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OPTIMALITY AND OPPOSED HANDSHAPES IN TAIWAN SIGN LANGUAGE

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Abstract: This paper provides a linguistic account of opposed handshapes in Taiwan Sign Language (TSL). Examination of TSL opposed handshapes reveals that not all of the 29 logically possible opposed handshape types are attested. Of the ones that are attested, they differ (often drastically) in frequency of occurrence. We provide an analysis of the statistical data using Optimality Theory, showing that the various attested frequencies of opposed handshapes are systematic. The implications of this study for language change and acquisition are explored.

1. Introduction

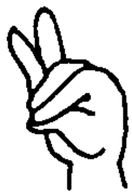
Handshapes play a central and critical role in sign languages. This paper examines all of the handshapes that belong to the set of what we call *opposed handshapes* in Taiwan Sign Language (henceforth, TSL). We focus on several problems that concern the frequency of occurrence of these handshapes and provide an analysis of these problems by using Optimality Theory (henceforth, OT) as proposed in Prince and Smolensky (1992).

We use the term "handshape" to refer only to the particular configurations that the four fingers and the thumb assume. We are not concerned with which way a hand is facing, namely, its orientation. One sub-type of handshape identified in the studies of sign languages – in particular, American Sign Language (henceforth, ASL) - involves the thumb pad making contact with the pads of some subset of other fingers, or the thumb tip making contact with the tips of some subset of other fingers.[1] In the handshape in the ASL sign SIX,[2] for example, the thumb

1 In a paper which details very close phonetic differences between handshapes, Liddell and Johnson (1989) state that there are four kinds of contact with the thumb that a finger might have in ASL. These are (i) thumb pad to finger pad contact, (ii) thumb pad to finger tip contact, (iii) thumb pad to finger nail contact and (iv) thumb pad to radial side of finger contact. Ann (1993), upon which we base the data discussed in this paper, did not make these distinctions.

2 In this paper, we adhere to the standard practice of writing the English glosses for ASL signs in capital letters. Similarly, we gloss TSL signs by the Chinese characters listed in Smith and Ting (1979, 1984). We use the romanized spelling known as pinyin for Chinese words. After the capitalized Chinese gloss, an English translation appears capitalized and in parentheses.

opposes one finger- the pinky. In ASL EIGHT, the thumb opposes the middle finger. This kind of handshape is referred to in the literature with various names such as contact or opposed handshapes. Here, we refer to them as *opposed handshapes*. Like ASL, TSL has opposed handshapes in its inventory. We provide two examples in (1).

1. a.  b. 

In the handshapes of (1a) and (1b), some fingers are "selected" and some are "unselected". The fingers that oppose the thumb are selected and those that do not oppose the thumb are unselected. In (1a), the index and middle oppose the thumb and all three are therefore selected. The ring and pinky fingers are unselected. In (1b), the selected fingers are the thumb and the index. The middle, ring and pinky are unselected. Note that unselected fingers may be extended (1a) or closed (1b).

An opposed handshape, by definition, always involves the thumb. Handshapes in which, say, the index "opposes" the pinky may be logically possible, however they are physiologically impossible. Though the thumb is always selected in an opposed handshape, there is a choice as to which one(s) of the remaining four fingers is/are selected in opposing the thumb, giving rise to a total of 29 logically possible opposed handshapes. Ann (1993) shows that not all of the logically possible handshapes are attested; nor are they attested with equal frequency in TSL. This paper presents a linguistic account of the frequencies of opposed handshapes first reported in Ann (1993).

The essence of our analysis, framed in terms of OT, is that three types of constraints are necessary to account for the problems involving opposed handshapes in TSL. These are listed in (2).

2. a. Finger Selection Constraints
   b. Adjacency Constraint
   c. Extension Constraint

The Finger Selection Constraints in (2a) and the Adjacency Constraint in (2b) apply to selected fingers. The Finger Selection Constraints are a collection of five constraints that place conditions on the selection of each of the five fingers. Each constraint requires that a particular finger be selected. The Adjacency Constraint requires that selected fingers be adjacent. The Finger Selection Constraints and Adjacency Constraint are ranked, predicting that handshapes in which some fingers are selected will be more optimal than handshapes in which other fingers are selected. The Extension Constraint in (2c) applies to unselected fingers. The Extension Constraint states that unselected fingers must be extended. Our central claim is that the different frequencies of opposed handshapes in TSL are not random. They follow from a limited set of linguistic constraints and the ranking of these constraints.

This article is organized as follows. In section 2, we propose the constraints and their ranking with a brief illustration of why they are needed. In section 3, we present statistical data concerning opposed handshapes in TSL along with our analysis of the data. Section 4 provides physiological and crosslinguistic evidence in support of the analysis we advance in section 3. Section 5 discusses the implications for historical change and language acquisition.

2. Outline of Our Proposal

This section is divided into two parts. First we briefly introduce the basic assumptions of OT that are important to our analysis of TSL opposed handshapes. Following this introduction, we lay out in detail the constraints that we propose for TSL opposed handshapes.

2.1. Optimality Theory

OT assumes that Universal Grammar possesses a set of universal constraints that determine the wellformedness of linguistic structures. The basic operation of OT is illustrated in (3). An input enters the system. A function called the Generator (GEN) generates a set of candidate structural descriptions of the input. The Harmony Evaluator (H-EVAL), which contains universal constraints, evaluates these structural descriptions according to how well they obey the set of universal constraints. The output of the grammar is the most well formed or optimal structural description.

3. /input/ → GEN → { Candidate 1, Candidate 2, … } → H-EVAL → Optimal Candidate

Exemplified in (3), H-EVAL is responsible for determining which of the possible candidate representations is optimal. Within OT, the constraints may be violated. But the costs such violations impose on a grammar vary: violation of a higher-ranked constraint exacts a higher cost than violation of a lower-ranked constraint. Thus, if two candidate representations both violate some constraints, the one that violates a lower ranked constraint (B) is preferred to one that violates a higher ranked constraint (B). In (4), we illustrate this with a tableau, which shows that Candidate 1 is optimal as it violates Constraint B, a lower ranked constraint than Constraint A.

