13 hearing, non-signing individuals (15–30 years). A "native" signer learned ASL from his/her parents as a first language; our participants were also profoundly deaf, went to residential schools for the Deaf, have Deaf spouses, and have used ASL as their primary language throughout their lives. They would be expected to show the strongest effects of the grammar on word segmentation. The non-signing participants had never had any exposure to a sign language, not even to fingerspelling. They were native speakers of English, born and raised in the Mid-West (Illinois, Indiana, Ohio, and Michigan). Both signing and nonsigning subjects had completed high school.

2.2. Stimulus Materials

All stimuli were 'pseudo-signs' (i.e., nonsense signs), with a total of 168 items in all. There were 6 movement conditions x 5 handshape conditions x 2 POA conditions. Here "condition" means a particular combination of properties of that parameter, which will be described in detail below. The items were recorded on a digital Canon OpturaPI camcorder and digitized and compressed at 30 frames per second using Adobe Premier 6.0 software. The signer who produced the stimulus items on video was a Deaf, life-long user of ASL, went to a residential school for the Deaf, and is a member of the Deaf Community. The items were practiced before recording to insure a neutral non-manual expression across each entire form with no intervening eye blinks, and to insure that there was a 80–120 ms pause between the two movements of the disyllabic forms, consistent with pauses between words in a phrase (Brentari, Poizner and Kegl, 1995).[4] If a 2-handed sign was included, the non-dominant hand was present in the production throughout the entire item; that is, across both movements.[5]

In all, there were 28 cells, in which handshape, place of articulation, and movement cues were placed in conflict with each other in order to determine the most resilient word segmentation strategies in each group of participants. Each of the cells has six items – three items with one, and three with two, distinctive places of articulation.

Handshapes were separated into marked (abbreviated HSm) and unmarked (abbreviated HSu) groups as described earlier. B, A, S, C, O, 1, five were the unmarked handshapes, and the rest were considered marked handshapes. There were five handshape conditions. Fifty-four items were phonotactically permissible signs from the point of view of handshape: (i) 24 had one handshape, and (ii) 30 had one set of selected fingers with an aperture change ([open]←→[closed]). Another 114 items were not permissible monomorphemic signs: (iii) 36 forms in which both handshapes were unmarked (i.e., the index or all fingers), (iv) 36 with one unmarked handshape (groups (iii) and (iv) are possible compounds, but not monomorphemic signs), and (v) 36 items in which both handshapes were marked, combinations which do not occur in single signs of any type.

There were two place of articulation conditions. In each of the 28 cells, three items had one place of articulation and three have two places of articulation (i.e., head, torso, H2, arm, and the three dimensional planes). In all, 84 items had one place of articulation and 84 had two places of articulation. The forms with two places of articulation may occur in compounds, but not in monomorphemic signs.

Regarding movement, there were six conditions. Sixty items were permissible structures: (i) 30 had one movement and (ii) 30 had two movements that were permissible in monomorphemic signs. The other 108 items are not permitted in monomorphemic signs or compounds: (iii) 24 combinations of non-permissible local movements (e.g., combinations of handshape changes and orientation changes), (iv) 30 illicit combinations of two path movements (e.g. straight+arc), (v) 24 combinations of a path movement and a handshape change, and (vi) 30 combinations of a path movement and an orientation change. The organization of the stimuli is shown in Table 2; bold typeface indicates that a form is given in Figure 6 as a example stimulus item. By putting cues in conflict in this way, we can directly evaluate the following word segmentation factors.

Table 2. Distribution of items in stimulus set. HSu=unmarked handshape; HSm= marked handshape; M=movement; POA=place of articulation; OR=orientation; Δ=change;. Grey cells indicate physically impossible forms. Bold typeface indicates places from which the sample stimulus items are extracted; see Figure 6.

