Morpheme structure constraints on two-handed signs in American Sign Language

Notions of symmetry

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In ASL, two-handed signs fall into three major sets. In one set the hands have different shapes and either only the dominant hand moves or the hands move as a unit. Battison's Dominance Condition was intended to account for the fact that the non-dominant hand typically assumes an unmarked shape when it is stationary. However, we show that the non-dominant hand does this even when the hands move as a unit. In the second set the hands have the same shape and only the dominant hand moves. These signs are unrestricted for handshape. In the third set the hands have the same shape and both move. Battison's Symmetry Condition was intended to account for restrictions on the parameters of these signs. We argue that four basic types of symmetry transformations occur, with various complications: reflection, rotation, translation, and glide reflection, all of which call for conditions specific to them, and lead to an overriding condition on movement in symmetry transformation signs. The conditions uncovered here might be morpheme structure constraints or, instead, simply follow from physiological limitations of hands in motion.

Keywords: American Sign Language, lexical database, handshapes, handshape changes, symmetry, movement, morphology, physiological constraints

1. Introduction

This work is a detailed exploration of a particular dictionary corpus of two-handed signs in ASL, with an eye toward testing the generalizability of two well-known conditions on their form.

American Sign Language has a morpheme structure constraint on two-handed signs known as the Symmetry Condition. It was first proposed in Battison (1974) and restated in Battison (1978: 33–34) as follows:

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(1) Symmetry Condition
(a) If both hands of a sign move independently during its articulation, then (b) both hands must be specified for the same location, the same handshape, the same movement (whether performed simultaneously or in alternation), and the specifications for orientation must be either symmetrical or identical.

Battison explains that the "same location" is to be understood as in the same area or in mirror-image locations with respect to the "line of bilateral symmetry." Likewise, "symmetrical orientation" is to be understood as mirror-image orientation with respect to the "plane which separates them," and "identical orientation" is to be understood as the same with respect to the body.

The Symmetry Condition is "inversely related," according to Battison, to another morpheme structure constraint, which he calls the Dominance Condition (1978: 34):

(2) Dominance Condition
(a) If the hands of a two-handed sign do not share the same specification for handshape (i.e., they are different), then (b) One hand must be passive while the active hand articulates the movement, and (c) The specification of the passive handshape is restricted to be one of a small set: A, S, B, 5, G, C, and O.

Battison says that part (c) of the Dominance Condition has very few exceptions. He argues that these seven handshapes are unmarked in that they are the naturally most basic handshapes in a phonological sense.[1]

So far as we know, although Battison's conditions are frequently cited, no in-depth study of the particulars of the Symmetry Condition has been published, nor has anyone scrutinized the division of two-handed signs into three major sets, ones that observe the Symmetry Condition, ones that observe the Dominance Condition, and ones that are not covered by either condition. In this third set fall signs in which both hands move, but not independently, and signs in which only one hand moves but both hands have the same shape. Both conditions demand close study, as does this tripartite division.

The present work examines the full range of two-handed signs with these aims. We conclude that signs group in a similar way to how Battison would have it, but with some differences once the conditions are properly understood. We argue for the existence of four conditions on signs involving symmetry transformations, one each on reflection, rotation, translation and glide reflection, which together bring us to an overriding generalization stated in our Movement Symmetry Condition. This condition replaces (1), and is augmented by a new Complexity Condition on Handshape, to account for constraints on signs involving symmetry transformations. The

1. Please note that G here is to be interpreted as a conflation of G and 1 (index finger).

Expanded Dominance Condition replaces (2). And we propose the Markedness Condition on Handshape change, which is pertinent to all signs. Signs fall into three sets, then: (a) those that involve symmetry transformations (which observe the Movement Symmetry Condition and the Complexity Condition on Handshape), (b) those in with the handshapes differ and only the dominant hand moves (which observe the Expanded Dominance Condition), and (c) those in which the handshapes are the same and only the dominant hand moves (ie. all the rest). We conclude that whether one uses the formulations in (1) and (2) or our replacement conditions, these conditions are largely motivated by physiological factors. It is yet to be established whether they are, then, extrinsic to morphology per se or are *bona fide* morpheme structure conditions.

2. Our database

In gathering an inventory of two-handed signs to study, we used *The American Sign Language Handshape Dictionary*. This dictionary serves our study well because the descriptions of the signs are admirably clear, both in illustrations and words. Further, this source was assembled without bias toward any particular linguistic analysis of signs. However, the book has a clear functional goal (to be as accessible as possible to the general public), so the number of handshapes is limited to meet this end. This simplification of the database can lead to overlooked generalizations.[2] However, our hope is that the signs in this source are representative of the signs in ASL with respect to the particular questions we are asking. Following each sign we give in parentheses the page number where it is found in our source.

This study includes every two-handed sign in that work. A caveat is in order at the start. The definition of a two-handed sign is a bit tricky. Certainly, any sign in which the articulators are both hands or in which one hand is an articulator and the other is the location of articulation must be included. Many signs, however, involve one hand as articulator, where the location of articulation is a part of the other arm, including the wrist. Other signs involve one forearm as articulator, where the location of articulation is the other forearm. Our source specified the handshape for the non-dominant hand whenever the location of articulation was the wrist (as in NURSE (235)). But for the other signs of this type, our source generally listed the non-dominant hand as "passive". From looking at the pictures, we filled in the shape of the nondominant hand, which was often the same handshape as the dominant hand. We

2. For example, when we discuss signs that involve handshape changes, we simply list these changes separately, whereas, in fact, with a larger database, generalizations about systematic changes in joint configuration might well emerge.

have included all these signs in our study, but we mark those that our source listed as having a "passive" nondominant hand with a double asterisk just for the reader's information. Those signs are grouped together in Appendix A.[3]

Sometimes a sign has two distinct parts, where each part is of a different type (among the seven major types we distinguish in this work). In most instances, these signs are compounds. If one element of the compound already appears elsewhere in our study, then we list the compound under the type of the element not already appearing elsewhere. We make note of all those choices in the text below.

The inventory of handshapes used in this study is given in Appendix B. We have followed our source in distinguishing between the handshapes **G** and **1**. If the thumb being parallel to the index finger matters, we have **G**. Otherwise, we have **1**. We use the term "claw" for **bent5**. We use the term "flat" for flattened (for **O** only).

It is a common phenomenon for citation forms of lexical entries (i.e. forms like those in our study) to differ somewhat from those lexical entries in ordinary conversation. This phenomenon can be quite exaggerated in ASL. So the planes of symmetry that we talk about below may actually vary considerably in a conversation stream. Still, since we are focusing on morpheme structure conditions, we consider our database appropriate for our interests.[4]

We also note that many predicates of motion that occur in ordinary conversation use two hands at once, moving independently and without any of the conditions we will discuss in this paper. For example, if someone were talking about a car accident, each hand might assume the vehicle classifier for handshape, and come at the other on paths that are somewhat representative of the paths the actual vehicles took, which are unlikely to be symmetrical to one another. As an anonymous reviewer pointed out to us, in these conversations each hand might really be performing a one-handed sign. Consistent with that analysis is the fact that classifier predicates are unrestrained as to

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3. Another important issue is distinguishing between redundant data and distinct data. For example, our source lists ASSOCIATION (152), FAMILY (221), GROUP (228), and other signs separately, but these signs form a family (the formal definition of which is offered in Fernald and Napoli 2000) — and the whole family has the same characteristics with respect to the issue of symmetry. So each sign in a family is not giving new information about the range of symmetry possibilities in ASL. Still, we have not attempted to group together families of signs, especially since not all sign-family analyses we would offer would be uncontroversial. We simply alert the reader to this redundancy and proceed, following our source.

4. Two caveats are in order here. First, we have not considered facial gestures in our study, focusing, instead, on the relative shapes, positions, and movements of hands with respect to what they tell us about symmetry in ASL morpheme structure conditions. Second, there is much variation in signs, just as in speech. Beyond dialectal variation, however, we also find variation that is somewhat political in nature. Some signers use fewer initialized signs than others, for example. Our source includes many initialized signs, and we have therefore done the same. We have not noted any significant differences that the inclusion of initialized signs makes on our conclusions, however.

handshape (witness the use of **3** for vehicles, **v** for people, **bentv** for animals, **L** for various types of guns, for example), just as one-handed signs are. Thus, these signs should not be included in a study of two-handed signs, like ours. Certainly, this analysis calls for further support. We therefore note that whatever findings this paper presents are to be taken as relevant to morpheme structure as presented in citation forms. The study of the spatial relationships of the hands in conversations must be a separate work, which we are not presently undertaking.

3. Signs that should not fall under Battison's Symmetry Condition

We present three types of signs that should not fall under Battison's Symmetry Condition: those in which the hands assume different shapes and only the dominant hand moves, what we call Type 1; those in which the hands assume the same shape and only the dominant hand moves, what we call Type 2; and those in which the hands assume different shapes and both hands move, but as a unit (not independently), what we call Type 3.

3.1 Type 1 signs: Two-handed signs in which the handshapes differ and only the dominant hand moves

Type 1 signs should conform to the Dominance Condition in (2), but should in no way be constrained by the Symmetry Condition in (1). Our data base includes 300 signs of Type 1, listed in Appendix C. We note that in our corpus generally the dominant hand makes contact with the nondominant hand. However, in one sign in our corpus (SWALLOW (326)) the hands do not make contact.[5] And many signers we have questioned (in the Philadelphia area) do not make contact of the two hands for several of these signs (such as READ (286)).

Fifteen handshapes are attested for the nondominant hand, but this number can be reduced to ten if we conflate varieties of single handshapes as Battison clearly did in formulating his Dominance Condition. It seems phonologically sensible to conflate in this way, since we know of no minimal pairs of full lexical items that differ only by whether the hand or hands are **B** versus **bentB** or **O** versus **flatO**, or so forth. However, there are classifiers that differ in this way. **OpenB** and **bentB** are different classifiers; **babyO** and **flatO** are different classifiers; **V** and **bentV** are different classifiers; and so on. If our study were not limited to morpheme structure constraints, and, instead, looked at conversation streams involving classifier predicates, such a conflation would,

5. This version of the sign has a **C** for the nondominant hand and a **1** for the dominant hand.

therefore, be questionable. Preferring to err on the side of caution, we list separately for the reader all varieties of handshapes in all our tables and appendices. But when we calculate percentages of signs that use marked versus unmarked handshapes, we group all varieties of a given handshape together.

Among the handshapes listed in the Dominance Condition, we find attested in Type 1 signs **A** (two varieties), **B** (three varieties), **C**, **1** (**G** in Battison's terms), **O**, **S**, and **5** — that is, all of them. But we also find **H**, **L**, and **V**. These 300 signs, then, use only fifteen of the 39 handshapes in our inventory. In one sign the nondominant hand changes shape (as, in fact, does the dominant hand) from **C** to **S**; that is, from one unmarked handshape to another. Table 1 gives an inventory and distribution of the nondominant handshapes used by Type 1 signs, and Figure 1 shows a representative sign: BUTTER (234).[6]

Table 1. Inventory and distribution of nondominant handshapes for Type 1 signs.

Type 1 — non-dominant hand	number	Type 1 — non-dominant hand	number
A	4	**O**	6
openA	1	**flato**	1
B	10	**S**	38
bentB	1	**V**	2
openB	179	**1**	31
C	11	**5**	10
H	3	**open8**	1
L	1	**C >S**	1

In one sign, NOT^GUILTY (201), the first half of the compound is an imperfect reflection across the midsaggital plane (NOT(169), included in Type 4A* below), but the second half is a Type 1 sign (ACCUSE, with nondominant **openB** and dominant **A**).[7]

Clearly, **openB** is the most prevalent nondominant handshape, accounting for almost 60% of Type 1 signs. If we lump the three varieties of **B** together, that percentage climbs to over 63%. The next most prevalent, but far behind **B**, is **S**, with 13%, and then **1** (Battison's **G**), with more than 10%. Straggling behind are **C**, **5**, **O** (two varieties), and **A** (two varieties). Then there are from one to three examples each with **H**, **V**, **L**, and **open8**, and the single example of changing handshapes, **C** > **S**. All together, 294 signs out of 300 have a nondominant handshape listed in Battison's Dominance Condition — that is, 98%.

6. All figures exemplifying signs in this article come from Tennant and Brown (1998). We thank Gallaudet University Press for their generous permission here.

7. We follow our source in identifying compounds. But a sign like NOTˆGUILTY might well be a sequence of two signs.

butter

Handshape: H : Open B
Orientation: right palm down, wrist bent down; left palm up
Location: neutral space
Movement: brush right fingertips off left palm twice
Note: Right fingers can bend each time.

Figure 1. BUTTER (234)

not guilty
(compound: not + accuse)

Handshape: Open B > A : Open B
Orientation: palms down, hands crossed
Location: neutral space
Movement: separate hands, then change right hand to A handshape and brush right hand across back of left hand
Nonmanual signal: head shakes "no" during first part of sign

Figure 2. NOT^GUILTY (201)

This total percentage is good evidence for the Dominance Condition. Further, this distribution of handshapes suggests a hierarchy of markedness, where **B** (all varieties lumped together), **S**, and **1** are less marked than the other unmarked handshapes. This finding makes physiological sense. If you drop your hands by your sides, in a relaxed stance, the handshape assumed is closer to **B** than to any other ASL handshape. Certainly the fingers are not pressed together (as in a citation **B**), but they are far from abducted (as in a **5**). **B**, then, is, arguably, the physiologically least marked of all handshapes. **S** is also physiologically unmarked in that all five fingers are in the same closed position, so all ligaments and muscles that affect movement of the fingers are doing the same job (MacConaill & Basmajian 1969). Extending just the index finger, as in **1**, is physiologically favored, compared to extending any other single digit except the thumb (Woodward 1982; Ann 1993).

In contrast, there are few restrictions on the handshape of the dominant hand. Of the 39 handshapes in our database of two-handed signs, all but five of them occur in our Type 1 signs. Missing are **W**, **4**, **6**, **8**, and **L-I**. 268 signs of Type 1 have a dominant hand that does not change handshape during the sign. Of these, 148 use an unmarked handshape (in any of its variants) — that is, 55%. In other words, unmarked handshapes occur most often, period. However, the contrast in both the range of possible handshapes and the relative preponderance of unmarked handshapes between the nondominant and the dominant hands of Type 1 signs is sharp. When 98% of the signs use an unmarked handshape for the nondominant hand, but only 55% use an unmarked handshape for the dominant hand, we can conclude that the nondominant handshape is restricted, while the dominant one is not. We give the relevant numbers for the dominant hand in Table 2. Here and elsewhere we call handshapes that do not change "fixed."

We note that one sign made with an **open8** dominant hand has the thumb curved forward (EARTH (367)).

There are also 32 signs in which the handshape of the dominant hand changes. Seven of these signs use marked handshapes on the dominant hand, and an additional four change from or to a marked handshape. So 66% (21 out of 32) use only unmarked handshapes, while 78% (25 out of 32) use unmarked handshapes at least part of the time. Again, that percentage is significantly different from the percentage of signs that use unmarked handshapes for the nondominant hand — so the dominant

Table 2. Inventory and distribution of dominant fixed handshapes for Type 1 signs.

Type 1 — dominant hand	number	Type 1 — dominant hand	number
A	11	**O**	3
openA	12	**babyo**	4
B	3	**flato**	6
bentB	16	**R**	3
openB	9	**S**	7
C	14	**T**	2
D	5	**V**	21
E	3	**bentv**	8
F	9	**X**	9
openF	1	**Y**	7
G	3	**1**	46
H	16	**3**	3
I	2	**bent3**	2
K	12	**5**	6
L	4	**CLAW**	8
bentL	1	**open8**	9
M	1	**1-I**	2

hand here is not restricted. The changes are shown in Table 3 and a representative sign is given in Figure 3: MELON (364).

Figure 3. MELON (364)

Table 3. Inventory and distribution of handshape changes for the dominant hand for Type 1 signs.

Type 1 — dominant changes	number	Type 1 — dominant changes	number
C > flato	2	1 > X	1
C > S	3	5 > A	1
C > 5	1	5 > flato	5
openF >F	2	CLAW > A	1
G > babyo	1	CLAW > S > 5	1
flato > 5	6	8 > open8	1
T > openA	1	open8 > S	1
V > H	1	open8 > 5	1
V > T	1	open8 > 8	1
V > bentv	1		

We conclude that in Type 1 signs the nondominant hand is restricted to unmarked shapes, with few exceptions. While the dominant hand is free (although unmarked handshapes, naturally, still occur with high frequency). Type 1 signs are found in Appendix C.

3.2 Type 2 signs: Two-handed signs in which the handshapes are identical and only the dominant hand moves

In Type 2 signs the hands have the same shape, but only the dominant hand moves. These signs should not be constrained by either the Dominance Condition (since requirement (a) is not met) or the Symmetry Condition (again since requirement (a) is not met).

Of the 39 handshapes in our inventory, 21 are found in Type 2 signs. Table 4 gives the number of signs using each handshape out of a total of 149 signs. Figure 4 gives a representative sign: CAREFUL (243).

Figure 4. CAREFUL (243).

Table 4. Inventory and distribution of fixed handshapes for Type 2 signs

Type 2 handshape	Number	Type 2 handshape	Number
A	5	V	2
openA	6	bentV	2
B	6	W	1
bentB	2	X	2
openB	61	Y	1
F	3	1	16
H	12	4	2
I	4	5	6
K	2	open8	1
L	2	1-I	2
S	11		

Again, **openB** stands out as the most prevalent handshape for Type 2 signs, just as it was for the nondominant hand in Type 1 signs. The next most prevalent handshape is **1**, another shape we already identified as extremely unmarked. 76% (114 out of 150) of these signs use the seven unmarked handshapes (in all their variants) identified by Battison. That figure is similar to the figure for the dominant hand in Type 1 signs — and we conclude that handshape is not restricted in Type 2 signs. Consistent with that conclusion is that the third most prevalent handshape is H, in 8% (12 out of 149) of the signs. (Contrast to Type 1, where **H** occurs as the nondominant handshape in less than 1% and, in fact, as the dominant in only 6%.)

In addition to the 149 signs described above, there were sixteen other two-handed signs in which only the dominant hand moves, but the dominant hand changes shape. In nine cases the dominant hand starts with the same handshape as the nondominant. In six cases it ends with the same handshape as the nondominant. And in one case it both starts and ends with the same handshape as the nondominant, changing to another shape in between. The handshape changes of the dominant hand are given in Tables 5–7 with a representative sign for each in Figures 5–7.