4.

Input	Constraint A	Constraint B
☞ Candidate 1		*
Candidate 2	*	

In (4), '*' indicates that a constraint is violated by a candidate. The pointing finger '☞' indicates that a particular candidate is the optimal output. Note that an optimal candidate may be one that violates the less serious constraint than other candidates (as in (4)) or no constraint at all.

According to OT, Universal Grammar contains a set of structural descriptions for each input and a set of universal constraints. Linguistic variation stems from the fact that languages rank these constraints differently. Knowledge of a language consists of the universal set of structural descriptions, the set of universal constraints on these descriptions, and a language-particular ranking of these constraints. OT expresses the relations of markedness via constraint ranking. Some constraints are inviolable and are thus given a high ranking in language after language, others may be violated in some languages, and still others are often violated and ranked lowest cross-linguistically. The rankings of constraints express the strength of a particular constraint and consequently its status of markedness.

Turning our attention now to TSL, let us suppose that TSL has three constraints - A, B, C – that hold of handshapes and these constraints are ranked as A>B>C where A has the highest ranking, C the lowest ranking with B in the middle. Further suppose that there are three candidate handshapes, each of which violates one of the constraints, as exemplified in (5):

5.

Input	Constraint A	Constraint B	Constraint C
☞Handshape 1			*
Handshape 2		*	
Handshape 3	*		

According to (5), Handshape 1 is the optimal representation as it violates only the lowest-ranked constraint. Handshape 2 follows close behind as it violates a higher-ranked constraint than Handshape 2. Handshape 3 is the least optimal handshape because it violates a higher-ranked constraint than Handshapes 1 and 2. These rankings have implications for whether and how frequently a handshape is attested in a given sign language. If Handshape 1 is more optimal than Handshape 2 which is more optimal than Handshape 3, we expect that one manifestation of this ranking is that Handshape 1 is attested most often, Handshape 2 less often, and Handshape 3 least often or not at all in a given sign language. This interpretation of OT makes it possible to make sense of statistical data, providing us with a way of accounting for the frequencies of occurrence of the opposed handshapes in TSL.

2.2. TSL Constraints

THE FINGER SELECTION CONSTRAINTS. To account for the fact that each finger can be selected by itself or in combination with others to oppose the thumb, we propose a set of constraints that provides for each of the five fingers to be selected singly or together with other fingers. We refer to these five constraints collectively as the Finger Selection Constraints, which we state formally in (6).

6. Finger Selection Constraints
   a. Thumb: Parse the thumb
   b. Index: Parse the index
   c. Middle: Parse the middle
   d. Ring: Parse the ring
   e. Pinky: Parse the pinky

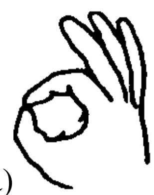
We identify each of the five constraints by the names of the fingers it applies to. We capitalize the initial letter of the names of fingers when they refer to constraints, and not simply the fingers of a hand. We state the Finger Selection Constraints as parsing constraints in (6) because they resemble the parsing constraints in OT accounts of spoken languages.[3] Thus, 'Parse the index' means that the index must be selected or *parsed* to oppose the thumb. In an opposed handshape in which the thumb opposes only the index, the two constraints – Thumb in (6a) and Index in (6b) - are both satisfied. But such a handshape violates Middle (6c), Ring (6d), and Pinky (6e) as they are not parsed.

These Finger Selection Constraints are ranked with respect to one another. We propose the ranking in (7).

7. Thumb > Index > Middle > Pinky > Ring

According to (7), Thumb is ranked the highest, followed by Index. Middle follows Index, but is ranked higher than Pinky. Ring receives the lowest ranking. At present, we do not have strong linguistic evidence from TSL to determine the relative ranking of Ring and Pinky, although there is some physiological evidence for support the placement of the pinky over the ring finger.

Out of the 29 logically possible types of opposed handshapes, only some are attested in TSL. Those that are attested vary (quite often, drastically) in the frequency of occurrence. The justification for the ranking in (7) is that it provides an account of the differing frequencies of opposed handshapes in TSL. Take, for example, the two opposed handshapes below. In (8a), the thumb opposes the index in (8a); in (8b) the thumb opposes the middle.

8. (a)  (b) 

Both (8a) and (8b) satisfy Thumb and violate Pinky and Ring. But (8a) violates Middle, while (8b) violates Index. Because Middle is a lower-ranked constraint than Index, (8a) is preferred to (8b). We present statistical evidence from TSL in support of this claim in section 3.

The ranking in (7) resembles the Opposition Hierarchy for ASL proposed in Mandel (1981, 99). However, one aspect of our proposal distinguishes it from Mandel's hierarchy: Mandel's hierarchy does not mention the thumb. This difference may seem trivial because, as we mentioned, the thumb always participates in opposed handshapes, given the physiology of the hand and the definition of what constitutes an opposed handshape. We include the constraint on the selection of the thumb because it is selected in opposed handshapes just like other fingers and our theory needs a way to describe the contribution of the thumb. We include the constraint Thumb as part of the ranking because it is logically possible (even though physiologically

3 Equivalent examples are parsing constraints such as "Parse the nasal" or "Parse the coronal". In OT analyses of spoken languages, these constraints have the effect of requiring that the nasal or coronal features be linked to some segments in the output.

impossible) that an opposed handshape might not involve the thumb. The physiological impossibility is captured by the ranking of Thumb as the highest constraint. Opposed handshapes in which the thumb is not selected are not desirable as they violate the most serious of the five Finger Selection Constraints. In this respect, Thumb resembles those constraints in spoken languages that are never violated.

THE ADJACENCY CONSTRAINT. We state this constraint formally in (9).

9. The Adjacency Constraint

   All selected fingers must be adjacent.

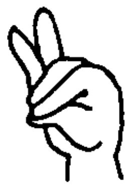
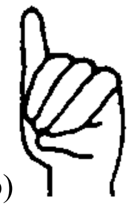
This constraint holds over the four fingers - index, middle, ring, and pinky - but not the thumb.[4] Crucially, for the Adjacency Constraint to be applicable to a handshape, the thumb must oppose two or more fingers. In a handshape such as (1a) in which the thumb opposes the index and middle, the Adjacency Constraint is relevant as the thumb opposes two fingers. In this case, the Constraint is met because there is no unselected finger intervening between the index and middle fingers. However, a handshape in which the thumb opposes, say, the index and ring fingers violates the constraint because the unselected middle finger intervenes between the selected index and ring fingers.

