LANGUAGE AND LINGUISTICS 6.2:217-246, 2005
2005-0-006-002-000150-1

A Functional Explanation of Taiwan Sign Language Handshape Frequency*

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Linguistic exploration of sign languages has been going on for nearly half a century. Yet, much remains to be learned about sign language structure and use. Although frequency effects have long been known to be important in functional approaches to linguistics, and exploration in this area is now gaining momentum in mainstream linguistics, questions of frequency effects have hardly been explored in sign languages. This work is a small step in the direction of filling that gap. Smith & Ting (1984) identify 56 handshapes in TSL. The null hypothesis predicts that all 56 ought to occur with equal frequency in TSL. I show, using a very small corpus, that this is not the case; in fact, some handshapes have a much greater token frequency than others. Why should this be? Knowing that any thorough answer will encompass competing factors, I appeal to the notion of ease of articulation and see how far it can go. Following Ann 1993 and 1996, I categorize handshapes into three groups: easy to articulate, hard to articulate and impossible to articulate, and show how logically possible handshapes, including attested TSL handshapes, fit into this paradigm. Then I show that the most frequently occurring handshapes tend to be the easiest to articulate, but that the least frequently occurring handshapes are not necessarily those that are hard to articulate. The results presented here are admittedly preliminary, but they serve to open the door to future investigation of frequency effects in TSL.

Key words: sign language, Taiwan Sign Language, functional linguistics, ease of articulation, frequency, corpus linguistics

1. Introduction

In the late 1960s, a surprising claim was made: that the gestures that American Deaf people use in communication with each other actually had all the properties of a language (Stokoe, Casterline & Croneberg 1965). Part of the evidence advanced to support this claim was that ASL signs, analogous to spoken words, were composed of parts. The parts

* I thank Susan Fischer, James Myers, Long Peng, Jane Tsay and an anonymous reviewer for helpful comments and criticisms of all the ideas within. All remaining shortcomings are mine.

originally proposed are handshape, palm orientation, location, and movement (Stokoe, Casterline & Croneberg 1965, Battison 1978). With this, American Sign Language (ASL) became a topic of interest to linguists. Since this time, many sign languages have been investigated. In this paper, I examine a puzzle that concerns handshape in Taiwan Sign Language (TSL). The term "handshape" refers to the configuration of the fingers as a sign is articulated. A handshape is just part of a sign; excluded from consideration here are palm orientation, location, and movement. The handshape puzzle about which this paper has something to say has to do with how often a given handshape occurs. Smith & Ting (1984) identify 56 handshapes in TSL. The null hypothesis predicts that all 56 ought to occur with equal frequency in TSL. I show that this is not the case; in fact, some handshapes occur with much greater frequency than others. Why should this be?

To explain this puzzle, I make an appeal to ease of articulation. In order to make this argument, I discuss in §2 the construct of frequency of occurrence in spoken languages and explain how it has been understood to relate to sign languages. Next, I discuss the construct of ease of articulation in spoken languages and explain how it has been used in sign language research. In so doing, I review Ann (1993) and explain my system for determining ease of articulation for handshapes, then I present the results: the handshapes of TSL ranked according to ease of articulation. In §3, I present the puzzle of interest here that has to do with the token frequency of TSL handshapes and their ease of articulation. I show that the most frequently occurring handshapes tend to be the easiest to articulate, but that the least frequently occurring handshapes are not necessarily those that are hard to articulate. In §4, I draw some conclusions and discuss the implications of these findings.

2. Functionalism and the constructs of *frequency of occurrence* and *ease of articulation*

Linguists have explored the constructs of frequency of occurrence and ease of articulation largely in the context of an approach known as functionalism, as opposed to formalism. It is certainly beyond the scope of this paper to characterize the exact properties of functional as opposed to formal approaches, and in no way can the brief discussion that follows be taken to be an apt summary of all of functionalism or formalism. Both are diffuse sets of ideas and methodologies that result in two rich and complex research paradigms that would be impossible to describe or summarize thoroughly. But, although this is true, there do seem to be two identifiable approaches to linguistics that can, at least tentatively, be described (Newmeyer 1998:7-14).

Simply put, functional linguists believe that constraints over languages can arise from anatomy or physiology of the articulators, the perceptual system, general cognitive constraints, psychological, psycholinguistic, or sociolinguistic concerns. It is these constraints that they want to explore and describe. Formal linguists take a very different view. They believe that languages are internally constrained; that is, that although outside factors may have some effects, grammars have their own internal logic, separate from anything else in human cognition. The constraints internal to language are the ones they would like to explore. Understandably, these differing perspectives cause their proponents to have divergent views on some rather serious issues. Among them are the endeavors listed in (1):

(1) a. the goals of linguistic analysis (Haspelmath 2000:236)
    b. the facts about language that need to be "explained"
    c. the domains worth exploring in search of "explanation"
    d. what counts as an "explanation" (Newmeyer 1998)

In syntax, the gulf between functional and formal ideologies and consequent research paradigms is reflected by the fact that although functional syntacticians have made a number of observations that most formal syntacticians accept as true, these observations have not been made part of formal syntactic theories (Bybee 2001:4-5).

In phonology, however, this dichotomy is much less pronounced. It has long been tacitly understood that functionalism in phonology "is phonetic in character" (Hayes 1999:243).[1] Moreover, phonologists have long accepted the idea that the tension between the requirements of minimization of articulatory effort on the one hand and minimization of perceptual confusion on the other results in human languages sounding the way they do (Passy 1891, Boersma 1998:2). It is easy to see how these requirements are functionalist in nature. Even formal phonologists consider phonetics a part of phonology, since phonetic motivation has always been sought as a motivation for phonological phenomena (Bybee 2001:4); in fact, phonetic motivation plays a crucial role in theories of phonology such as Grounded Phonology (Archangeli & Pulleyblank 1994).

