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The complexity of handshapes: perceptual and theoretical perspective

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1. Introduction

The aim of this thesis is to understand how the current theoretical phonological models predict the perceptual articulatory complexity. In formal linguistics, the concept of complexity is closely linked to the linguistic notion of markedness: a marked form is a form with a complex structure. Lehmann (1974) proposed that complexity is determined by the number of features needed to describe an expression. In Dependency Phonology (Anderson and Ewen 1987), complexity is based on the number of branches contained in a given structure. On the contrary, in language acquisition, complexity is linked to the concept of effort. In a nutshell, a complex form is more difficult to articulate. Locke (1983) provides data indicating that children from different spoken-language backgrounds produce the same set of consonants earlier than others because they are easier to articulate. Other studies show the correlation between complexity and perception. Perception plays an important role, and it is generally assumed that categorization in phonology follows directly from the nature of perception as proposed by Hume and Johnson (2001).

Since SLs have been recognized as fully-fledged languages (Stokoe, 1974), evidence has accumulated showing that SLs have a coherent internal organization, in many respects similar to that of spoken languages (Sandler and Lillo-Martin, 2006). The structure of signs is articulated into several subcomponents. Whereas spoken languages create words combining phonemes, signed languages create signs by combining four formational parameters: handshape, movement, place and orientation. These articulatory bits of information are meaningless minimal units, just like phonemes in spoken languages.

Several models have been proposed in the literature of sign languages that formally describe the phonology of signs at the lexical level (among others see Brentari, 1998 and Van der Kooij, 2002). Brentari (1998), which is the phonological model I will start with, adopts a mixed perspective: dependency phonology and optimality theory. Specifically, binary branching trees are used to model the feature setting of signs. In this model, the four parameters are not independent, rather they are part of an integrated structure in which phonological features are hierarchically organized. In Brentari (1998), as in Dependency phonology, phonological complexity is based on the number of branches specified in the structure of a given form, and the markedness of a handshape is determined by its degree of complexity (i.e., the number of branches the structure has) (Brentari 1998: 214).

The notion of complexity is also crucial in psycholinguistics, where forms of various phonological complexities are normally used to test cognitive abilities (e.g. short-term memory) and as diagnostics for language pathologies (e.g. special language impairment, SLI).

For instance, Morgan et al. (2006) created a repetition test of non-signs in order to spot SLI in British Sign Language (BSL), manipulating phonological complexity. Non-signs (or pseudo-signs) are phonologically well formed signs which do not corresponds to any real word in the language. Like the sequence "rot", which is phonologically well formed in English, but does not correspond to any meaningful word in the language. However, studies like these do not rely on well defined notions of phonological complexity, with the risk of creating tools which are only partially adequate. Specifically, Morgan et al. (2006) did not use any theoretical model to scale the items according to their phonological complexity. Rather, a more naïve phonological criterion was used to manipulate handshape complexity: handshapes that may occur in the non-dominant hand in asymmetric two-handed signs are considered less marked than those that cannot occur. This partition produced a distinction between the so called "BASCO15" handshapes and the remaining others (around 30 handshapes). This partition is far from satisfactory, since it does not provide any further distinction in complexity among the majority of handshapes that cannot occur in the non-dominant hand environment.

Therefore, the key point of this thesis is to understand if current phonological models, such that of Battison (1978), Brentari (1998) and Ann (2006), predict perceptual articulatory complexity by signers and non-signers. I would like to understand which of these models can be used to calculate phonological complexity of a given handshape in order to have a valid instrument that allows to balance items in psycholinguistic tests.

The thesis is organized as follows: Chapter 2 presents the phonological proprieties of Signed Language (henceforth, SLs). In particularly, I focus on Italian Sign Language (LIS) phonological properties. Chapter 3 presents Prosodic Model developed by Brentari (1998). The Prosodic Model which is a model based on binary structures in which features are specified. Chapter 4 presents the notion of complexity that come from Brentari's model. Afterwards, in chapter 4 I present the other two models that I tested: Battison's (1978) and the Ease of articulation model proposed by Ann (2006). Battison's model is based on the BASCO15 generalization. On the contrary, the Ease of articulation model is based on physiological and anatomical facts. Each model predicts a different phonological complexity of handshapes. Finally, Chapter 5 is the most important part of the thesis. In this section, I test phonological complexity of 31 LIS handshapes. Results show that the best model is our implementation of Brentari (1998) in which handshapes complexity is based on the number of the branches and features specified in the structure. An analysis per group shows that this model predicts only hearing people results. The difference between deaf and hearing results can be explained saying that the perception of articulatory complexity by hearing participants is based on articulation criteria while the perception by deaf participants is not.

2. Sign Language Phonology

2.1. Introduction

In this chapter I illustrate the phonological properties of Sign Languages (SLs). In particular, I focus on Italian Sign Language (LIS). In the first section I illustrate Sign Language's parameters which are phonological categories of minimal units, I also show some examples of minimal pairs in LIS based on simultaneous and sequential contrast. In the other sections I describe the main characteristics of LIS phonology and following Radutzky (1992) I show the phonemic inventory contained into each class of parameter.

2.2. Sign Languages

Signs are not holistic gestures but have internal structure. The structure is articulated into several subcomponents. While spoken languages create words combining phonemes, signed languages create signs combining the formational parameters. Battison (1978) identified four minimal units for SLs:

- Handshape: the shape of the hand(s);
- Location: the place where the sign is articulated;
- Orientation of the palm: the position of the palm of the hand(s);
- Movement: the way that the hands move;

The four formational parameters are categories of signed languages phonemes. One of the most important difference between SLs phonology and spoken languages phonology is that in SLs phonemes are produced simultaneously. This characteristic does not exclude presence of sequential production. Therefore as spoken languages, sign languages have “minimal pairs” which are two signs that differ for only one parameter. SLs minimal pairs can be based on simultaneous or sequential contrast. In (1), I show some examples of minimal pairs in LIS that are based on simultaneous contrast:

(1) *Minimal pairs in LIS* (Geraci 2009)

a. BICYCLE vs. CHANGE (handshape)

b. KNOW/MEET vs. SPEAK (place of articulation)

c. WORK vs. PHARMACY (movement)

d. FOG vs. ERROR (orientation)

As I said before minimal pairs can also be based on a sequential contrast like in spoken languages. An example of a sequential contrast in LIS can be seen in the pair of signs MAYOR and SENATOR given in (2). The two signs differ in one features, the initial location.

(2) Sequential contrast in LIS

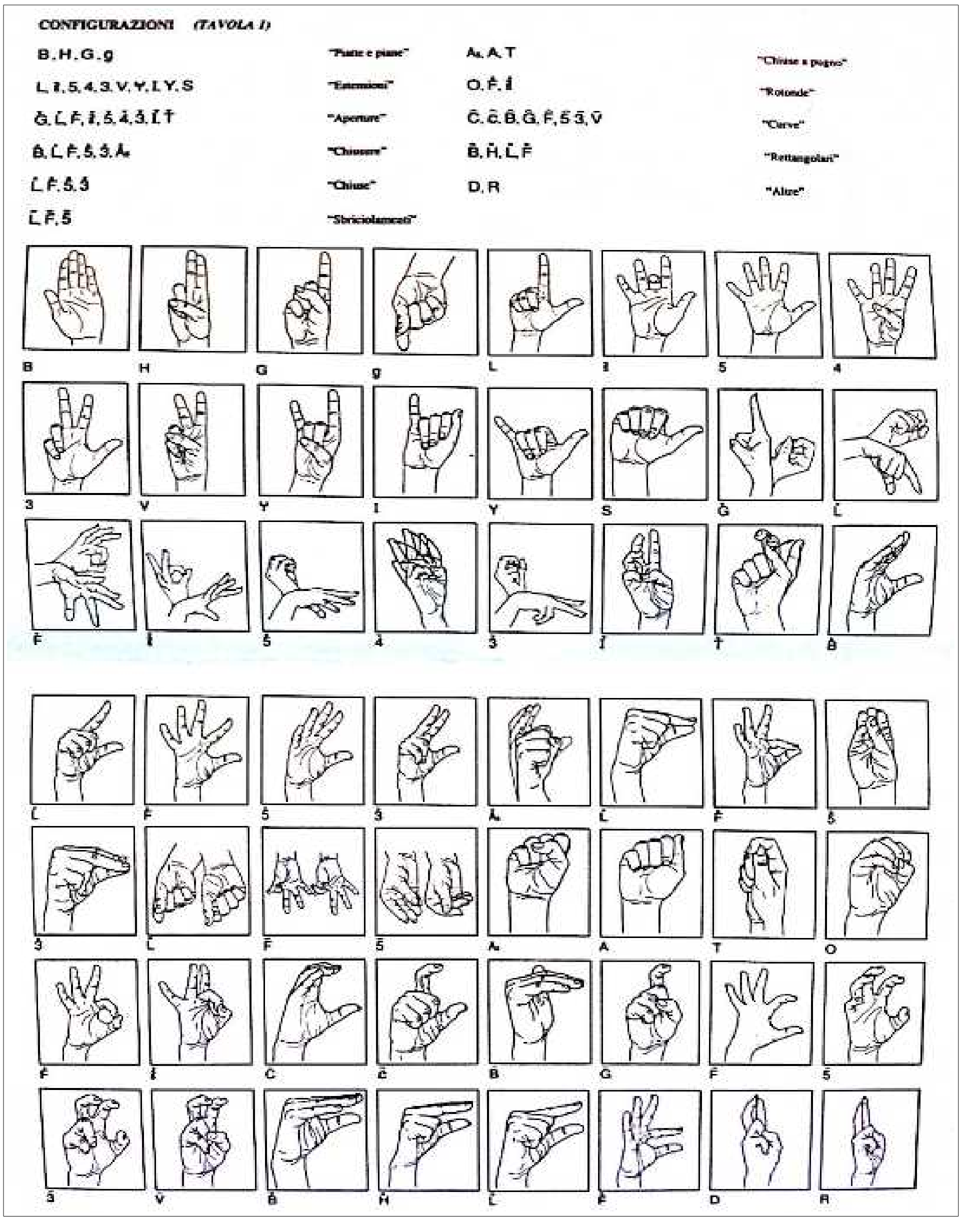
a. MAYOR

b. SENATOR

2.3. Handshapes

The handshape parameter concerns the shape of the hand(s). In SLs, signs can be one-handed (the signer uses only one hand for the articulation of the sign) or two-handed (the signer use two hands for articulation). Two-handed signs can be symmetric or asymmetric. Following Battison's generalization (1978), in symmetrical signs, both hands have the same handshapes and they can articulate all of the handshapes which are part of the phonological inventory. On the contrary, in asymmetrical signs, hands have different handshapes: Whereas the dominant hand can articulate all handshapes of the phonological inventory, the non-dominant hand can articulate only 7 handshapes, namely B, A, S, C, O, 1, 5. In table (3) I show the set of handshapes that Radutzky (1992) proposed for LIS.

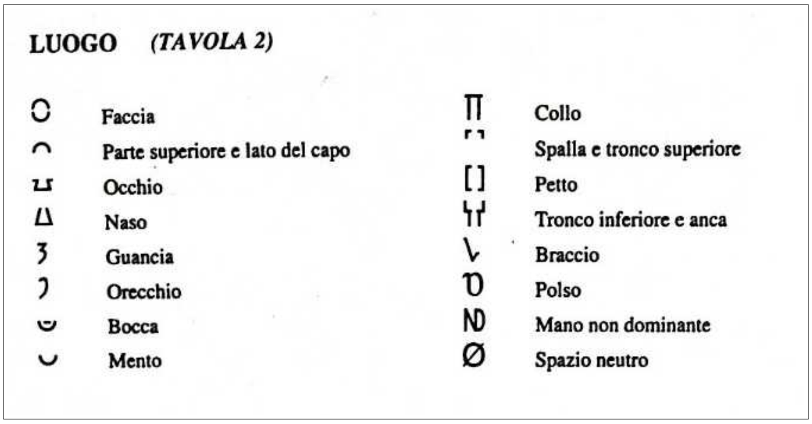
(3) *LIS handshapes. Radutzky (1992:1001-8)*



2.4. Locations

Location identifies the place in which the hand(s) articulate the signs. Radutzky identified for LIS 16 locations. (see table (4)): 15 of them are placed on the signer body and one is on the neutral space. The neutral space is the space in front of the signer used for articulation of the sign. As regards the signs articulated on the body, the hands do not need to touch the body, they can stay very close to it.