The Adjacency Constraint is strictly obeyed in TSL. No opposed handshape with non-adjacent selected fingers is attested in any sign of TSL. Apart from its role in determining well-formed handshapes, this constraint is useful in helping us to understand the relative frequencies of opposed handshapes involving different numbers of fingers making contact with the thumb. The Finger Selection Constraints in (6) predict that the more fingers participate in opposing the thumb, the more desirable the resulting handshapes are. This is because when more fingers are parsed, fewer Finger Selection Constraints are violated. Thus, the Finger Selection Constraints predict by themselves that a handshape in which the thumb opposes four fingers is preferred to one in which the thumb opposes three fingers. Similarly, a handshape in which the thumb opposes three fingers is preferred to one in which the thumb opposes two fingers, which is in turn preferred to a handshape in which the thumb opposes one finger.

We demonstrate in section 3 that while handshapes in which the thumb opposes all four fingers are the most commonly attested type, the second most attested type of opposed handshapes involves the thumb opposing one of the four fingers. Handshapes in which the thumb opposes two or three fingers are rare in comparison. The explanation of this statistical distribution lies in the Adjacency Constraint. An opposed handshape in which all four fingers participate with the thumb satisfies the five Finger Selection Constraints and the Adjacency Constraint; consequently, it is most desirable of all possible handshapes. Opposed handshapes in which the thumb opposes only one of the four fingers can never violate the Adjacency Constraint, either. This is because two fingers are required for adjacency to be relevant. Only

4 Mandel (1981, 101) proposes a similar constraint for ASL called the Adjacency Principle. He formulates this principle as follows: "All selected fingers are adjacent unless the specifications force non-adjacency." We drop the "unless" part of Mandel's condition. This part is taken care of automatically by OT, according to which constraints may be violated, but at a cost to the grammar. Under Mandel's formulation, the Adjacency Principle applies only to the index, middle, ring or pinky fingers. The thumb is excluded in determining whether two or more selected fingers are adjacent. See also Kegl and Wilbur (1977) on other constraints of adjacency in ASL.

handshapes in which the thumb opposes two or three fingers may violate the Adjacency Constraint. We should therefore expect to find more handshapes in which the thumb opposes one finger than handshapes in which the thumb opposes two or three fingers such as [thumb↔index & middle] as in (10a) or [thumb↔index & middle & ring] as in (10b).

10. (a)  (b) 

Some logically possible opposed handshapes in which the thumb opposes two fingers such as [thumb ↔ index & ring] or three fingers such as [thumb↔index & ring & pinky]. are in violation of the Adjacency Constraint. We show in section 3 that none of these handshapes that violate the Adjacency Constraint is attested in TSL, which provides the empirical basis for this constraint and the overall rarity of TSL signs with this kind of handshape.

THE EXTENSION CONSTRAINT. Unlike the Finger Selection Constraints and the Adjacency Constraint that apply to selected fingers, the Extension Constraint applies to unselected fingers. In opposed handshapes, the unselected fingers are those that do not participate in opposing the thumb. We find that, statistically, handshapes with extended unselected fingers are preferred to those in which unselected fingers are closed. To account for this fact, we propose the Extension Constraint.

11. Extension Constraint

In an opposed handshape, unselected fingers must be extended.

We restrict the application of this constraint to opposed handshapes for the time being. But we suspect that this constraint may be part of a larger constraint that governs the behavior of unselected fingers in general. If future studies determine that it is preferable to extend – rather than close- unselected fingers in other handshape types, the reference to opposed handshapes may be dropped.

We will take up these constraints again in section 4 in our discussion of the physiological, perceptual and crosslinguistic bases for these constraints. For now, let's turn our attention to the TSL data and our analysis of the data in terms of the constraints proposed here.

3. Data and Analysis

In this section, we present statistical data which show the frequency of occurrence of TSL opposed handshapes. These data are taken from Smith and Ting (1979, 1984). The two Smith and Ting books form a TSL course. All of the signs introduced in the books appear in the glossaries at the end. Following Stokoe, Casterline and Croneberg (1965), these glossaries are arranged by the location in which the sign is produced (i.e. chin, neutral space etc.) and within each location, by handshape. There are a total of 1336 entries in Smith and Ting's glossaries. These entries are counted to arrive at the TSL frequency of occurrence. The data in this paper were presented first in Chapter 5 of the first author's doctoral thesis (Ann 1993). We show that these statistical data can be accounted for by the proposal laid out in section 2. Our central claim here is that the different frequencies of opposed handshape configurations found in TSL signs reflect a regular pattern, a pattern that may be captured by the interaction of the Finger Selection, Adjacency and Extension Constraints.

In opposed handshapes, the thumb may oppose one, two, three and all four of the remaining fingers. In what follows, we refer to a handshape in which the thumb opposes one finger as 1-finger opposed handshapes and a handshape in which the thumb opposes two fingers as a 2-finger opposed handshape and so on. We begin with 1-finger opposed handshapes first before proceeding to 2-, 3-, and 4-finger handshapes in TSL.

3.1. 1-finger handshapes

Consider 1-finger opposed handshapes first. There are a total of 8 logically possible 1-finger handshape types. In a 1-finger handshape, the thumb can oppose the index, middle, ring or pinky individually, while unselected fingers may be extended or closed (4 for selected fingers x 2 for unselected fingers). We illustrate 1-finger opposed handshapes here. We provide in (12a) an example of a handshape in which the thumb opposes the middle with the unselected fingers extended. In the handshape in (12b), the thumb opposes the index, with the unselected fingers closed.

12. (a) (b)

In (13), we show that not all of the eight logically possible handshapes are attested in TSL signs. Those attested occur with different frequencies. We partition the data in (13) into three columns: a) where unselected fingers are extended, b) where unselected fingers are closed, and c) the combined total of a) and b).