Figure 5. NEXT^YEAR (279)

One could ask whether these sixteen signs really belong in Type 2 or, rather, belong in Type 1, since the two hands have different shapes at least part of the time. This is the approach Brentari (1998: 256–267) takes. If we compare the range of handshape changes for Type 1 signs to those for Type 2 signs, however, we find little in common. **G** > **babyo** in one Type 1 sign, while **H** > **G** > **babyo** in one Type 2 sign. **CLAW** > **S** in one Type 2 sign, while **CLAW** > **S** > **5** in one Type 1 sign. Other than that,

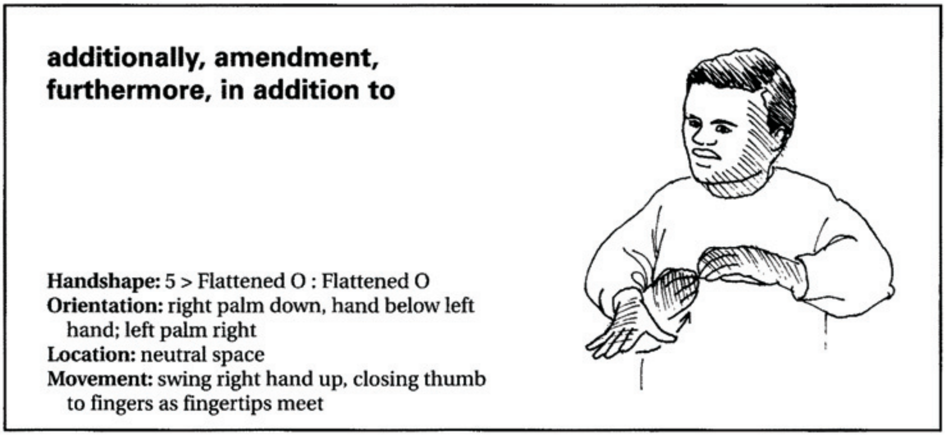


Figure 6. ADDITIONALLY (351)

Table 5. Inventory and distribution of handshape changes where the dominant hand starts the same as the nondominant for Type 2 signs

Type 2 — dominant change: starts same as non-dominant	number
openB > A	1
openB > bentB	4
openB > S	1
H > G > babyo	1
S > 1	1
bentV > V	1

Table 6. Inventory and distribution of handshape changes where the dominant hand ends the same as the nondominant one for Type 2 signs

Type 2 — dominant change: ends same as non-dominant	number
bentB > openB	2
flatO > openB	1
5 > flatO	1
CLAW > flatO	1
CLAW > S	1

Table 7. Inventory and distribution of handshape changes where the dominant hand starts and ends the same as the nondominant hand for Type 2 signs

Type 2 — dominant change: starts same, changes, ends same	number
bentL > L > bentL	1

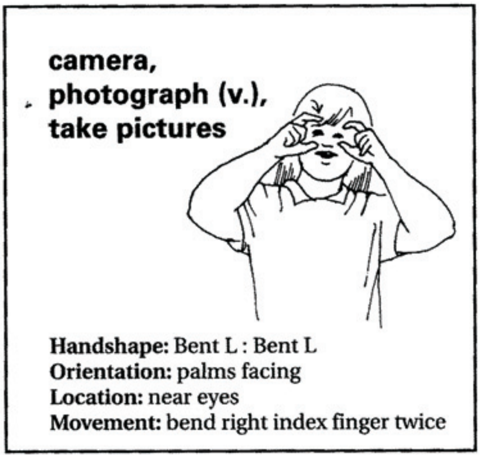


Figure 7. CAMERA (251)

there is no overlap. Given that, we classify these sixteen signs as Type 2.

We conclude that Type 2 signs are not restricted by the Dominance Condition. All 165 examples of Type 2 signs are given in Appendix D.

3.3 Type 3 signs: Two-handed signs with different handshapes in which the hands move as a unit

Signs in which both hands move but not independently should not be constrained by the Symmetry Condition (since they fail to meet requirement (a)). However, if the handshapes are different, they should be constrained by the Dominance Condition to the effect that they should not even exist. Further, if the handshapes are the same and move as a unit, then neither condition should constrain them.

We have found that when the handshapes are the same and move as a unit, these signs are not constrained with respect to handshape — just as Battison would predict — however, they are, indeed, constrained with respect to matters of symmetry. They fall into two sets. One set behaves like all other signs in Type 4^* below. The other is covered in Type 6^+ below. So we do not discuss them here.

Here we explore, instead, precisely the kind of sign that should not exist: signs in which the hands have different shapes and move together as a unit. We call these Type 3 signs.

We found nineteen signs of Type 3. In eighteen of these signs, the hands touch the entire time. In the remaining one the hands come together and then move forward touching, as seen in Figure 8.

In seven of these signs the dominant hand seems to move the nondominant hand (pushing it down (as in OPPRESS (345)) or up (as in REINFORCE (268)), pulling it

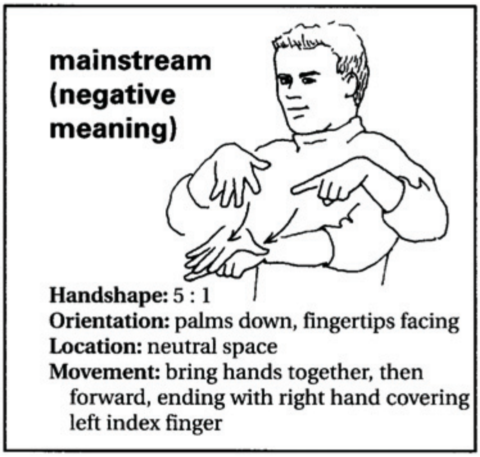


Figure 8. MAINSTREAM (346).

Table 8. Inventory and number of handshapes for Type 3 signs.

Type 3 — different handshapes	number as non-dominant	number as dominant
A		1
openA		1
B	1	
bentB		1
openB	10	1
F		1
openF		1
H		1
flatO		1
R		2
S	4	1
V		2
X		1
1	3	1
3	1	1
5		3

forward (as in LEAD (156)), rocking it (as in EARTH (367)), shaking it (as in MEAT (227) in Figure 9). But in the others, the two hands simply move together.

We give the handshape inventory and distribution for both hands for all nineteen signs in Table 8 and a representative sign in Figure 10, UNIQUE (226).

Among the signs in Type 3 are two agreeing verbs: HELP (164) and SHOW (320), and it is agreement that accounts for the movement in these signs.

In all but one of these signs, the nondominant hand is one of the seven handshapes (with all their variants) identified by Battison as being least marked. So in 95% of these

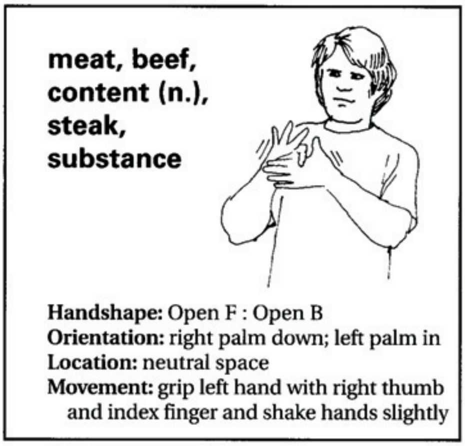


Figure 9. MEAT (227)

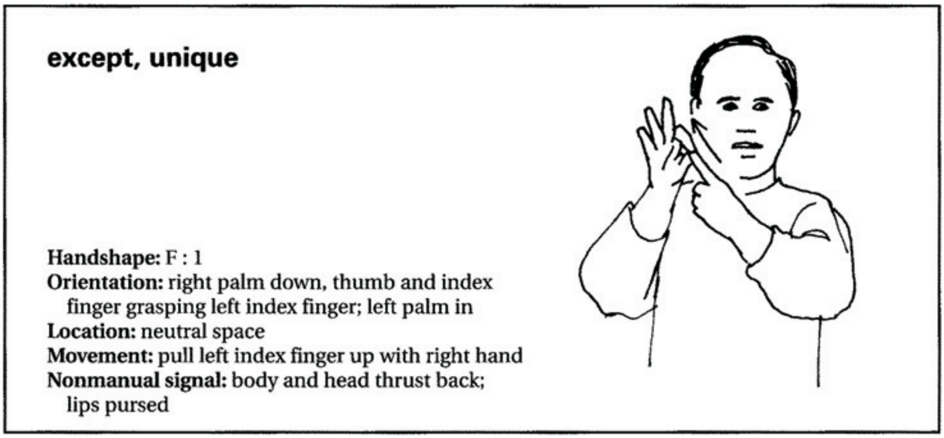


Figure 10. UNIQUE (226).

signs, the nondominant hand is unmarked.

There are only fifteen different handshapes attested in the dominant hand, but that number is not low given that there are only nineteen signs in the sample and that fully seven are marked. So only 53% (8 out of 15) are unmarked.

It would appear, then, that Type 3 signs are really just Type 1 signs in motion. Indeed, the sign SHOW (320) is precisely the Type 1 sign NOTICE (320) in motion.

4. Signs that should fall under Battison's Symmetry Condition

In Section 3 we looked at all the logical possibilities for signs that are not covered by the Symmetry Condition. We are now ready to examine the remaining two-handed signs, in most of which both hands move. These are the signs that should be constrained by the Symmetry Condition. We start with a discussion of five types of mathematical symmetries, then demonstrate that four of them occur in ASL two-handed signs.

4.1 Mathematical symmetries

Mathematicians define five basic manipulations of a structure that yield a symmetry of that structure. These are called transformations, and four of them are relevant to the morpheme structure conditions of ASL.

One is reflection, typically called mirror image. If we are talking in two-dimensions, we would talk about an axis of symmetry and reflection across that axis; if we are talking about three-dimensions (as in sign languages), we would talk about a plane of symmetry and reflection across that plane. A reflection of "R" across a vertical axis is backward "R", as in Figure 11.[8]

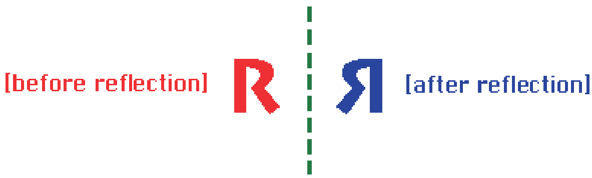


Figure 11. Reflection symmetry

A second transformation is rotation, which yields a symmetry often called point symmetry. To get a rotational symmetry of a given object, simply turn the object around a point.

While Figure 12 shows a 90 degree rotation to the right, the rotation can be any number of degrees and in either direction.

A third transformation is translation. To translate an object, you move it, without reflecting or rotating it.

While the illustration shows displacement on a diagonal, down and rightward, the displacement can be in any direction.

8. The image in Figures 11 through 14 come from the Math Forum's website at http://mathforum.org/sum95/suzanne/symsusan.html.

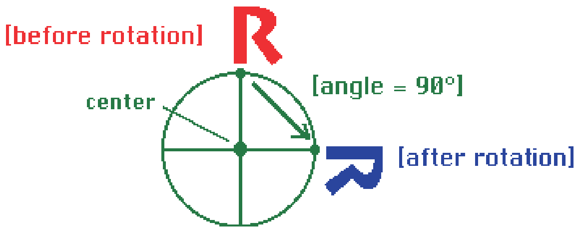


Figure 12. Rotation symmetry

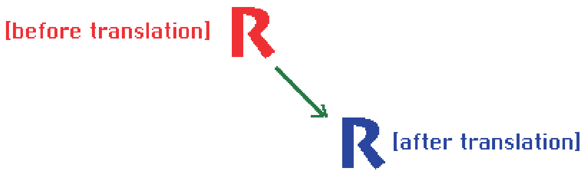


Figure 13. Translation symmetry

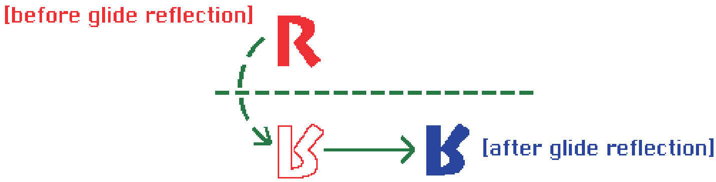


Figure 14. Glide reflection symmetry

R R

Figure 15. Dilation symmetry

The fourth transformation relevant to our study is glide reflection. A glide reflection is the result of both reflection and translation. The translation is along the direction of the mirror line or plane. In mathematics, glide reflections are the only type of basic transformation yielding symmetry that involves more than one step. Again, while Figure 14 shows the translation to the right, it can go either direction.

The fifth transformation that mathematicians talk about is dilation. A given structure can be scaled up or down to yield a dilation symmetry. The R's in Figure 15 are dilation symmetries of one another.

We have found no dilation symmetries in our source nor do we know of any in ASL. Certainly, the fact that the two hands are almost identical in size makes dilation an unlikely symmetry. However, we could imagine signs in which one hand makes a smaller, tighter version of a handshape than the other hand. **o** and **c**, for example, are potentials here. But once we consider putting the hands into motion, we face the fact that it is very hard for two hands to make the same motion along two paths with one path being larger than the other. Even if we take a simple line, to make two hands travel straight paths of different lengths, always staying at a comparable point to each other along their path, requires that the hands move at different rates, which is hard to do (as much of the research on motor coordination of the two hands shows, going back as early as von Holst 1939, but certainly with a robust and replicable finding over the years, as reported in Wing, Haggard, and Flanagan 1996). We therefore conclude that dilation transformations do not occur in ASL for reasons having to do with physiology and motor coordination, reasons extrinsic to morphology proper. Their absence, then, tells us nothing about restrictions on language.

4.2 ASL symmetries: Reflection

We can now ask which types of symmetries are observed in ASL. The Symmetry Condition talks about mirror-image, so we explore reflections first.

Given that a two-handed sign consists of hands either in a fixed location or in motion on a well-defined path in well-defined locations, we define *reflection* for signs in the following way.

(3) Definition of *reflection*: A two-handed sign involves simple reflection if the handshapes, palm orientations, locations, and movements are mirror images across a static plane.

We distinguish two major sets that involve simple reflection: Type 4, which exhibits only reflection, and Type 4-i, which exhibits reflection with inversion (where inversion is defined below). A third set, Type 4*, exhibits imperfect reflection (sometimes with inversion), where the imperfection is due to physics. We will discuss reflection with inversion and imperfect reflection later. First, we offer a discussion of six subsets within Type 4, accounting for a total of 303 signs.

4.2.1 *Simple reflection: Type 4*

4.2.1.1 *Vertical midsaggital plane: Type 4A.* Externally the two sides of the human body reflect across a vertical plane that cuts us into a right and left half. We call this the vertical midsaggital plane. 271 ASL signs in our corpus involve simple reflection across this plane; we dub these Type 4A. Consider first those Type 4A signs with fixed handshapes, of which there are 211. Fully 33 handshapes are attested; the only missing ones are open **F**, **M**, **3**, **bent3**, **6**, and **8**. The range of handshapes is clearly unconstrained. 142 out of 211 signs use some variant of an unmarked handshape — that is, 67%. We conclude that handshape is unconstrained. The inventory and distribution of these handshapes is given in Table 9 and a representative sign appears in Figure 16, DIVORCE (218).

Table 9. Inventory and number of fixed handshapes for Type 4A signs.

Type 4A — handshape	number	Type 4A — handshape	number
A	9	flato	7
openA	4	R	2
B	5	S	10
bentB	11	T	2
openB	31	V	5
C	6	bentV	4
D	4	W	1
E	2	X	4
F	6	Y	7
G	3	1	19
H	3	4	2
I	4	5	20
K	3	CLAW	12
L	6	open8	5
bentL	6	L-I	1
O	3	1-I	2
babyO	2		

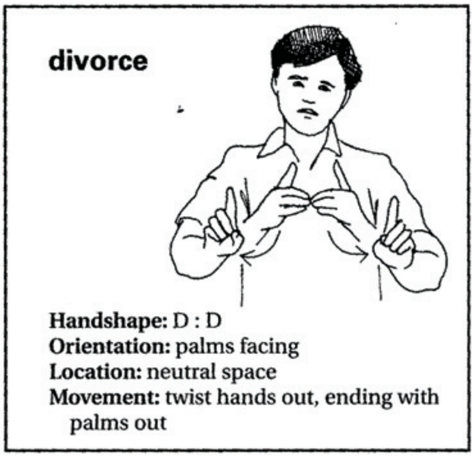


Figure 16. DIVORCE (218).

In two of these signs, SQUIRREL (293) (see Figure 17) and the compound FEED (266), the dominant hand moves, then both move. Once both hands are moving, they reflect across the midsaggital plane. These signs could be analyzed as having two syllables, the first of which is one-handed, with Weak Hand Anticipation, and the second of which belongs properly in Type 4A.

In a third sign, BIBLE (238), the first half of the compound is a Type 1 sign (with nondominant hand open B and dominant hand H — it is found under the entry HOLY

squirrel

Handshape: Bent V : Bent V
Orientation: right palm left; left palm right
Location: right hand above mouth; left hand in neutral space
Movement: move right hand down to left hand, then tap fingertips together several times
Nonmanual signal: shoulders rounded; head lowered; cheeks puffed

Figure 17. SQUIRREL (293).

Bible
(compound: holy + book)

Handshape: H > Open B : Open B
Orientation: right palm down, hand above left hand; left palm up
Location: neutral space
Movement: slide right hand down in an arc on left hand, then bring hands together and open them

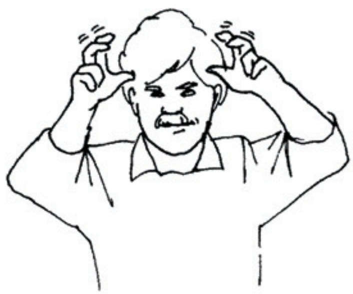
Figure 18. BIBLE (238).

(235) in Appendix C). The second half is a reflection across the vertical midsaggital plane (with both hands being **openB**); hence it is included here (see Figure 18).

Another 60 signs reflect across the vertical midsaggital plane and involve handshape changes. 41 (that is 68%) use only unmarked handshapes, while an additional fourteen change from or to an unmarked handshape. Nevertheless, given the range of handshapes used in Table 10, these signs appear unconstrained for handshape, especially since the range of initial handshapes and final handshapes is, again, broad, including 26 different ones. These changes involve three of the missing handshapes above: **3**, **bent3**, and **8**. The total of 271 Type 4A signs, then, make use of 36 out of our inventory of 39 handshapes. A representative sign appears in Figure 19.

One of these signs, INJUSTICE (201) (shown in Figure 20), is a compound, the first

devil, demon, Satan



Handshape: 3 > Bent 3 : 3 > Bent 3
Orientation: palms out
Location: thumbs on temples
Movement: bend index and middle fingers down twice
Nonmanual signal: "mischievous" expression
Note: See page 134 for a one-hand variation of this sign.

Figure 19. DEVIL (333).

Table 10. Inventory and number of handshape changes for Type 4A signs.

Type 4A — handshape-changes	number	Type 4A — handshape-changes	number
A > openA	1	babyo > 1	4
A > 5	3	flato > A	1
openB >A	1	flato > 5	7
openB > bentB	2	S > 5	6
bentB > openB	1	T > openA	1
C > S	2	1 > X	1
C > S > C > S	1	3 > openA	1
D > babyo	1	3 > bent3	3
F > 5	1	5 > A	1
G > 1	1	5 > bentB	1
H > C	1	5 > flato	4
L > bentL	1	5 > S	2
L > babyo	1	5 > CLAW	1
L > S	1	CLAW > flato	1
bentL > babyo	2	CLAW > S	1
O > K	1	8 > 5	2
O > 5	1	8 > open8	1

half of which is a Type 4A* sign below (NOT (169)), and the second half of which belongs to Type 4A (EQUAL (202)). In another compound, COUCH (238), the first half is a Type 2 sign above (SIT (233)), and the second half belongs to Type 4A (LONG-SEAT).