(4) *Table of LIS locations. Radutzky (1992:1001-8)*



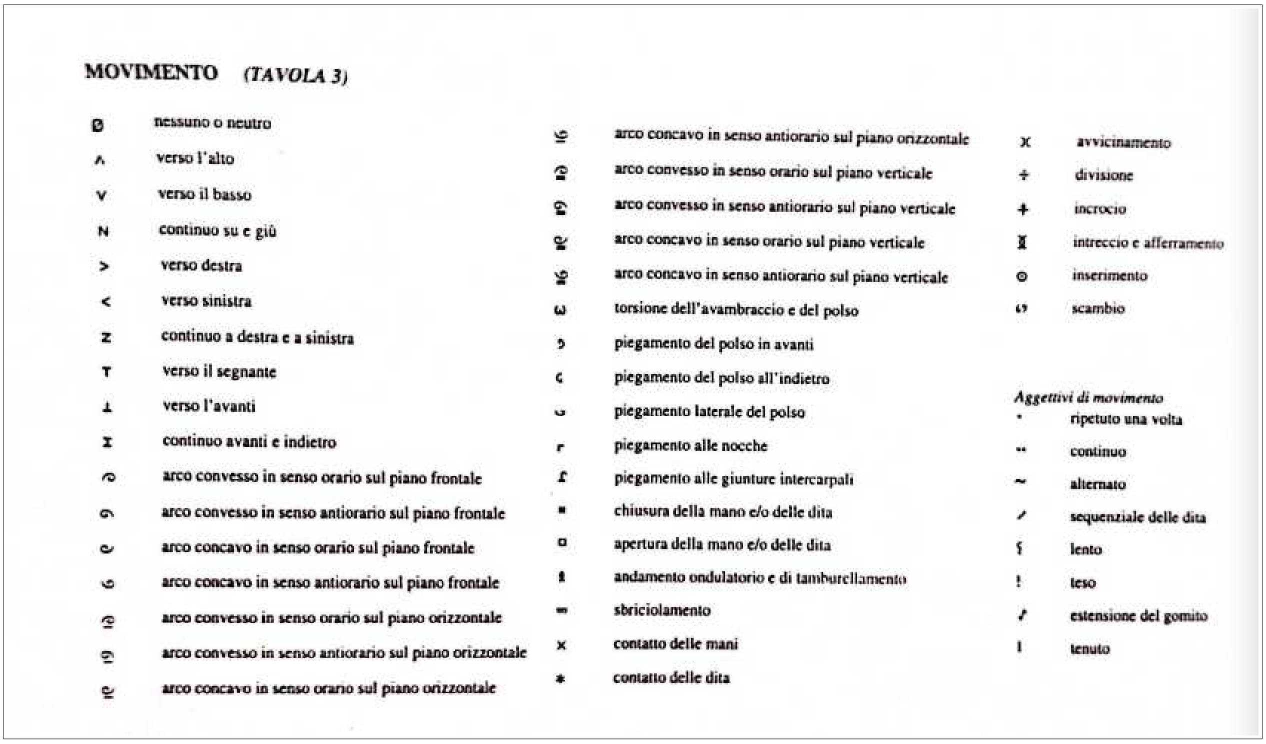
LUOGO *(TAVOLA 2)*

Faccia
Parte superiore e lato del capo
Occhio
Naso
Guancia
Orecchio
Bocca
Mento
Collo
Spalla e tronco superiore
Petto
Tronco inferiore e anca
Braccio
Polso
Mano non dominante
Spazio neutro

2.5. Movement

Movement regards the way in which the hands move during articulation of the sign. A given sign can simultaneously incorporate more types of movement and they can also be performed in various way (for detail, see Table (5)). Friedman (1978) proposed that movement is composed by four features: Direction, Manner, Contact, Interaction. Radutzky (1987) proposed for LIS movements the same features (see Table (5)).

(5) *Table of LIS Movement. Radutzky (1992:1001-8)*



MOVIMENTO *(TAVOLA 3)*

nessuno o neutro
verso l'alto
verso il basso
continuo su e giù
verso destra
verso sinistra
continuo a destra e a sinistra
verso il segnante
verso l'avanti
continuo avanti e indietro
arco convesso in senso orario sul piano frontale
arco convesso in senso antiorario sul piano frontale
arco concavo in senso orario sul piano frontale
arco concavo in senso antiorario sul piano frontale
arco convesso in senso orario sul piano orizzontale
arco convesso in senso antiorario sul piano orizzontale
arco concavo in senso orario sul piano orizzontale
arco concavo in senso antiorario sul piano orizzontale
arco convesso in senso orario sul piano verticale
arco convesso in senso antiorario sul piano verticale
arco concavo in senso orario sul piano verticale
arco concavo in senso antiorario sul piano verticale
torsione dell'avambraccio e del polso
piegamento del polso in avanti
piegamento del polso all'indietro
piegamento laterale del polso
piegamento alle nocche
piegamento alle giunture intercarpali
chiusura della mano e/o delle dita
apertura della mano e/o delle dita
andamento ondulatorio e di tamburellamento
sbriciolamento
contatto delle mani
contatto delle dita
avvicinamento
divisione
incrocio
intreccio e afferramento
inserimento
scambio

Aggettivi di movimento

ripetuto una volta
continuo
alternato
sequenziale delle dita
lento
teso
estensione del gomito
tenuto

2.6. Orientation

As I say above, orientation specifies the position of the palm of the hand. Following Radutzky (1992) orientation can be forward, toward, right side, left side, up or down. In the two-handed signs the orientation of a hand with respect the other should also be considered.

(6) *Table of LIS orientation. Radutzky (1992:1001-8)*

POSIZIONE DELLA MANO O DELLE MANI ***(TAVOLA 4)***

Orientamento del palmo e direzione del metacarpo

∧	verso l'alto
∨	verso il basso
>	verso destra
<	verso sinistra
⊤	verso il segnante
⊥	verso l'avanti

Posizione di una o due mani rispetto al luogo

×	contatto della mano con una parte del corpo
*	contatto delle dita con una parte del corpo

Posizione nello spazio delle mani in segni a due mani

ı	una mano vicina all'altra
·ı·	una mano lontana dall'altra
∦	mano destra sopra quella sinistra
∦	mano sinistra sopra quella destra
ȯ	mano sinistra davanti alla destra
♀	mano destra davanti alla sinistra
×	contatto delle mani
*	contatto delle dita
+	mani incrociate
⧗	mani intrecciate e afferrate
⊙	una mano dentro l'altra
gd	contatto con gomito dominante

2.7. Conclusions

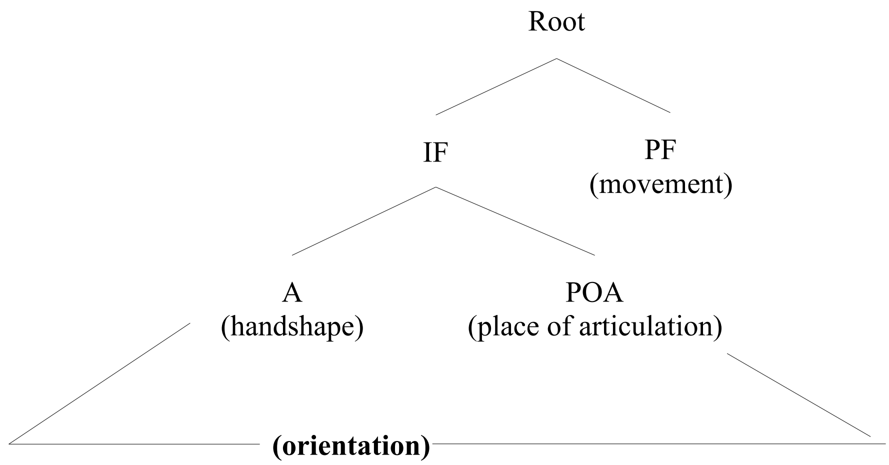
In this chapter I presented the main phonological properties of SLs. In particularly, I introduced that SLs are fully-fledged languages like spoken languages and I explained that, in SLs, the production of segmental materials can be simultaneous and/or sequential. Afterwards, I showed some examples of minimal pairs in LIS based on simultaneous and sequential contrasts. Then, I focused on LIS parameters and, following Radutzky (1992), I explained the main characteristics of LIS parameters and I showed the tables in which the phonemes included in each class of parameter are listed.

3. The Prosodic Model

3.1. Introduction

This chapter introduces a formal model for the phonology of SLs. It is based on the Prosodic Model proposed by Brentari (1998). Originally, the model was designed to describe the phonological structure of ASL. However it can be easily extended to the phonology of other SLs. The model uses a binary structure in which the parameters are not independent, but are part of an integrated structure. Brentari distinguishes two types of phonological features: P*rosodic features* (PF) and *Inherent features* (IF). Inherent features do not change during the production. Prosodic features change or are realized as dynamic properties. One of the advantages of the Prosodic Model is that the four parameters are represented via feature specification in one single representation. The schema in (7) shows the ASL phonological structure as proposed in Brentari (1998) and how the four formational parameters described are captured in the model.

(7) *Parameters in the model* (Brentari 1998:26)



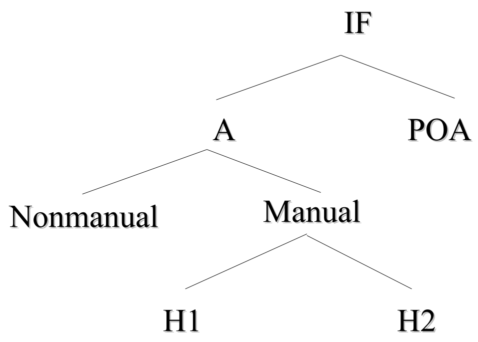
The IF branch encodes handshape, location, and orientation. It is clearly visible that in the model, the orientation is not considered as separate parameter, but rather it is derived from the relationship between handshape and location. In PF, instead movement is encoded which can be realized in one of the following ways: handshape change, orientation change or location change.