13.

1-FINGER OPPOSED HANDSHAPES	UNSELECTED FINGERS		COMBINED TOTAL
	EXTENDED	CLOSED	
Thumb↔index	51	37	88
Thumb↔middle	11	0	11
Thumb↔ring	0	0	0
Thumb↔pinky	1	1	2

According to (13), the most commonly attested 1-finger opposed handshape is one in which the thumb opposes the index, with a combined total of 88. The thumb↔middle handshape is a distant second, with a total of 11 occurrences. The thumb↔pinky handshape is attested in two signs, while the thumb↔ring handshape is not attested at all.

These statistical frequencies are accounted for by the ranking of the Finger Selection Constraints proposed in (7). To see how our proposal accounts for these data, consider the tableau in (14).

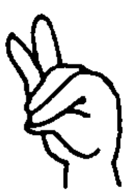
14.

Types of handshape	Thumb	Index	Middle	Pinky	Ring
☞thumb↔index			*	*	*
thumb↔middle		*		*	*
thumb↔ring		*	*	*	
thumb↔pinky		*	*		*

In (14), no opposed handshape violates Thumb, the highest-ranked constraint; all handshapes listed in (14) make use of the thumb. According to (14), thumb↔index is the optimal handshape, as it is the only one that does not violate Index, the second highest ranked constraint. The thumb↔middle handshape comes second, as it does not violate Middle. The thumb↔pinky and thumb↔ring handshapes violate Middle and are therefore less optimal. The thumb↔pinky comes next as it violates only Ring, a lower ranked constraint than Pinky. The thumb↔ring handshape is the least optimal because it violates Pinky. The attested frequencies of 1-finger opposed handshapes in (13) are exactly what we would expect given the proposed ranking of the Finger Selection Constraints in (7).

3.2. 2- and 3-finger opposed handshapes

Let's turn now to opposed handshapes in which the thumb opposes two or three fingers. We provide two examples of TSL handshapes as an illustration: (15a) shows a 2-finger opposed handshape and (15b) shows a 3-finger opposed handshape. In both, the extended fingers are open.

15. (a)  (b) 

There are a total of 12 logically possible handshape types in which the thumb opposes two fingers. Of these, only three are attested, as shown in (16). The thumb↔index-middle handshape with unselected fingers extended is attested in 4 signs. The handshape with the same selected fingers in which the unselected fingers are closed is found in 5 signs. The thumb↔middle-ring handshape with unselected fingers extended shows up in 10 signs.

16.

2-FINGER OPPOSED HANDSHAPES	UNSELECTED FINGERS		COMBINED TOTAL
	EXTENDED	CLOSED	
Thumb↔index-middle	4	5	9
Thumb↔index-ring	0	0	0
Thumb↔index-pinky	0	0	0
Thumb↔middle-ring	10	0	10
Thumb↔middle-pinky	0	0	0
Thumb↔ring-pinky	0	0	0

Thus, the thumb opposes two fingers in a combined total of 19 signs. In comparison with 1-finger opposed handshape that shows up in 101 signs, the number of signs with 2-finger opposed handshapes is rather small. As shown in (17), the number of signs with 3-finger opposed handshapes is much smaller. We find only one sign with a 3-finger opposed handshape in TSL.

17.

3-FINGER OPPOSED HANDSHAPES	UNSELECTED FINGERS		COMBINED TOTAL
	EXTENDED	CLOSED	
Thumb↔index-middle-ring	1	0	1
Thumb↔index-middle-pinky	0	0	0
Thumb↔index-ring-pinky	0	0	0
Thumb↔middle-ring-pinky	0	0	0

Despite the overall small number of attested 2- and 3-finger opposed handshapes, some generalization may be drawn from the data in (16) and (17). Out of the 10 logically possible 2- and 3-finger opposed handshape types, 5 violate the Adjacency Constraint as they involve non-adjacent selected fingers. These are listed in (18).

18. 2-finger opposed handshapes:
- a. thumb↔index-ring
- b. thumb↔index-pinky
- c. thumb↔middle-pinky

3-finger opposed handshapes:
- d. thumb↔index-middle-pinky
- e. thumb↔index-ring-pinky

None of the handshapes listed in (18) is attested in any TSL sign. This means that all attested 2- and 3-finger opposed handshapes obey the Adjacency Constraint. We take this as evidence that the Adjacency Constraint, which regulates the parsing of selected fingers, operates in TSL.

Consider next the ranking of the Adjacency Constraint in relation to the Finger Selection Constraints as both constraints are relevant to 2- and 3-finger opposed handshapes. One possibility is to rank the Adjacency Constraint below the Finger Selection Constraints. Some evidence from 2-finger opposed handshapes in TSL suggests that this ranking cannot account for the data in (16), specifically, the three 2-finger opposed handshape types in (19). According to (16), the first two types are not attested. The third type is attested in 10 signs.

19. a. thumb↔index-ring not attested

b. thumb↔index-pinky not attested

c. thumb↔middle-ring attested in 10 signs

If the Adjacency Constraint is ranked below the Finger Selection Constraints, we predict that (19a) and (19b) are more desirable than (19c). Though (19a) and (19b) violate the Adjacency Constraint while (19c) does not, the lower ranking of the Adjacency Constraint makes it irrelevant in determining which handshape type is optimal. (19c) violates Index, a higher ranked constraint than the Adjacency Constraint. (19a) and (19b) satisfy Index. Consequently, (19a) and (19b) are more desirable than (19c) according to the H-Eval.

The second possibility is to assign the Adjacency Constraint a higher ranking than the Finger Selection Constraints. This ranking predicts that (19c) is more desirable than (19a) and (19b), which violate a higher ranked constraint, namely, the Adjacency Constraint.[5] This is illustrated in (20), where AC is short for the Adjacency Constraint.

20.