The research reported here is functionalist in nature because it seeks to explain an aspect of TSL use (i.e., frequency data) by claiming that ease of articulation plays a role in the explanation.

[1] This discussion is not meant to imply that "phonology = formal, phonetics = functional." In fact, Keating (1996:58-9) cautions against this. Dichotomizing these two approaches makes them seem as though they are competing, with the result that one is better than the other. But she reasons that phonology and phonetics are not accounts of the same phenomena; rather they are accounts of different phenomena. Therefore, both are necessary.

2.1 Characterization of frequency of occurrence and what it has been invoked to explain

Linguists want to explain the most robust of patterns in language, but exactly how do linguists tell that a given pattern is robust? I examine this question from the point of view of frequency. The idea of frequency of occurrence has a history in the literature. It has been suggested that the relative frequency of linguistic forms correlates with other properties of language. For example, Zipf (1935) claimed that the most frequent forms in a language are also the shortest. This claim was not explored much in the literature (Bybee & Hopper 2001:1). Today there is a sharp contrast between the ways frequency of occurrence is thought about in formalist vs. functionalist theories. For example, formal phonologists have traditionally conceived of patterns as either attested or unattested. This "all or nothing" view is beginning to change in the face of a growing realization that many patterns appear to be gradient. For example, a pattern could hold in a language only 60% of the time (Hayes 2001, Ann & Peng 2001).[2] On the other hand, linguists whose work embodies a more functionalist perspective have always had a deep interest in frequency of occurrence. They claim that speakers "have an extraordinary sensitivity to frequency," for example, in that "certain sound changes are diffused through the lexicon earliest in frequently-occurring items…" (Labov 1994:598 in Newmeyer 1998:123f.). In fact, frequency of occurrence is said to be central to the thinking of functional linguists (Newmeyer 1998).

In functional theories, two kinds of frequency are theoretically interesting and useful: token frequency and type frequency. As explained by Bybee (2001:10), token frequency refers to the "frequency of occurrence of a unit, usually a word, in running text—how often a particular word comes up. Thus *broke* (the past tense of *break*) occurs 66 times per million words in Francis & Kučera (1982), while the past tense verb *damaged* occurs 5 times in the same corpus. In other words, the token frequency of *broke* is much higher than that of *damaged*."

Linguists have appealed to the idea of token frequency to explain two effects in phonology and morphology. First, phonetic change seems to progress more quickly in items with high token frequency. An example is the loss of schwa in frequent words like *every*, *camera*, *memory* and *family*, making them two-syllable words for many speakers. But the schwa remains in similar, though less frequent words such as *mammary*, *artillery* and *homily.* The presence of the schwa ensures that they remain three syllable words for many speakers (Bybee 2001:11).

The second puzzle for which token frequency provides an explanation is that some

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[2] I thank Long Peng for a number of enlightening conversations about this phenomenon.

words "are more resistant to other kinds of change such as analogical change or grammatical change" (Bybee 2001:12). For example, consider the following data. Analogical leveling occurs when a paradigm such as *weep/wept* regularizes to *weep/weeped*, *creep/crept* to *creep/creeped* and *leap/lept* to *leap/leaped*. But some paradigms like *sleep/slept* and *keep/kept* do not regularize to *sleep/sleeped* or *keep/keeped.* Functional linguists have shown that verbs like *weep*, *creep*, and *leap* regularize the irregular pasts (*wept*, *crept*, *lept*) to *-ed* past tense forms because they have a lower token frequency than verbs like *sleep* or *keep*. *Sleep* and *keep* have a high enough token frequency to maintain the irregular past. Thus, we can say that high frequency irregular verb paradigms are also conservative. The same effects show up in syntax as well (Bybee 2001:12).

Type frequency (Croft 1990) refers to "the dictionary frequency of a particular pattern (e.g., a stress pattern, an affix, or a consonant cluster)" (Bybee 2001:10). Consider, for example, two-syllable English words. If every such word has one stress, then there are two possible stress patterns: either (i) stress the first syllable (such as in *knitting*, *staple*, and *context*) or (ii) stress the second syllable (*implore*, *allege*, and *descend)*. If we were to ask which is the more frequent pattern in English, we would be counting a pattern of first or second syllable stress, not a particular lexical item that adheres to that pattern.

Type frequency plays a role in constructing explanations for linguistic puzzles. For example, type frequency "helps determine productivity;" in other words, the "extent to which a pattern is likely to apply to new forms such as borrowings or novel formations" (Bybee 2000:12f.). For example, nonce forms take morphology that has higher type frequency than lower type frequency.

2.2 Frequency of occurrence in sign language research

In sign language research, the few studies that deal with frequency do not conceptualize their questions or data as some functional linguists might. Woodward (1982, 1985, 1987) examined the frequency of particular handshapes across ten sign languages, using essentially dictionary data. He examined handshapes with what he called "single finger extension" (apparently, handshapes in which one finger is extended with the rest of the fingers closed) (1982), "two finger extension" (two fingers extended with the rest closed) (1985), and "single finger contact" (handshapes in which one finger contacts the thumb) (1987). Through Woodward's work, several observations about handshapes, reported in (2), came to light for the first time.

(2) a. The extended index finger occurs in all of the sign languages. The extended ring finger occurs in only one of the sign languages.
b. The extended index finger occurs in a relatively large percentage of signs, compared, for example, to the extended ring finger, which occurs in a tiny percentage of signs.
c. Single finger extension handshapes occur more commonly than two finger extended handshapes.
d. Single finger extension handshapes are more common than handshapes in which a single finger contacts the thumb.