3.2. Inherent Features

In this section I present the IF branch of the structure and specify each node and each feature present in it. For each node we also present an example of sign to have a correspondence between the structure and the real sign

The overall structure that Brentari (1998) proposes for the phonological representation is given in (8):

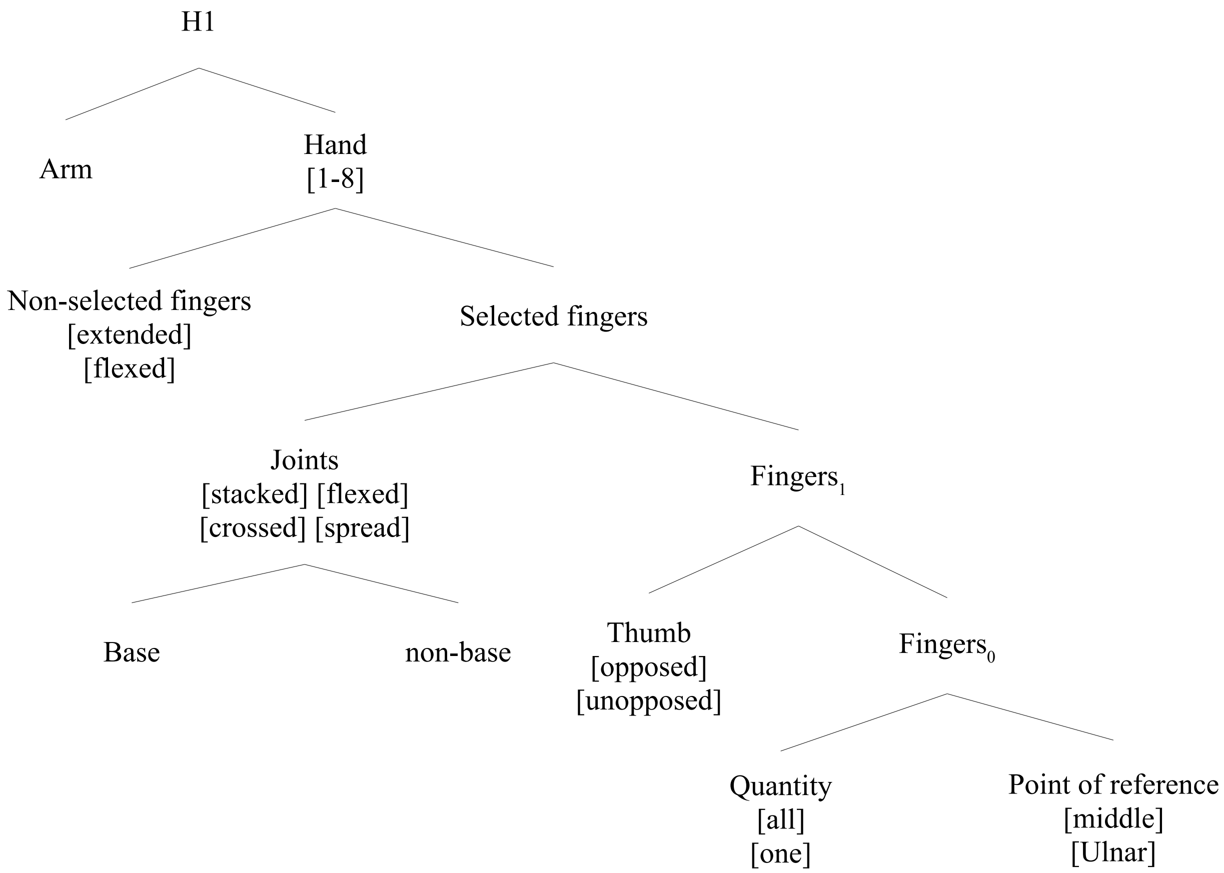
(8) Brentari overall Structure



Following the model, features are organized in a hierarchical structure in a top-down fashion. The more branched is the structure, the greater the number of features required to describe a configuration is. The IF node branches into *Articulator* (A) node and *Place of articulation* (POA) node. The POA branch encodes the features needed to describe the location of signs. The *Articulator* node branches into *non-manual* (mainly encoding facial expressions at the lexical level) and *manual* nodes which dominate inherent handshape features. The latter further splits into *dominant hand* (H1) and *non dominant hand* (H2).

The description of the features which captures the various handshapes branches below the *Manual* nodes. The schema in (9) shows the overall structure of the dominant hand node (H1). The features needed to describe handshapes are listed under each node. I illustrate each of them in turn.

(9) *The H1 branch of the structure*



The H1 branch dominates *arm* and *hand nodes*. The *arm* node is activated when signs use the arm as part of the sign, like in the case of LIGHTHOUSE in (10):

(10) LIGHTHOUSE

The *hand* node includes part of the information required to capture orientation (the remaining part of information to capture orientation is provided by the POA branch of the structure). It further splits into *Selected* and *non-selected fingers. Selected fingers* are those fingers that play a crucial role in the articulation of a sign. For instance, in the sign TRUE the selected fingers are the index and the middle, as in (11):

(11) TRUE

The Non-selected finger part of the schema encodes features that capture the behavior of non-selected fingers. These can be either extended or flexed (mostly depending on the status of the selected fingers, as explained in section 3.3). In the case of TRUE, the non-selected fingers including the thumb are flexed (while the selected index and middle are extended).

Selected finger dominates *Joints* and *Finger$_1$* nodes. For open handshapes, no joints are specified, for the rest of handshape the *Joints* node dominates the features of the handshape contours ([Stacked], [Flexed], [Crossed] and [Spread]) and the joints involved in a given handshape (Base and Non-base). In more detail, [Stacked] is specified when the fingers are one on top of another one, like in the example (8a). [flexed] is specified in closed, bent, curved and flat handshapes like in (8b), [crossed] specifies the position in which the middle finger crosses over the index finger like in (8c) and [spread] specifies open fingers like in example (8d). An example of handshape for each feature is shown in (12):

(12) Signs for [Stacked], [Flexed], [Crossed] and [Spread] feature

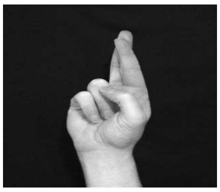
a.

[stacked]

b.

[flexed]

c.



[crossed]

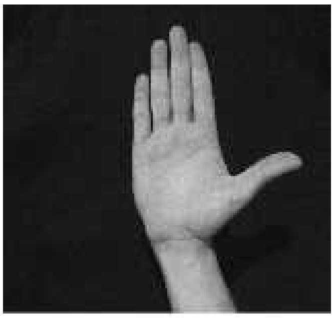
d.

[spread]

Joints node dominates also *Base* and *Non-base* nodes. In (13), the seven types of handshape are provided, each of which is associated with its phonological structure according to Brentari (1998).

(13) Joints specifications in LIS

a. Fully open



No joints specification

b. Curved open

Selected fingers

Joints

Base non-base

c. Curved closed

Selected fingers

Joints
[flexed]

Base non-base

d. Flat open

Selected fingers

Joints

Base

e. Flat closed

Selected fingers

Joints
[flexed]

Base

f. Bent closed

Selected fingers

Joints
[flexed]

non-base

e. Fully closed

Selected fingers

Joints
[flexed]

Finger$_1$ branch encodes and specifies which fingers are selected. *Finger$_1$* splits into *Thumb* and *Finger$_0$* nodes. *Thumb* is an independent branch because in many cases it acts like the other selected with respect to joint specification and handshape. When the thumb is non selected there is no thumb branch under *Finger$_1$* and thumb acts like non-selected fingers, on the contrary if it is specified it dominates the features [opposed] and [unopposed] (in section 3.3 it is explained when the features [opposed] and [unopposed] are specified). In (14) two types of handshape are shown: one with selected thumb and the other one with non-selected thumb.

(14) Selected and non-selected thumb

a.

Selected thumb

b.

Non-selected thumb

Whereas *Finger*$_1$ encodes the thumb specification, *Finger*$_0$ encodes the other four fingers of the hand. It specifies how many and which of these four fingers are selected, in fact it branches into *Quantity* and *Point of reference* nodes.

Quantity specifies the number of selected fingers. It dominates the features [all] which selects all four finger and [one] which selects only one finger. *Point of reference* encodes the finger which is used as reference point. It encodes the features [Ulnar] and [mid]. [ulnar] specifies that the pinkie finger side of the hand is used as the reference point and [mid] specifies that the middle finger is used. The feature [One] may appears with [mid] or with [ulnar]. When [one] appears with [mid] produces the handshape given in (15):

(15)

Fingers$_0$

Quantity
[one]

Point of reference
[middle]

When [one] appears with [ulnar] produces the handshape given in (16):

(16)

Fingers$_0$

Quantity
[one]

Point of reference
[ulnar]

Furthermore, If the two quantity features [all] and [one] are specified and [all] dominates [one], all possible handshapes with three adjacent fingers selected are specified; If [one] dominates [all], all handshapes with two adjacent fingers are selected.

For example, when [one] dominates [all] and the point of reference is [mid] the handshapes produced is the one given in (17):

(17)

Fingers$_0$

Quantity
[one]
[all]

Point of reference
[mid]

When [one] dominates [all] and the point of reference is [ulnar] the handshapes produced is the one given in (18):

(18)

Fingers$_0$

Quantity
[one]
[all]

Point of reference
[ulnar]

3.3. Generalizations and geometry of features

In this section I briefly introduce the main generalizations of Brentari's model concerning handshapes. The first generalization concerns the fact that the realization of non-selected finger is normally predictable from the selected finger joints specification. This generalization is expressed in the constraint shown in (19):

(19) *Maximize finger contrast: Redundancy rule.* (Brentari 1998:104)

If selected fingers are [a flexed], non-selected fingers are [-a flexed].

An Other important generalization concerns the thumb. When the thumb is not selected, there is no thumb branch under Fingers_1 and it has the same specification of the other non-selected fingers as expressed in the non-selected thumb generalization given in (20):

(20) R*edundant thumb behavior when the thumb is not selected.* (Brentari 1998:113)

a) If the non-selected fingers are [extended] and [unopposed], the thumb is open and unopposed;

a) If the non-selected fingers are [flexed], the thumb contacts the other non-selected fingers.

When the thumb is selected it can have different joint specifications with respect to other selected fingers. If the joint features of selected finger is specified (for curved, flat and closed handshapes) the default thumb setting is [opposed], instead for bent and open handshapes the default thumb setting is [unopposed]. In (21) the generalization for thumb as selected finger is shown:

(21) Redundant specification ([opposed]|[unopposed]) for the thumb as a selected finger. (Brentari 1998:114)

a) open, bent: [unopposed]

b) curved, flat, closed: [opposed]

The last generalization expresses the constraint of the thumb to act as independent finger as shown in (22):

(22) Constraint on independent thumb behavior. (Brentari 1998:116)

The thumb may behave independently from other selected fingers only in cases where the fingers1 node is otherwise non-branching.

3.4. Conclusions

In this chapter I illustrated the Prosodic Model proposed by Brentari (1998). In particularly, I showed that the model allows to captures all four parameters which are encoded via features specification. I focused on the phonological structure of handshapes and I showed in detail the tree and the main characteristics of each node and each feature. As I said, the model was proposed to describe phonological properties of ASL but it can be extended to other Sign Languages. In the next chapter, I explain how Brentari's model, as other currents models, allows to capture the phonological complexity of handshapes.