Types of handshape	AC	Thumb	Index	Middle	Pinky	Ring
☞thumb↔index-middle					*	*
Thumb↔index-ring	*			*	*	
Thumb↔index-pinky	*			*		*
Thumb↔middle-ring			*		*	
Thumb↔middle-pinky	*		*			*
Thumb↔ring-pinky			*	*		

5 The Adjacency Constraint can be placed logically between the Finger Selection Constraints. For instance, we may assign it a lower ranking than Index but a higher ranking than Middle. For the same reason discussed here, this and other logically possible rankings are ruled out. To account for the higher attested frequency of thumb↔middle-ring, the Adjacency Constraint must be ranked at least higher than Index. We have no evidence as to the relative ranking of the Adjacency Constraint and Thumb because these two constraints are so strong that they are never violated. We tentatively place the Adjacency Constraint above Thumb in TSL.

There are two reasons to be somewhat cautious about drawing a firm conclusion about the ranking of the Adjacency Constraint above the Finger Selection Constraints, however. First, the overall number of attested 2- and 3-finger handshapes is quite low. Second, the 10 attested thumb↔middle-ring opposed handshapes include some iconic signs, a point to which we will return shortly. Thus, the number of attested tokens of (19c) (that is, 10) may not be significantly different from the total absence of (19a) and (19b). With this note of caution in mind, we conclude tentatively that the Adjacency Constraint is ranked higher than the Finger Selection Constraints in TSL.

Our analysis predicts that thumb↔index-middle, thumb↔middle-ring and thumb↔ring-pinky are more desirable than thumb↔index-ring, thumb↔index-pinky and thumb↔middle-pinky. The first three conform to the Adjacency Constraint while the latter three violate it. With respect to the first three, our analysis predicts that thumb↔index-middle is more optimal than thumb↔middle-ring, which is in turn better than thumb↔ring-pinky. With respect to the second three, our analysis predicts that thumb↔index-pinky are better than thumb↔index-ring which is better than thumb↔middle-pinky. Thus, our analysis predicts the following ranking of optimality for the 6 types of 2-finger handshapes, disregarding, of course, the configurations of unselected fingers.

21. a. thumb↔index-middle — more optimal

b. thumb↔middle-ring

c. thumb↔ring-pinky

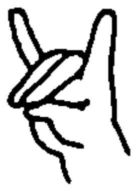
d. thumb↔index-pinky

e. thumb↔index-ring

f. thumb↔middle-pinky — less optimal

The types of 2-finger opposed handshapes in (21c) through (21f) are not attested at all in TSL. This supports the predicted ranking of optimality in (21). If any type is not attested, it should be those toward the bottom of the list, because they are less optimal than those at the top of the list in (21).

However, the ranking between (21a) and (21b) calls for some explanation. The type in (21a) is attested in 9 TSL signs while (21b) is attested in 10 signs. On the surface, this appears to contradict the prediction in (21), according to which (21a) is more desirable than (21b) and consequently should be attested more than (21b). There is an explanation for the relatively high number of thumb↔middle-ring handshapes. Out of the 10 signs with this opposed handshape, as many as 7 are iconic (or "richly grounding" signs (Macken, Perry and Haas 1993)). TSL has several types of iconic signs. One type mimics the shape of object the sign denotes. The second type is also known as character signs, as they mimic the shape of corresponding written Chinese characters (Ann 1998, Smith and Ting 1979, 1984). These iconic signs are known to violate language-internal constraints. An example is the handshape in (22), which occurs in the TSL sign CHUANG (BED).

22. 

The sign CHUANG (BED) involves two hands. Both assume the handshape in (22) and the tips of the opposed fingers of both hands contact each other, forming the shape of a bed. That is, the four extended fingers represent the four poles of a Chinese bed. The middle and ring fingers represent the flat surface for sleep. Given the structure of a bed, a handshape in which the outer fingers – index and pinky – are extended best represents the four standing poles of a bed. The remaining six instances of the handshape in (22) are glossed in Smith and Ting (1979, 1984) as: LANG (WOLF), LONG (DRAGON), HU LI (FOX), SHANG DANG (DECEIVED), PIAN (SWINDLE) and YING XIAN (SLY) (two forms). We take (22) to be iconic in the signs which name animals in that the opposed fingers represents the animal's snout and the extended fingers represent the ears. In addition, we take the use of the handshape in (22) in signs that mean "sly", "deceived" or "swindle" to be semantic extensions of the same sign. Excluding the iconic signs, there are two TSL signs in which the handshape in (22) is not iconic: a) ZHONG ZI (RICE TAMALE) and b) FU (BUDDHISM). Once the iconic signs are excluded, the attested frequencies of thumb↔index-middle and thumb↔middle-ring are consistent with the ranking of optimality in (21).

Let's turn now to 3-finger opposed handshapes. Our proposal makes a clear prediction about the ranking of the four types of 3-finger opposed handshapes even though we see that TSL has only one sign that makes use of this type of handshape. We provide a tableau in (23) for the 3-finger opposed handshapes.

23.

Types of handshape	AC	Thumb	Index	Middle	Pinky	Ring
☞thumb↔index-middle-ring					*	
Thumb↔index-middle-pinky	*					*
Thumb↔index-ring-pinky	*			*		
Thumb↔middle-ring-pinky			*			

Our proposal predicts that thumb↔index-middle-ring is the most desirable type of 3-finger opposed handshape, followed by thumb↔middle-ring-pinky. Both conform to the Adjacency Constraint. Next comes thumb↔index-middle-pinky, with the worst type being thumb↔index-ring-pinky. Unfortunately, we cannot confirm the predictions made by our proposal, given the almost total absence of 3-finger opposed handshapes.

3.3. Overall comparison of opposed handshapes

We have analyzed 1-finger, 2-finger and 3-finger opposed handshapes separately. Another problem that calls for an account can be seen in the comparison of the frequencies of opposed handshapes that require different numbers of selected fingers. In (24), we provide the numerical data that show the frequency of occurrence for 1-, 2- and 3-finger opposed handshapes, together with the total number of handshapes in which the thumb opposes all four fingers.

24.