Handshape types → Movement types ↓	1HS	HSm+HSm	HSu+HSu	HSu+HSm	1HS+aperture Δ
1 MOV	1 POA (3) 2 POA (3)	1 POA (3) 2 POA (3)	1 POA (3) 2 POA (3)	1 POA (3) 2 POA (3)	1 POA (3) 2 POS (3)
ORΔ+HSΔ		1 POA (3) 2 POA (3	1 POA (3) 2 POA (3	1 POA (3) 2 POA (3	1 POA (3) 2 POA (3
path+path	1 POA (3) 2 POA (3	1 POA (3) 2 POA (3	1 POA (3) 2 POA (3	1 POA (3) 2 POA (3	1 POA (3) 2 POA (3
path+HSΔ		1 POA (3) 2 POA (3	**1 POA (3)** 2 POA (3	1 POA (3) 2 POA (3	1 POA (3) 2 POA (3
path+ORΔ	**1 POA (3)** 2 POA (3)	1 POA (3) 2 POA (3	1 POA (3) 2 POA (3	1 POA (3) 2 POA (3	1 POA (3) 2 POA (3
2 M	1 POA (3) 2 POA (3	1 POA (3) 2 POA (3	1 POA (3) 2 POA (3	**1 POA (3)** 2 POA (3	1 POA (3) 2 POA (3)

Figure 6. Sample stimulus items. 1 HS x 1 POA x 2 Ms (1 path+1 ORΔ; left); 2 HS (5[open] 5[closed]) x 1 POA x 2 Ms (path+ aperture change; center); 2 HSs (8O) x 1 POA x 2 Ms (repeated path; right).

First, specifically with respect to group, if signers and nonsigners show a general difference in the items that are permissible sequences of handshape or movement, we will see an effect of ASL phonological constraints on signers' word segmentation judgments. For handshape, this is column 5, for movement, this is row 6. If, however, both groups' word segmentation patterns are the same for these conditions, we will conclude that there is less of an effect of the phonological constraints, and more of a more general modality effect. Second, specifically with respect to the units, if either group responds to specific sequences of handshapes or place we will see an effect of the segment. If we see either group respond to specific sequences of movements, this will be an effect of the syllable.

2.3. Procedures

The task was run on a Dell 4600 computer with an 18-inch computer monitor. A program was constructed specifically for this experiment that randomized the items for each subject, presented the instructions in English, inserted 'READY' printed in the middle of the screen as a prompt before each item, and registered the responses in individual files for each participant according to item number. Instruction was presented in printed English to be read by all participants, and they were also signed in ASL to the Deaf participants. Participants were instructed to watch the item and to decide if the form looked like one sign or two signs, based on their best intuitions. They were told that these stimuli were not real ASL signs. Items were shown only once. Participants were told that accuracy was important, but not speed, and that they were to consider their choice as long as needed to make as accurate a selection as possible. There were three practice items, after which further clarification could be provided. Participants initiated the presentation of items by hitting the space bar, and the mouse was used to register their responses by clicking on one of two 2-inch x 3-inch squares on the computer screen, with '1-sign' or '2-signs' written inside, both of which were presented simultaneously on the screen after each item. No reaction times were recorded. The average session duration for both groups was approximately equal, 44 minutes.

2.4. Results

An analysis of variance (ANOVA) was conducted on the between subjects factor of Group (2: signers vs. nonsigners) and repeated measures of Stimulus Value (2: judgments of one vs. two signs) and Parameter (3: handshape, place of articulation, and movement). The results are given in Figure 7, reported as percentage of 2-sign judgments. There were significant main effects of Stimulus, $F_{(1,24)} = 42.5$, $p < .001$, and Parameter, $F_{(3,73)}=55.8$, $p < .001$. There were also significant interactions of Stimulus x Parameter, $F_{(3,72)} =6.78$, $p < .001$, and of Group x Parameter, $F_{(3,72)} = 2.9$, $p < .04$.