All 271 Type 4A signs are given in Appendix F. Type 4A signs have the widest range of handshapes and the most freedom of handshape changes of any of the types of signs we have distinguished in our study. We conclude that since reflection across the vertical midsaggital plane does not constrain handshape in any way, this is the least marked of the symmetry transformations.

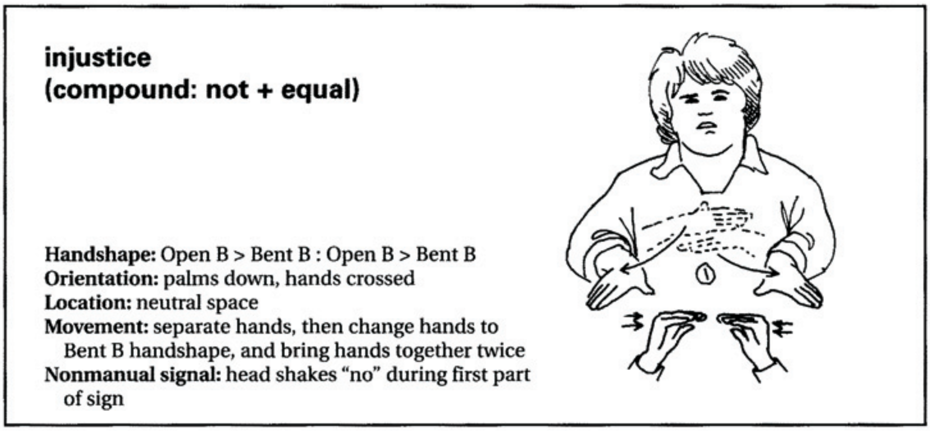


Figure 20. INJUSTICE (201).

4.2.1.2 *Vertical wall plane: Type 4B.* The next relationship that comes close to reflection symmetry on the human body is that between the front of the body and the back of the body. So we might expect to find signs that reflect across a vertical plane that stands in front of the body like a wall we are facing. There are five such signs in our study, with the handshapes given in Table 11, one of which changes handshape. A representative sign appears in Figure 21, PERFECT (221).

Physiology can impose itself in ways that make the reflection less than perfect in these signs. If you put your hands together, palms and fingers touching, and hold them in front of your chest with the back of your right hand facing your chest, your elbows will naturally go off to each side. To maintain a perfect reflection of the hands, the

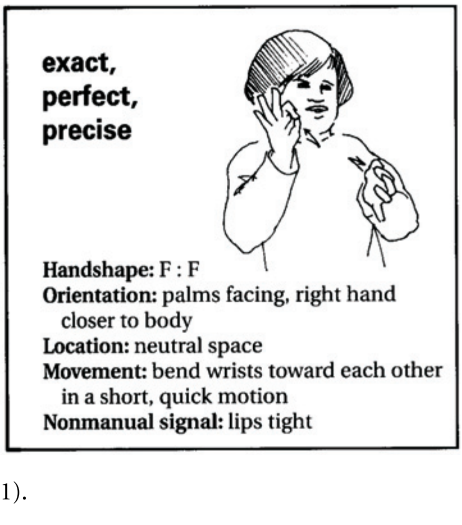


Figure 21. PERFECT (221).

Table 11. Inventory and number of fixed handshapes and handshape changes for Type 4B signs.

Type 4B — handshapes	Number	Type 4B — handshapes	Number
F	2	1	1
K	1	5 > F	1

zwrists must angle away from the line of the arm and elbow. Three of our signs involve this wrist adjustment. However, in two of our signs (BELONG (JOIN, UNITE) (222) and BELONG (JOIN) (347)) the wrists stay in a straight line with the arm to the elbow. Accordingly, each hand is angled about 45 degrees off center, making a total of 90 degrees between the hands. We have marked with an asterisk those signs in the appendix in which the angle of the elbows is responsible for a 90 degree difference between the angles of the hands.

There is no evidence that handshape in these signs is restricted. Only four handshapes are attested, two of which are marked. Three out of the five signs use only marked handshapes, and a fourth sign has a handshape change involving a marked shape.

These signs are listed in Appendix G.

4.2.1.3 *Horizontal plane: Type 4C.* Again looking at the body we can note a final extremely imperfect reflection across a horizontal plane that cuts our body into a top and a bottom. That is, the arms are, in a rough way, symmetrical to the legs. We might, then, look for ASL signs that reflect across a horizontal plane — Type 4C signs. We find seven signs that fall into this set, none of which call for handshape change. They are given in Table 12 and a representative example appears in Figure 22, ASSEMBLY-LINE (334).

The remarks we made about physiology interfering with true reflection for Type 4B signs above hold here, as well. We have marked with an asterisk those signs in the appendix in which the angle of the elbows is responsible for a 90 degree difference between the angles of the hands.

Again, there is no evidence that these signs are restricted with regard to handshape. Of the six handshapes attested, half of them are marked. Only four out of seven use unmarked handshapes. We conclude there are no restrictions on handshape in Type 4C.

These signs are listed in Appendix G, with Type 4B signs.

4.2.1.4 *Rotated vertical midsaggital plane: Type 4D.* At this point there are no other obvious or even obscure natural reflections in the body. However, there are several remaining ASL signs that seem to involve simple reflection. Six of these reflect across a midsaggital plane that has been rotated 45 degrees to one side or the other. (Note

Table 12. Inventory and number of handshapes for Type 4C signs.

Type 4C	number
openB	2
C	1
babyO	1
V	1
X	1
4	1

Table 13. Inventory and number of fixed handshapes and handshape changes for Type 4D signs

Type 4D — handshapes	number
openB	1
V	1
bentV	1
5	2
5 > flatO	1

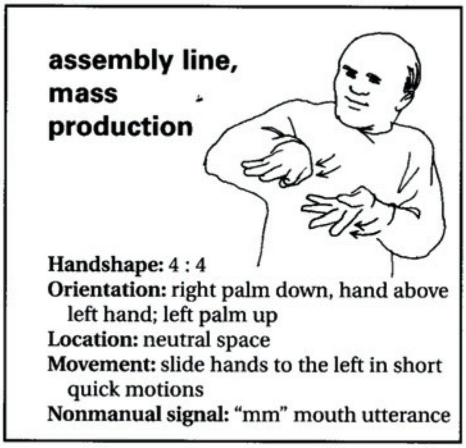


Figure 22. ASSEMBLY-LINE (334)

that the plane has rotated, not the signs. So this is simple reflection, not a complex transformation.) We have found no signs that reflect across a rotated vertical wall plane or across a rotated horizontal plane. The rotation of the midsaggital plane seems particularly natural, given that the human eye is located at the front of the skull (the typical predator eye) and each can easily view 45 degrees off to the contralateral side (and see Siple 1978 for distribution facts about signs that follow from data on visual acuity).

Of the six signs of Type 4D, one exhibits handshape change, as seen in Table 13. A representative sign of Type 4D appears in Figure 23, FATHER (honorific) (340).

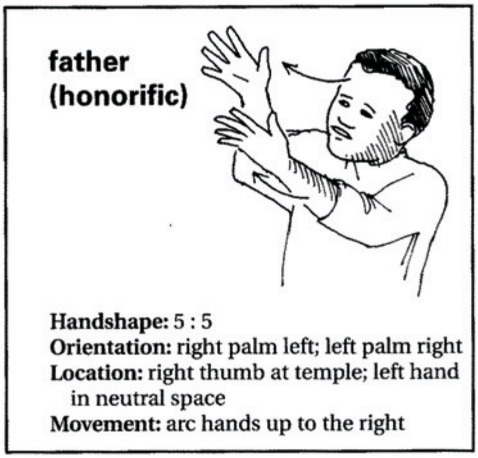


Figure 23. FATHER (honorific) (340).

Another caveat is in order here. The two signs made with the handshape 5 are the honorifics for FATHER (340) and MOTHER (340). As the hands come out from either side of the forehead or the jaw, respectively, the hand on the side ipsilateral to the diagonal (that is, the right hand if the plane has been rotated to the right) comes forward more than the hand on the contralateral side. This appears to be an artifact of physiology again. If you put your hands out in front of you, with the palms down and you swing them to the right, the right hand naturally moves a little further forward from the front plane of the body than the left hand. If you swing them to the left, you find the opposite effect. So we have included these signs here because it seems they are as close to simple reflections as physiology allows.

Again, handshape is not restricted. Of the five handshapes attested, two are marked. Four out of these six signs use unmarked handshapes — a percentage within the range for unrestricted signs.

Type 4D signs are found in Appendix G, along with Types 4B and 4C.

4.2.1.5 *Semantically selected plane: Type 4E.* Three of our signs reflect across a different plane parallel to the vertical midsaggital plane, a plane that appears to be chosen for semantic reasons. In two (RESPONSIBILITY (204) and SINCE (310)) the plane cuts through the dominant shoulder (which can be seen as carrying the burden, and which is the plane of the time line). In the other (HEART (312)) the plane cuts through the heart. The handshapes are given in Table 14 and a representative sign appears in Figure 24, RESPONSIBILITY (204).

With such a tiny sample, conclusions about restrictions on handshape are hard to justify. However, we will find below in the discussion of Type 7E signs that marked handshapes do occur with signs that exhibit glide reflections across a semantically

Table 14. Inventory and number of handshapes for Type 4E signs

Type 4E — handshape	number
bentB (plane through shoulder)	1
1	2

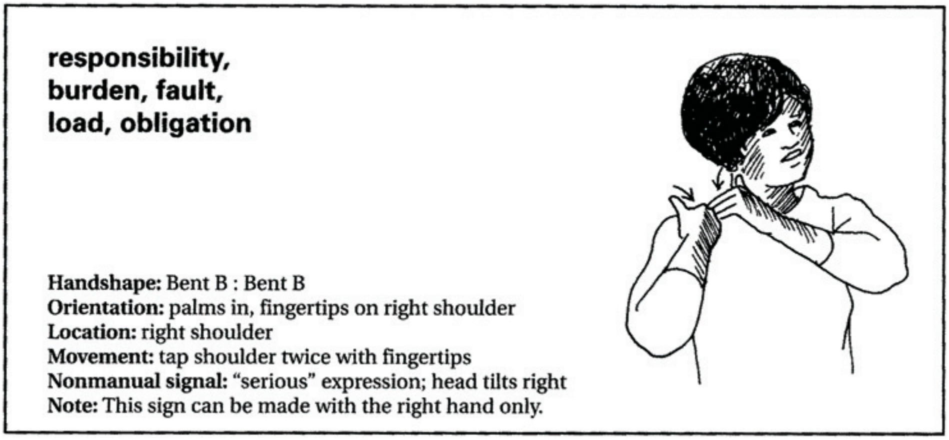


Figure 24. RESPONSIBILITY (204).

selected plane. Our tendency, then, is to group Type 4E signs with the other Type 4 signs in not restricting handshape.

These signs are listed in Appendix G, along with Types 4B, 4C, and 4D.

4.2.1.6 *Vertical midsaggital plane over time: Type 4F.* There is at least one other type of simple reflection across a plane that occurs in ASL, but the reflection is realized over time rather than at a single moment. In these signs at any given moment the hands are not reflections of one another. However, if we analyze the signs into two separate time frames, T1 and T2, we can see that T1 and T2 are reflections of each other across the midsaggital plane. These are Type 4F signs.

Our database contains nine such signs. In seven of them both hands play roles at all times: The hands do something on one side of the midsaggital plane at T1, then do the reflection act on the other side of the midsaggital plane at T2. Two have only one hand involved at a time; that is, one hand does something at T1 then the other hand does the same thing in mirror-image at T2.

In three of them, the dominant hand acts on the nondominant one, then vice-versa. The hands have different shapes, then, essentially, swap shapes. That is, the hands take turns doing something. We give the handshape changes in Table 15 and a representative sign in Figure 25. This table is to be read as having the first handshape at T1 and the second handshape at T2. In all three signs the hand that acts as non-

Table 15. Inventory and number of handshapes for Type 4F signs in which handshapes differ and take turns

Type 4F — hands take turns : Non-dominant T-1 > T-2	Dominant T-1 > T-2	Number
OpenB > 1	1 > **openB**	1
5 > **open8**	**open8** > 5	2

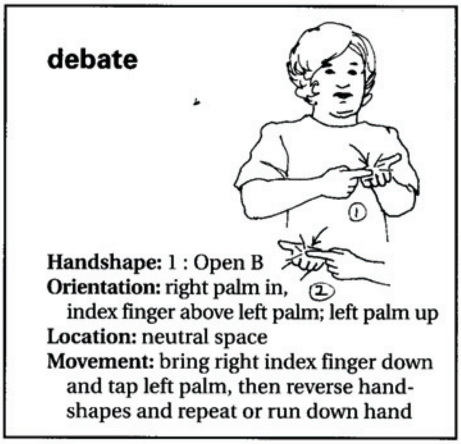


Figure 25. DEBATE (322).

dominant at T1 and at T2 has an unmarked shape. It is reasonable to analyze these signs as consisting of two parts, where each part could be seen as a Type 1 sign. That is, just as Type 3 signs appear to be Type 1 signs in motion, these signs appear to be two Type 1 signs which, over time, can be seen as reflections of each other.

In two more signs, shown in Table 16, the hands assume the same handshape, and they take turns acting upon each other, just as in the three signs in Table 15. The handshapes are unmarked. One sign is shown in Figure 26.

In two more signs, given in Table 17, the hands assume the same shape and both do the same act on one side of the midsaggital plane and then on the other side of the midsaggital plane. The handshapes are both unmarked. One sign appears in Figure 27.

The final two signs, shown in Table 18, have the dominant hand move at T1, then the nondominant move at T2, and so forth, alternating. Again the handshapes are unmarked.

The relevant handshapes are unmarked for all these signs. That is, even though **open8** appears in the first group (in Table 15), it appears only when it is acting as the dominant hand. In all other instances the handshapes are unmarked. When we look at glide reflection over time in Type 7F signs below, however, we do find one sign using a marked handshape (out of a total of six signs). If we lump together all sixteen signs, 94% (15 out of 16) use unmarked handshapes. This is the strong type of effect we saw

Table 16. Inventory and number of handshapes for Type 4F signs in which handshapes are the same and take turns

Type 4F — hands take turns	number
openB	1
C	1

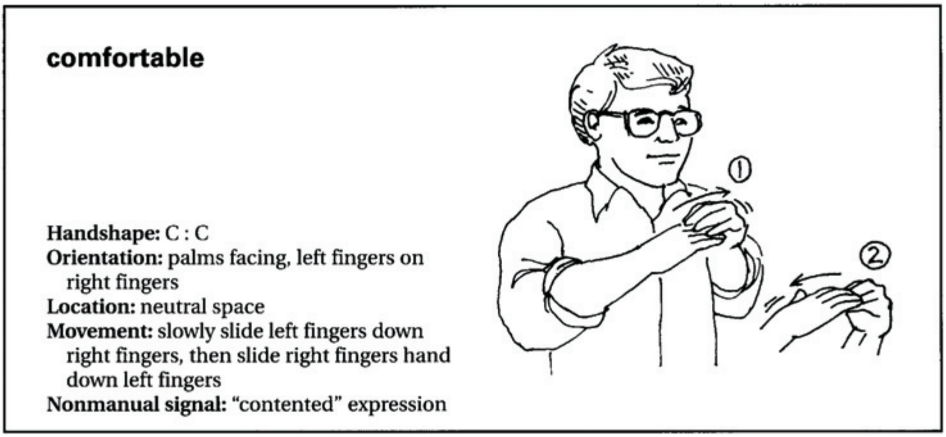


Figure 26. COMFORTABLE (212)

for Type 1 and Type 3. We conclude that the complication of reflection over time calls for unmarked handshapes.

Type 4F signs are given in Appendix H.

4.2.2 *Reflection with inversion: Type 4-i*

We have found 82 signs in which the hands reflect across a plane and both perform the same movement along a path, but one hand begins the movement at a different point along the path from the other. (These are the signs that Battison referred to as alternating.) These reflections, then, have an extra condition on their movement that Type 4 signs (in Section 4.2.1) do not have.

Typically, if the path of movement is straight, the endpoints of the path are well-defined, and each hand moves from one endpoint to the other and back, repeatedly, as in the sign EXPLAIN (223), seen in Figure 29.

Let us define one endpoint of the path as +1 and the other as −1, with the midpoint being 0. The path each hand travels is a number line from −1 to 1 and back. We can then define the position of one hand along this path as the additive inverse of the position of the other hand. That is, if the position of one hand is −0.5 along its path, the position of the other hand will be +0.5 along its path. So the position of one hand is always -1 times the position of the other hand.

Table 17. Inventory and number of handshapes for Type 4F signs in which hands do the same action at all times

Type 4F — both hands do same action at all times	Number
B	1
1	1

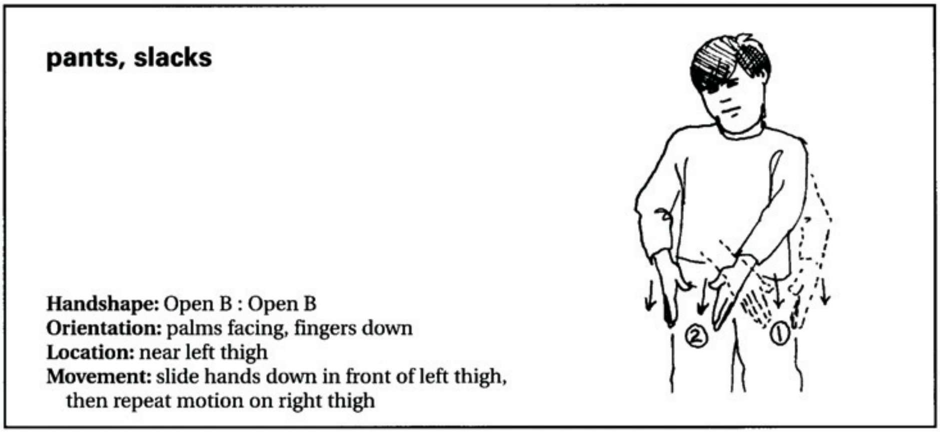


Figure 27. PANTS (175).

Table 18. Inventory and number of handshapes for Type 4F signs in which hands take turns with only one active at a time

Type 4F — hands take turns, only one active at a time	number
S	1
1	1

The same remarks can be made for the signs in our study for which the path is an arc or the movement is secondary, involving a wrist twist or a wrist bend (whether or not the wrist bend travels — as in VARIETY (313), seen in Figure 30). In these signs the hands or the wrists move in one direction, reach an end point, and then move in the other direction to the other end point (in the case of VARIETY (313), these paths are angled in a zig-zag, so that the hands are constantly moving away from the midsaggital plane). Again, we can call one end point +1 and the other end point −1; the position of one hand is −1 times the position of the other hand. Their positions are additive inverses of each other.