4. From Markedness to complexity

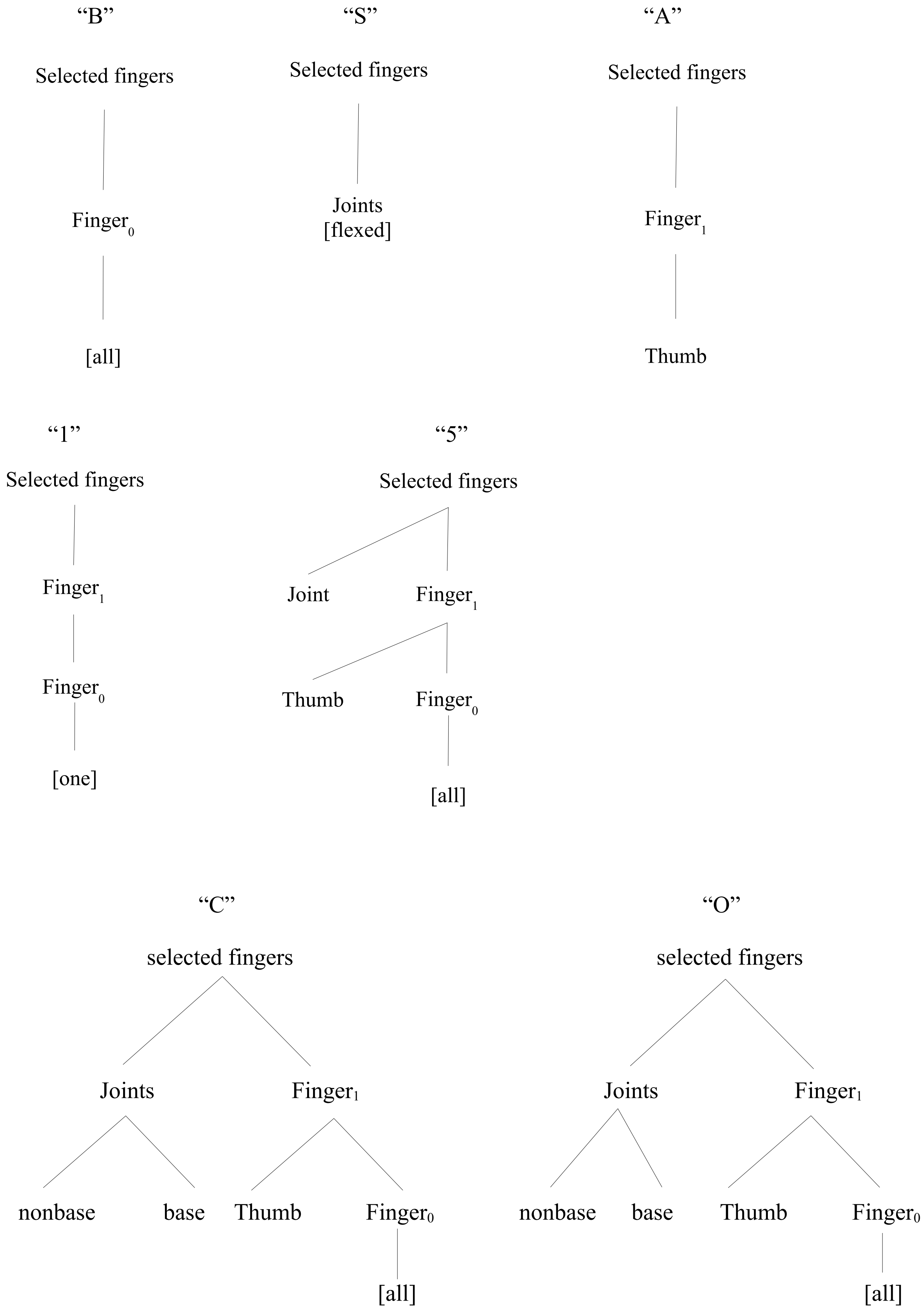
4.1. Introduction

Complexity is closely linked to the linguistic notion of markedness. Marked variants are usually more complex than the unmarked variants and they are acquired later and are substituted for unmarked variants in earlier steps of the language acquisition process (Cheek, Cormier, Repp, & Meier, 2001). Phonological complexity, as described in Dependency Phonology (Anderson and Ewen 1987), is based on the number and type of branching structures that a given form contains.

In Brentari's model, the phonological complexity of a sign is determined both by IFs and PFs because complexity can be in the handshape, POA or movement and “The markedness of a handshape is determined by its degree of complexity (i.e., the number of branches the structure has)” (Brentari 1998: 214). For example, the handshape  is less marked than the handshape , because the first handshape has no joint specification. More generally, structures with the features [All] and [one] are simpler, therefore unmarked structures. These structures are also acquired first, they are more frequent and they are the handshapes that can appears on H2 (Brentari 1998: 216).

Connected to the role of H2 in two-handed signs, a generalization that is often observed in several sign languages including LIS is that in a two-handed sign with the hands having different handshapes, the handshape of H2 ranges over a limited set of possibilities. Specifically, the handshape of a two-handed non symmetrical sign can be one of the following: B, A, S, C, O, 1, 5. In the literature of SLs, the natural class represented by these configuration has been often associated to the fact that they are in a sense easier to articulate than other handshapes, therefore less marked. However, the Prosodic Model representation of these handshapes shows that even though they are considered less marked than others, even within the “BASCO15” handshapes, various degrees of complexity are found. This is illustrated by the examples in (23) where the structure of each handshape is provided. Specifically, we can see that while only one branch is needed to capture the S handshape, seven are necessary to capture handshapes like O and C.

(23) Handshapes that may appear on H2



The notion of complexity is also crucial in psycholinguistics, where forms of various phonological complexities are normally used to tests cognitive abilities (e.g. short-term memory) and as diagnostics for language pathologies (e.g. SLI). In spoken languages, experimental items are always strictly balanced for several phonological factors. In spoken languages items are often balanced in terms of syllabic complexity and metrical complexity. Like in spoken languages, in sign languages it is possible to manipulate phonological complexity. Therefore, identifying reliable criteria to detect phonological complexity in sign languages is of extreme value because the outcome of a fine-grained analysis can be fruitfully used to create balanced items for psycholinguistic experiments of various type. For instance, following the hypothesis of existence of deaf children with SLI, Morgan et al.(2007) have manipulated phonological complexity of signs in order to create a non-sign repetition task equivalent to non-words repetition tasks.

In the following sections I illustrate different criteria based on three phonological model of SLs: Brentari (1998), Battison (1978) and Ann (2006). These criteria allow to calculate phonological complexity of handshape even if they do different predictions. I start from the criterion used by Morgan et al.(2007) based on Battison's (1978) generalization, then I discuss two criteria that come from Brentari's Prosodic Model and finally, I conclude with the criterion based on the Ease of articulation model proposed by Ann (2006).

4.2. The natural class criterion

In this section I discuss the criterion used by Morgan et al.(2007) in order to manipulate phonological complexity of non-signs in their non-sign repetition task. Following Battison's (1978) generalization their handshapes is divided into two categories:

- Unmarked: handshapes that can take the non-dominant hand signs in asymmetric signs namely B, A, S, C, O, 1, 5.
- Marked: other handshapes remaining (around thirty handshapes)

For movement they followed Brentari and designated as ‘‘marked’’movements which have a path movement and a hand-internal movement, and as “unmarked” movements which have just a single movement (path or hand-internal). They have chosen to not include location as variable. Morgan et al.(2007) manipulated phonological complexity as in table (24):

(24) Manipulation of handshapes and movements (Morgan et al.2007)

Movement		Handshape: Simple	Handshape: Complex
	Simple	H1 unmarked 1 movement (hand-internal or path) (degree of complexity = 0)	H1 unmarked 1 movement (hand-internal or path) (degree of complexity = 1)
	Complex	H1 unmarked Two movements (hand-internal and path) (degree of complexity = 1)	H1 unmarked Two movements (hand-internal and path) (degree of complexity = 2)

Complexity of handshapes and movements are manipulated orthogonally. Simple handshapes have an unmarked dominant handshape (H1), while complex handshapes have a marked dominant handshape. Simple movements have a hand-internal movement or a path movement, while complex movements have both hand-internal and path movements.

As we can see from the table (24), Morgan et al. (2007) manipulated phonological complexity but they used a non fined-grained scale of complexity and, in their works, they made the underlying assumption that the overall complexity of a sign/non-sign increases linearly. This assumption may not be empirically correct in that complexity may follow an independent path for each phonological parameter and the complexity of a sign need not to derive from the sum of the complexity of each phoneme.

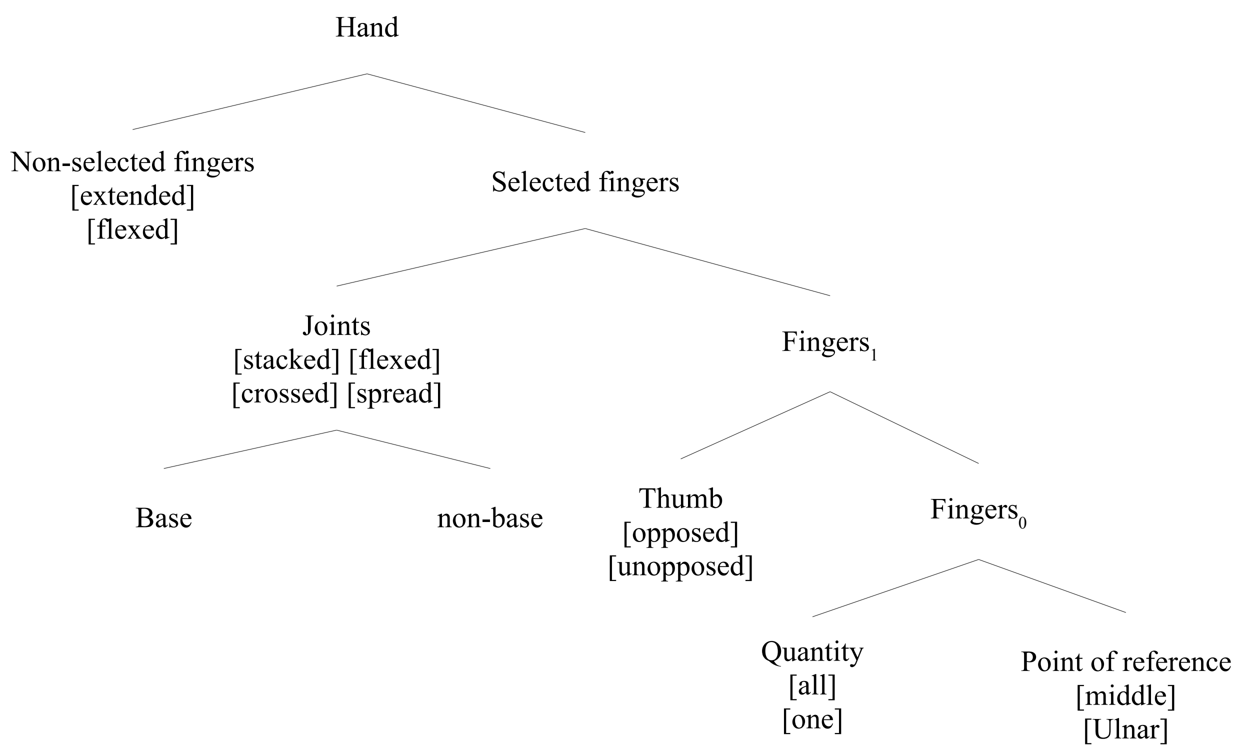
As for handshape complexity, their partition produced a distinction between the so called “BASCO15” handshapes and the remaining others (around thirty handshapes). This partition is far from satisfactory, since it does not provide any further distinction in complexity among the majority of handshapes the thirty handshapes that appear in the dominant hand.