Woodward's observations alone were a great contribution when they were made, but the issue of an explanation for these observations was never examined.

Both Ann 1993 and 1996 were concerned with type frequency of handshapes in two unrelated sign languages, ASL and TSL. Both used as data all the handshapes listed in the Smith & Ting (1979, 1984) glossaries for TSL and the *Dictionary of American Sign Language* (DASL: Stokoe, Casterline & Croneberg 1965) for ASL. Both tried to explain frequency of occurrence data by making an appeal to ease of articulation, which I discuss in the next section. Both conceptualized frequency as a condition in which a handshape occurred more often than expected. What was expected was calculated by means of a mathematical formula. The present work differs from Ann (1993, 1996) in three ways. First, here I calculate frequency in terms of how many times a handshape occurs, not whether it is expected to occur at all. Second, Ann (1993, 1996) did not couch the discussion of frequency and ease of articulation in functionalist theory. Third, Ann (1993, 1996) ascertained frequency in only one way: they examined only type frequency ascertained from dictionary entries. This work expands that attempt by examining conversational data, albeit a very small amount.

Finally, psycholinguistic work on the acquisition of ASL handshapes by deaf children by Siedlecki & Bonvillian (1993) and Bonvillian & Siedlecki (2000) use token frequencies of errors of children in conversation with their parents. They showed that children got location and movement correct more often than handshape. They conclude that handshape is the most challenging parameter of a sign to acquire.

2.3 Characterization of *ease of articulation*

Phonologists express ease of articulation only indirectly in formal theories, for example, when considering notions like "marked" and "unmarked." Far more helpful here are phoneticians' ways of thinking about ease of articulation. Phoneticians attempt both to characterize exactly what "ease of articulation" in spoken languages might entail, and to establish what use it may have as a theoretical construct; in other words, what linguistic phenomena could explain ease of articulation. I examine both of these areas now.

The intuitively pleasing notion of "ease of articulation" is extremely difficult to quantify. It is not surprising that linguists generally agree that the attempts to explain what makes a sound relatively easy or difficult to articulate have not yet adequately characterized ease of articulation in spoken languages (Ohala 1990:260, Lindblom 1990:148, Nelson, Perkell & Westbury 1984:945, Keating 1988, Stevens 1971). Ladefoged (1990 cited in Lindblom 2000:304) suggests that ease of articulation is language-dependent and cannot be measured; therefore appeals to it are unscientific. Lindblom (1998:250) acknowledges that ease of articulation is "difficult to define," but suggests that "recent developments indicate that this situation is about to change." Lindblom (2000:304) suggests that worries about "uncritical use of articulatory ease…[are] well taken… but… appear overly pessimistic." Next, I outline four attempts to characterize ease of articulation in the spoken language literature.

2.3.1 Departure from normal/neutral position makes a sound more difficult

Two strands of research, the bite block studies and studies of spontaneous voicing, point to the conclusion that sounds whose articulators depart from a normal or neutral position can be considered more difficult than sounds whose articulators remain in normal or neutral position. I shall briefly examine each in turn.

A bite-block is a device that, placed in the mouth, prohibits the jaw from moving normally. In the bite-block studies, speakers produce vowels both normally and with their jaws restrained by a bite-block. Researchers find that formant values for bite-block vowels correspond very closely to those of normal vowels (Lindblom & Sundberg 1971, Gay, Lindblom & Lubker 1981). How is this possible? The researchers surmise that subjects compensate for the lack of mobility in the jaw by exaggerating a gesture in the tongue; in other words, they create "supershapes" of the tongue (Lindblom & Sundberg 1971:1177). This suggestion has implications for the study of ease of articulation. If speakers can produce the same vowel with either the normal shape or a supershape of the tongue, why do they choose the normal shape? The researchers conclude that it must be because the supershapes are simply too demanding. Therefore, they reason that speech, like other motor behaviors, evolves according to "minimum expenditure of energy or least effort" (Willerman 1991:22-23, see also Lindblom 1983:243, Lindblom 1990:149).

The second strand of research that examines which sounds are relatively difficult to articulate has to do with spontaneous voicing. Spontaneously voiced sounds include liquids, nasals, glides and vowels. In order for voicing to occur, two conditions must be met: first, the vocal cords must be relatively close together and second, there must be air crossing over the vocal cords (Ohala 1983:194). Both conditions are met in the normal articulation of liquids, nasals, glides, and vowels, therefore they are considered “spontaneously” voiced. In contrast, stops and fricatives are spontaneously unvoiced, since when they are produced, there is no airflow to set the vocal cords into vibration (Ohala 1983, Westbury & Keating 1986). Of course, it is possible to produce both unvoiced sonorants and voiced fricatives and stops. These compensations, however, are said to be more effortful than the “natural” versions (Willerman 1991:37-38). Therefore the spontaneous voicing studies make claims about which sounds will be more difficult than others.

2.3.2 Higher rates of displacement make a sound more difficult

Moving an articulator the same distance in a shorter (vs. longer) period of time requires an increase in velocity. An increase in velocity is associated with greater force, or more effort. Nelson, Perkell & Westbury (1984) found that subjects attempted to reduce the time it took to say “sasa” by trading the use of greater velocity (more effort) for shorter distance. In other words, in order to speak faster, speakers move their articulators a shorter distance (by reducing vowels, for example) rather than work harder (by producing a full vowel).