If, instead, the path of movement is circular, whether the circle is in one place or

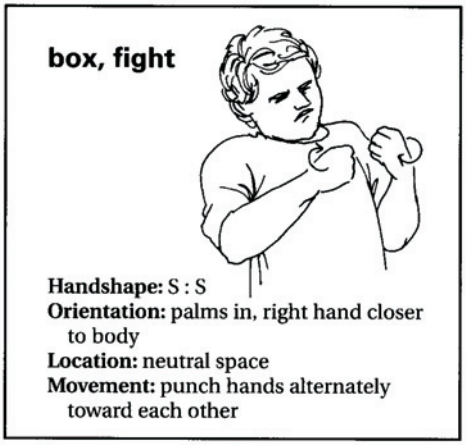


Figure 28. BOX (FIGHT) (272)

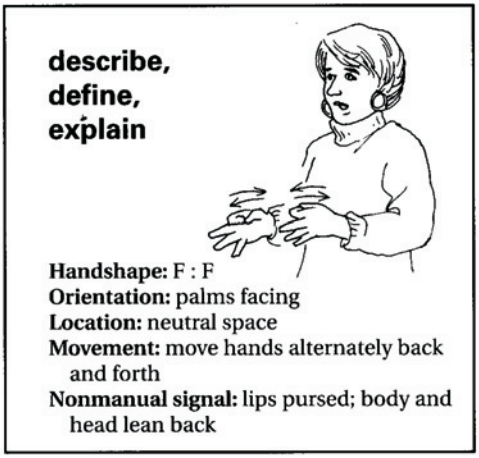


Figure 29. EXPLAIN (223).

travels, the hands always travel in a single direction 180 degrees apart. This is true of the signs in our study whether both hands travel on the same circular path (as with EXCHANGE (298), seen in Figure 31) or each hand travels on its own circular path (as with BIKE (272)).

That is, the hands are always maximally distant from each other in their movement path. To see the formal nature of this restriction, place a circle on a Cartesian plane with its center at the origin. Label the two points where it crosses the x axis $(-1, 0)$ and $(1, 0)$. Label the two points where it crosses the y axis $(0, -1)$ and $(0, 1)$. Hands moving on this circle at a distance of 180 degrees apart will have the coordinates (x, y) and $(-x, -y)$. That is, their x coordinates will be additive inverses, as will their y coordinates.

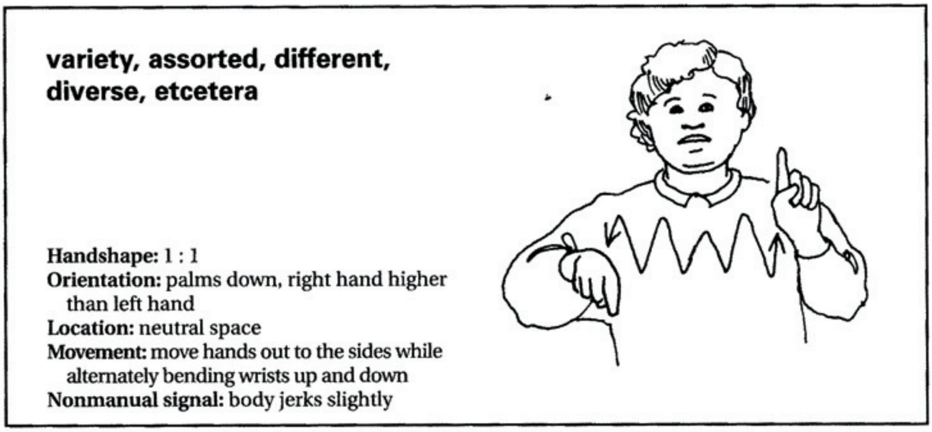


Figure 30. VARIETY (313).

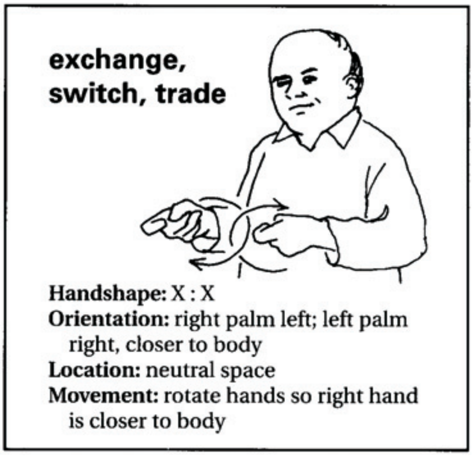


Figure 31. EXCHANGE (298).

Thus, signs with this kind of out-of-phase movement on a circular path are also exhibiting what we call inversion. This leads us to a condition on reflection.

(4) Reflection Condition:
In reflection signs (a) the hands must be on the same position along their respective paths at the relevant times (as in Type 4 signs), or (b) the hands must exhibit inversion (as in Type 4-i signs).

For Type 4F, we interpret this condition to mean that the position of the dominant hand at any time during the T1 portion of the sign is the same as the position of the nondominant hand at the comparable time during the T2 portion of the sign. Part (4b) is to be interpreted to mean that the hands be in positions that are additive

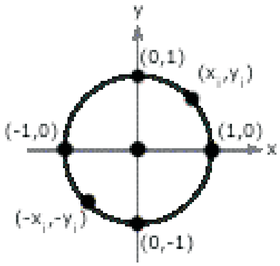


Figure 32. Inversion for signs with arc path

inverses of each other (as in Type 4-i signs).

Of the 82 signs in Type 4-i, 72 reflect across the midsaggital plane (the unmarked plane). Only five Type 4-i signs involve change of handshapes, and four of those reflect across the unmarked plane. It appears that signs involving the complexity of reflection with inversion avoid other complexities.

4.2.2.1 *Vertical midsaggital plane with inversion: Type 4A-i.* Type 4A-i signs exhibit reflection with inversion across the vertical midsaggital plane. In 32 of them the path of movement is straight; in two it is an arc; in nineteen it is circular. In four more the path is a circle that travels forward or backward with respect to the front of the body. 21 different handshapes are found in these signs, quite a wide range. 61% (35 out of 57) of these signs use unmarked handshapes. Table 19 shows these facts, and Figure 29 earlier gave a representative example.

In one of these signs, CRUEL (361), seen in Figure 33, the movement is not repetitive. Each hand goes in only one direction on the path, and the position of one hand is the additive inverse of the position of the other hand.

Additionally, fourteen Type 4A-i signs have secondary movement (rather than primary movement), as shown in Table 20. Ten of them involve a wrist twist, of which two change handshape. The other four involve wrist bending, of which one travels, and was already illustrated above in Figure 30. Eleven handshapes are found in just these fourteen signs. 64% (9 out of 14) use unmarked handshapes.

Overall, then, handshape is not constrained in Type 4A-i signs. Type 4A-i signs are found in Appendix I.

4.2.2.2 *Horizontal plane with inversion: Type 4C-i.* The remaining option for signs which involve reflection with inversion is the horizontal plane. We found ten signs exhibiting reflection with inversion across the horizontal plane, Type 4C-i (Table 21). Two of these signs involve a straight path. Seven involve a circular path, of which two travel (one appears in Figure 34). One involves the secondary movement of wrist twist.

In one of these signs, DESTROY (361) the movement is not repetitive, comparable

Table 19. Inventory and number of handshapes for different path shapes of Type 4A-i signs which involve primary movement

Type 4A-i	straight path	arc path	circular path
A	1		1
openA	2		3
B			1
bentB	1		
openB	3	1	3 (all travel)
D	1		
E			2
F	2		1
H	1		1 (it travels)
I	1		
K			1
flatO	3		2
S	1	1	3
V			1
bentV	3		
X	3		1
1	5		2
3	2		
5	1		
CLAW	1		
open8			1
CLAW > S	1		

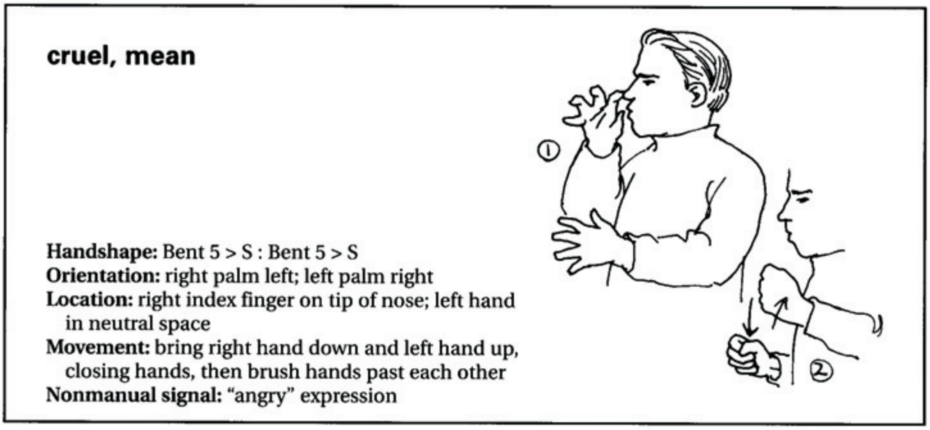


Figure 33. CRUEL (361).

to the lack of repetition in CRUEL seen in Figure 33 above. Each hand goes in only one direction on the path, and the position of one hand is the additive inverse of the

Table 20. Inventory and number of handshapes for different path shapes of Type 4A-i signs which involve secondary movement

Type 4A-i — secondary movement	wrist twist	wrist bend
openA	1	
openB		2
F	2	
flato	1	
bentv	1	
W	1	
1	1	1 (it travels)
5	1	1
openF > F	1	
5 > flato	1	

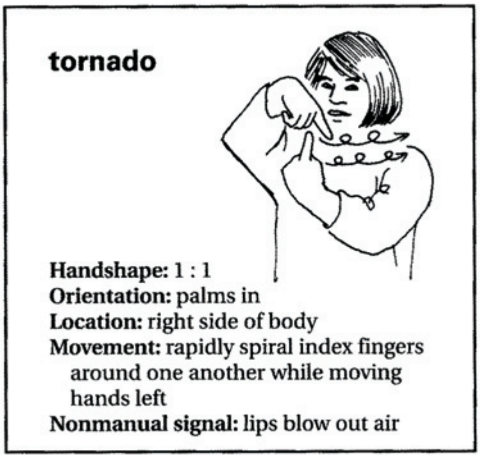


Figure 34. TORNADO (313).

position of the other hand.

All the handshapes here are unmarked. We conclude that the complication of inversion across the marked horizontal plane is as much complication as these signs allow; accordingly, they restrict handshape, just as the complication of reflection over time restricts both handshape and plane of reflection. These signs are found in Appendix J.

4.2.3 *Imperfect reflection: Type 4**

We found 76 signs that exhibit an imperfect reflection due to matters of physics, all of which reflect across the midsaggital plane, and only two of which exhibit inversion. That is, many signs that reflect across the midsaggital plane at some point(s) during

Table 21. Inventory and number of handshapes for different path shapes of Type 4C-i signs

Type 4C-I	straight path	circular path	wrist twist
A		2	
openA		1	
1		2 (one travels)	
CLAW	1	2 (one travels)	1
CLAW > S	1		

Table 22. Inventory and number of handshapes for Type 4A* signs

Type 4A* — handshapes	Number	Type 4A* — handshapes	Number
A	1	1	6
openA	1	4	1
B	1	5	6
openB	7	CLAW	7
C	1	1-I	1
F	2	openB > bentB	1
G	1	C > S	1
H	4	F > 5	1
I	1	S > B	1
K	4	S > openB	1
M	1	S > 5	1
O	1	S > CLAW	1
R	2	1 > X	2
S	8	5 > flato	1
bentv	1	5 > S	3
X	2	CLAW > S	2

the movement have one hand on top of the other, or thumbs overlapping, or the fingers passing through each other, and so forth, which contact, by physical necessity, involves having one hand slightly out of mirror-image of the other. Often these signs start or end with the hands crossing the midsaggital plane, which, again, necessitates imperfect reflection at the moment of crossing. (The hands cannot cross through each other; they cannot occupy the same space in any given moment.) At other times during the sign the hands may be perfect reflections of each other. We call signs with this sort of imperfection Type 4*, most of which are Type 4A* and two of which are Type 4A-i*, involving inversion. The 74 of them in Table 22 use a range of 23 handshapes, where fifteen signs involve handshape change. 52 of these signs use unmarked handshapes only — that is 70%. A representative example is given in Figure 35, EGG (230).

Three of the signs in the set reported on in Table 22 call for a comment. In both ALGEBRA (153) and KNIT (312) the dominant hand in the illustrations in our source seems to exhibit a slight rotation of the palm toward the contralateral side, a rotation

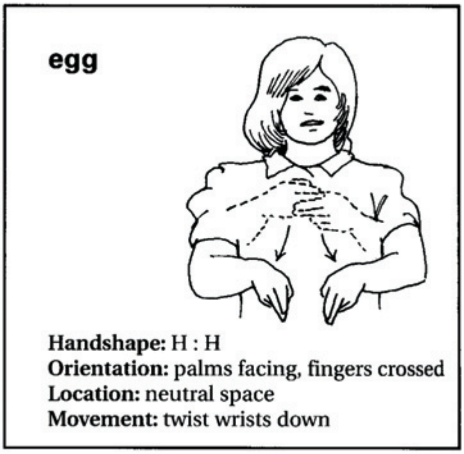


Figure 35. EGG (230).

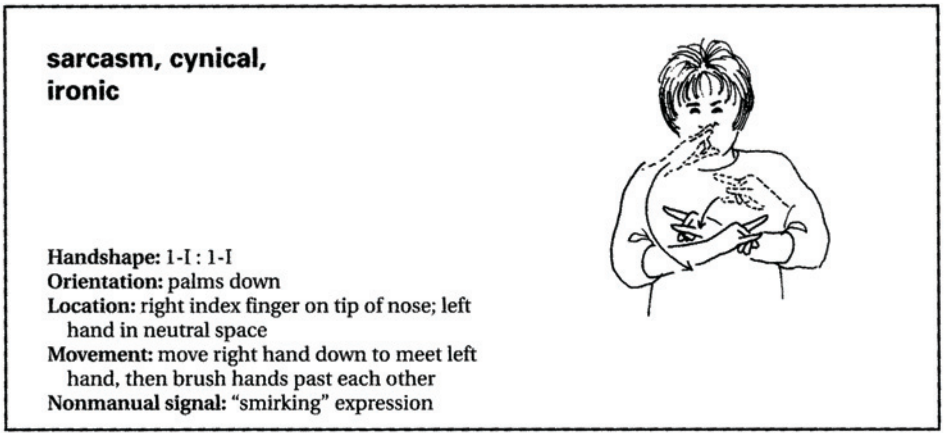


Figure 36. SARCASM (305).

that is not exhibited by the nondominant hand. In another sign, SARCASM (305), seen in Figure 36, the dominant hand moves and brushes the waiting nondominant hand on the top, then both move. Once both hands are moving, they reflect across the midsaggital plane. But their position at the start of the movement is an imperfect reflection.

There are two more signs involving inversion with imperfect reflection, Type 4*-i. In these signs the hands touch at the beginning and ending of the movement. Both of these signs use marked handshapes. One appears in Figure 37.

The handshape range for Type 4* is wide, just as it is for perfect reflections. And if we consider signs with and without inversion together, 68% use unmarked handshapes. We conclude that handshape is not restricted for these signs.

Table 23. Inventory and number of handshapes for Type 4A*-i signs which involve primary movement

Type 4A*-i — handshapes	Number	Type 4A*-i — handshapes	Number
K	1	W	1

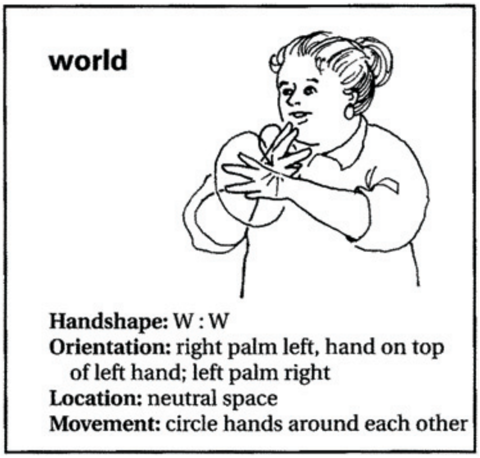


Figure 37. WORLD (296).

Given that we found no signs that imperfectly reflect across any but the unmarked plane, and given that only two involve inversion, it would appear that signs involving the complexity of imperfect reflection avoid other complexities on reflection.

In some of our Type 4* signs the hands move as a unit. As we noted earlier (when introducing Type 3 signs), signs in which the hands have the same shape and move as a unit should not be constrained by either of Battison's conditions. In fact, however, these signs behave just like other Type 4* signs. Consider the sign STAY (CONTINUE) (159), for example, shown in Figure 38.

Both hands assume the **openA** shape and imperfectly reflect across the midsaggital plane, with the thumbs overlapping. The hands move forward as a unit. If such signs were not constrained with respect to symmetry, we might expect to find a sign in which the two hands do not reflect, even imperfectly. For example, both hands might assume the **openA** shape with the palm of the nondominant one oriented down and the palm of the dominant one oriented in. Then the thumb of the nondominant hand might nestle into the palm of the dominant hand, squeezed in among the curled fingers. This is a perfectly natural way to hold the hands — the elbows are relaxed and nothing is awkward about it. And we can imagine other, equally comfortable, alternatives. But such signs, which show no symmetry, do not occur. We conclude that signs in which the hands have the same shape and move as a unit are subject to the same

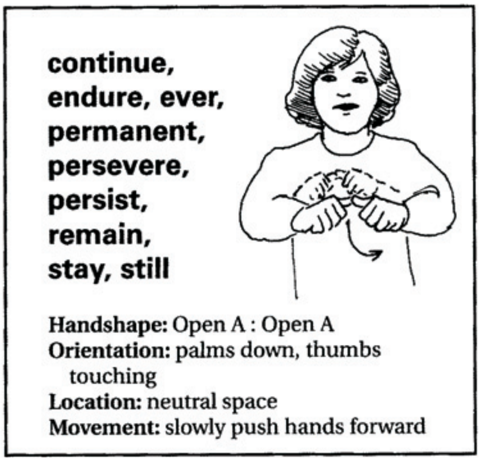


Figure 38. STAY (CONTINUE) (159).

sorts of symmetry conditions as signs in which the hands move independently.

Type 4* signs are found in Appendix K.

4.3 Rotation: Type 5

The next transformation we would like to discuss is rotation. A strict definition of *rotation* for signs might be the following. A two-handed sign involves simple rotation if the hands rotate around a fixed point, maintaining a constant palm orientation and handshape with respect to that point. With this definition, none of the signs in our study involves rotation, nor can any signs anywhere. That is because the hands are attached to the wrists as reflections of one another, and even if we twist one, the hands will never look like duplicates of one another from any single point of view. This factor of physiology cannot be dissociated from any two-handed sign.

We must therefore relax our definition of *rotation* in a sensible way to allow for the constraints of physiology.

(5) Definition of *rotation*: A two-handed sign involves simple rotation if the hands form the same handshape and rotate around a fixed point, maintaining a constant palm orientation with respect to that point.