4.3. Geometrical complexity

In this section I discuss how I built a scale of values to measure the handshape phonological complexity using Brentari's model. As, I said above, in Brentari's Prosodic Model (1998) complexity is closely linked to the linguistic notion of markedness. In this model the features are organized in a hierarchical structure from top to bottom; The more branched is the structure, the higher the number of features required to describe a sign is. In Brentari's model, complexity is linked to the number of branches necessary to describe a sign and this number is an index of articulatory complexity. In conclusion, the greater is the number of branches and features in the structure in order to describe the sign, the greater the phonological complexity is. This theoretical model allows to have a finer-grained scale of the complexity with respect to that used in Morgan et al. (2007). In order to calculate the phonological complexity of handshapes, I decided to use two methods named “Geometrical Complexity 1” and “Geometrical Complexity 2”. The first method consists in counting only the tree's branches specified. In this case the complexity increases with the increase of the branches specified in the structure. The second method consists in adding the number of the features specified to the number of the tree's branches. The general structure used to calculate handshape complexity with both methods is given in (25)

(25) General Structure

Handshape: ? = n coefficient of complexity



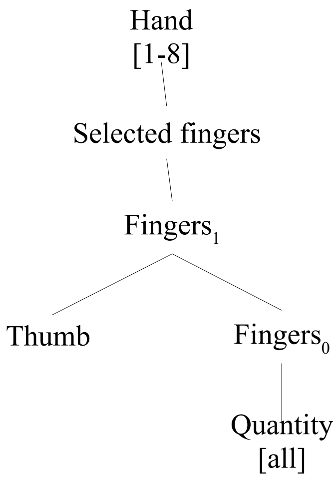
4.4. Geometrical complexity 1

The scheme that shows the coefficient of complexity for handshape B  and handshape F  with this method is shown in (26) and (27):

(26) Structure of handshape B

Geometrical Complexity 1

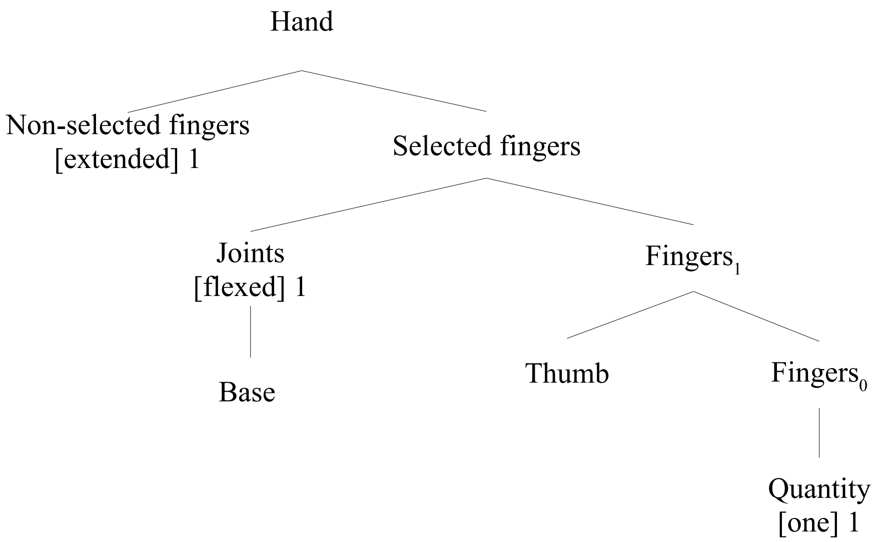
Handshape: B thumb  = 5



(27) Structure of handshape F

Geometrical Complexity 1

Handshape:  = 8



4.5. Geometrical complexity 2

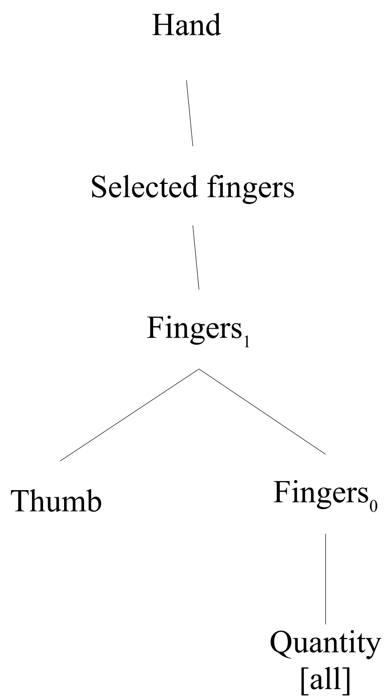
As mentioned before, in order to calculate the complexity of handshapes with this method, I add the number of the features specified to the number of the tree's branches.

In (28)and (29) we provide two examples to illustrate how the mechanism works. The first one is the handshape B  and the second one is the handshape F .

(28) Structure of handshape B

Geometrical Complexity 2

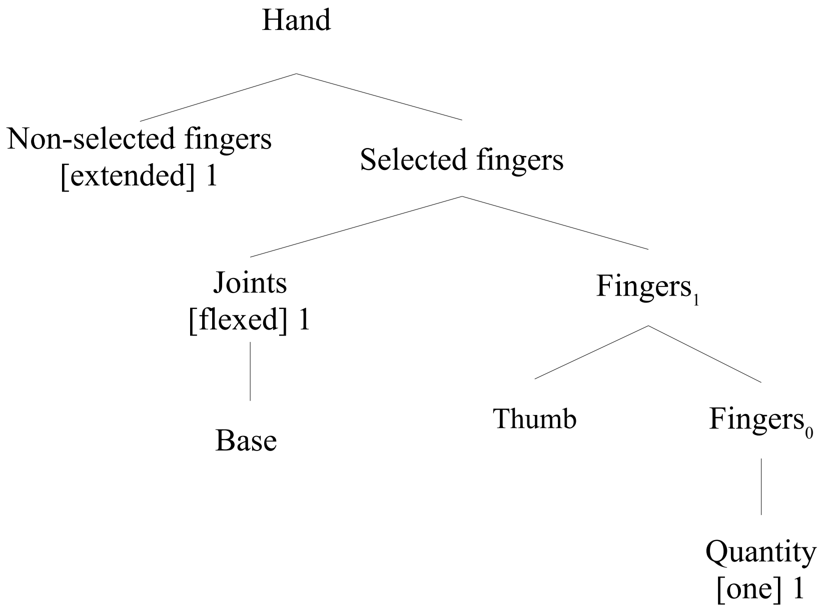
Handshape: B thumb  = 6



(29) *Structure of handshape F*

Geometrical Complexity 2

Handshape:  = 11



4.6. Ease of articulation: The case of LST

In this section I explain the "Ease of articulation" model proposed by Ann (2006) for Taiwan Sign language (LST). The model is based on anatomical and physiological criteria.

Ann (2006) observed that in sign language a handshape can not involve all fingers in more than two groups. Handshapes with one group of fingers are those in which all fingers doing the same thing (see fig. (30)). Handshapes with two groups of fingers are those in which fingers can have two types of the following joints: extended, bent, curved, and closed. For example, the handshape in fig. (31) has two groups of fingers. The first one is formed by index and medium and has an extended joint, the second one is formed by ulnar, pinky and thumb and it has a closed joint. The author clarifies that it seems that in natural sign languages handshapes using more than two groups of joints are not possible. For example, the handshape in fig. (32) should be ungrammatical in sign languages because it has three groups of handshapes: the first one is formed by index and medium and it has extended-crossed joint, the second one is formed by ulnar and thumb and it has closed joint, the last one is formed by pinky and has extended joint.

(30) Handshape with one group of fingers

(31) Handshape with two groups of fingers

(32) Handshape with more than two groups of fingers

Ann (2006) says that the anatomy and physiology of the fingers, hand and wrist, provide good motivations to say that handshapes with the four types of joints are different in terms of articulatory difficulty.

In order to determine the scores of articulatory complexity, Ann (2006) proposes five criteria based on hand physiology. The five criteria are: muscle opposition in configurations of handshapes, support for extension, support for flexion, tendency to oppose the thumb, and tendency to spread. The complexity of handshapes articulation is calculated adding all the scores that came from each criteria. From this analysis, Ann (2006) divides handshapes into three groups: easy (handshapes with lowest score), difficult (handshapes with intermediate ease score), and physically impossible (handshapes with highest ease score).

4.6.1. Muscle opposition in configurations of handshapes criteria (MOC)

Muscle opposition in configuration of handshapes criterion (henceforth, MOC) is based on the assumption that it is more difficult to articulate an handshape when there is opposition between muscle groups. Similar assumptions have been made in the literature of spoken languages, in fact Archangeli and Pulleyblank (1994) use the terms “synergy” and “antagonism” in phonology in order to explain the concept of muscle opposition. In spoken languages, the combination of the features [+high] and [- advanced tongue root] are antagonistic because the instruction [+high] raises the tongue body and pushes it forward, but the instruction [-advanced tongue root] retracts the tongue root. In contrast, the combination of [+advanced tongue root] and [+high] features are synergistic: both move the tongue forward and raise it. The MOC criterion is based on same notions. Therefore more opposition involves more difficulty to produce a given handshape. Handshapes that involve only one group of muscles have no opposition while handshapes that involve two muscle groups have muscle opposition. The necessary and non necessary muscles in handshapes articulation are showed in table (33):

(33) *Table of muscle necessary in hand configuration* (Ann 2006)

Configuration	***Extensors***	***Flexors***	***Intrinsics***
Closed	not necessary	necessary	not necessary
Bent	not necessary	not necessary	necessary
Extended	necessary	not necessary	necessary
Curved	necessary	necessary	not necessary

From this table derives the table that contains the difficulty level for each type of joints. The ranking of difficulty of the handshape's group is given in (34):

(34) *Ranking of Difficulty of Hand of handshape's group* (Ann 2006)

Configuration	***Relative ease***	***Level of opposition***	***Level of difficulty***
Curved	Most difficult	Maximal	3
Extended	Next most difficult	Less	2
Bent	Easier	Even less	1
Closed	Easiest	Least	0

4.6.2. Support for extension (SE)

The support for extension (SE) criterion refers to the abilities of individual fingers, or sub groupings of fingers to act together. The SE criterion determines whether the extended fingers have an independent extensor or a support to extend. There are, in fact, combinations of fingers that cannot extend together because they have no independents extensors. The table of possible fingers combination is given in (35):

(35) *Possible fingers combination based on extended support* (Ann 2006)

Extension possible with support	Extension non possible because fingers do not have support
Index, middle, ring, pinky	Thumb, middle, ring
Thumb, index, middle	Thumb, index, ring
Index, middle, ring	Thumb, middle, pinky
Index, middle, pinky	Thumb, middle
Index, ring, pinky	Thumb, ring
Middle, ring, pinky	Index, ring
Index, middle	Middle, ring
Ring, pinky	Middle, pinky

This criterion applies to handshapes with two groups of fingers. The assigned scores is: 0 if the extended fingers have an independent extensor or a support to extend, 1 if the extended fingers do not have either an independent extensor or support to extend.

4.6.3. Support for flexion (SF)

Support for flexion criterion (SF) applies to the middle, ring, pinky as selected finger when they act together in flexion and extension. As the SE criterion, SF apply only to handshapes that have two groups of fingers and specifically to the flexed handshapes because this criterion allows to find out how the fingers flex. The scores assigned by SF criterion is: 0 if the middle, ring, and pinky fingers act together in flexion or extension, 1 if the middle, ring, and pinky fingers do not act together in flexion or extension.

4.6.4. Tendency to oppose the thumb (TOT)

The tendency to oppose the thumb (TOT) criterion concerns the tendency of the thumb to be opposed to the other fingers. The physiological facts show that the thumb naturally opposes only to flexed index and middle. On the contrary the opposition to ring and pinky is not natural, so more complex. This criteria applies to handshapes that have one-group or two-groups of fingers and only when some fingers are opposed to the thumb. An example of handshapes where TOT criterion applies is showed in (36):

(36)

The score assigned by TOT is: 0 if all the opposed fingers have the tendency to oppose the thumb, 1 if they do not.

4.6.5. Tendency to spread (TS)

The TS criterion concerns the tendency of fingers to spread. Physiologically facts show that fingers are incapable to spread in bent or closed handshapes. On the contrary spreading is naturally in extended or curved handshapes. Therefore, in extended and curved handshapes, spreading is easier than unspreading because for unspread fingers in articulation more muscles are required. The TS criterion applies to both one-group and two-group of fingers and only when all fingers or a subset of finger are unspread. In (37) is given an handshape where TS criterion applies:

(37)

The score assigned by TS criterion is: 0 if the handshape does rely on natural spreading, 1 if the handshape does not rely on natural spreading. In other words, in an unspread handshape that corresponds to a spread handshape, the score is increased by 1.