2.3.3 Higher number of articulatory events per unit time make a sound more difficult

The theory of articulatory phonology (Browman & Goldstein 1985, 1990, 1995) claims that the behavior of each of the articulators used in producing a sound, such as the velum, the tongue body, the lips and the glottis, can be represented as a “motor score.” A motor score represents as separate events the articulatory gestures of various articulators during an utterance. These events must be coordinated in time. Two given utterances may have different numbers of necessary articulators; this will correspond to the same number of tiers and the degree of difficulty. The greater the number of articulators that must be coordinated to produce a sound, the more difficult the sound.

2.3.4 Greater degrees of articulatory precision make a sound more difficult

Stevens (1971) measures and compares the area of constriction above the glottis in various sound classes. Vowels require a constriction in a particular range. Fricatives must be constricted in an area far smaller. Thus, fine motor control for fricatives is greater than that for the vowels. These facts are interpreted to mean that vowels are easier to articulate than fricatives.

2.3.5 What ease of articulation has been claimed to explain

Having explored how ease of articulation has been characterized, I now consider five claims about what ease of articulation has been said to explain, at least partly, in spoken languages.[3]

Claim 1: Inventory of linguistic sounds can be explained by ease.

Lindblom (1990) suggests that of the logically possible sounds, speech sounds are just those that require the least effort to produce.

Claim 2: Distribution facts about the phonetic makeup of different-sized consonant inventories can be explained by ease.

A hypothesis that the size of an inventory correlates to the phonetic content of the inventory has been advanced (Lindblom & Maddieson 1988, Lindblom 1992). For example, the phonetic character of the consonants in languages with a large number of consonants such as !Xu (95 consonants) is much more complicated than the phonetic character of consonants in languages like Hawaiian with an inventory of 8 (Willerman 1991:2).

Claim 3: First language acquisition of phonemes by children can be explained by ease.

Locke (1980) claims that children with different language backgrounds produce approximately the same sounds at the same time. Therefore something independent of language background or input must be responsible. Some notion of ease of articulation causes the children to acquire the same sounds in roughly the same order.

Claim 4: Certain phonological processes can be explained by ease.

Natural Phonology (Stampe 1979, Donegan 1985) holds that the reason for certain processes to occur in natural languages is to get rid of sounds or sound sequences which are in some way difficult.

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[3] Discussion of synchronic variation, diachronic change, and second language acquisition might be included here.

Claim 5: Rarity of some sounds across languages can be explained by ease.

Sounds that are the most "natural" are so because they are easier to either articulate or perceive (Westbury & Keating 1986:145). Common sounds have been characterized as those that have the greatest acoustic energy (described in Maddieson 1984:50), and those that are the most distinctive (rarely confused with other sounds) (described in Maddieson 1984:70). Sounds that are believed to be rare and difficult might not be as difficult to articulate as originally thought (Maddieson 1998).

Although neither the question of how to characterize ease of articulation, nor the question of what ease of articulation can explain has been well developed in the sign language literature, some important insights can be captured from the literature. I explore these in the next subsection.

2.4 Ease of articulation in sign language research

To consider the question of ease of articulation requires familiarity with the role of hand and forearm anatomy and kinesiology, fields of inquiry within which few linguists are comfortable (Wilbur 1987:28). Yet it seems clear that from the earliest days, sign language researchers suspected a connection between what hands naturally do and what aspects of sign languages look like. With this came the tacit realization that some signs must be easier to articulate than others. Battison (1978:11-12) outlined a research direction calling for the discovery of "the relation between the form of the signs and the dynamics of the machine which articulates them—the human body." He suggests further that one goal of phonological description is to "seek motivation for these structures and constraints in the articulatory and perceptual processes which encode and decode the forms of the language" (p.19f.). Though Battison's work was consonant with functionalism, and seminal in that it suggested that linguists think about these sorts of constraints, it neither characterizes ease of articulation, nor uses it as a solution for a specific linguistic puzzle. Next I review claims about ease of articulation and signs as a whole. Following that, I review claims about ease and handshape in particular.

Mathur & Rathmann (2000) make the most far-reaching claim: that physiology affects the grammar of sign languages, not just the construction of signs. Their argument is that some verbs in four sign languages do not have agreement with objects because there is "a conflict in the motor requirements of the joint movements that are needed…" (p.30). Despite the appeal to ease of articulation as an explanation for a linguistic puzzle, they do not characterize ease of articulation.

Mandel (1979:220) predicts the direction in which signs with both handshape change and path movement will move in space, based on the well-known observation that when the wrist is flexed, the fingers tend to extend and when the wrist is extended, the fingers tend to flex. This tendency is referred to as tenodesis. Mandel hypothesizes that in a sign in which the handshape changes from closed (a fist) to extended (the "5" handshape of American Sign Language) the fingers extend, which causes the wrist to tend to flex, which in turn moves the hand forward. (Mandel defines "forward" as "in the direction that the palm is facing".) Conversely, in a sign with a handshape change from extended to closed, the fingers flex, which causes the wrist to extend, which moves the palm backward (in the direction that the back of the hand is facing). Mandel's investigation of the *Dictionary of American Sign Language* (Stokoe, Casterline & Croneberg 1965) reveals that of the 62 signs with either opening or closing of the fingers, and path movement through space, 46 signs favor tenodesis and only 16 oppose it (Mandel 1979:220). Mandel's (1979, 1981) work makes an attempt both to characterize ease of articulation and to use it to solve linguistic puzzles.

Loncke (1984) suggests that kinesiology plays a role in several phonological characteristics of Belgian Sign Language. First, Loncke notes that it is highly predictable that signs produced in the signing space will have flexion, abduction, and inward rotation as opposed to other combinations of movements or single movements. Second, Loncke notes that in one-handed signs that are articulated in both the left and right of the signing space, the preferred direction of movement is contralateral to ipsilateral. This holds true for right-handed and left-handed signers. Third, circular movements in signs tend to go in the same direction no matter which plane (horizontal, vertical, or sagittal) they occur in. Even non-signers who were asked to produce a sign after hearing a description that did not include instructions on which way to make the circular movement, respected the directionality that signers used. In his explanation of what could account for these data, Loncke concludes they must be attributable to what is "kinesiologically comfortable." Although all of Loncke's observations are interesting, they are not explored in any greater detail and no attempt is made to capture exactly what makes some movements easier or more comfortable.