We have found nine such signs, in all of which both hands rotate around the same fixed point.

In mathematics, rotation can occur over any number of degrees. But in these ASL signs one hand is always separated from the other by 180 degrees as both travel in the same direction on a circle, maintaining a constant palm orientation toward the point of rotation (or as constant as physiology allows). That is, the hands keep the maximum possible distance between them on the path at all times. This distance between the hands has the effect of making the hands look as though there is a plane of symmetry between them (but the plane would, of course, be moving, as the hands rotate). This appearance is strictly an artifact of the 180 degrees distance (plus the physiological reflection of the hands); these are simple rotations — they do not involve a plane of symmetry (and, with our definitions, planes of symmetry do not move). As in reflections with inversion, if we were to graph the path of the hands on a Cartesian plane with the center of the circle at the origin, the x coordinates of the positions of the two hands would be additive inverses of each other, just as the y coordinates would be. So rotation in ASL calls for inversion. Furthermore, in our database the hands touch at the beginning of the sign, make a full 360 degree rotation (or as nearly full as physiology allows), and then touch again. The signers we have consulted (all from the Philadelphia area) do not all have their hands actually touch at these points, but, certainly, the hands are close to touching. We have discovered a morpheme structure constraint then:

(6) Rotation Condition
In a sign involving rotation symmetry, the hands must (a) exhibit inversion, and (b) (almost) touch at least at the points before and after the movement.

4.3.1 *Vertical wall starting point: Type 5B*

Five rotation signs, Type 5B, are oriented at the start as though lined up on either side of the vertical wall plane, as shown in Table 24. (Please recall the impositions of physiology here, where the line of the arm and elbow can cause the hands to be orthogonal to one another.) Only 20% use an unmarked handshape (one out of five). A representative sign appears in Figure 39: TRANSLATE (280).

We note that one of these signs involves handshape change. We will return to the significance of this fact in Section 6, in our discussion of our proposed Markedness Condition on Handshape Change (given in (13)).

4.3.2 *Horizontal starting point: Type 5C*

The remaining four rotation signs are oriented at the start as though lined up on either side of the horizontal plane: Type 5C, shown in Table 25. 75% of these (three out of four) use an unmarked handshape. Table 25 gives this information, and Figure 40 gives a representative example.

The range of handshapes overall in these tables shows that handshape is not restricted in rotation transformations. Type 5 signs are found in Appendix L.

4.3.3 *Ambiguous signs: Type 5A or reflection?*

We need to account for an obvious gap: There are no Type 5A signs. With our present

Table 24. Inventory and number of handshapes for Type 5B signs

Type 5B — handshapes	number	Type 5B — handshapes	number
H	1	1	1
T	1	T > L	1
X	1		

Figure 39. TRANSLATE (280)

analysis of the signs in this study, rotation starting with the hands oriented as though they are lined up on either side of the vertical midsaggital plane does not occur in ASL, even though this is certainly the most common plane for reflection transformations. The reason, however, is obvious. If you put your hands in prayer position, fingertips pointing up, and try to rotate them a full (or nearly full) 360 degrees, you will quickly find that you cannot. Anatomy accounts for the lack of Type 5A signs.

Accordingly, one might expect that Type 5A signs would occur with one major (and physiologically necessitated) difference from Types 5B or 5C: The hands could rotate only 180 degrees (or nearly) in one direction, then rotate back 180 degrees (or nearly) in the other direction. Some of the signs we analyzed as belonging to Type 4A-i are open to such an analysis.

Consider the signs COMPARE (DISTINGUISH) (173) and CAR (272). We analyzed them as exhibiting reflection across the midsaggital plane with inversion, making them only two signs of Type 4A-i in which the hands followed an arc path. These signs could as easily, however, be analyzed as involving rotation around a point. Physically, there is no way to distinguish between these two analyses. The analyses we gave called for no new formal mechanisms that were not already needed in order to analyze the other signs in Type 4-i. And with those analyses we were able to fill out a paradigm, since

Table 25. Inventory and number of handshapes for Type 5C signs

Type 5C — handshapes	number	Type 5C — handshapes	number
OpenB	1	S	1
C	1	X	1

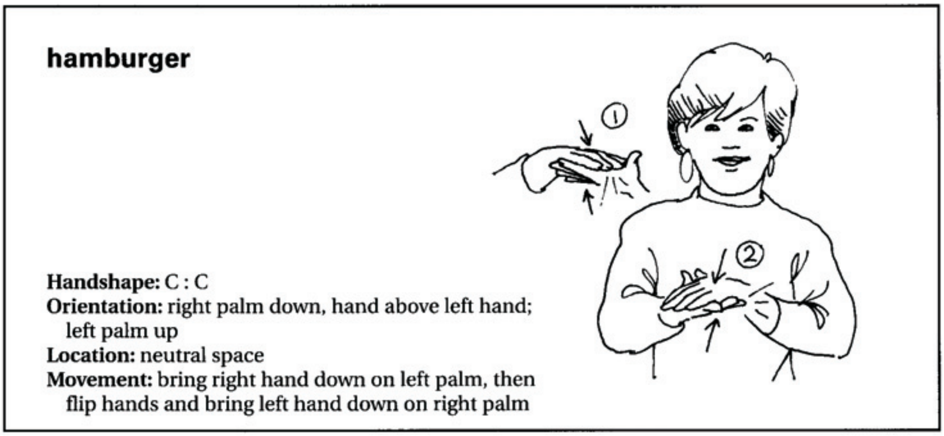


Figure 40. HAMBURGER (212).

without them, inversion signs would have been restricted to having straight or circular paths only — a strange restriction. If, on the other hand, we were to analyze these two signs as involving rotation, they would be distinct from all other instances of rotation in this section, in two ways. First, the hands never come anywhere near close to touching, so they do not conform to the Rotation Condition in (6). Second, the hands go in two directions, instead of a single direction, unlike any other rotation transformations. However, if we were to analyze these signs as involving rotation, we would be able to fill out a different paradigm in that we would then have some Type 5A signs. And the change in direction of movement would be a natural consequence of physiological limitations.

Ten other signs in Type 4A-i are also open to a rotation analysis, all of them involving secondary movement of the wrist. Some of these signs involve rotations of the wrists (while others are really sideways wrist bends — as in CONTEST (161)), and can, therefore, appear to exhibit rotation symmetry. Consider INTERPRET (223) in this regard, shown in Figure 41. If we look just at the path of the extended three fingers, we see two arc paths. The considerations that arise in the analysis of these signs are analogous to those that arise in the analysis of COMPARE (173) and CAR (272), discussed above.

We therefore leave the question open. In the rest of this paper we will proceed assuming our original analyses, allowing the reader who adopts the alternative analyses

interpret, translate

Handshape: F : F
Orientation: right palm out; left palm in, thumbs and index fingers touching
Location: neutral space
Movement: twist wrists to switch hand positions

Figure 41. INTERPRET (223).

to make appropriate changes to the Rotation Condition (eliminating part (6b)) and add appropriate limitations on reflection with inversion signs (to the effect that arc paths are not allowed).

4.4 Translation: Type 6 and Type 6$^+$

The third mathematical transformation to discuss is translation. With a strict definition, a two-handed sign would involve simple translation if the hands are identical in shape and palm orientation, and perform the same movement, but in different locations. With this definition, none of the signs in our study involve translation, nor can any signs anywhere. We face the same problem of physiology that we faced for rotation: The built-in physiological reflection of the hands means they will never look like duplicates of each other no matter what locations we put them in .

We must therefore relax the definition sensibly. Our second attempt at a definition might be the following: A two-handed sign involves simple translation if the hands form the same handshape, have the same palm orientation, and move in the same direction along the same shaped path, just starting and ending at different points. Even with this relaxation, however, there are several signs in our study that we believe are best analyzed as translations, but which do not satisfy the new definition. Consider a sign that is not in our corpus: ASIDE (PUSH ASIDE). In this sign the hands form an open B and move from the nondominant side of the signing space to the dominant side, with both palms facing the dominant side. Signs in which both palms face the same side are unusual. Both palms can easily face down or up. But if both palms face the same side, one elbow will have to be raised while the other elbow is not, as happens in signing ASIDE. Again, this is purely for reasons of physiology. But this unevenness of the elbows seems to be eschewed by ASL signs.

So we make a third stab at a definition that will allow for the fact that the hands are natural reflections of one another and for the fact that if the orientation is sideways, the hands naturally both go either in or out (to keep the elbows symmetrical). Our third attempt might be the following.

(7) Definition of *translation*: A two-handed sign involves simple translation if the hands form the same handshape, and the palms are oriented in the same or the most naturally paired directions, and the hands move in the same direction along the same shaped path.

With this final definition, we found 26 signs involving translation symmetries. We organize these into two sets.

4.4.1 *Hands parallel: Type 6*

Nineteen translation signs fall into what we call Type 6 (Table 26). In all Type 6 signs the movement paths of the hands are parallel to one another and the hands are located on the same position along their movement path. Essentially, the hands look like they reflect across a plane that separates the two movement paths, although sometimes one is slightly higher or more forward than the other. In other words, these signs give the appearance of having a plane of symmetry between the hands, where that plane moves as the hands move. This perception of a moving plane of reflection is an artifact of physiology with respect to the handshapes and the palm orientation, as we noted above. However, the fact that the hands maintain a constant distance between them is not. Thus, while a mathematical translation of a given form can be in any location, an ASL sign involving a translation observes the following condition.

(8) Translation Condition (first formulation)
In a translation sign the hands move on parallel paths, always located at the same point on their respective paths.

In eight of these signs the movement path obviously mimics a movement associated with hands in the meaning of the sign (and one could argue for non-obvious mimicking in other instances), so the path is semantically motivated. An example appears in Figure 42, BASEBALL (270).

Sixteen handshapes show up in these nineteen signs. Two signs involve a handshape change. 79% (fifteen out of nineteen) use unmarked handshapes.

The range of handshapes and the percentage of signs that use unmarked handshapes suggest that markedness is not a factor in Type 6 signs. Type 6 signs are found in Appendix M.

Table 26. Inventory and number of handshapes for Type 6 signs

Type 6–handshapes	arbitrary path	Semantically motivated path
A		1
openA		1
B	1	
openB	1	1
C	1	1
K	1	
R	1	
S		2
W	1	
1	1	1
4	1	
5	1	1
G > babyO	1	
flato > 5	1	

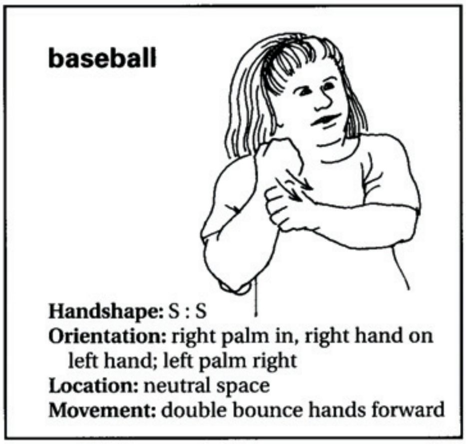


Figure 42. BASEBALL (270)

4.4.2 *Moving as a unit: Type 6⁺*

Translation is also found in an additional seven signs in which the hands have the same shape, but they move as a unit — Type 6^+. In four of them, the path the hands follow is a circle. In two, the path is semantically motivated (again mimicking an action included in the sense of the sign). An example is given in Figure 43.

Fifty percent (three out of six) use unmarked handshapes, again suggesting handshape is not restricted in translation symmetries.

The seventh sign that we analyzed as belonging to Type 6^+ is anomalous with respect to palm orientation: In BEST-FRIEND (297) the hands are oriented as we would

Table 27. Inventory and number of handshapes for Type 6+ signs

Type 6+ — handshapes	Circular path	Semantically motivated path	morpheme path
A		1	
openB		1	
F	1		
K	1		
X			1
Y	1		
5	1		

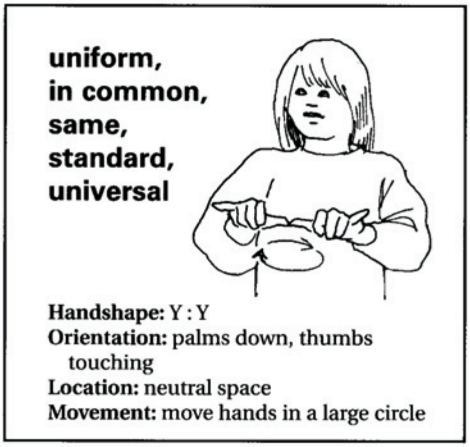


Figure 43. UNIFORM (STANDARD) (302).

expect for reflection across the horizontal plane. However, the movement path cuts across that plane, so this sign cannot be analyzed as involving reflection symmetry, and must be analyzed as involving translation. We note that the path of this sign may be the same morpheme found in STILL (159), a Type 4A* sign shown in Figure 38 above. It would seem that the sign FRIEND (299) has combined with the path for STILL (159) to produce a translation. The path in this sign is, then, a morpheme.

As we have noted twice before, signs in which the hands move as a unit do not meet requirement (a) of Battison's Symmetry condition, so we might expect them not to be constrained with regard to matters of symmetry. But the hands are, indeed, constrained. So in SUPERVISE (242), for example, the hands are oriented at the outset as an imperfect reflection across the midsaggital plane (imperfect because the dominant hand sits on the nondominant one). If symmetry were irrelevant to such signs, we might expect to find ones in which both hands had the K shape, for example, and the nondominant palm was oriented down while the dominant palm was oriented in. Then the middle finger of the dominant hand could touch the tip of the index finger

Table 28. Inventory and number of handshapes for Type 7A signs

Type 7A — handshapes	number	Type 7A — handshapes	number
A	1	5	7
B	2	CLAW	1
bentB	2	open8	2
openB	9	L > bentL	1
O	1	flato > 5	1
R	2	S > 5	2
Y	1	open8 > 8	1
1	1		

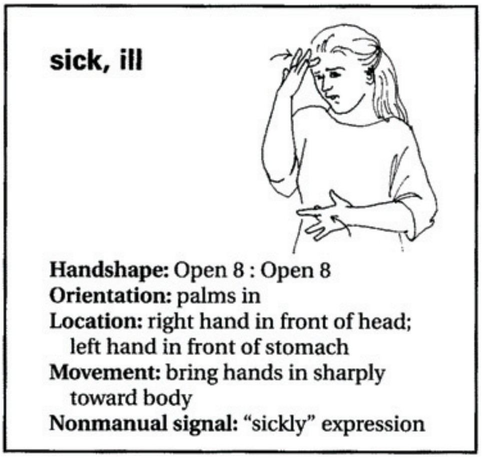


Figure 44. SICK (365)

of the nondominant hand. This arrangement is perfectly comfortable, and the elbows are symmetrical and relaxed. One can easily imagine other comfortable arrangements of the hands. Yet that sort of thing simply does not happen (just as it did not happen with Type 4* signs). We reconfirm our earlier claim that signs in which the hands have the same shape and move as a unit are constrained with respect to symmetry just as signs in which the hands have the same shape and move independently. Thus the seven signs in Table 27 are properly categorized as involving translation. We now revise the Translation Condition:

(9) Translation Condition (final formulation)
In a translation sign, the hands are always at the same point (a) on a single path, moving as a unit, or (b) on their respective parallel paths.

Type 6^+ signs are also found in Appendix M.

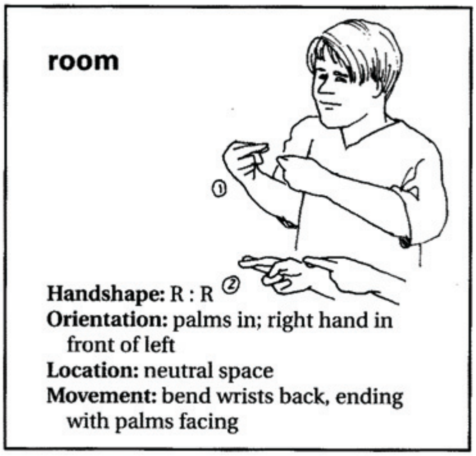


Figure 45. ROOM (267)

4.5 Glide reflection: Type 7 signs

Reflection plus translation along the plane of symmetry is the complex transformation known in mathematics as a glide reflection. We define *glide reflection* for signs in the following way.

(10) Definition of *glide reflection*: A two-handed sign involves glide reflection if the handshapes, palm orientations, locations, and movements are displaced mirror images across a fixed plane.

Glide reflection occurs in 43 of our signs.

4.5.1 *Vertical midsaggital plane: Type 7A*

34 signs have glide reflection across the vertical midsaggital plane: Type 7A, listed in Appendix N, reported on in Table 28, and exemplified in Figure 44. 79% (27 out of 34) have unmarked handshapes. That is higher than in most other types of signs involving symmetry, but significantly lower than in Type 1 and Type 3 signs. We conclude that handshape is not constrained.

In one of these signs, HEAVEN (182), the dominant hand moves and goes under the waiting nondominant hand, then both move. Once both hands are moving, they reflect across the midsaggital plane. But their position at the start of the movement is translated. In three other signs, during the first syllable of the sign the hands are a glide reflection of one another but during the second syllable they are simple reflections (BOX (179), OFFICE (253), and ROOM (267), the third of which is exemplified in Figure 45).