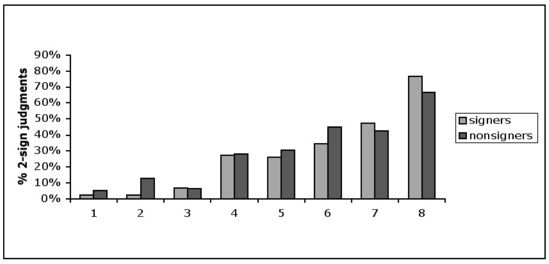

Figure 7. Mean percentages of 2-sign judgments for one- and two- value stimuli in eachparameter.

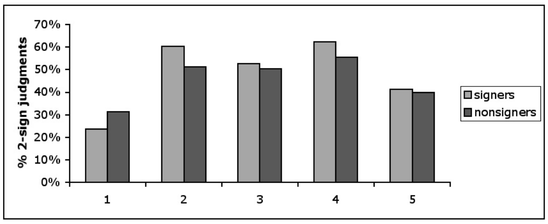

Figure 8. Mean percentages of 2-sign judgments across all handshape conditions.

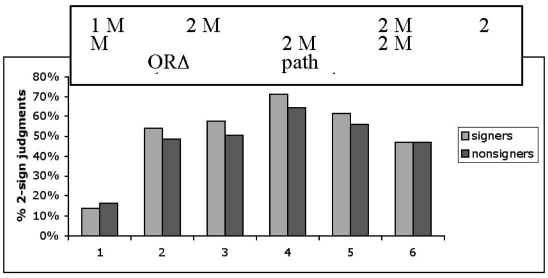

Figure 9. Mean percentages of 2-sign judgments across all movement conditions.

An analysis of variance (ANOVA) was also conducted on each of the parameters of handshape, place of articulation, and movement alone, using the between subjects factor of Group (2: signers vs. nonsigners) and repeated measures of Stimulus Value (2: judgments of one vs. two signs) and Parameter. For handshape, there was a main effect of Parameter, $F_{(4,96)} = 78.4$, $p < .001$, a significant interaction of Stimulus x Parameter, $F_{(4,96)} = 14.2$, $p < .001$, and a significant interaction of Group x Parameter, $F_{(4,96)} = 3.5$, $p < .05$. For movement, there was a main effect of Parameter, $F_{(5,120)} = 7.04$, $p < .001$, and a significant interaction of Stimulus x Parameter, $F_{(5,120)} = 135.9$, $p < .001$

There were no other significant statistical effects; however, the difference between the means of 1- and 2-sign judgments for each of the parameters differed between the two groups. The difference between the means of 1- and 2-sign judgments for handshape was 24% (signers) versus 13% (nonsigners); for place of articulation it was 14% (signers) versus 17% (nonsigners); and for movement it was 36% (signers) versus 33% (nonsigners.). If we take these differences in mean percentages between 1- and 2-sign judgments as an indication of how heavily each of the parameters was relied upon, we see that signers depend on movement, handshape, then place of articulation (in descending order) while nonsigners depended on movement, place of articulation, then handshape.

3. Discussion

In this section, we will address our results in terms of group comparisons, effects that relate to the use of phonological units, and finally, the degree to which the parameters of handshape, place of articulation and movement were relied upon in making word segmentation judgments. It was hypothesized that both groups would rely on the same word-level strategy to make word segmentation judgments in a sign language; that is, we expected a strong modality effect. Second, it was hypothesized that signers would be able to utilize a greater number of simultaneous cues in making word segmentation judgments. Third, we expected language-particular phonological constraints on sequences of handshapes, places of articulation, and movements to be used by signers but not nonsigners in making word segmentation judgments.

3.1. Group comparisons

The first hypothesis concerning group was that signers and nonsigners would use the same overall strategies. This hypothesis was supported. There was no significant Group x Stimulus Value interaction for any of the parameters; however, there were some results that did not achieve statistical significance, but will be discussed in the section below on sign parameters. The second hypothesis concerning group was that signers would be more sensitive to a greater amount of simultaneous information. This hypothesis was supported by the significant interaction between Group x Handshape Parameter, showing that signers make significantly greater use of handshape information in word segmentation judgments than nonsigners do; this is the only parameter which shows this interaction. Despite native exposure to languages in different modalities, both groups relied on the same strategies overall in making word segmentation judgments in a sign language.