4.6.6. The ease of articulation scores

In this paragraph I explain how to calculate the ease of articulation score of handshapes with Ann's model. For all spread and unopposed handshapes, it is necessary to multiply the sum of the SE and SF criteria by the value that come from the MOC criteria. Following Ann (2006), I use the following algorithm proposed by Ann (2006):

(SE+ SF) x MOC of least flexed fingers in a rest-closed handshape and most flexed fingers in a rest-open handshape

Some examples of handshapes that can be calculated with the preceding algorithm are shown in (38):

(38)

a)

b)

c)

In order to calculate the ease scores of these type of opposed and unspread handshapes I have to use the score that comes from TOT and TS criteria. The following algorithm applies to handshapes with opposed fingers:

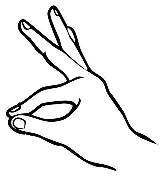
(SE+ SF) X MOC of least flexed fingers in a rest-closed handshape and most flexed fingers in a rest-open handshape+ TOT

Some examples of handshape that can be calculated with this algorithm are given in (39) :

(39) *Examples of opposed handshape* (Ann 2006)

a)

b)



The final score of the handshape showed in 39b is given in (40):

(40) *Final score for handshapes*  (Ann 2006)

FINAL EASE SCORE RESULTING FROM TOT CRITERION				
Configuration: one finger opposed; rest of the fingers extended				
	Bent score	TOT criterion	Temporary ease score	Final ease score
Index opposed Thumb	0	+(0)	0	0

On the contrary, the following algorithm applies to unspread handshape:

(SE+ SF) X MOC of least flexed fingers in a rest-closed handshape and most flexed fingers in a rest-open handshape + TS

An handshape that can be calculated with this algorithm is showed in (41):

(41) Unspread handshape

The final score for this handshape is given in (42):

(42) Final score for handshape  (Ann, 2006)

FINAL EASE SCORE RESULTING FROM TOT CRITERION				
Configuration: some number of finger unspead; rest of the fingers closed				
Fingers unspread	Extended spread	Curved Spread	Final ease score	
			Extended/unspread	Curved/unspeard
Thumb, index, medium, ring, pinky	0	-(1)	1	1

4.7. Conclusion

In this chapter I explained the notion of phonological complexity for spoken and sign languages. I illustrated the four criteria that we used to calculate the handshape's phonological complexity. As mentioned previously, the first one follows Battison's generalization (1978), the other two follow Brentari's Prosodic Model (1998) and the last one follows the Ease of articulation model by Ann (2006). All these models make different predictions about phonological complexity of LIS handshapes. In next chapter I explain how I tested these models in order to see if they predict perceptual phonological complexity. I aim to understand which of these models can be used as instruments that allows to balance items in psycholinguistic experiments.

5. Testing Phonological Complexity

The notion of complexity is crucial in psycholinguistics, where forms of various phonological complexities are normally used to tests cognitive abilities (e.g. short-term memory) and as diagnostics for language pathologies (e.g. special language impairment, SLI). As for sign languages, there are several theoretical models that predict phonological complexity of signs. In chapter five I illustrate the four criteria that I used in order to calculate phonological complexity of LIS handshapes. These criteria based on Prosodic Model, Ease of articulation model and Battison's generalization, make different predictions about handshape complexity. In this chapter I present methodology and materials used to test how perceptual articulatory complexity of 31 handshapes is predicted by currents phonological models. I also describe and discuss the results of the test mentioned above.

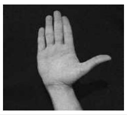
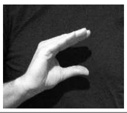
5.1. Handshape Complexity

As I said before, phonological complexity is closely link to concepts such that of markedness, effort or perception. Therefore, it is possible to say that if perception is linked to phonological complexity then phonological models of SLs should predict phonological perceptual complexity. I focus only on LIS handshape parameter and I decide to create an experimental test in order to investigate this point.

5.1.1. Materials and method

In this section I describe the methodology and materials used to test the perceptual complexity of LIS handshapes. I selected 31 handshapes as stimuli. Seven come from the results of a previous experiment on pseudo-signs (see table (43)). Three stimuli are ungrammatical handshapes in LIS (see table (44)). The remaining 22 handshapes are included in order to have an experiment with an adequate number of stimuli. These are listed in table (45):

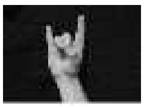
(43) Table of the seven handshapes

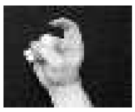
Handshape's name	
S	
B	
B flat	
B flat thumb	
3	
F	
T	

(44) *Impossible handshape*

Handshape's name	
R-Thumb-Ring	
Medium-Ring-Open	
Medium	

(45) Remaining Handshapes

Handshape's name	
A	
C	
O	
Medium-Thumb Closed	
5	
2	
L	
5 Medium	
Index-Pinky Extended	
2 Curved	
H-Flat-thumb	

Handshape's name	
L Curved	
4	
5 Curved	
G	
W	
1	
I	
3 Curved	
H	
1 Curved	
Y	

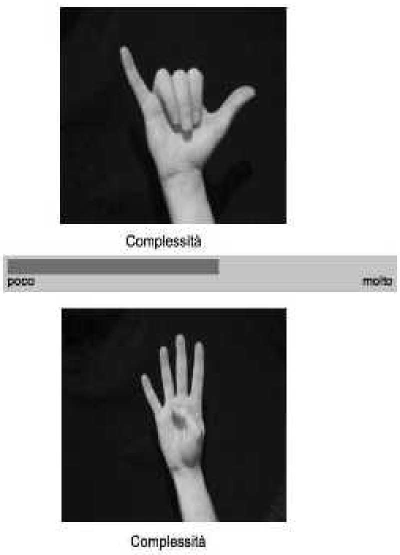
For each stimulus I have also calculated the complexity value that come from all four criteria. The table in (46), summarizes the phonological complexity values of the 31 handshapes that come from all four criteria:

(46) Summary of phonological complexity values

Handshapes	Battison Generalization	Geometyrical Complexity 1	Geometrical Complexity 2	Ease of articulation
S	Unmarked	2	3	0 Easy
A	Unmarked	3	3	0 Easy
B	Unmarked	5	6	0 Easy
1	Unmarked	5	7	0 Easy
4	Marked	5	7	0 Easy
L	Marked	6	8	0 Easy
5	Unmarked	6	8	0 Easy
B flat	Marked	7	8	0 Easy
B flat thumb	Marked	7	9	0 Easy
5 curved	Marked	7	9	0 Easy
L-curved	Marked	8	10	0 Easy
F	Marked	8	11	0 Easy
Medium	Marked	6	9	4 Impossible
C	Unmarked	8	9	1 Difficult
O	Unmarked	8	10	1 Difficult
H flat thumb	Marked	8	11	1 Difficult
5 Medium	Marked	9	12	1 Difficult
G	Marked	10	15	1 Difficult
I	Marked	6	9	2 Difficult
2	Marked	6	10	2 Difficult
Extended Index Pinky	Marked	6	10	2 Difficult
Y	Marked	7	10	2 Difficult
3	Marked	7	11	2 Difficult
Medium Thumb Closed	Marked	10	14	2 Difficult
W	Marked	10	14	2 Difficult
H	Marked	5	8	3 Difficult
2 Curved	Marked	7	11	3 Difficult
3 Curved	Marked	8	12	3 Difficult
T	Marked	8	11	4 Impossible
R Pinky Thumb	NA	NA	NA	4 Impossible
Extended medium ring	Marked	10	15	4 Impossible
1 Curved	Unmarked	7	9	0 Easy

Each stimulus consists of an image containing two handshapes, positioned one above the other (see fig.(47)). The picture above serves as the baseline against which should be evaluate the one below of. I chose the “Y” handshapes as baseline handshape because with the two “Geometrical Complexity criteria” it has a complexity score a little bit higher than the central value of complexity. The presentation scheme is fixed: the Y handshape is always on the top, while the second handshape is one of the 31 remaining handshapes part of the stimuli set. At the bottom of each picture there is a complexity bar. The value on the reference bar is fixed for the Y handshape and serves as baseline to judge the complexity of the handshape at the bottom of the image. I asked the subjects to provide a complexity judgement for the picture on the bottom by clicking on the lower complexity bar.

(47) Example of stimulus



The handshape pictures have a dark blue background. I took the handshape photos with a digital camera and the bar photo with a picture of the Cogexpe web site. Then, I cut, assembled and saved the pictures using Libre Office Draw software.

The experiment was created in HTML format by using the Cogexpe software available from the LSCP laboratory website. A sample of the HTML code is given in (48):

(48) Sample of the code

```
[[[Training ::1]]]
[[]]
[Y_1]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_1Curved.jpg">
[[ ]]
```

The code allows to specify blocks (triple brackets), groups (double brackets) and items (single brackets). Inside the brackets the name and the relative order of presentation of the blocks are specified. If no specification is provided, the blocks, the groups or the items are presented in a pseudo-random order. In the code in (48), the "Training" block trial will be the first to be presented. Double brackets specify the groups of items and code for the page layout. In our case, only one item per group is selected. This results in a presentation set where only one stimulus at a time appears on the screen. Since no instruction about order of presentation is provided, items will appear in a pseudo-random order. The name of the item is written within single brackets. The format of our stimuli is indicated in the tag between angle brackets: jpeg images in our case.

For the experiment, I created two blocks, a training block and an experimental block. In the training block there are three trial stimuli corresponding to the following handshapes: 5, 1-Curved and R-Pinky-thumb. The remaining 27 stimuli were included in the experimental block. At the end of the experiment a brief questionnaire was presented.

I tested two groups of participants: hearing and deaf people. Deaf participants were contacted through a video posted on Facebook and Vlog website[1].The video contained experiment instruction in LIS, it was recorded by a high quality camera and realized using IMovie software. Hearing participants were contacted with a message only through Facebook. Experiment instruction for hearing people was written at the beginning of the experiment. As for the questionnaire, four questions are the same for both groups of participants and they are related to sex, age, city and school grade while deaf participant have two more questions that were related to the age of sign language acquisition and the presence of deaf relatives. While two of the six questions contain open questions, the remaining four are single choice questions and participants answer by clicking. The four questions for both groups are listed in (49):

(49) Questions for both groups

- Sex
  - Male
  - Female
- How old are you?
- In what city do you live?

1 Vlog is a website wherenews about deaf italian community are posted. For more information http://www.vlog-sordi.com

- What's your school grade?
    - Elementary school
    - Middle school
    - High school
    - University

The two questions only for deaf participants are listed in (50):

(50) Deaf participants questions

- At what age did you start signing?
    - Before six years old
    - Between 7 and 12 years old
    - Between 13 and 18 years old
    - After 19 years old
- Do you have deaf relatives?
    - Parents
    - Brothers or sisters
    - Other relatives
    - Nobody

In order to do the experiments, participants used an internet link that was posted with the video and the message. For deaf participant the link was: http://cogexpe.scicog.fr/Judgments/Experience/Intro.php?exp=269, for hearing participant was: http://cogexpe.scicog.fr/Judgments/Experience/Intro.php?exp=276.

5.1.2. Results

The data come from 44 deaf and 56 hearing participants and were analyzed using the statistic software R. The cleaned dataset consisted of 2589 datapoints. Data have been removed because the answer was not registered correctly, resulting in NAs (not available) cells in the spreadsheet.

Information concerning the predicted handshape complexity for all the theoretical models was added to each datapoint as well as information about the feature make up of the handshapes. Specifically, I added information about [± curved] feature and number of selected fingers.