In RUN (252), shown in Figure 46, we find all the attributes of a glide reflection across the midsaggital plane, but the index finger of the nondominant hand (which is

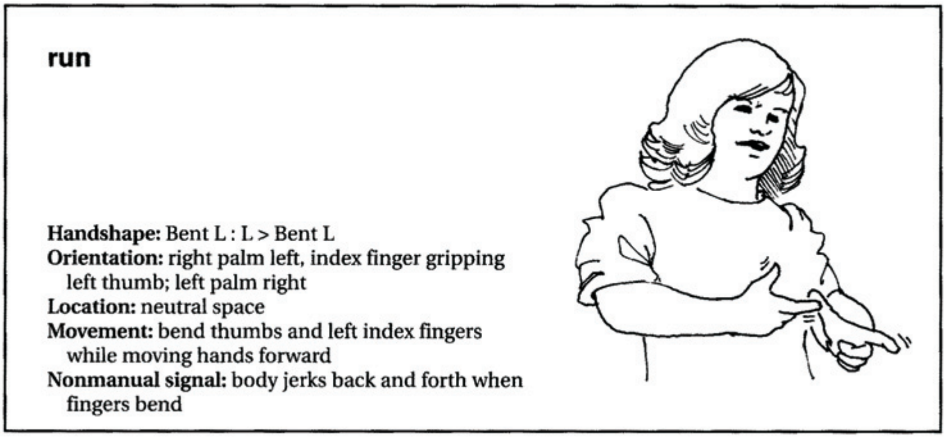


Figure 46. RUN (252)

Table 29. Inventory and number of handshapes for Type 7E signs

Type 7E — reflection plane semantically motivated	number
A	1
openB	1
8	1

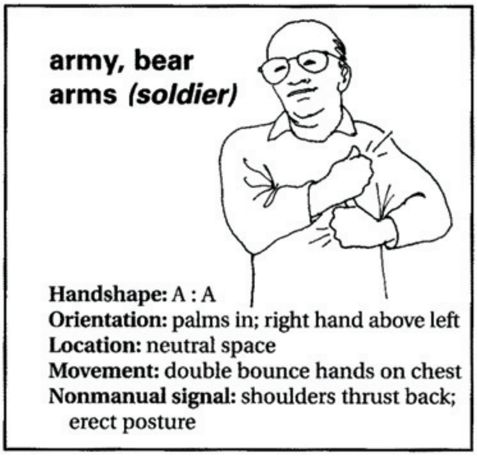


Figure 47. ARMY (SOLDIER) (153)

in front) wiggles (a fact our source describes as the change L > **bent**L repeatedly), while the thumb of the dominant hand wiggles. Since the hands are linked (the index finger of the dominant hand interlocks with the thumb of the nondominant hand), the movement

Table 30. Inventory and number of handshapes for Type 7F signs

Type 7F — glide reflection over time	Number	Type 7F — glide reflection over time	Number
openA	1	H	1
bentB	2	S > CLAW	1
openB	1		

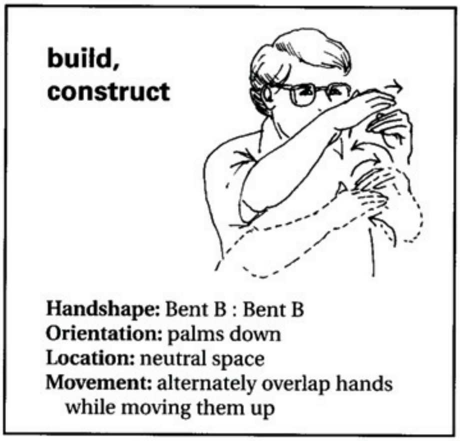


Figure 48. BUILD (205)

of the index finger of the dominant hand causes the thumb of the nondominant hand to wiggle. We conjecture that the wiggle of the thumb of the dominant hand occurs in a kind of sympathy with that of the nondominant thumb, maintaining identical movement in both hands. The two hands together form a single shape. Both hands use the handshape change L > **bentL** with the addition of thumb wiggling as the L bends.

4.5.2 *Semantically selected plane: Type 7E*

In three more signs, Type 7E, reported on in Table 29 and exemplified in Figure 47, the reflection plane is semantically selected: the side of the chest and the heart. In this tiny sample, one sign uses a marked handshape — so only 67% (2 out of 3) use an unmarked handshape. There is no strong evidence that handshape is restricted for these signs (see our earlier comments on Type 4E). These signs are in Appendix O.

4.5.3 *Vertical midsaggital plane over time: Type 7F*

In six signs, Type 7F, the reflection plane is the vertical midsaggital plane, but the reflection is defined over time. In all of these, each hand stays on its own side of the plane of symmetry, and the hands take turns doing the same action, moving forward or upward as they repeat the action. These signs are reported on in Table 30 and exemplified in Figure 48.

Given that simple reflection over time (Type 4F) calls for unmarked handshapes, the presence of H in the table above is a bit of a surprise. However, as we noted earlier, if we lump together all sixteen signs (ten of Type 4F and six of Type 7F), 94% (fifteen out of sixteen) use unmarked handshapes. We conclude that the complication of reflection over time, with or without an added translation (as in glide reflection) calls for unmarked handshapes. We note further that the only marked handshape here, H, also occurs as the nondominant handshape in three of our Type 1 signs. It is the only marked handshape to occur as the nondominant handshape in more than one Type 1 sign. These facts suggest that H is less marked than other marked handshapes.

At this point we might want to go back and take a second look at Type 2 signs, asking again whether handshape might be constrained. But even if we were to include H in our tally of unmarked handshapes, only 84% (126 out of 150) of Type 2 signs would use an unmarked handshape. We maintain our earlier conclusion that handshape is not constrained in Type 2 signs. Type 7F signs are found in Appendix O along with signs of Type 7E.

We have found no glide reflections that exhibit inversion. Accordingly, we offer the following condition:

(11) Glide Reflection Condition.
In a glide reflection, the hands must always be on the same position along their respective paths at the relevant times

For Type 7F, this condition means that the position of the dominant hand at any time during the T1 portion of the sign is the same as the position of the nondominant hand at the comparable time during the T2 portion of the sign.

5. Oddities

At this point nine remaining signs in our database present peculiarities that need to be described.

5.1 Multiple transformations

In TEAR (RIP) (254), the wrists twist, giving what looks like a rotation symmetry in the first syllable (but only at most a 90 degree rotation), then the hands separate in a simple reflection of one another across the vertical wall plane in the second syllable. Both hands use the **babyo** handshape.

In Figure 50 DIE (180), the hands are located at the outset as though they are set up to be glide reflection symmetries of one another across the horizontal plane. Then they, instead, rotate, but around separate points. So the hands can be said to be

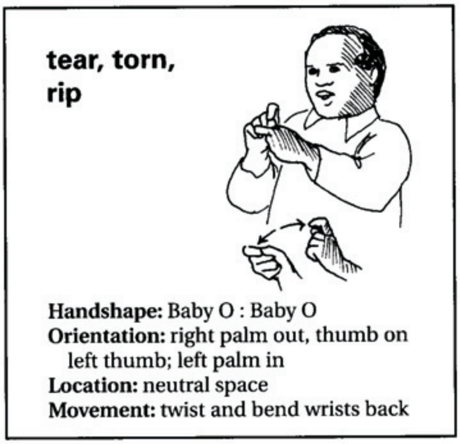


Figure 49. TEAR (RIP) (254).

rotation symmetries of each other at a distance — a kind of "glide rotation" (comparable to a glide reflection). Both hands use the **openB** handshape.

In Figure 51 CHAIN (224), we have translation. But as the hands do their primary movement, the wrists also twist, giving a rotation symmetry. It is as though the hands are drawing a chain; so the complexity here is semantically motivated. Both hands use the F shape.

5.2 Partial symmetry

Some signs involve partial symmetry, typically involving handshape discrepancies or movement discrepancies, but sometimes multiple discrepancies.

5.2.1 *Handshape discrepancies*

In TOTAL-COMMUNICATION (281) we have reflection across the midsaggital plane with inversion for all parameters of the sign except one: handshape. The dominant hand is a T; the nondominant hand is a **C**. The partial asymmetry is due to initialization. Given that the activity that this sign signifies is so difficult to do, there is a certain semantic appropriateness to its morphological ill-formedness.

In TOAST (287) the palms face each other, then the wrists twist so that both palms are oriented in toward the signer's chest, but the dominant hand is slightly lower than the nondominant hand. So this looks like a glide reflection across the midsaggital plane. But the handshapes differ (the dominant is a **V**; the nondominant is an **openB**). The fingertips of the **V** hand stab the middle of the palm, then the middle of the back, of the **openB** hand.

The difference in handshape here is semantically motivated (in mimic of sticking a fork in the sides of a slice of bread).

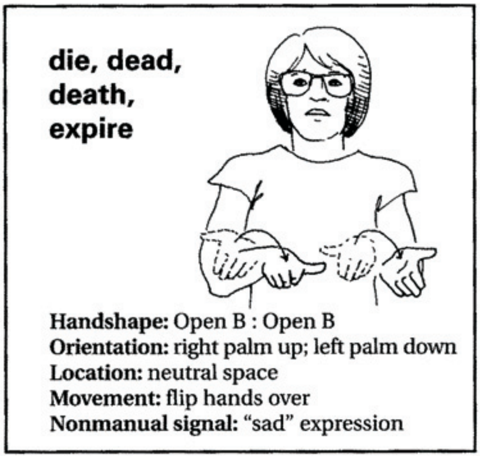


Figure 50. DIE (180).

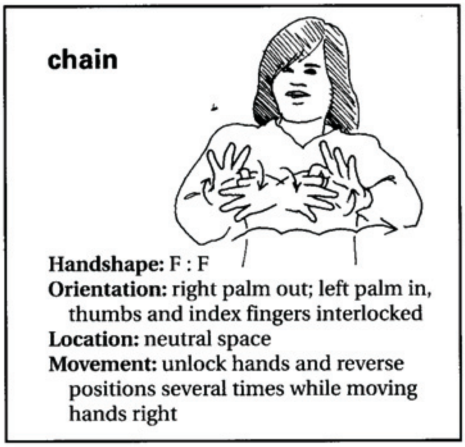


Figure 51. CHAIN (224).

5.2.2 *Movement discrepancies*

In CHASE (162), we find almost all the attributes of a glide reflection across a rotated midsaggital plane (that is, the handshapes, orientation, and direction of movement all reflect, but one hand is behind the other). However the movement path differs in that the nondominant hand goes in a straight line whereas the dominant hand spirals after it (in a traveling circle). The hands use the **openA** handshape.

In PLAY-CARDS (299) we find almost all the attributes of a translation of Type 6^{+}. However, instead of constantly touching, the hands touch, then separate, then touch, repeatedly. The movement path differs in that the nondominant hand moves in a wide arc while the dominant hand moves in repeated in-and-out straight lines, coming in

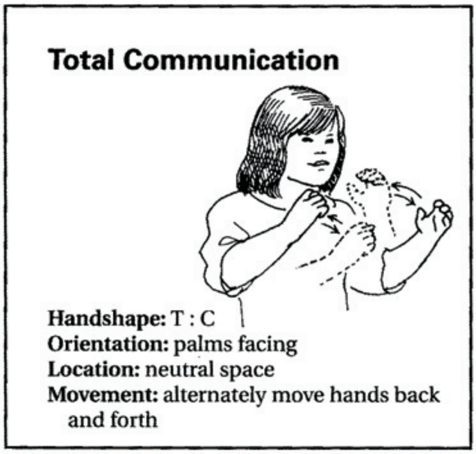


Figure 52. TOTAL-COMMUNICATION (281).

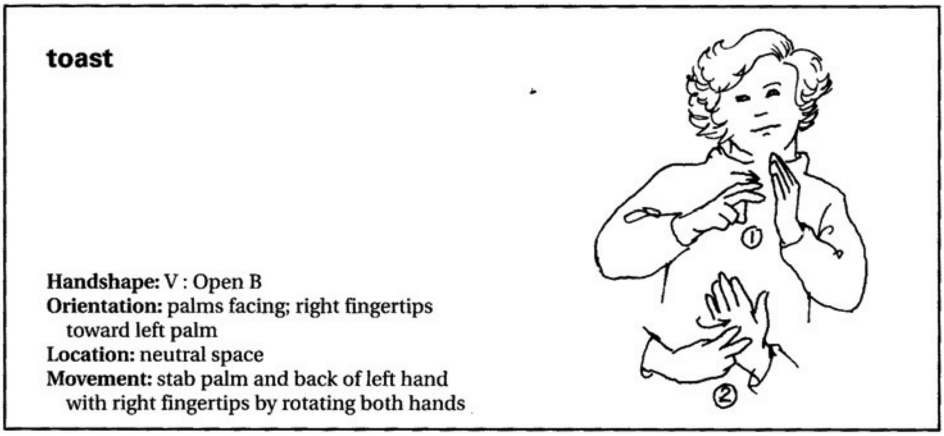


Figure 53. TOAST (287).

contact with the nondominant hand on the in-moves, and losing contact on the out-moves. The hands use the **x** shape.

In both of these signs it would appear that the partial asymmetry is motivated semantically (in mimic of the actions of running in circles after someone and dealing cards).

5.2.3 *Multiple discrepancies*

We found one sign in which the only similarity between the hands was the direction of movement, from nondominant side to dominant side: SHOPPING (260). The handshapes differ (nondominant is **openB**; dominant is **flatO**) and the path of movement differs.

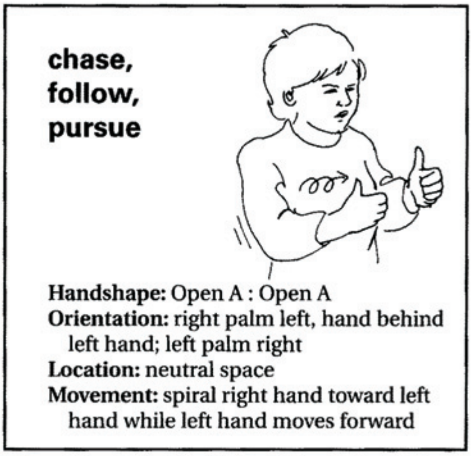


Figure 54. CHASE (162).

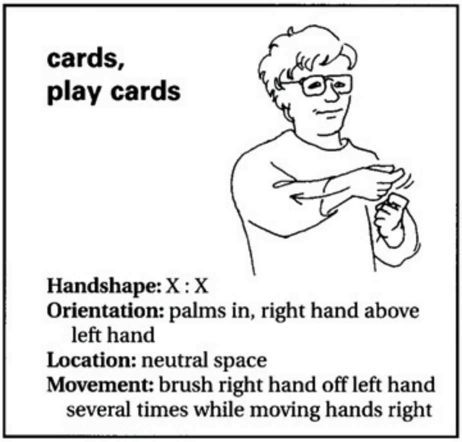


Figure 55. PLAY-CARDS (299).

This sign is similar to PLAY-CARDS, but much farther from symmetrical because of the contrast in handshapes.

6. Conclusions

Both the Dominance Condition and the Symmetry Condition have been shown to need revision, and several additional Conditions have emerged along the way.

6.1 The Dominance Condition

For signs in which the handshapes are different and only one hand moves (Type 1), the Dominance Condition holds with few exceptions, as Battison claimed. Further, signs in which the handshapes are different and the hands move as a unit (Type 3 signs) call for an unmarked shape for the nondominant hand. In fact, Type 3 signs might well be best analyzed as Type 1 signs in motion. Given that analysis, we offer an expanded condition:

(11) Expanded Dominance Condition:
In a two-handed sign in which the hands have different shape, the non-dominant hand must have an unmarked shape.

This condition restricts signs in which only one hand moves as well as signs in which the two hands move as a unit (i.e. Types 1 and 3). Signs in which the two hands move independently and have different handshapes are rare indeed.

6.2 Conditions restricting complexity

In this subsection we propose two conditions restricting signs, one involving handshape and complexity, and one involving handshape change and markedness.

6.2.1 *The Complexity Condition on Handshape*

The remarks in this subsection hold of signs in which the hands have the same shape and both move, whether independently or as a unit, that is, Types 4 through 7, the symmetry transformation signs.

ASL makes use of three different planes of reflection: the vertical midsaggital one

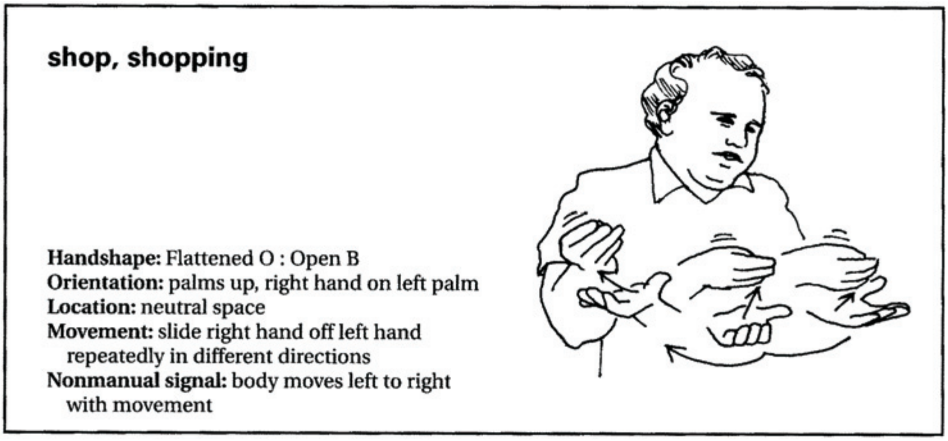


Figure 56. SHOPPING (260).

(for Type 4A), which is the predominant one and which can be rotated 45 degrees to either side (for Type 4D); the vertical wall one (for Type 4B); and the horizontal one (for Type 4C). It also makes use of semantically selected planes of reflection for a handful of signs (in Type 4E). Simple reflections are the most common kind of symmetries in ASL, and the addition of the factor of time allows complications on simple reflections (as in Type 4F). Simple reflections can be accompanied by inversion (Types 4A-i and 4C-i). And simple imperfect reflections occur across the vertical midsaggital plane (Type 4A*), sometimes with inversion (Type 4A*-i), where the imperfection is due to physics (that is, two hands cannot occupy the same space).

Handshapes are unconstrained for all reflections except those over time (Type 4F) and those that reflect across the horizontal plane with inversion (Type 4C-i), which, instead, limit themselves to unmarked handshapes. It is significant that reflections over time occur only across the vertical midsaggital plane. In other words, this is the unmarked plane — the one that occurs in most reflections and that allows the most complexities.

Rotations (Types 5B and 5C) also result in symmetries in ASL, but they are infrequent, just as translation symmetries are infrequent, whether the hands move independently or as a unit (Types 6 and 6^+). Neither rotations nor translations restrict handshapes. Planes are not relevant for rotations nor for translations, but we did note that all rotations begin and end with the hands opposite each other across a plane utilized by reflection transformations (the only one that does not occur, the midsaggital one, is precluded for physiological reasons — but see our comments in Section 4.3.3). Likewise, all translations begin with the hands in a position opposite each other across a plane utilized by reflection transformations.

The complex translation of glide reflection occurs across the unmarked plane in ASL (Type 7A), and, in a handful of cases, across a semantically selected plane (Type 7E). Glide reflections over time also occur (Type 7F), typically with unmarked handshapes (although other glide reflections do not limit the handshapes).

ASL tolerates rare partial symmetry on two-handed signs in which both hands move. The asymmetry is typically motivated semantically. No obvious generalization about handshapes jumps at us from the data.

What emerges is a general principle to the following effect:

(12) Complexity Condition on Handshape:
The greater the complexity of a two-handed transformation sign, the more likely the sign is to use unmarked handshapes and to reflect across the unmarked plane.

6.2.2 *The Markedness Condition on Handshape change*

At this point we take a look across all seven types of two-handed signs with regard to which ones allow the hands to change shape. In Type 1 there are 300 signs, in only one of which does the nondominant hand change shapes (that is 0.3%). But in 32 of them the dominant hand changes shape, which is 10.6%. In Type 2 there are 165 signs, and in 16 of them the dominant hand changes shape, which is 9.6%. There are only 19 Type 3 signs, which suggests that this is a marked set. None of them exhibit handshape change.

Now consider signs that involve symmetry translations. The least marked signs are those that reflect across the midsaggital plane, including glide reflections and imperfect reflections, with or without inversion or rotation, regardless of whether the reflection is over time. The data are given in Table 31.

Table 31. Number of signs that reflect across the midsaggital plane and the number and percent that involve handshape change.