Meier, Mauk, Mirus & Conlin (1998) investigate several hypotheses apparently known in the physiological literature about early sign acquisition. They suspect that "three tendencies in infant motor development … may have particular consequences for early sign acquisition." These are:

(3) a. Fine motor control over small muscle groups (e.g., those in the hand) lags behind gross motor control over large muscle groups (e.g., those in the shoulder or arm) (p.64).

b. Development of motor control generally proceeds from proximal articulators (e.g., the shoulder) to distal ones (e.g., the wrist and fingers), where "proximal" and "distal articulators" are defined by distance from the torso (p.64).

i. If a child uses a joint that would not be anticipated in the adult citation-form sign, that joint will likely be proximal to the most proximal of the expected joints (p.67).

ii. If joint activity is omitted from a sign that involves action at two or more joints, children will typically omit distal articulation (p.69).

c. Repetitive, cyclic motor patterns are characteristic of infant motor development (p.64).

They find that these "three principles of infant motor development may account for certain broad patterns that we have detected in young children's articulation of their first signs" (Meier, Mauk, Mirus & Conlin 1998:70). Though this work did not characterize ease of articulation, it tried to explain acquisition phenomena, by making reference to articulation.

Explored next are works that are concerned exclusively with handshape. There seem to be two main sources of discussion of ease of articulation and handshape: first, discussion of phonological features, and second, early acquisition.

There was early concern about expressing what fingers do alone or in concert with other fingers in handshapes; this complex question was approached in several ways. Kegl & Wilbur (1976) and Wilbur (1987) propose the Adjacency Convention. It is part of a feature system made up of the following features: [extended], [closed], [2adjacent] and [3adjacent]. The feature [extended] refers to some unspecified number of fingers that are extended. The feature [closed] refers to some unspecified number of fingers that are closed. The features [2adjacent] and [3adjacent] specify the exact number of fingers, excluding the thumb, which are adjacent and "relevant" in handshapes that are [+extended]. Kegl & Wilbur (1976) claim a relation exists between [+closed] or [-closed] and the features [2adjacent] and [3adjacent]. So for example, if in a particular handshape the combination of features [+closed], [+extended] and either [2adjacent] or [3adjacent] is assigned, the counting of fingers starts at the index edge of the hand. A handshape that has the features [+extended], [-closed] and either [2adjacent] or [3adjacent] starts counting at the pinky edge. The features [2adjacent] and [3adjacent] are not relevant for handshapes that are [-extended]. Though Kegl & Wilbur (1976) do not make explicit reference to physiological facts about the fingers in explaining their observations, clearly they see a pattern in what fingers act together in handshapes.

In another attempt to describe what fingers are capable of doing individually and with other fingers, Mandel (1981:81) proposes four hierarchies: Number of Fingers Hierarchy, Extension Hierarchy, Flexion Hierarchy, and Opposition Hierarchy. The hierarchies “act upon the underlying general specifications to determine just what fingers are to be used, and to some extent what positions they are to assume.” The Extension, Flexion and Opposition Hierarchies rank each of the four fingers singly in terms of its ability to assume an extended, flexed or opposed configuration. Mandel’s work included discussion of anatomy of the hand. As such, it is an example that both tried to characterize ease of articulation, to some extent, as well as to use the idea to explain a linguistic puzzle.

In an attempt to establish phonological features for ASL handshapes, Ann (1991, 1992a, b) examines various physiological properties of the human hand. Ann (1991, 1992b) explores constraints on one- and two-finger handshapes respectively, and claims that certain handshapes have physiological support to assume various configurations and others do not. Ann (1992a) discusses the physiological tendency for fingers to spread. Ann (1991, 1992a, b) made an attempt to both characterize ease of articulation and use it to explain a linguistic puzzle.

Boyes-Braem’s (1981, 1991) work uses ease of articulation as an explanation for a linguistic puzzle, namely, the order of acquisition of handshapes by an American Deaf child. To a lesser extent, her work also attempts to characterize ease of articulation based on anatomy. She found that the child acquired (in other words, was able to produce) handshapes in four stages. At Stage 1, the “simplest” of handshapes is acquired. At Stages 2, 3, and 4, progressively “more complex” handshapes are acquired. She explains this set of data (1991:126) as a result of the anatomy of the hand. Boyes-Braem’s (1991) discussion of anatomy includes some attention to muscles and to the radial/ulnar distinction in the hand; however, she does not make an explicit proposal about how to characterize ease of articulation in handshape.

Ann (1993, 1996), concerned neither with phonological features nor with early acquisition, explored the connection between frequency of occurrence of handshape and ease of articulation of handshape. Ann (1993) examines hand physiology and proposes a model for how to assign handshapes to categories of ease of articulation. To do this, Ann (1993) makes several propositions. They are first, that *five physiologically-based criteria apply*, second, that *these apply to all the fingers, some subset of fingers, or a single finger, depending on several factors*. The application of the five criteria results in scores for various aspects of a handshape such that, third, each handshape’s values are put through an algorithm which results in *each handshape being assigned an “ease score;”* that is, a number which reflects its relative ease of articulation. Next, following Ann (1993), I explain as briefly as possible each of these aspects of the model in turn, and then I provide examples of how an ease score is determined for three different handshapes. The five criteria are listed in (4).