A part of the data set is shown in table (51)

(51)

subject	date_time	ip	Qplace_29_	Qreponse_2	Qplace_30_	Qreponse_3	Qplace_32_
8507	2013-03-20_	151.60.72.1(	1	Uomo	2	57	3
8507	2013-03-20_	151.60.72.1(	1	Uomo	2	57	3
8507	2013-03-20_	151.60.72.1(	1	Uomo	2	57	3
8507	2013-03-20_	151.60.72.1(	1	Uomo	2	57	3
8507	2013-03-20_	151.60.72.1(	1	Uomo	2	57	3
8507	2013-03-20_	151.60.72.1(	1	Uomo	2	57	3
8507	2013-03-20_	151.60.72.1(	1	Uomo	2	57	3

For both hearing and deaf participants, the mean and the standard deviation of each handshape was calculated. Overall the standard deviation is similar across handshapes, although a little bit higher for deaf participants (see table (52))

(52)

Handshape	*Deaf_mean*	*Deaf_standard_deviation*	*Hearing_mean*	*Hearing_standard_deviation*
Bthumb	0.32314	0.3812015	0.1112963	0.1820654
L	0.33211	0.3552921	0.2125818	0.1829494
4	0.35434	0.3332269	0.2499623	0.202989
H	0.3420976	0.3277502	0.3098929	0.2072242
5Medium	0.5723	0.326971	0.6826538	0.21235
MediumThumbClosed	0.55801	0.3289507	0.6493818	0.2187984
2Curved	0.4134632	0.3018568	0.5392453	0.2231651
Lcurved	0.3810872	0.3450019	0.3996727	0.2263739
A	0.3289789	0.3541085	0.2069818	0.2296186
C	0.3744878	0.3437362	0.3662182	0.2315691
1	0.3041714	0.3692218	0.2566182	0.2320989
F	0.3803902	0.3144221	0.4408519	0.2339687
S	0.334359	0.3572901	0.2274909	0.2343847
Bflat	0.3912718	0.3079276	0.3641786	0.2368721
3Curved	0.4082927	0.314012	0.5408214	0.2413428
2	0.3472105	0.3481915	0.4391111	0.2464803
G	0.41301	0.3149228	0.4927857	0.2471786
3	0.3640541	0.3005811	0.4435	0.2478349
W	0.49986	0.3396721	0.5009286	0.2525437
HflatThumb	0.4289854	0.2930197	0.5712143	0.2556827
BflatThumb	0.33266	0.282499	0.4811636	0.2567534
O	0.3792	0.336315	0.4915	0.2652569
T	0.38661	0.3332293	0.4928889	0.2734158
I	0.3327795	0.3385044	0.4086909	0.2752188
IndexPinkyOpen	0.44895	0.311036	0.4596786	0.2798207
5Curved	0.3514154	0.3107897	0.3826786	0.280045
Medium	0.419581	0.3666733	0.4535636	0.2831714

In order to establish the predictive power of the theoretical models a series of Spearman correlation tests was conducted. For each model, I compared subjects' answers with the predicted complexity. Notice that at this stage no distinction is made between the hearing and deaf groups. The results are illustrated in table (53):

(53) *Table of correlations*

Criterium	***Correlation***
Ease of articulation	-0.170
Natural Class	0.149
Geometrical Complexity 1	0.283
Geometrical Complexity 2	0.306

The Ease of Articulation model is the worst predictor of complexity. It has a barely different from zero inverse correlation (R = -0.170). The Natural class model has an almost null correlation (R = 0.149). Geometrical Complexity 1 has a better correlation (R = 0.283). Geometrical Complexity 2 is the best predictor of subjects' behavior showing a consistent positive correlation (R = 0.306).

At this point a separate analysis for each group (hearing and deaf) was conducted. The results show that overall the theoretical models are better predictors of the hearing group. Indeed none of the models show strong correlation between the complexity values estimated by deaf subjects and those estimated by the models, as shown in table (54).

(54) *Deaf Group correlation*

Criterium	***Correlation***
Ease of articulation	-0.092
Natural Class	0.033
Geometrical Complexity 1	0.163
Geometrical Complexity 2	0.184

On the other hand, a much stronger correlation is found when hearing subjects are considered. Geometrical Complexity 2 is still the best predictor showing a relatively high level of correlation (R = 0.449).

(55) *Hearing group correlation*

Criterium	***Correlation***
Ease of articulation	-0.252
Natural Class	0.195
Geometrical Complexity 1	0.397
Geometrical Complexity	0.449

The following step of the analysis was to check the effects of features in both two groups. I first focused on the [± curved] feature. Table (56) summarizes the feature specification.

(56) *Curved Feature*

Handshape	+ ***Curved/ -Curved***
1	-Curved
2	-Curved
2Curved	+Curved
3	-Curved
3Curved	+Curved
4	-Curved
5Curved	+Curved
5Medium	-Curved
A	-Curved
Bflat	-Curved
BflatThumb	-Curved
Bthumb	-Curved
C	+Curved
F	-Curved
G	-Curved
H	-Curved
HflatThumb	-Curved
I	-Curved
IndexPinkyOpen	-Curved
L	-Curved
Lcurved	+Curved
Medium	-Curved
MediumThumbClosed	-Curved
O	-Curved
S	-Curved
T	-Curved
W	-Curved

A regression analysis is conducted with a mixed effects models (Baayen, Davidson & Bates, 2008). The Results show that, in the hearing group there is a clear effect of [+curved] over complexity. Handshapes with the feature specification [+curved] are perceived as more complex. For deaf group the results show not effect of the [+curved] feature. Deaf signers perceive handshapes with [+curved] feature as complex as those without it.

In addition, I decided to analyze for both groups, the minimal pairs of handshapes differing only for the [± curved] feature. In this case, I used a T-test. For the hearing group, results show that the handshapes with [+curved] are perceived as more complex than their minimal counterpart (see table (57)). As for the deaf group, the Wilcoxon test did not show any significance for any of the minimal pairs considered (see table (58)).

(57) Pair of [± curved] in hearing group

Handshape	***df value***	***T value***	***P value***
2 [± curved]	101.467	-2691	0.008
3[± curved]	106.998	-28263	0.005
L [± curved]	89.759	-28263	0.001

(58) Pair of [± curved] in deaf group

Handshape	***W value***	***P value***
2 [± curved]	599	0.204
Y_3[± curved]	660	0.431
L [± curved]	702	0.449

The last step was to analyze the effect of the features connected to the number of selected fingers ([one], [all], [one/all], [all/one]) in both groups. I specified [one] or [all] for handshapes with this feature specification, [none] for handshapes with no feature specification and [many] for handshapes with [one/all] or [all/one] specification (see table (59)).

(59) Number of selected finger features

Handshape	***Finger node feature***
1	[one]
2	[many]
2Curved	[many]
3	[many]
3Curved	[many]
4	[all]
5Curved	[all]
5Medium	[one]
A	[none]
Bflat	[all]
BflatThumb	[all]
Bthumb	[all]
C	[all]
F	[one]
G	[many]
H	[many]
HflatThumb	[many]
I	[one]
IndexPinkyOpen	[many]
L	[one]
Lcurved	[one]
Medium	[one]
MediumThumbClosed	[one]
O	[all]
S	[none]
T	[one]
W	[many]

A regression analysis is conducted with a mixed effects models. The results show that there is a significant effect of number of selected fingers in the hearing group. Interestingly, the pattern goes partially with Brentari's model. Brentari's model predicts the following scale of increasing complexity: [none] < [all] = [one] < [many]. In the hearing group the results are only partially consistent with that scale. In fact, the hearing group scale is: [none] < [all] < [one] < [many]. The main difference between the two scales is that there is a significant difference between handshapes with feature specification [all] and feature specification [one] (see table (60)).

For the deaf group the levels of the variable have been collapsed into [many] and [one/none]. The results show that number of fingers that requires two features to be specified are perceived as more complex than number of fingers specified by one or zero features as in table (60).

(60)

Brentari	**[none] < [all] = [one] < [many]**
Hearing results	[none] < [all] < [one] < [many]
Deaf results	[none] = [all] = [one] < [many]

5.1.3. Discussion

In this section I discuss the results that I illustrated above. As I said, the aim of this investigation is to understand how perceptual articulatory complexity of handshapes is predicted by theoretical models of sign language phonology. After creating a scale of complexity for 31 handshapes using the available theoretical models such that of Brentari, Battison and Ann, my goal was to investigate how articulatory complexity of handshapes is perceived by signers and non-signers. Therefore I tested signers and non signers in order to understand which of the three models is the best predictor. The results show that the best model is that of Brentari (1998). In particularly, the best model is Geometrical Complexity 2 in which handshapes complexity is based on the number of branches and features specified in the structure.

One interesting thing is that Geometrical Complexity 2 predicts only results by hearing people. This seems weird because each model was proposed in order to explain sign languages' phonology. Therefore, they should predict handshape complexity of deaf participants.

Afterwards, an accurate analysis shows a possible explanations of the difference between deaf and hearing results. In particular, while hearing participants are more sensible to [± curved], deaf participants are not. The difference means that perception of articulatory complexity of hearing participants is based on articulation criteria. On the contrary, the fact that deaf participants are not sensible to [± curved] could be explained by saying that the [± curved] feature do not produce different phonemes. In fact, there are not minimal pairs based on [± curved] feature. Deaf participants probably use a phonological criterion to evaluate articulatory complexity.

As for the number of fingers feature, results show two important aspects:

1. In Brentari's model, complexity of the number of fingers is not based on linear counting of selected fingers. If it was based on a quantitative criterion the complexity scale should be:

[none]<[one]< [many]<[all]. On the contrary the scale is [none] < [all] = [one] < [many];

2. Hearings and deaf number of fingers complexity scales are both compatible with Brentari's model but they are different. The hearing scale is more fined-grained and more compatible with articulatory aspects. This reflects the fact that hearing participants are not sensible to quantitative criterion but to articulatory complexity which is linked to difficulty in articulation.

6. Conclusions

Although, the better model is the Prosodic Model proposed by Brentari in which handshape complexity is calculate adding branches and features of the structure, this thesis show that deaf and hearing people react differently to the same stimuli. In fact, while Brentari's Prosodic model predicts results by hearing people, no SLs phonological models predict perceptual complexity of LIS signers. In table (61) I show the scale predicted by the model and the scale that come from deaf results.

(61)

	Handshapes scale	*Deaf_mean*
1	1	0.3041714
2	B	0.32314
3	A	0.3289789
4	L	0.33211
5	BflatThumb	0.33266
6	I	0.3327795
7	S	0.334359
8	H	0.3420976
9	2	0.3472105
10	5Curved	0.3514154
11	4	0.35434
12	3	0.3640541
13	C	0.3744878
14	O	0.3792
15	F	0.3803902
16	Lcurved	0.3810872
17	T	0.38661
18	Bflat	0.3912718
19	3Curved	0.4082927
20	G	0.41301
21	2Curved	0.4134632
22	Medium	0.419581
23	HflatThumb	0.4289854
24	IndexPinkyOpen	0.44895
25	W	0.49986
26	MediumThumbClosed	0.55801
27	5Medium	0.5723

	Handshapes scale	*Geometrical Complexity 2*
1	S	3
2	A	3
3	B	6
4	1	7
5	4	7
6	L	8
7	B flat	8
8	H	8
9	B flat thumb	9
10	5 curved	9
11	Extended Medium	9
12	C	9
13	I	9
14	L-curved	10
15	O	10
16	2	10
17	Extended Index Pinky	10
18	F	11
19	H flat thumb	11
20	3	11
21	2 Curved	11
22	T	11
23	5 Medium	12
24	3 Curved	12
25	Medium Thumb Closed	14
26	W	14
27	G	15

For example while in the deaf results scale the handshape  is in eleventh place, in the scale based on Geometrical Complexity 2 it is in fourth place. As for handshape  it happens the same thing. In deaf scale it is in the twentieth place while in Geometrical Complexity 2 scale it is in the last place. The only handshape which has the same place in both scales is the handshape .

These results suggest that it is better to use deaf perception scale in a psycholinguistic test, especially if it is necessary to balance LIS handshapes. Nevertheless, the results of this thesis are only the first step in this field of study. It is necessary to extend this type of investigation also to the other three remaining parameters (movement, location and orientation). Only in this way it will be possible to calculate the overall complexity of signs or pseudo-signs and to ascertain whether the overall complexity of a sign/non-sign is derived from the sum of the complexities of each parameter or if it increases or decreases in a non-linear manner because of the possible influence of other factors.