Type 4A		Type 4A-i		Type 4A*		Type 4A*-i		Type 4D		Type 4F		Type 7A		Type 7F	
271	60	71	2	74	15	2	0	6	1	9	0	34	5	6	1
22%		2.8%		20%		0%		16.6%		0%		14.7%		16.6%	

Some remarks on the data are called for here. Type 4A*-i (imperfect reflection across the midsaggital plane with inversion) exhibits no handshape change. But Type 4A* (imperfect reflection across that plane) does, as does Type 4A-i (reflection with inversion across that plane). This suggests that the lack of handshape change in our sampling for Type 4A*-i is accidental (and we note that our sampling is tiny). Type 4F (reflection across the midsaggital plane over time) also does not exhibit handshape change, however Type 7F (glide reflection across the midsaggital plane over time) does. Again, we conclude that the lack of handshape change in Type 4F is an accident (and, again, our database is relatively small). We conclude that handshape change is allowed in signs that reflect across the midsaggital plane, regardless of other complexities.

The only signs that reflect across the vertical plane are those in Type 4B. One of these five signs exhibits handshape change: 20%

Two types of signs reflect across the horizontal plane: Types 4C and 4C-i. Of the seven 4C signs, none exhibits handshape change. Of the ten 4C-i signs, one exhibits handshape change (10%). That Type 4C (reflection across the horizontal plane) does not exhibit handshape change, while Type 4C-i (reflection with inversion) does, again suggests that the lack of handshape change in our sampling for Type 4C is accidental (and we note that the database here is small).

Two types of signs reflect across a semantically selected plane: Types 4E and 7E. Both types have only three signs in our sample, and none of them exhibits handshape change. The sample is so small, however, that we do not feel confident claiming any restriction operative here.

We conclude that handshape change is allowed in all reflections and glide reflections (Types 4 and 7). Still, it appears that handshape change is more prevalent across the unmarked plane (the midsaggital plane).

With respect to rotation, of the four signs in Type 5C (rotation with palms oriented initially as though reflecting across a horizontal plane), none exhibits handshape change. But one of the five signs (that is 20%) in Type 5B (rotation with palms oriented initially as though reflecting across a vertical wall plane) does: TRANSLATE (282). Here the handshape changes from T to L. However, our source gives an alternative sign TRANSLATE (280), in which the hands maintain the T shape, and every other dictionary we have consulted uses an unchanging T handshape for this sign. Indeed, no signer we have consulted (in the Philadelphia area) exhibits handshape change for TRANSLATE. We conclude that changing handshape in TRANSLATE is disfavored. Given our small sample of rotation signs, it is difficult to arrive at firm conclusions, but it may well be that handshape change is disfavored in rotation symmetries.

Finally, consider translation symmetries. Two of the 19 signs in Type 6 (that is, 10.5%) exhibit handshape change. On the other hand, none of the six signs in Type 6^+ sign exhibits handshape change. These are two-handed signs in which both hands have the same shape and both move, but as a unit. In Type 3 signs the hands also move as a unit, and, likewise, they exhibit no handshape change. Now we can look back at Type 5 and recognize that all rotation signs in our study begin and end with the hands touching or close to touching (as per the Rotation Condition in (6)), so even though the hands may separate in the middle part of the sign, in a loose sense they move as a unit. Indeed, in our study all signs in which both hands move as a unit and exhibit handshape change involve reflection (with many possible complications, as we discussed above) across the midsaggital plane (all are in Types 4A* and 7A), the unique exception being the disfavored version of TRANSLATE (282). We take the above as indicative of a restriction:

(13) Markedness Condition on Handshape change:
With the exception of (glide) reflection across the midsaggital plane, only signs in which the hands move independently exhibit handshape change.

While (13) does not, in fact, mention markedness, we take it as a markedness condition for several reasons. First, signs in which the hands move as a unit (Type 3, Type 6^+, and some signs in Type 4* and Type 7A) are fewer by far than signs in which the hands move independently, so they are marked. Second, handshape change is less common than fixed handshape by far, so handshape change is a marked complication. Third, reflection across the midsaggital plane is the unmarked condition for signs, if we consider the fact that fully 472 signs in our sample (the ones appearing in Table 31) exhibit it. So (13) delimits already marked signs from being further marked by exhibiting the complexity of handshape change.

6.3 Conditions replacing The Symmetry Condition

Along the way we have uncovered four conditions that relate to transformations and the various symmetries they produce. We repeat them here.

(14) Reflection Condition (= (4) above)
In reflection signs (a) the hands must be on the same position along their respective paths at the relevant times (as in Type 4 signs), or (b) the hands must exhibit inversion (as in Type 4-I signs).

(15) Rotation Condition (= (6) above)
In a sign involving rotation symmetry, the hands must (a) exhibit inversion, and (b) (almost) touch at least at the points before and after the movement.

(16) Translation Condition (= (9) above)
In a translation sign, the hands are always at the same point (a) on a single path (if they move as a unit) or (b) on their respective parallel paths.

(17) Glide Reflection Condition (= (11) above)
In a glide reflection, the hands must always be on the same position along their respective paths at the relevant times.

We see an overriding generalization concerning movement and symmetry:

(18) Movement Symmetry Condition:
In two-handed signs in which the hands have the same shape and both move, the positions of the hands along their respective paths at the relevant times must be (a) identical, or (b) inverse.

The Movement Symmetry Condition holds whether the movement of the hands is as a unit or independent.

6.4 Three sets of signs

There are three sets of two-handed signs with respect to the conditions presented in this paper. In one set the hands have different shapes, and, whether or not they move, the nondominant hand is unmarked (Types 1 and 3). That is, they obey the Expanded Dominance Condition. In another set the hands have the same shape and only the dominant one moves. These are unconstrained regarding handshape or handshape change, and they show no symmetry transformations (Type 2). In the third set, the set that includes most two-handed signs, the hands have the same shape and both move, whether independently or as a unit. Each hand must be a transformation symmetry of the other. That is, they obey one of the four symmetry conditions. In general, this third category obeys the Movement Symmetry Condition, the Complexity Condition on Handshapes, and the Markedness Condition on Handshape Change.

6.5 Suggestion for future research

The Complexity Condition on Handshapes plus the fact that dilation transformations do not occur in ASL (a fact noted in Section 4.1 on mathematical symmetry) nor do rotation transformations that start with the hands oriented as though lined up across the midsaggital plane (but see our comments in Section 4.3.3) all come together to underscore the importance of physiology and motor coordination to signing. Our work, then, echoes that of others who have shown how physiology is responsible for various constraints on signing (see, for example, Mandel 1979; Poizner, Newkirk & Bellugi 1983; Ann 1993). Among two-handed signs in which both hands move and have the same handshape, those that reflect across the midsaggital plane are the simplest to perform from a motor-coordination point of view, as the work on general hand movement shows (Kelso, Southard & Goodman 1979). It is no surprise, then, that they account for a total of 433 signs (in Types 4A, 4D, 4F, 4A-i, 4A* and 4A*-i). Overall, there are 535 signs in Types 4 through 7. 81% exhibit simple reflection across the midsaggital plane. When we add in those glide reflections that reflect across the midsaggital plane (40), the percentage jumps to 88%.

Additionally, inversion conditions on reflection (in (14)) and rotation (in (15)) and the identity condition on glide reflection (in (16)) may be motivated by motor-coordination restrictions. It is extremely difficult to move the two hands along two identical paths at any relative positions other than identical or inverse. The parallelism condition on translation (in (17)) may be similarly motivated.

It looks like motor coordination considerations motivate symmetry conditions. And since markedness of the hands is based on motor coordination conditions (as argued in Battison 1978), a dominance condition may be similarly motivated. Research in this direction would be parallel to research that seeks to account for morpheme structure conditions in oral languages with physiological explanations, as in the work on segmental sequencing constraints in Ohala and Kawasaki-Fukumori (1997) and Ussishkin and Wedel (2003).

The question of whether the conditions outlined in the present paper are morpheme structure constraints or, instead, physiologically motivated limitations that do not even bear on language constraints per se can be explored by comparing ASL to other sign languages. Conditions that follow from general biological limitations not specific to language should be universal. Any that are true morpheme structure conditions might well be language specific.

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Appendix A

Signs listed in our source as having "passive" nondominant hand

	NONDOMINANT	DOMINANT
made on elbow		
AUTUMN (168)	A	openB
COUNTRY (345)	5	5
COUNTRY (FOREIGN (303)	A	Y
CRACKER (157)	A	A
FOREIGN (226)	A	F
PENALTY (PUNISH) (327)	S	1
POOR (352)	S	5 > flato
TEMPT (300)	A	X
made on forearm		
BRIDGE (288)	S	V
EPISCOPAL (326)	V	1
IMPROVE (194)	openB	openB
LONG (326)	B	1
MIGHT (POWER) (328)	A	1
PAIL (BUCKET) (326)	openB	1
POETRY (246)	openB	K
POWER (194)	openB	openB
ROB (290)	A	V > bentV
SHEEP (288)	A	V
WORSEN (193)	openB	openB
made on wrist and back of hand		
STAGE (276)	openB	S
made on back of hand		
NIGHT (209)	openB	bentB
made on forearm with other forearm		
DAY (219)	openB	D
DAY (325)	openB	openB
TODAY (304) (second part of compound)	openB	openB
MORNING (195)	openB	openB
AFTERNOON (195)	openB	openB
ALL AFTERNOON (196)	openB	openB
ALL DAY (195)	openB	openB
ALL NIGHT (196)	openB	openB
MIDNIGHT (194)	openB	openB
NOON (195)	openB	openB
SUNRISE (253)	openB	O
SUNSET (254)	openB	O
TABLE (196)	openB	openB
TREE (345)	openB	5

Appendix B: Handshape Inventory

A	G	R	bent3
openA	H	S	4
B	I	T	5
bentB	K	V	CLAW
openB	L	bentv	6
C	bentL	W	8
D	M	X	open8
E	O	Y	l-i
F	babyo	1	
openF	flato	3	

Appendix C

Type 1: nondominant hand does not move and the hands have different shapes
(Note: ** indicates that our source lists the nondominant hand as passive.)

nondominant A
- **dom openA**
  - DANGER (163)
- **dom F**
  - FOREIGN (226)**
- **dom X**
  - TEMPT (TEMPTATION) (300)**
- **dom Y**
  - COUNTRY (FOREIGN) (303)**

nondominant openA
- **dom 1**
  - FIRST (318)

nondominant B
- **dom openB**
  - STRAIGHT (FAITHFUL) (197)
- **dom F**
  - FIELD (PROFESSION) (225)
  - VERY RELIGIOUS (RELIGION) (225)
- **dom K**
  - PURE (PROFESSIONAL) (244)
- **dom S**
  - STAGE (276)**
- **dom V**
  - INDECISION (284)
- **dom 1**
  - DAY (325)**
  - TODAY (304) (second half of compound)
  - LONG (LENGTH) (326)**
- **dom changes**
  - **flato > 5**
  - ADVISE (264)

nondominant bentB
- **dom openB**
  - SLIGHT (INSULT) (197)

nondominant openB
- **dom A**
  - DOLLAR (156)
  - EXPERT (156)
  - HIDE (157)
  - IRON (156)
  - KNOCK (155)
  - NOT GUILTY (201) (second half of compound)
  - POLISH (SHINE SHOES) (155)
  - TURTLE (156)
- **dom openA**
  - BLAME (164)
  - CARVE (SCULPT) (163)
  - DOOR BELL (163)
  - ESTABLISH (164)
  - IMPRESS (EMPHASIZE) (163)

dom R
- REHABILITATION (267)
- RESEARCH (268)
- RULE (268)

dom S
- BELL (276)
- CERTIFY (276)
- CREDIT CARD (276)
- STATE (276)

dom T
- TIME (abstract) (281)

dom V
- ARISE (286)
- DANCE (285)
- DROWN (285)
- FALL DOWN (286)
- FORK (285)
- LIE DOWN (285)
- LOSE (a competition) (285)
- MEAN (SENSE) (286)
- PREDICT (284)
- READ (286)
- STAND (285)
- TWICE (287)

dom bentV
- HILARIOUS (293)
- KNEEL (293)

dom X
- COST (CHARGE) (300)
- KEY (300)

dom Y
- FAT (WADDLE) (303)
- IMPOSSIBLE (303)
- NEW YORK (303)
- THAT (303)

dom 1
- ALARM (325)
- APPEAR (319)
- BEGIN (318)
- CANCEL (CRITICIZE, CORRECT) (322)
- CHECK (INSPECT) (321)
- COIN (CHANGE) (321)
- DEPTH (DETAIL) (325)
- DISAPPEAR (319)
- DISCUSS (322)
- ESCAPE (319)
- HALF HOUR (324)
- HOUR (324)
- KILL (MURDER) (320)
- LAST WEEK (322)
- MINUS (NEGATIVE) (325)
- MINUTE (325)
- NEXT WEEK (322)
- NOTICE (OBSERVE) (320)
- OCCASIONALLY (323)
- ONCE (323)
- OWE (DUE, AFFORD) (321)
- PAY (321)
- TALL (HEIGHT) (324)
- THIS (321)
- WEEK (321)
- WHAT (323)

dom 3
- CHEAT (331)
- GARAGE (331)
- PARK (331)

dom bent3
- TICKET (333)

dom 5
- GLORY (344)
- STUDY (344)
- TREE (345)**

dom CLAW
- BOIL (358)
- COOKIE (358)
- CRUDE (ROUGH) (357)
- GRAPES (359)
- WEAK (358)

dom open8
- CENTER (MIDDLE) (366)
- MEDICINE (366)
- SHINY (BRIGHT) (366)
- TAKE ADVANTAGE OF (RIP OFF) (366)
- TECHNOLOGY (TECHNICIAN) (367)
- TOUCH (BEEN THERE) (366)

dom changes
- **C > flatO**
  - DEFLATE (FLAT TIRE) (216)
  - XEROX (217)
- **C > S**
  - EXPIRE (RUN OUT) (217)
  - SUBTRACT (REMOVE) (217)
- **openF > F**
  - FIND (228)

- **G > babyo**
  - NEWSPAPER (230)
- **flato > 5**
  - EXPENSIVE (264)
  - EXTRAVAGANT (265)
  - RICH (265)
  - OVERFLOW (265)
- **V > T**
  - VIDEOTAPE (289)
- **V > bentv**
  - JUMP (290)
- **5 > flato**
  - LEARN (350)
  - STUDENT (350)
- **CLAW > A**
  - GREEDY (362)
- **CLAW > S > 5**
  - REMOVE (DISCARD) (362)
- **open8 > s**
  - HEART ATTACK (368)
- **open8 > 8**
  - GREASY (GRAVY, FAT) (368)

nondominant C
- **dom B**
  - SLIPPER (168)
- **dom H**
  - GET INTO BED (236)
- **dom flato**
  - INSTALL (INVESTMENT) (261)
- **dom bentv**
  - GET IN (293)
  - GET OUT (294)
- **dom 1**
  - SWALLOW (326)
- **dom CLAW**
  - BEG (359)
- **dom changes**
  - **flato > 5**
    - GROW (265)
  - **1 > X**
    - PRY (NOSY) (330)
  - **5 > flato**
    - DISAPPEAR (351)
    - INCORPORATE (WHOLE) (351)

nondominant H
- **dom V**
  - DIVE (287)
  - SALT (287)
- **dom changes**
  - **C > S**
    - NAB (CATCH) (217)

nondominant L
- **dom 1**
  - THEN (OR) (327)

nondominant O
- **dom F**
  - TEA (226)
  - VOTE (225)
- **dom H**
  - JOIN (ENLIST) (236)
  - RESIGN (DROP OUT) (237)
- **dom flat O**
  - IN(TO) (261)
- **dom CLAW**
  - DRAT (359)

nondominant flato
- **dom 1**
  - ABOUT (CONCERNING) (327)

nondominant S
- **openA**
  - DEFECATE (165)
  - ESTABLISH (165)
  - GAS (165)
- **dom B**
  - BUSY (168)
- **dom openB**
  - BLOW UP (HOT TEMPER) (197)
  - COVER (LID) (197)
  - EARTH (367)
  - FIRE (TERMINATE) (198)
  - FULL (COMPLETE) (197)
- **dom C**
  - CHURCH (214)
  - CHOCOLATE (215)
- **dom F**
  - WATCH (WRIST WATCH) (226)
- **dom H**
  - BANDAID (237)
  - NATION (237)
  - USE (WEAR) 237)
- **dom K**
  - PASSOVER (246)
  - PRINCIPAL (246)

- **dom L**
  - AIDE (ASSISTANT) (248)
- **dom T**
  - TEMPLE (281)
- **dom V**
  - BRIDGE (288)**
  - SAVE (288)
- **dom bentV**
  - HARD (294)
  - IRISH (294)
  - POTATO (294)
- **dom X**
  - TIME (300)
- **dom 1**
  - EPISCOPAL (326)**
  - MIGHT (POWER)**
  - PENALTY (PUNISH) (327)**
  - TOMATO (327)
- **dom 5**
  - ENOUGH (345)
- **dom open8**
  - EARLY (367)
  - NAKED (BARE) (367)
- **dom 1-I**
  - WHISKEY (306)
- **dom changes**
  - **C > 5**
    - INCOMPETENT (218)
  - **T > openA**
    - CHAMPAGNE (281)
  - **5 > flatO**
    - POOR (352)**
  - **8 > open8**
    - MELON (PUMPKIN) (364)
  - **open8 > 5**
    - SODA POP (369)

nondominant V

- **dom 1**
  - SECOND (SECONDLY) (328)
- **dom changes**
  - **openF > F**
    - CHOOSE (228)

nondominant 1

- **dom A**
  - BANANA (157)
  - PRACTICE (157)
  - TRICK (158)
- **dom B**
  - PARTIAL TO AN INDIVIDUAL (168)
- **dom openB**
  - CONVINCE (198)
  - FLAG (198)
- **dom bentB**
  - REMIND ONE PERSON (209)
- **dom C**
  - CULTURE (215)
  - FORCE (215)
- **dom E**
  - ENVIRONMENT (221)
- **dom G**
  - WORD (229)
- **dom K**
  - PROFESSION (246)
- **dom S**
  - HIT (277)
  - SITUATION (277)
- **dom V**
  - PLUG (OUTLET) (289)
  - PLUMBING (WRENCH) (288)
  - TABLE IT (SHELVE IT) (288)
  - VOCABULARY (288)
- **dom bentV**
  - NAB (294)
- **dom X**
  - FROM (300)
  - HANG (CLOSET) (301)
  - NAG (300)
  - TELEGRAM (CALL TTY) (301)
- **dom Y**
  - BIG WORD (303)
  - CURSE (304)
- **dom bent3**
  - CHAMPION (333)
- **dom 5**
  - CANDLE (346)
  - POPULAR (346)
- **dom CLAW**
  - POPULAR (359)
- **dom 1-I**
  - CIGARETTE (306)
- **dom changes**
  - **5 > A**
  - PRETEND (350)

nondominant 5
- **dom openB**
  - THROUGH (198)
- **dom flato**
  - CHERRY (BERRY) (261)
- **dom X**
  - SANDALS (THONGS) (301)
- **dom 1**
  - AMONG (AMID) (329)
  - INSULT (329)
  - REVIEW (329)
  - FRESHMAN (328)
  - JUNIOR (328)
  - PREPARATORY (YEAR) (328)
  - SOPHOMORE (328)

nondominant open8
- **dom 1**
  - SKIP CLASS (329)

nondominant changes
- **C > S**
- **dom changes**
  - **V >H**
  - BOTH (289)

Appendix D

Type 2: nondominant hand does not move and the hands have the same shape
(Note: ** indicates that our source lists the nondominant hand as passive.)