(4)

The five physiologically based criteria	
a. Muscle Opposition in Configuration	How much opposition exists between the muscles necessary to produce a configuration?
b. Support for Extension	Do the extended fingers have either (a) an independent extensor or (b) "sufficient support"?
c. Support for Flexion	Are the middle, ring, and pinky either all included or all excluded from this group of fingers?
d. Tendency to oppose the thumb	Does the thumb tend to oppose the relevant finger(s)?
e. Tendency to spread	Does the handshape rely on natural spreading of fingers?

The five criteria refer mostly to muscle function; the joint structures in the hand contribute less prominently. In some handshapes, which I refer to as "one-group handshapes," all five fingers are doing the same thing. In most handshapes, all five fingers are *not* doing the same thing. In these handshapes, the fingers are divided into no more than two "groups" (Mandel 1981) and for this reason, I refer to them as "two-group handshapes." It should be reasonably clear that a handshape is a fairly complicated entity, and several important factors have to be taken into consideration. This results in the fact that the five criteria in (4) apply to different parts of handshapes when assessing ease of articulation. The criteria apply to handshapes as outlined in (5).

(5)

Criterion	**How the criterion applies…**	
	…to one-group handshapes	**…to two-group handshapes**
Muscle Opposition in Configuration	All fingers	Least flexed fingers in a rest-closed handshape; Most flexed fingers in a rest-open handshape
Support for Extension	(not applicable)	Least flexed fingers
Support for Flexion	(not applicable)	Most flexed fingers
Tendency to Oppose the Thumb	All fingers	Fingers opposed to the thumb
Tendency to Spread	All fingers	Fingers which are unspread

The effect of applying (4a) to a handshape is that we derive some sense of the difficulty of the main configuration of the handshape. My physiologically based ranking of each of the configurations used in signs appears in (6).

(6) Ranking of Hand Configurations

Configuration	**Relative Ease**	**Level of Opposition**	**Number indicating difficulty**
Curved	Hardest	Maximal	3
Extended	Next hardest	Less	2
Bent	Easier	Even less	1
Closed	Easiest	Least	0

Zero indicates the least difficulty and 3 indicates the most difficulty.

(4b-e) seek to rate other properties of a given handshape in terms of ease of articulation. (4b) cares about how much physiological support a particular finger has to extend, and (4c) cares about how much physiological support a finger has for flexion. (4d) applies to fingers in handshapes that are opposed to the thumb, and (4e) applies to handshapes in which fingers are spread apart from each other.

Numbers are assigned to the answers that (4b-e) generate, and an ease score is arrived at by using the algorithms in (7), (8) and (9).

(7) Algorithm to calculate ease scores for logically possible Spread and Unopposed Handshapes

(SE + SF) × MOC

SE = Support for Extension
SF = Support for Flexion
MOC = Muscle Opposition in Configuration (of least flexed fingers in a "rest closed" handshape and most flexed fingers in a "rest open" handshape)

(8) Algorithm to calculate ease scores for Opposed Handshapes

BENT EASE SCORE + TENDENCY TO OPPOSE THE THUMB CRITERION

(9) Algorithm to calculate ease scores for Unspread Handshapes

SPREAD EASE SCORE + TENDENCY TO SPREAD CRITERION

An ease score for each logically possible handshape is arrived at depending on how the criteria are answered for a given handshape. According to the final ease scores, all TSL handshapes fall into the categories “easy,” “difficult” or “impossible.”

Next, I illustrate the entire process for three handshapes: one easy, one difficult and one impossible. Consider the handshape in (10).

(10) 

In the handshape in (10), the index finger is extended and the rest of the fingers are closed. Therefore, (4a) (Muscle Opposition in Configuration) applies to the configuration of the index finger since the index is the least flexed finger in the handshape. The fact that the index finger is extended, where extension has a difficulty ranking of 2 (as in (6)), gives (10) a value of 2 so far. The answer to the question posed by (4b) (Support for Extension) is YES; the index finger has the physiological support to extend.[4] Answers of YES are worth 0 and answers of NO are worth 1. The answer to the question posed in (4c) (the Support for Flexion criterion) is YES. It is obvious that the middle, ring and pinky are all included in a group of fingers in the handshape in (10). The criteria in (4d) (Tendency to Oppose the Thumb) and (4e) (Tendency to Spread) are irrelevant to the handshape in (10). Putting all the numbers together according to the algorithm in (7) we arrive at the ease score for (10) of 0 as follows: $(0 + 0) \times 2 = 0$.

The score of 0 puts the handshape in (10) in the “easy to articulate” category. In my system, an easy handshape always has an ease score of 0. Consider next the handshape in (11).

(11) 

The same criteria that applied to (10) apply to (11). The numerical result of applying the criteria in (4a) is a value of 2 as it was for (10). (4b) is answered YES because the pinky has physiological support to extend. This gives (11) a value of 0. The answer to (4c) is NO because in (11), the middle, ring and pinky are not all in one group. Once again, (4d) and (4e) are irrelevant. Finally, applying the algorithm in (7) would yield a score of 2 as follows: $(0 + 1) \times 2 = 2$.

Scores of 2 often mean that a handshape falls into the category of “difficult to ar-

4 In this paper I have not explicated the physiological facts about the hand that make it possible to answer YES to this question. Interested readers can find this in much of my previous work including Ann (1991, 1992a, b, 1993, 1996), as well as Mandel (1981) and Boyes-Braem (1981, 1991).

ticulate." Consider next the handshape in (12).[5]

(12) 

Again, working through the five physiologically-based criteria, we find that (4a) would derive a score of 2. (4b) is answered NO because the ring finger does not have physiological support to extend. Therefore, it gets a value of 1 for this criterion. (4c) too is answered NO because the middle, ring, and pinky are not all in one group; on this criterion (11) gets a value of 1. Again, (4d) and (4e) are irrelevant. Putting the numbers through the algorithm in (7), we arrive at an ease score of 4 as follows: $(1 + 1) \times 2 = 4$.