Surprisingly, the signing participants seem not to use ASL phonological constraints in making word segmentation judgments. This is inferred from the lack of difference in signing and nonsigning participants in column 5 in Figure 8 (for handshape) and column 6 in figure 9 (for movement). These are the items that had permissible sequences – either aperture changes for handshape, or types of repetition or circle+straight combinations in movement.

3.2. Sign Language Unit of Word Segmentation is the Word

As discussed earlier, the stimuli were constructed to address the question of potential differences in the unit of analysis used by signers and nonsigners in the experimental task. The permissible handshape sequences and permissible place of articulation sequences were included to determine segmental-level effects. The permissible movement sequences were included to determine syllable-level effects. Importantly, the set of permissible disyllabic forms in column 6 of Figure 9 were employed to disambiguate word-domain effects from syllable effects, in order to determine whether the strong reliance on syllables by users of spoken languages carries over into their word segmentation judgments of signs, and to see whether signers employ the syllable in their own word segmentation judgments, given that the phonological constraints concerning the timing of handshape changes are based on the syllabic unit (Perlmutter 1992; Brentari 1998).

With regard to the segment, there was no statistical evidence that signers or nonsigners treated the permissible 2-handshape sequences differently than the non-permissible 2-handshape sequences. There was, instead, a strategy of ‘1 value = 1 word’.

Regarding the syllable, both groups relied most heavily on movement cues to make word segmentation judgments. As described earlier, the syllable is possibly the most important unit used in making word segmentation judgments in spoken languages when other cues are in conflict with it, even though it has been shown that the segment in English (Cutler et al. 1986), the syllable in French (Mehler 1981), the word as the domain of vowel harmony in Finnish (Suomi, McQueen and Cutler 1997), and the metrical foot in English, Dutch, Finnish (Vroomen, Tuomainen, and de Gelder 1998) are all used in some capacity to segment words.[6] Finnish is the most relevant to the discussion here because it is the only spoken language for which both the word domain cue of vowel harmony and the syllable domain cue of rhythm were put in conflict in an experiment very similar to the ASL study reported here (Vroomen, Tuomainen, and de Gelder 1998).[7] When the rhythmic effects of stress conflicted with those of vowel harmony, native Finnish subjects relied more heavily on stress cues, associated with the syllable.

A key question for the sign segmentation task presented here is whether the reliance on movement cues is a word effect or a syllable effect. I would argue that it is a word effect, for the following reasons. First, when deciding which unit is relevant, the one that captures the most generalizations should be selected. In this case, the strategy used by participants across all three phonological parameters is best captured by the word domain. The generalized strategy is '1 value = 1 word'; it did not matter if this value involved a segmental unit, such as handshape or place of articulation, or a syllabic unit, such as movement. Second, the pattern of performance by both groups was not based on a regularly alternating pattern. Crucially, neither set of participants used an alternating pattern to make word segmentation judgments, such as the 'strong' unit of trochaic stress, or any other pattern that included a repetitive sequence. In order for the syllable to be the relevant unit, there would not only have to be a sequential pattern involved, but a sequence of a particular sort. Instead, like word segmentation based on vowel harmony, *every change* in value triggered the perception that it signaled the beginning of a new word.

3.3. Sign Language Parameters

In this section, the sign language parameters that are used most heavily to make word segmentation judgments in our groups are examined and discussed in terms of the existing ASL literature. First, concerning movement and place of articulation, Corina and Hildebrandt (2002) found that combinations of movement and place of articulation also generated the strongest "similarity" responses in both signing and non-signing subjects; that is, forms with the same movement and place of articulation are judged to be most similar in both signing and non-signing subjects (see also Corina and Knapp, this volume). This would be consistent with the results presented here, since the place of articulation and movement parameters showed a great deal of similarity between groups.