TYPES OF HANDSHAPES	UNSELECTED FINGERS		COMBINED TOTAL
	EXTENDED	CLOSED	
1-Finger Opposed Handshape	63	38	101
2-Finger Opposed Handshape	14	5	19
3-Finger Opposed Handshape	1	0	1
4-Finger Opposed Handshape	Not Applicable		75

According to (24), there are 101 signs that make use of 1-finger opposed handshapes in TSL. 4-finger opposed handshapes rank second in number with a total of 75 signs.[6] 2- and 3-finger opposed handshapes rank last with a combined total of 20 signs. In absolute numbers, 4-finger handshapes are attested less frequently than 1-finger handshapes. But this comparison is a bit deceptive. The reason for this has to do with the total number of logical possibilities of a given type of handshape.

Recall that there are 8 types of 1-finger opposed handshapes. In contrast, there is one logically possible type of 4-finger opposed handshape. If we divide 101 (the number of 1-finger opposed handshape types) by 8, each type of 1-finger handshapes is attested roughly 13 times, a much smaller number than 75. This comparison reveals that 4-finger opposed handshape is attested most frequently,[7] followed by 1-finger handshapes, while 2-finger and 3-finger opposed handshapes are attested least frequently.

Our proposal provides an account of these statistical frequencies. The Finger Selection Constraints favor selection of more rather than fewer fingers. The more fingers are selected in an opposed handshape, the more constraints are satisfied, and consequently, the more desirable the resulting handshapes. Thus, according to the Finger Selection Constraints, 4-finger opposed handshapes are optimal because they satisfy all five of the Finger Selection Constraints. By these constraints, 2- and 3-finger opposed handshapes should be more desirable than 1-finger opposed

6 In this discussion, we make no distinction between the handshapes sometimes referred to as flat 0 and 0, though TSL uses both. Smith and Ting (1979, 1984) list them separately.

7 Many researchers such as Boyes (1973), Battison (1974), Woodward (1976), McIntire (1977), etc. have considered this handshape unmarked in ASL. Woodward (1976:89) summarizes the reasons for considering this as an unmarked handshape. First, most, if not all, of the world's sign languages make use of this handshape. Second, children learning ASL acquire this handshape the earliest. Lastly, its distribution is least restricted in ASL because it is one of the few handshape types that can be used in signs that require the non-dominant and the dominant hands act differently.

handshapes. How can we account for the fact that the exact opposite obtains: 1-finger opposed handshapes are attested more often than 2 and 3-finger opposed.

This is where the Adjacency Constraint comes in. Neither 4-finger opposed handshapes nor 1-finger opposed handshapes can violate the Adjacency Constraint. Only 2- and 3-finger opposed handshapes may violate the Adjacency Constraint. Recall that 6 of the 12 logically possible 2-finger opposed handshape types and 4 of the 8 logically possible 3-finger handshapes violate the Adjacency Constraint. As opposed handshape types that violate the Adjacency Constraint are not attested at all in TSL, they disproportionately affect the number of attested signs with 2- and 3-finger opposed handshapes. To see this more clearly, let's see the comparison of the numbers of logically possible opposed handshapes involving 1, 2, and 3 fingers once those handshape types that violate the Adjacency Constraint are removed.

25. a. 1-finger opposed handshape: 8

b. 2-finger opposed handshape: 6

c. 3-finger opposed handshape: 4

According to (25), 1-finger opposed handshapes have the highest number of types that obey the Adjacency Constraint, followed by 6 and 4 for 2- and 3-finger opposed handshapes, respectively. As there are more 1-finger opposed handshape types that conform to the Adjacency Constraint, it is not surprising that 1-finger opposed handshapes occur more than 2-finger opposed handshapes, which in turn occur more than 3-finger opposed handshapes.

In TSL, we see the statistical results of two competing types of constraints. The Finger Selection Constraint favor 4-finger opposed handshapes and disfavor 1-finger opposed handshapes. The Adjacency Constraint favors 4- and 1-finger opposed handshapes at the expense of 2- and 3-finger handshapes. As both types of constraints favor 4-finger opposed handshapes, they are attested most frequently. 1-finger opposed handshapes, which conforms to the Adjacency Constraint, is statistically more frequent than 2- and 3-finger opposed handshapes, which may disobey the adjacency requirement.

3.4. The Extension Constraint and unselected fingers

The distinction between "groups" of fingers in a particular handshape was made early in the literature. Handshapes are thought of as containing a maximum of two groups of fingers. The essential insight stated in Mandel (1981:81-84) is that one group is "selected" and the other is "unselected." This has never been abandoned, although it has taken different forms throughout the years. A handshape in which all fingers participate has only one group. But some handshapes have two groups of fingers, one group of fingers assuming one configuration and the other assuming a different configuration. So far, we have focussed on accounting for the statistics involving the selected fingers of an opposed handshape. But most opposed handshapes have two groups of fingers: a subset of index, middle, ring, and pinky participate in opposing the thumb (the selected fingers), and some other fingers doing something else (the unselected fingers). The unselected fingers can assume two configurations: a) extended and b) closed (Mandel 1981:82). We now examine a problem we have heretofore ignored.

Compare the number of opposed handshapes in which unselected fingers are extended with that of opposed handshapes in which unselected fingers are closed. These numbers are shown in (26) with a breakdown in terms of the number of selected fingers opposing the thumb.

26.

1,2 and 3-FINGER OPPOSED HANDSHAPES	UNSELECTED FINGERS	
	EXTENDED	CLOSED
1-Finger Opposed Handshape	63	38
2-Finger Opposed Handshape	14	5
3-Finger Opposed Handshape	1	0
Total	78	43

According to (26), 78 opposed handshapes have extended unselected fingers while 43 opposed handshapes have unselected fingers that are closed. Clearly, it is preferable to have unselected fingers extended rather than closed. Extended unselected fingers total 78, close to twice as many as 43 of closed unselected fingers. To account for this, we proposed in section 2 the Extension Constraint, which requires that unselected fingers be extended. When unselected fingers of opposed handshapes are extended, they conform to the Extension Constraint. When unselected fingers are closed, they violate the Extension Constraint, which accounts for the lower frequency of attested signs with closed unselected fingers. Because the Extension Constraint applies to unselected fingers and the Adjacency Constraint and the Finger Selection Constraints apply to selected fingers, we have no evidence from TSL which would argue for a relative ranking of the Extension Constraint with respect to either the Finger Selection Constraints or the Adjacency Constraint.