A
- CRACKER (157)**
- EACH (EVERY) (155)
- GUITAR (155)
- PASS BY (155)
- ZIP (155)

openA
- AHEAD (162)
- BEHIND (162)
- EVADE (AVOID) (162)
- FAR (162)
- MOST (161)
- REMEMBER (163)

B
- AUTUMN (168)**
- DOOR (OPEN DOOR) (167)
- MAJOR FIELD OF STUDY (167)
- PARTIAL TO (FAVOR) (168)
- SOCCER (167)
- WINDOW (167)

bentB
- EASY (205)
- EXCEED (205)

openB
- ABOVE (184)
- ACROSS (OVER) (186)
- AFTER (BEYOND, NEXT) (191)
- AFTER (NEXT) (191)
- AFTERNOON (195)**
- AGAINST (PREJUDICE) (189)
- ALL (192)
- ALL DAY (195)**
- ALL AFTERNOON (196)**
- ALL NIGHT (196)**
- ALL RIGHT (188)
- ALMOST (NEARLY) (188)
- APPROACH (NEAR, NEXT TO) (192)
- ARRIVE (REACH) (188)
- AVERAGE (MEDIUM) (190)
- BAKE (184)
- BEFORE (192)
- BELOW (184)
- BETWEEN (191)
- BIRTH (BORN) (193)
- CAMCORDER (VIDEOTAPE V.) (193)
- CHEAP (190)
- CHEESE (187)

AIM (GOAL) (315)
ALLERGY (315)
CAN'T (318)
CORRECT (318)
CUT (318)
DIGRESS (316)
MONTH (317)
POINT (a noun) (316)
SPECIFIC (316)
STRAY (317)
TEMPERATURE (317)
TOWARD (316)
TURN BACK (TURN AROUND) (317)
UNTIL (316)
WHEN (315)

4
JAIL (334)
LINE (FORM A LINE) (334)

5
BLOOD (343)
BLURRY (VAGUE) (344)
COUNTRY (345)**
FILM (MOVIE) (343)
SCHEDULE (344)
SENIOR (343)

open8
CUT CLASS (365)

1-I
LIQUOR (WHISKEY) (305)
TRICK (DECEIVE, FRAUD) (305)

change handshape of dominant

nondominant is same as start

openB > A
CALL (SUMMON) (199)

openB > bentB
CENTER (MIDDLE) (200)
FREQUENT (OFTEN) (200)
PET (TAME) (200)
PIE (199)

openB > S
COLLECT (200)

H > G > babyo
TOO LATE (TRAIN GONE) (238)

S > 1
NEXT YEAR (279)

bentV > V
CHANGE THE TOPIC (295)

nondominant is same as end

bentB > openB
SEND (209)
REJECT (CAST OFF) (210)

flatO > openB
PUT DOWN (REGISTER) (264)

5 > flatO
ADDITIONALLY (AMENDMENT) (351)

CLAW > flatO
PEAR (362)

CLAW > S
WIN (363)

nondominant is same as start and end

bentL > L > bentL
CAMERA (251)

Appendix E

Type 3: hands have different shapes and move as a unit

Hands are touching constantly

non-dom B

dom V
RIDE (as on bike or horse) (284)

non-dom openB

dom A
LEAD (156)

dom openA
HELP (164)

dom bentB
ENGLISH (208)

dom openF
MEAT (227)

dom flatO
FLEXIBLE (261)

dom R
REQUIRE (268)
dom S
SAMPLE (SYMBOL) (276)
dom X
DEMAND (INSIST) (299)
dom 1
SHOW (320)
dom 3
SHIP (331)
non-dom S
dom H
USED TO (USUALLY) (237)
dom R
REINFORCE (268)
dom V
WATCH (287)
dom 5
PRESSURE (OPPRESS) (345)
non-dom 1
dom openB
OPPRESS (198)
dom F
UNIQUE (EXCEPT) (226)
non-dom 3
dom 5
HELICOPTER (346)
Hands touch some of the time
non-dom 1
dom 5
MAINSTREAMING (negative connotation) (346)

Appendix F

Type 4A: reflection across the vertical midsaggital plane

A
AREA (152)
ASSOCIATION (152)
BATH (BATHE) (154)
CABINET (153)
CAN (153)
COAT (154)
GO STEADY (152)
TRY (153)
WITH (ACCOMPANY) (152)
openA
ADDRESS (159)
CHALLENGE (158)
DENY (159)
DOWN PAYMENT (159)
B
BLANKET (166)
CORNER (166)
OPEN (horizontal) (165)
OPEN (vertical) (166)
SHUT (CLOSE) (165)
bentB
DEMOTE (202)
EQUAL (FAIR) (202)
EVEN (202)
HAVE (204)
HEAVY (202)
HOPE (203)
HOW (203)
PROMOTE (202)
SEPARATE (APART) (203)
TIRED (204)
YOUNG (204)
openB
ADVANCE (168)
ALLOW (171)
ATTENTION (170)
BET (173)

SELL (STORE) (258)
TEACH(ER) (257)

R

DOUGHNUT (267)
RABBI (267)

S

ACCIDENT (270)
BREAK (270)
CAN (269)
CARPENTRY (269)
COLD (269)
MOTORCYCLE (269)
POWER (STRENGTH) (268)
SHOES (270)
SKI (268)
STRETCH (269)

T

TEAM (281)
TRY (280)

V

FUNERAL (282)
SCORN (282)
TENT (CAMPING) (283)
VAIN (FLATTERY) (282)
VERY (283)

bentv

ANALYZE (290)
DEAD (for animals) (290)
QUOTE (290)
SQUIRREL (293)

W

WINTER (295)

X

AWARD (296)
DANGEROUS (296)
SKI (297)
URGE (COAX) (297)

Y

CONTRARY (301)
COW (BULL) (302)
MEASURE (302)
NOW (301)
PLAY (301)
STILL (302)
TODAY (first half of compound) (304)

1

ALIKE (SAME) (310)
ANNOUNCE (311)
ANSWER (311)
CHINESE (311)
COINCIDE (PARALLEL) (307)
COME HERE (307)
COMPUTER (308)
DURING (WHILE) (307)
FAME (312)
FINALLY (308)
GO TO (ATTEND) (307)
HAPPEN (308)
LAUGH (311)
OPPOSITE (306)
QUAKE (SCARED) (307)
SIN (306)
SMILE (311)
SUCCEED (308)
WHEELCHAIR (309)

4

CURTAINS (333)
HANUKKAH (334)

5

ABANDON (336)
AFRAID (338)
CHAT (335)
COOL (AIR) (337)
DEER (340)
DRESS (WEAR) (341)
EMBARRASS (337)
EXCELLENT (MARVELOUS) (336)
FINISH (OVER) (339)
FIRE (338)
FLIRT (339)
FRIENDLY (337)
HOLIDAY (342)
MOOSE (340)
NERVOUS (338)
RETIRED (342)
RUSSIA (342)
SNOW (338)
WELL! (SO!) (335)
WHAT (335)

CLAW

ANIMAL (356)
AUDIENCE (353)
AUDIOLOGIST (RADIO) (353)
BALL (SPHERE) (352)

DISSOLVE (FADE) (346)

5 > bentB

PANTS (TROUSERS) (347)

5 > flato

ACCEPT (348)

FOOTBALL (BALL) (348)

MEETING (CONFERENCE) (348)

WET (HUMID) (347)

5 > S

ADOPT (TAKE UP) (349)

BRAVE (HEALTHY) (350)

5 > CLAW

ICE (FREEZE) (350)

CLAW > flato

SOFT (360)

CLAW > S

DRAWER (360)

8 > 5

AWFUL (363)

HATE (363)

8 > open8

AUSTRALIA (363)

Appendix G

Reflection across other planes

Type 4B: reflection across a vertical wall plane in front of the body
Note: * indicates that the reflection is not perfect. Instead, the angle of the elbows is responsible for a 90 degree difference in the angle of the hands.

F

*BELONG (JOIN, UNITE) (222)

PERFECT (221)

K

PERFECT (242)

1

MEET (309)

hands change

5 > F

*BELONG (JOIN) (347)

Type 4C: reflection across a horizontal plane

openB

CLAP (175)

HINGE (174)

C

*MARRY (212)

babyo

EXACT (254)

V

FORNICATE (283)

X

*PULL (299)

4

ASSEMBLY LINE (334)

Type 4D: reflection across a rotated midsaggital plane

openB

HATE (AVOID, ABHOR) (172)

V

LOOK FORWARD TO (282)

bentv

LAID UP (290)

5

FATHER (honorific) (340)

MOTHER (honorific) (341)

hands change

5 > flato

SUM (TOTAL) (347)

Type 4E: reflection across a semantically selected plane

plane cuts through center of dominant shoulder

bentB

RESPONSIBILITY (204)

plane cuts through center of heart

1

HEART (312)

SINCE (ALL ALONG) (310)

Appendix H

Type 4F: reflection over time

hands take turns

openB

HANDS (181)

C

COMFORTABLE (212)

S

BOX (FIGHT) (272)

non-dominant openB > 1

dom 1 > openB

DEBATE (322)

non-dominant 5 > open8

dom open8 > 5

BIBLE (369) (second part of compound)

JESUS (369)

hands have same shape and do same act first on one side of the plane, then on the other

B

PANTS (SLACKS) (175)

1

ACCORDING TO (AS, ALSO) (310)

WEEP (315)

Appendix I

Type 4A-i: reflection with inversion across vertical midsaggital plane **straight path**

A

DRUM (154)

openA

BRAG (161)

WHICH (160)

bentB

BALANCE (205)

openB

MAYBE (180)

ENTHUSIASTIC (ZEALOUS, METHODIST) (182)

WASH, TOWEL (the body; the face) (183)

D

DESCRIBE (218)

F

EXPLAIN (223)

JUDGE (223)

H

HURRY (231)

I

EGOTISTICAL (240)

- **flatO**
  - COSMETICS (259)
  - FIX (258)
  - PACK (258)
- **S**
  - DOUBT (WAVER) (272)
- **bentV**
  - DIFFICULT (291)
  - ROLLER SKATE (292)
  - TOURNAMENT (291)
- **X**
  - DIRECT (CONTROL) (298)
  - GRIMACE (298)
  - ICE SKATE (298)
- **1**
  - ARGUE (312)
  - LAME (313)
  - SOCKS (314)
  - STARS (313)
  - TALK (315)
- **3**
  - AWKWARD (CLUMSY) (331)
  - WALK (331)
- **5**
  - TRAFFIC (343)
- **CLAW**
  - TYPE (356)
- **hands change**
  - **CLAW > S**
    - CRUEL (361)

semicircular arc

- **openB**
  - COMPARE (DISTINGUISH) (173)
- **S**
  - CAR (272)

circular path

- **A**
  - TIE A KNOT (154)
- **openA**
  - AMBITIOUS (AGGRESSIVE) (161)
  - ACT (PERFORMANCE) (161)
  - SCIENCE (160)
- **B**
  - TROUBLE (167)
- **E**
  - EMOTION (220)
  - EVALUATE (220)
- **F**
  - EXCHANGE (223)
- **K**
  - PEOPLE (243)
- **flatO**
  - BUDGET (259)
  - FEAST (259)
- **S**
  - AGONY (273)
  - BAR/BAT MITZVAH (272)
  - BIKE (272)
- **V**
  - VISIT (283)
- **X**
  - EXCHANGE (298)
- **1**
  - CONSIDER (314)
  - SIGN LANGUAGE (314)
- **open8**
  - EXCITED (366)

circular path that travels

- **openB**
  - ANCESTORS (181)
  - DESCENDANTS (181)
  - KIND (GENEROUS) (183)
- **H**
  - HERITAGE (231)

secondary movement: wrist twist

- **openA**
  - CONTEST (161)
- **F**
  - INTERPRET (223)
  - OLYMPICS (224)
- **flatO**
  - NUMBER (259)
- **bentV**
  - PROBLEM (291)
- **W**
  - WEATHER (295)
- **1**
  - HURT (306)
- **5**
  - CROWDED (343)
- **hands change**
  - **openF > F**
    - STORY (228)

5 > flato
TELL A STORY (348)
secondary movement: wrist bend
openB
DOESN'T MATTER (182)
WALK (180)
5
FLATTER (MANIPULATE) (342)
wrist bend that travels
1
VARIETY (313)

Appendix J

Type 4C-i: reflection with inversion across horizontal plane

straight path
hands change
CLAW > S
DESTROY (361)
circular path
A
CHEW (154)
WASH (154)
openA
SOCIALIZE (160)
1
TRAVEL (313)
CLAW
LAUGH (hysterically) (356)
MIX (357)
circular path that travels
1
TORNADO (313)
CLAW
STORM (CLOUDS) (356)
secondary movement: wrist twist
CLAW
WASHING MACHINE (357)

Appendix K

Type 4*: imperfect reflection

Type 4A*: imperfect reflection across the vertical midsaggital plane

A
ALGEBRA (153)
openA
STAY (CONTINUE) (159)
B
QUIET (166)

openB
BLOCK (DEFEND, GUARD) (176)
DIVIDE (SPLIT, GO DUTCH) (175)
NOT (DON'T DO THAT) (169)
PEACE (179)
PREVENT (ME), BLOCK (ME) (176)
RELAX (177)
SANDWICH (175)

C
CALCULUS (211)

F
CONNECTION (RELATIONSHIP) (222)
FREE (doesn't cost) (221)

G
GEOMETRY (229)

H
EGG (230)
HIGHWAY (230)
NAMED (CALLED) (231)
RABBIT (230)

I
INDEPENDENT (239)

K
ARITHMETIC (243)
BORROW (242)
LEND (242)
WORSE (243)

M
MATHEMATICS (252)

O
NONE (252)

R
RELAX (267)
RELAY OPERATOR (266)

S
ACCUSTOM (270)
DEFEND (271)
FREE (EMANCIPATE) (271)
HOLD (270)
HUG (LOVE) (271)
MAKE (272)
NECK (KISS) (271)
SUPPORT (ENDORSE) (275)

bentv
POISON (291)

X
SPANISH (297)
SUSPEND (HOLD UP) (297)

1
BUT (309)
CONFLICT (CLASH) (310)
CONSISTENT (318)
CROSS (309)
DEPEND ON (317)
KNIT (312)

4
NET (SIEVE) (334)

5
FOOTBALL (340)
GERMANY (340)
GRAY (343)
MERGE (MAIN STREAM) (339)
PREGNANT (340)
WRESTLING (339)

CLAW
BEAR (356)
BREAKDOWN (COLLAPSE) (355)
COMBINE (MERGE) (355)
FIT (MATCH) (355)
MACHINE (FACTORY) (355)
ROOMMATE (353)
SPIDER (354)

1-I
SARCASM (305) (dom moves, then both move)

hand changes

openB > bentB
HYPOCRITE (199)

C > S
ABBREVIATE (216)

F > 5
DETACH (BREAK UP) (227)

S > B
SHELTER (280)

S > openB
HILL (280)

S > 5
BAWL OUT (278)

S > CLAW
EXPAND (279)

1 > X
COMPLEX (330)
UGLY (330)

5 > flato

WEDDING (348)
5 > S
ACQUIRE (GET) (349)
ARREST (GRAB) (349)
FASCINATE (349)
CLAW > S
SELF-CONTROL (SUPPRESS FEELINGS) (360)
TRUST (CONFIDENCE) (361)

Type 4A*-i: imperfect reflection with inversion across the vertical midsaggital plane

K
KIND (SORT) (243)
W
WORLD (296)

Appendix L: rotation

Type 5B: rotation starting from what looks like the vertical wall plane

H
CLOSET (LOCKER) (232)
T
TRANSLATE (280)
X
CHANGE (298)
1
RELATIVES (314)
change handshape
T > L
TRANSLATE (282)

Type 5C: rotation starting from what looks like the horizontal plane

openB
BECOME (179)
C
HAMBURGER (212)
S
GRIEVE (273)
X
FRIEND (299)

Appendix M: translation

Type 6: hands move on parallel paths
path is arbitrary

B
BEHAVIOR (166)
openB
ARRANGE (PLAN) (171)
C
DO (ACTION, DEED) (210)
K
PARTY (242)
R
READY (266)

W
WAR (295)

1
STRUGGLE (307)

4
WAR (333)

5
WIND (BREEZES) (336)

G > babyo
GOSSIP (230)

flato > 5
MOVE OUT (263)

path is semantically motivated

A
DIG (SHOVEL) (153)

openA
BAPTISM (159)

openB
BRING (170)

C
COCONUT (210)

S
BASEBALL (270)
CANOE (269)

1
CORN ON THE COB (310)

5
PLAY PIANO (336)

Type 6+: hands move as a unit
path is circular

F
COOPERATE (222)

K
SUPERVISE (242)

Y
UNIFORM (STANDARD) (302)

5
AMERICA (339)

path is semantically motivated

A
GOLF (152)

openB
BABY (176)

path is a morpheme

X
BEST FRIEND (297)

Appendix N

Type 7A: glide reflection across the vertical midsaggital plane

A
- PULL (152)

B
- RELIEF (166)
- SATISFIED (CONTENT) (167)

bentB
- LIMIT (RESERVED, RESTRICT, CAPACITY) (201)
- SANDWICH (PICNIC) (203)

openB
- ADMIT (ACQUIESCE, CONFESS, YIELD) (178)
- BOX (179) (first half of sign)
- BREATHE (178)
- BUTTERFLY (174)
- DARK (173)
- ENJOY (JOY, PLEASURE) (178)
- GRATEFUL (APPRECIATIVE) (176)
- HAPPY (177)
- HEAVEN (182) (dom moves, then both move)

O
- OFFICE (253) (first half of sign)

R
- RESPOND (REACT) (267)
- ROOM (267) (first half of sign)

Y
- HUMOROUS (302)

1
- PASS BY (309)

5
- CATCH (335)
- PARADE (337)
- PARTY (verb) (336)
- SAD (337)
- TRAFFIC (337)
- VOMIT (DETEST) (341)
- WAIT (338)

CLAW
- SHOCK (354)

open8
- DISEASE (365)
- SICK (365)

hand changes

L > bentL
- RUN (252)

flatO > 5
- INFORM (263)

S > 5
- CAUSE (278)
- OBEY (277)

open8 > 8
- INTERESTING (368)

Appendix O: Other types of glide reflections

Type 7E: Glide reflection across a semantically selected plane

plane cuts through side of chest

A
- ARMY (SOLDIER) (153)

plane cuts through center of heart

openB
- DEVOTION (LOVE) (177)

open8
- TEND (365)

Type 7F: Glide reflection across a vertical midsaggital plane over time

openA
PUZZLE (GAME) (160)
bentB
BUILD (205)
PROGRESS (205)
openB
STAIRS (180)
H
BUILD (232)
S > CLAW
CLIMB (LADDER) (279)