Second, the heavier reliance on handshape by the signing group in the study may be explained in two ways. First, handshape can be considered the most arbitrary and the most categorical of the sign language parameters, and therefore, it may be accessible only to individuals with experience with a sign language. From the point of view of phonological description and analysis, handshape is much more "well-behaved" as a linguistic entity, than is movement or place of articulation. And, in this context, one can interpret "well-behaved" as being analyzable in a discrete fashion and able to conform most closely to the formalism of binary oppositions and hierarchical representations. There is also a great deal more consensus about representations of handshape – in particular, how they should be represented in a feature geometry and what parts of the handshape are distinctive within a sign language grammar – than there is about place of articulation or movement (see, for example, van der Hulst 1995; Sandler 1996; Brentari 1998). It is also true that it is comparatively easier to list a reasonably small number of handshapes based on their discrete component parts than it is to do this with movement or place of articulation. In the psycholinguistic literature, handshape is the parameter that shows the strongest divergence between the 'companion gestures' (McNeill 2000) that speakers use as they talk and the manual gestures of a sign language. In a study that compared three groups of subjects – hearing people using gestures that accompany speech, hearing people who were asked to gesture without speech, and home signers – Singleton, Morford, and Goldin-Meadow (1993) and Goldin-Meadow, McNeill, and Singleton (1996) found that the biggest difference between gestures that accompany speech and productions of home signers was that the home signers used a greater variety of handshapes in their output. This suggests that as gesture becomes more linguistic, handshape becomes more differentiated. Independent evidence also comes from a recent experiment on categorical perception (Emmorey, McCullough and Brentari 2002), in which handshape was found to exhibit categorical perception effects for signers (but not for non-signers), while place of articulation failed to exhibit such effects. The strong linguistic nature of handshape in sign languages is supported by these experimental findings. Second, handshape may be the most difficult parameter for non-signers to perceive because the joints involved are relatively distal (those closer to the extremities of the body), and as such are smaller in size and least likely to be used by the untrained eye in a task of word segmentation.[8]

To conclude this section, it is worth commenting on difficulties that have been reported when children attempt to learn artificial Manually Coded English systems of signs (MCE; e.g., Gustason, Pfetzing, and Zawalkow 1980). The work on MCE by Supalla (1990, 1991), Stack (1999), and Supalla and McKee (2002) shows that artificial systems fail to be learned by Deaf children because they follow no discernable phonological system, either signed or spoken. The experimental work just presented suggests that another difficulty of MCE systems is that they lack the strong cues to segmentation that are due to a modality effect. Those cues are important even to persons who lack exposure to a sign language.

In closing, we must note that despite the fact the instrumental measurements on sign languages and spoken languages must be carried out with different equipment and consideration for different types of sensory effects, the question of how much the medium infiltrates the code in language cannot be answered until both signed and spoken languages are studied with comparable tasks and experimental designs.

Notes

* I am grateful to Robin Shay for her help in constructing the stimuli, to the participants of LabPhon 8 for the discussion of these issues at the conference, and to Catherine Best and an anonymous reviewer for their helpful comments on an earlier version of this paper.

1. Lists of compounds from Klima and Bellugi (1979) and Liddell and Johnson (1986) were consulted.
2. This is not an absolute, but rather a matter of statistical tendency, since there are spoken languages that use tone or vowel harmony values to signal a minimal pair, and in ASL there are a few minimal pairs that use the segment.
3. I am considering only forms from different morphological paradigms, so FLY and FLY-THERE would not be a minimal pair.
4. Supalla (1990) demonstrated that neither pause length between two parts of a signed string nor the number of hands producing a sign influences subjects' judgments.

5. This would facilitate a judgment of ‘1 sign’, since well-formed words in ASL have one specification for the non-dominant hand (Brentari 1998).
6. Often these adult experiments were targeting a combination of word segmentation and word identification or lexical access.
7. For an excellent summary of vowel harmony as a word-based phenomenon, see Krämer 2001).
8. I am grateful to Onno Crasborn for this suggestion.

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