To summarize the discussion in section 3, we have demonstrated that the various attested frequencies of opposed handshapes are not random and that there is a pattern underlying these frequencies. We capture this pattern in terms of constraint interaction proposed in OT. Specifically, we have shown that three constraints are necessary: the Adjacency Constraint, the Finger Selection Constraints and the Extension Constraint. We have also presented some evidence from 2-finger handshapes that suggests that the Adjacency Constraint should receive a higher ranking than the Finger Selection Constraints in TSL.

4. Beyond TSL

Up to now, we have focused attention only on the TSL-internal evidence in support of the proposed analysis. We would like to shift our attention in this section to consider data and evidence that are beyond TSL. In so doing, we attempt to determine whether the proposed constraints and ranking of these constraints are specific to TSL or whether they hold of other sign languages as well. We look at each type of constraints in turn.

THE FINGER SELECTION CONSTRAINTS. We suggest that the Finger Selection Constraints do not need to be stated just for the grammar of TSL. These constraints are part of the set of universal constraints that hold of all sign languages. Though these constraints are proposed in connection with opposed handshapes discussed in this paper, they hold of any sign that makes use of handshape, since every handshape requires that either all the fingers or a sub-set of fingers participate.

Let's turn now to the ranking of the five Finger Selection Constraints. Our proposed ranking is based partially on consideration of the hand physiology, in particular, the mobility of each of the five fingers.[8] Two main aspects of hand physiology determine the ability of the five fingers to act. They are: a) relevant joint structure; and b) muscles and juncturae tendinum. These aspects of hand physiology divide the five fingers roughly into three groups in terms of their mobility: a) thumb; b) index and middle; and c) ring and pinky.

Of the five fingers, the thumb is the most mobile. Its carpometacarpal joint, known as a "saddle joint", is the most flexible joint in the hand; indeed it is partially responsible for allowing the thumb to oppose the fingers. In addition, the thumb has the greatest number of muscles of any digit that controls its movement.

The index and the middle fingers come next in terms of mobility. In order for fingers to perform precision movements (namely, for their actions to be controlled accurately), the "proximal bones [must] be stabilized while the distal bones perform the movement" (Wells 1966:54). Here, this means that the hand bones closer to the wrist must be held still at their joints, in order for the bones closer to the fingertips to accomplish precision movements. Physiologically, the carpometacarpal joints of the index and middle are quite different than those of the ring and pinky. This is because the index and middle are fixed (i.e. held still) at the carpometacarpal joint (the joint that attaches the hand to the wrist). This means that the more distal bones (which make up the index and middle fingers) can accomplish precision movements. Conversely, the ring and pinky are moveable at the carpometacarpal joint (i.e. not held still). This means that the more distal bones (which make up the ring and the pinky) have less ability to perform precision movements.

Aside from joint structure, the distribution and location of muscles and juncturae tendinum between the fingers ensure that of the index and middle, the index is the more moveable. Of the ring and pinky, the pinky is the more movable.[9] Thus, from a purely physiological point of view, the five fingers may be ranked in terms of mobility as in (27).

(27) thumb > index > middle > pinky > ring

8 There is a growing concern among the linguists working within the framework of OT regarding the unconstrained nature of linguistic constraints. This concern reflects itself in attempts to identify the physiological and perceptual bases for the constraints proposed in spoken languages. We share this concern in this paper. Our thinking on this issue is influenced by Grounded Phonology by Archangeli and Pulleyblank (1994), which attempts to systematically integrate physiology in theory building.

9 Clearly, there is a lot more to hand physiology than that summarized here. For instance, we have not considered neural structures that control the movement of the hand. To go into more detail would take us far beyond the scope of this paper. Those interested in a more detailed discussion of hand physiology as it pertains to sign languages should refer to Chapters 2 and 3 of Ann (1993). Some discussion of hand physiology is also found in Mandel (1979, 1981).

According to (27), the thumb is most mobile. The index finger comes next in terms of mobility, followed by the middle and the pinky. The ring finger is the least mobile of the five digits. We suggest that the relative mobility of the five fingers forms part of the basis for the ranking of the Finger Selection Constraints.

As the proposed ranking of the five Finger Selection Constraints has some physiological basis, we do not expect all aspects of the proposed ranking to be determined completely by individual sign languages. Some aspects of the ranking are expected to hold of other sign languages: e.g. the ranking of Thumb above Index, and the Ranking of Index above Middle, Pinky and Ring. The ranking of Index above Middle, Pinky and Ring is reflected in the Opposition Hierarchy which Mandel (1981, 99) proposes for ASL and supported by the data from ASL and other sign languages. In her study of TSL and ASL, Ann (1993, 272) finds that ASL has a total of 79 handshapes in which the thumb opposes the index. In contrast, the combined total of handshapes in which the thumb opposes the middle, ring or pinky is 4. In a crosslinguistic survey of what Woodward calls "single finger contact" handshape (what we call 1-finger opposed handshapes) in 9 sign languages (including ASL, but not TSL), Woodward (1987) finds that handshapes in which the index alone opposes the thumb are attested most frequently followed by handshapes in which the middle finger alone opposes the thumb. Handshapes in which the pinky alone opposes the thumb come next, with the handshapes in which the ring alone opposes the thumb attested least frequently in the sign languages surveyed. The ranking of Middle and Pinky above Ring is not expected to vary crosslinguistically, either. From the physiological perspective, the ring finger is the weakest, a point supported by Woodward's crosslinguistic data on single finger contact and extension handshapes.

The aspect of the ranking in (6) that may vary crosslinguistically is the relative strength of Middle and Pinky. Some aspects of the physiology favor the middle finger over the pinky. The middle finger is a bit closer and more mobile than the pinky and therefore easier for it to oppose the thumb. But the pinky has its advantage as well as it "has a special muscle (opponens digiti minimi) to oppose it to the thumb" according to Mandel (1981). The comparable strength of Middle and Pinky is reflected in the statistics as well. According to Ann (1993, 272), ASL has two signs in which the thumb opposes the middle. This is only slightly more (but statistically insignificant) than one occurrence each for thumb↔ring and thumb↔pinky. In a related study of "single finger extension" handshapes in the 9 sign languages, Woodward (1982) finds that handshapes with the extended pinky are attested slightly more that handshapes with the extended middle. What Woodward's study shows is that with respect to some specific configuration, the pinky finger may be more mobile than the middle and consequently attested more in sign languages.