A score of 4 puts the handshape in (12) in the range labeled "impossible to articulate."

Though this system can separate handshapes into the three categories (easy, difficult, and impossible to articulate), it is not able to stratify handshapes within these categories; in other words, for example, it does not help determine the easiest of the easy handshapes or the most difficult of the difficult handshapes. I discuss the ease scores for the TSL handshapes relevant to this discussion in the next section.

3. The current puzzle: TSL handshape type frequency

Now that we have examined the constructs of frequency of occurrence and ease of articulation in general and as they relate to sign languages, we are ready to ask some specific questions about TSL. The question of interest here appears in (13).

(13) Are handshapes with high token frequency easier to articulate, while handshapes with low token frequency are harder to articulate?

In order to answer (13), it is necessary to do two things. First, following Ann (1993), I assert that the TSL handshapes relevant here fall into one of three categories: easy to articulate, difficult to articulate, or impossible to articulate. Second, I use two sources of token frequency data for TSL handshapes: dictionary data and conversational data. Once the ease score and the token frequencies are known, we are in a position to answer the question in (13).

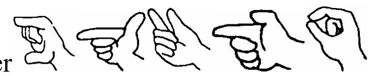
[5] The picture in (12) is to be interpreted as "ring finger fully extended with the rest of the fingers fully closed." It is not meant to refer to the attested TSL handshape in which the ring finger is not fully extended with the rest of the fingers closed.

3.1 Ease scores for TSL handshapes

The Smith & Ting (1984) inventory of TSL handshapes (slightly different than the 1979 version) contains 56 handshapes. Following Ann (1993), they fall into these groups.[6] In picture form in (14) through (17) are the handshapes in their categories.

(14) Easy TSL Handshapes

a. Two group handshapes

One finger	
Two finger	
Three finger	
Four finger	

b. One group handshapes

Whole hand	

(15) Hard TSL Handshapes

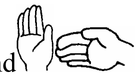
a. Two group handshapes

One finger	

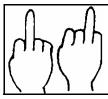
[6] Ann (1993) deals with logically possible two-group handshapes, not just these 56 attested handshapes. Ann (1993) has nothing to say about three-group handshapes.

Two finger	
Three finger	
Four finger	

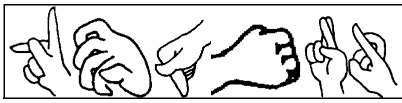
b. One-group handshapes

Whole hand	

(16) Impossible TSL Handshapes



(17) TSL handshapes not analyzed in Ann (1993)

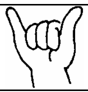
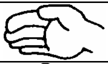


3.2 Token frequency of TSL handshapes: the naturalistic data

First I examine several minutes of a conversation between two deaf TSL signers from a videotape of a Taiwanese television program called “Hundred Kinds of Life.” This is admittedly an extremely small corpus, but it gives an indication of how the data might look when the corpus is more complete. Although “Hundred Kinds of Life” is rehearsed, conversation seems reasonably naturalistic. I counted the number of times a handshape occurred in the discourse (not the number of times a sign occurred). The data appear in (18), ordered from most- to least-frequent. A note to the right of the handshape frequency in (18) lists the category in which Ann (1993) places each of the handshapes. (18) contains 22 handshapes; it excludes TSL handshapes that do not occur in the data analyzed so far. A total of 172 instances of handshapes occur in this small corpus.

(18)

TSL Handshape	Frequency in TSL conversation	Ease of Articulation according to Ann (1993)
	41	Easy
	31	Hard
	17	Easy
	15	Easy
	12	Easy
	10	Easy
	8	Easy
	7	Easy
	5	Easy
	3	Hard
	3	Easy
	3	Not analyzed in Ann (1993)
	3	Easy
	2	Hard
	2	Not analyzed in Ann (1993)
	2	Easy
	2	Hard
	2	Hard
	1	Easy

	1	Hard
	1	Hard
	1	Easy

The conversational data are striking in three ways. First, the easy handshapes *are* the most signed handshapes, in some sense. Of the 172 tokens signed in these few minutes of conversation, 126 fall in the easy to articulate category according to Ann (1993), 39 are hard, and 5 handshapes are not analyzed in Ann (1993). Second, the data reveal that, of the nine most frequently occurring handshapes in this small TSL sample, 8 are easy and 1 is hard. Of the remaining 13 (including 4 handshapes that occurred only once in the data), 6 are easy, 5 are hard, 2 are not analyzed in Ann (1993). Third, if we compare all of the handshapes that use the hand as a whole with those that are "one-finger" handshapes, those that are "two-finger" handshapes, and those that are "three-finger handshapes", we get the results in (19).[7]

(19)	Whole hand	81
	One-finger	57
	Two-finger	20
	Three-finger	14
	Total	172

All of these data suggest that while the most frequently occurring handshapes are almost always easy to articulate, not all the easy handshapes are frequent. Some easy handshapes hardly occur in the conversation. A hard handshape that is particularly frequent in this data is the unspread 5 handshape.[8]

Although Ann (1993) analyzed a great many more handshapes in terms of both frequency and ease of articulation than those that appear in (18), only those in (18) occur in the naturalistic data. Therefore, next I examine the dictionary data and report the frequency of the 22 handshapes in (20).

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7 No four-fingered handshapes occurred in the conversational data.