THE ADJACENCY CONSTRAINT. We proposed the Adjacency Constraint to account for the fact that there is not a single TSL sign that makes use of opposed handshapes with non-adjacent selected fingers. This constraint also plays an important role in explaining the frequencies of occurrence of opposed handshapes that involve different numbers of selected fingers. Mandel (1981) proposes a similar condition that governs selected fingers in ASL. As this constraint is proposed for ASL, it is clearly not specific to TSL. We can understand the basis of the Adjacency Constraint partly by looking at hand physiology. The juncturae tendinum are three ligamentous bands located on the back of the hand that connect the fingers. One connects the index to the middle. A second connects the middle to the ring. The third connects the ring to the pinky. The bands pull on each other and cause the fingers to be affected by each other's movements. Some of the opposed handshapes involving non-adjacent selected fingers such as thumb↔index-pinky, thumb↔middle-pinky, thumb↔index-ring-pinky, thumb↔index-middle-pinky, etc. are physiologically harder, though not impossible. When we look at the Adjacency Constraint in relation to hand physiology, we may understand it as an attempt by sign languages to control the ease of signing, favoring those handshapes that are easier to sign physiologically.

THE EXTENSION CONSTRAINT. This constraint is proposed in conjunction with TSL frequency data. However, it is not applicable just to TSL. The preference for unselected fingers to be extended in opposed handshapes is evidenced in ASL. Ann (1993) shows that there are a total of 97 signs with opposed handshapes in which unselected fingers are extended. In sharp contrast, opposed handshapes with closed unselected fingers are attested in only 5 signs in ASL. The clear preference for unselected fingers to extend rather than close may be understood from the point of view of perception.

When we look at opposed handshapes from the view of perception, it is not hard to understand why it is preferable to extend unselected fingers in opposed handshapes. Opposition requires that the four fingers – index, middle, ring, and pinky - be bent at the metacarpophalangeal and/or proximal interphalangeal joints if they are selected in opposing the thumb. Extending the unselected fingers render them maximally different from the selected fingers. In contrast, closing the unselected fingers makes them similar to selected fingers. Extending unselected fingers has the effect of increasing visual acuity, while closing unselected fingers reduces it along the lines discussed in Siple (1978). Thus, it seems more desirable to have a handshape in which unselected fingers are extended, rather than closed.

To summarize, the constraints and rankings of these constraints proposed for TSL have their bases in hand physiology and perception. In addition, there is some support for these constraints and their rankings from the studies of ASL and crosslinguistic studies of other sign languages. However, in order to determine how applicable the proposal is to other sign languages, we will have to wait as more detailed studies of handshapes in other sign languages become available.

5. Implications

Handshape configurations are a central part of what makes up a sign. Of the three aspects of a sign – namely, location, movement and handshape -, handshapes appear to pose the most difficulty for children. Of the three components of a sign, handshapes are the last to be acquired by children (Siedlecki and Bonvillian (1993)). In the studies of historical evolution of ASL such as Frishberg (1975), Woodward and Erting (1975) and Woodward (1976), etc., it is shown that handshapes have come to play an increasing important role in encoding lexical and other linguistic information. Signs that formerly did not involve the use of hand have evolved to include a manual component. The difficulty handshapes pose for acquisition and the diachronic shift towards the use of handshapes underscore the importance of the study of handshape configuration. Thus this study of TSL handshapes is important not just to an understanding of the systematic structural properties of sign languages. It is also important in other aspects. We take this last section to discuss two possible implications of this study: a) language change and b) language acquisition.

In the studies of historical evolution of ASL, it is shown that the direction of change is not random. According to Battison, Markowicz and Woodward (1975) and Woodward (1976), these changes follow principles of markedness. Handshape changes reflect changes from the marked to unmarked handshapes, not the other way round. While we have no historical data because of lack of documentation of earlier TSL signs, the analysis of opposed handshape configurations proposed here makes specific claims about the markedness of various opposed handshapes and consequently the direction of diachronic handshape change. For instance, according to the analysis, 4-finger opposed handshapes are optimal and least marked, followed by 1-finger opposed handshapes. 2- and 3-finger opposed handshapes are least optimal and most marked. If 1-finger handshapes change, we would expect it to change to a 4-finger handshape rather than 2- or 3-finger handshape, as 4-finger handshape is less marked than 2- or 3-finger handshapes.

This study of handshape configurations has implications for language acquisition as well. In the studies of children's acquisition of ASL such as Boyes (1973) and McIntire (1977), it is shown that handshapes are acquired in stages, with some handshapes acquired before others. It is claimed that those handshapes that are acquired earlier tend to be those that are physiologically easier than those handshapes that are acquired later by children. In a later study, Schick (1990) acknowledges this claim, though she adds morphological and syntactic factors as contributing factors as well. In a cross-linguistic study, Woodward (1978) tested Boyes's hypothesis against synchronic data of handshapes in 9 sign languages. He found that signs that are claimed to be anatomically easy and acquired early by children are attested more frequently than signs that are anatomically difficult and acquired later. In this paper, the relative rankings of various opposed handshape configurations are based on the frequencies of handshapes that are attested in TSL. Thus, we would expect these rankings to be reflected in language acquisition as well. Specifically, we would expect handshapes that are optimal are acquired earlier than handshapes that are less optimal. For example, we would expect a handshape in which the thumb opposes the index to be acquired earlier than a handshape in which the thumb opposes the middle, ring or pinky. According to our analysis, the thumb↔index is more desirable than thumb↔middle, thumb↔ring and thumb↔pinky.

Our key point here is that the study of handshapes is not just important to an understanding of the internal structures of TSL. The study of handshapes proposed here makes specific claims about the degrees of optimality of various opposed handshape types, claims that can be tested by using data from diachronic change and child acquisition.

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