8 This handshape can be described as all five fingers extended and unspread. This handshape accrues points for difficulty because it is unspread, which goes against the natural tendency that when fingers are extended they spread (Ann 1992a).

3.3 Type frequency of TSL handshapes: the dictionary data

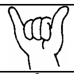
I determine type frequency for TSL handshapes from available dictionary data.[9] The "dictionary" is actually the glossary at the end of a collection of TSL lessons in two Smith & Ting volumes (1979, 1984). Each sign in the glossary is catalogued by location and handshape. All of the signs (a total of 1,336) appear in a glossary at the end of each of two books. Both glossaries are arranged by the location in which the sign is produced (i.e., chin, neutral space, etc), and within each location by handshape. These entries are counted to arrive at the type frequency of occurrence for each handshape (the number of signs in which each handshape occurs). Again the frequencies and the ease of articulation category appear for each handshape in (20).

(20)

TSL Handshape	Frequency in Smith and Ting (1979, 1984)	Ease of articulation according to Ann (1993)
	196	Easy
	119	Easy
	101	Easy
	75	Easy
	72[10]	Hard
	72[11]	Hard
	72[12]	Easy
	67	Hard
	54	Easy
	37	Easy

[9] A potential problem with this strategy brought to my attention by Susan Fischer is that the morphemic status of some handshapes might cause them not to show up in the dictionary as often as they really occur. I do not deal with this problem here, however.

[10, 11, 12] These handshapes are conflated because they are so similar.

	32	Hard
	28	Easy
	25	Easy
	22	Easy
	20	Hard
	18	Easy
	17	Easy
	17	Easy
	17	Hard
	5	Hard
		Not analyzed in Ann (1993)
		Not analyzed in Ann (1993)

The dictionary data are striking as well. Again, of a total of 922 handshapes counted, 213 are hard and 709 are easy; thus it seems the easy handshapes *are* the most signed handshapes. Second, the data reveal that of the nine most frequently occurring handshapes in this small TSL sample, 7 are easy and 2 are hard. Of the remaining 13, 7 are easy, 4 are hard, and 2 are not analyzed in Ann (1993). Third, if we compare all of the handshapes that use the hand a whole with those that are "one-finger" handshapes, those that are "two-finger" handshapes, and those that are "three-finger handshapes," we get the results in (21).

(21)

Whole hand	305
One-finger	345
Two-finger	232
Three-finger	40
Total	922

All of these data suggest that easy handshapes do indeed occur more often than hard ones, but the reverse (hard handshapes occur less frequently) does not seem to be quite true.

4. Conclusions and implications of this work

Now it is possible to see that there is a correlation between frequency and ease of articulation. It seems that the handshapes with the highest token frequencies are easy to articulate, but the handshapes that are easy to articulate are not necessarily the ones with the highest token frequencies. One hard to articulate handshape occurs frequently in the dictionary data and the conversational data. Of the hard handshapes, most are simply unattested in the conversational data. Four hard handshapes are attested, but have very low type frequencies. What could prevent easy handshapes from having a high token frequency? Conversely, what would allow a hard to articulate handshape to have a high token frequency?

Examining data of this sort raises more questions than can be answered in any one paper, but the implications of investigating questions of frequency and ease of articulation are not insignificant, particularly if they are exploited with a larger corpus. Some handshapes might have high token frequency and low type frequency (for example, the handshapes in BROTHER and SISTER respectively, similar to the handshapes pictured in (16), could have a high token frequency because of their meanings; both have a very low type frequency). These handshapes might behave in different ways from handshapes with high type and token frequencies, such as those in GOOD and ONE (the 'thumb's up' handshape and the 'number 1' handshape, respectively). We might find that knowing which signs are the most and least frequent, and which are the easiest and hardest to articulate, would connect to the study of language in important ways, as it has in the case of spoken languages, particularly as regards frequency. We stand to gain a great deal of understanding of language change over time, lexicalization, first and second language patterns of acquisition, and the like, in TSL and sign languages in general. Finally, theories of phonology and morphology of sign languages stand to be informed by knowledge of how TSL works. Without attention to this sort of data, we remain in the dark about a constellation of issues about sign languages and language in general.

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[Received 1 July 2003; revised 16 June 2004; accepted 20 July 2004]

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台灣手語手形頻率的功能探討

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手語的研究雖然已進行了近半個世紀之久，但是手語的結構和使用仍有很多值得進一步探討的地方。雖然頻率效應長期以來在功能語言學派扮演重要的角色，如今主流語言學也積極探討這個領域，但鮮少有手語頻率效應方面的探討，本文的研究爲塡補這方面的不足踏出一小步。史文漢和丁立芬 (1984) 列舉了台灣手語 56 個手形。根據無差異性假設 (null hypothesis)，所有 56 個手形應具有相同的發生頻率。作者以一個小型語料庫爲基礎說明事實並不是如此。事實上有些手形具有更高的發生頻率。爲何會如此？任何詳盡的解答都包含競爭的因素，作者認爲表達器官的容易程度 (ease of articulation) 可用來解釋此現象，並且試圖說明其解釋的極限。在 Ann (1993, 1996) 的文章中將手形依照表達的容易程度區分爲容易表達的手形，困難表達的手形和不可能表達的手形三類，並且將所有可能的手形及已發現的台灣手語手形放入這個分類表格中。本文的結論是最頻繁發生的手形傾向於最容易表達的手形，但最少出現的手形並不一定是困難表達的手形，雖然這只是這個研究領域的初步結果，但這確實爲台灣手語關於頻率效應的未來研究開啓了一扇門。

關鍵詞：手語，台灣手語，功能語言學，手語表達的容易度 (ease of articulation)，頻率，語料庫語言學