Appendix

A. Handshapes structures

Handshape: ? = n coefficient of complexity
Notes:

- Hand
  - Non-selected fingers [extended] [flexed]
  - Selected fingers
    - Joints [stacked] [flexed] [crossed] [spread]
      - Base
      - non-base
    - Fingers_1
      - Thumb [opposed] [unopposed]
      - Fingers_0
        - Quantity [all] [one]
        - Point of reference [middle] [Ulnar]

Handshape: B thumb  = 5 & 6
Notes: Thumb position is free due to phonetic alternation

- Hand [1-8]
  - Selected fingers
    - Fingers_1
      - Thumb
      - Fingers_0
        - Quantity [all]

Handshape: A  = 3 & 3

Notes: ASL A which corresponds to S in LIS

Hand

[1-8]

Selected fingers

Fingers_1

Thumb

Handshape: S  = 2 & 3

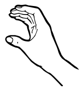
Notes: ASL S which corresponds to A in LIS

Hand

Selected fingers

Joints

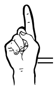
[flexed] 1

Handshape: C  = 8 & 9

- Hand
  - Selected fingers
    - Joints
      - Base 1
      - Non-base 1
    - Fingers$_1$
      - Thumb 1
      - Fingers$_0$
        - Quantity [all] 1

Handshape: O  = 8 & 10

- Hand [1-8]
  - Selected fingers
    - Joints [flexed] 1
      - Base 1
      - Non-base 1
    - Fingers$_1$
      - Thumb 1
      - Fingers$_0$
        - Quantity [all] 1

Handshape: 1  = 5 & 7

Hand
[1-8]

Non-selected fingers
[flexed] 1

Selected fingers

Fingers_1

Fingers_0

Quantity
[one] 1

Handshape: 5  = 6 & 8

Hand
[1-8]

Selected fingers

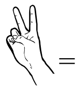
Joints
[spread] 1

Fingers_1

Thumb 1

Fingers_0

Quantity
[all] 1

Handshape: 2  = 6 & 10

Notes:

Hand

Non-selected fingers
[flexed] 1

Selected fingers

Joints
[spread] 1

Fingers_1

Fingers_0

Quantity
[one] 1
[all] 1

Handshape: 3  = 7 & 11

Notes:

Hand

Non-selected fingers
[flexed] 1

Selected fingers

Joints
[spread] 1

Fingers_1

Thumb

Fingers_0

Quantity
[one] 1
[all] 1

Handshape: L  = 6 & 8

Notes:

- Hand [1-8]
  - Non-selected fingers [flexed] 1
  - Selected fingers
    - $Fingers_1$
      - Thumb
      - $Fingers_0$
        - Quantity [one] 1

Handshape: B flat = 7 & 8

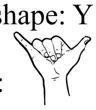
- Hand
  - Selected fingers
    - Joints
      - Base
    - $Fingers_1$
      - Thumb
      - $Fingers_0$
        - Quantity [all] 1

Handshape:  = 8 & 11

Notes:

- Hand
  - Non-selected fingers [extended] 1
  - Selected fingers
    - Joints [flexed] 1
      - Base
    - Fingers_1
      - Thumb
      - Fingers_0
        - Quantity [one] 1

Handshape: Y = 7 & 10

Notes: 

- Hand
  - Non-selected fingers [flexed] 1
  - Selected fingers
    - Fingers_1
      - Thumb
      - Fingers_0
        - Quantity [one] 1
        - Point of reference [Ulnar] 1

Handshape: T  = 8 & 11

Hand
[1-8]

Non-selected fingers
[flexed] 1

Selected fingers

Joints
[flexed] 1

Fingers$_1$

Non-base

Thumb

Fingers$_0$

Quantity
[one] 1

Handshape: 4  = 5 & 7
Notes:

Hand
[1-8]

Selected fingers

Joints
[spread] 1

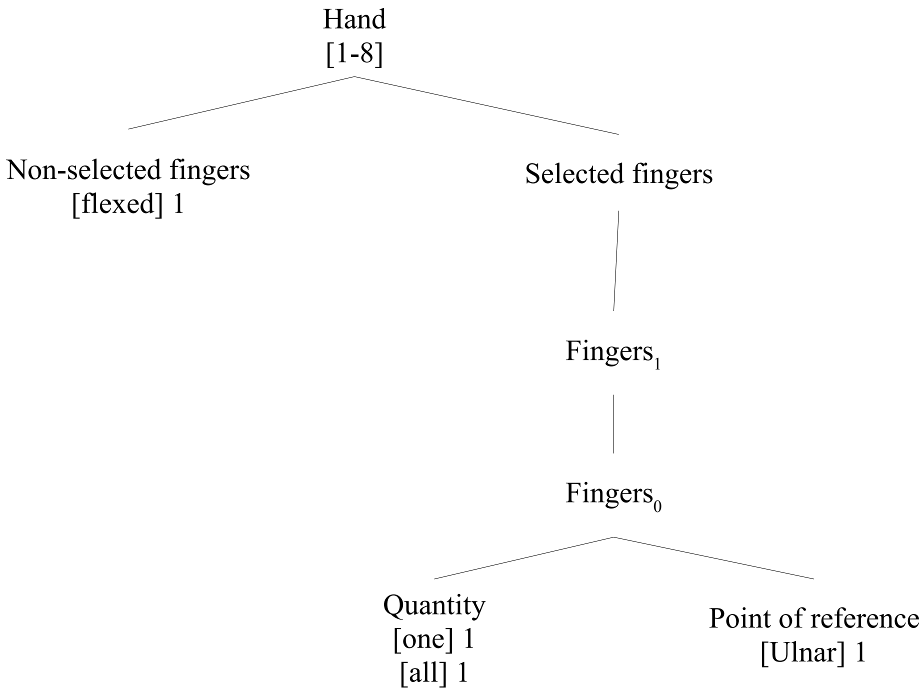
Fingers$_1$

Fingers$_0$

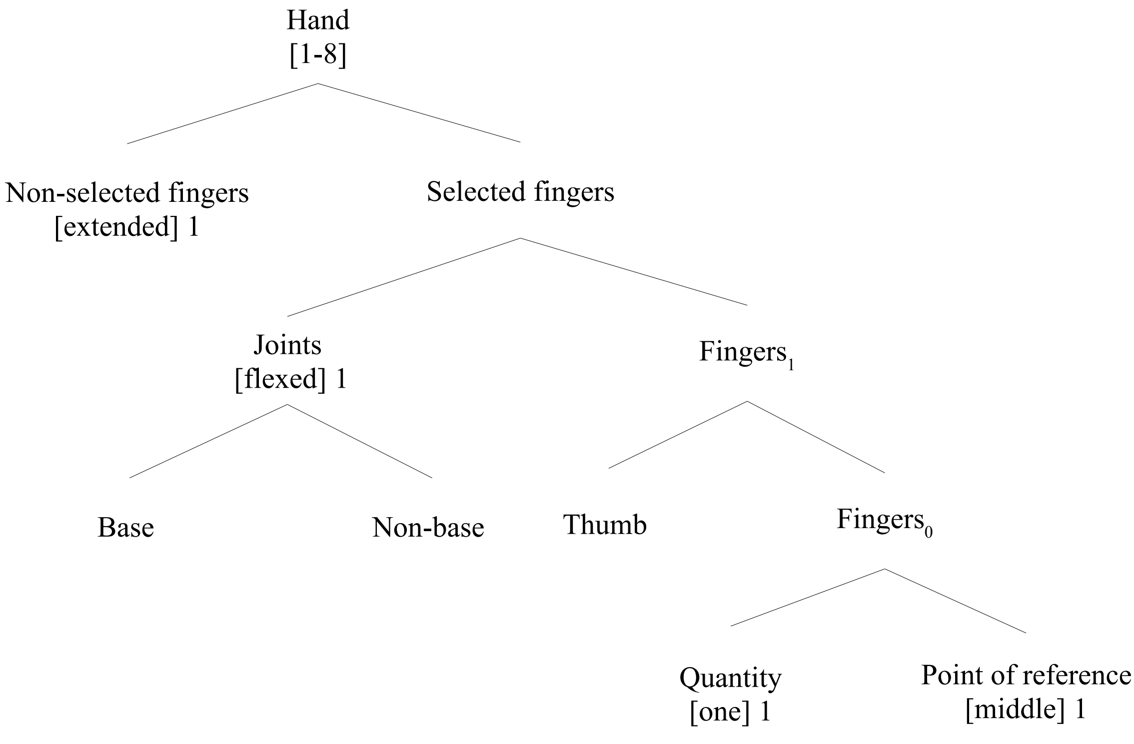
Quantity
[all] 1

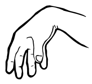
Handshape:  = 6 & 10

Notes:



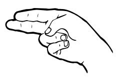
Handshape:  = 10 & 14



Handshape:  5 curved= 7 & 9

Hand
[1-8]

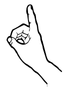
- Selected fingers
  - Joints [spread] 1
    - Non-base
  - Fingers$_1$
    - Thumb
    - Fingers$_0$
      - Quantity [all] 1

Handshape:  H =5 & 8

Notes:

Hand

- Non-selected fingers [flexed] 1
- Selected fingers
  - Fingers$_1$
    - Fingers$_0$
      - Quantity [one] 1 [all] 1

Handshape: G  = 10 & 15

Notes:

Hand

Non-selected fingers
[extended] 1

Selected fingers

Joints
[flexed] 1

Fingers$_1$

Base

Non-base

Thumb

Fingers$_0$

Quantity
[all] 1
[one] 1

Point of reference
[Ulnar] 1

Handshape: 5 medium  = 9 & 12

Hand
[1-8]

Non-selected fingers
[extended] 1

Selected fingers

Joints

Fingers$_1$

Base

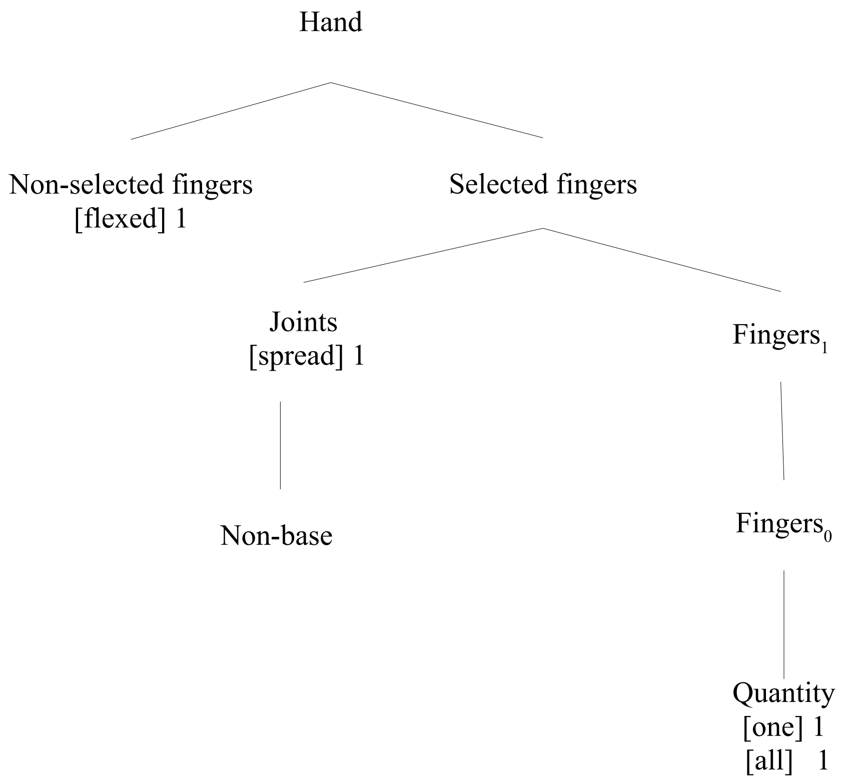
Thumb

Fingers$_0$

Quantity
[one] 1

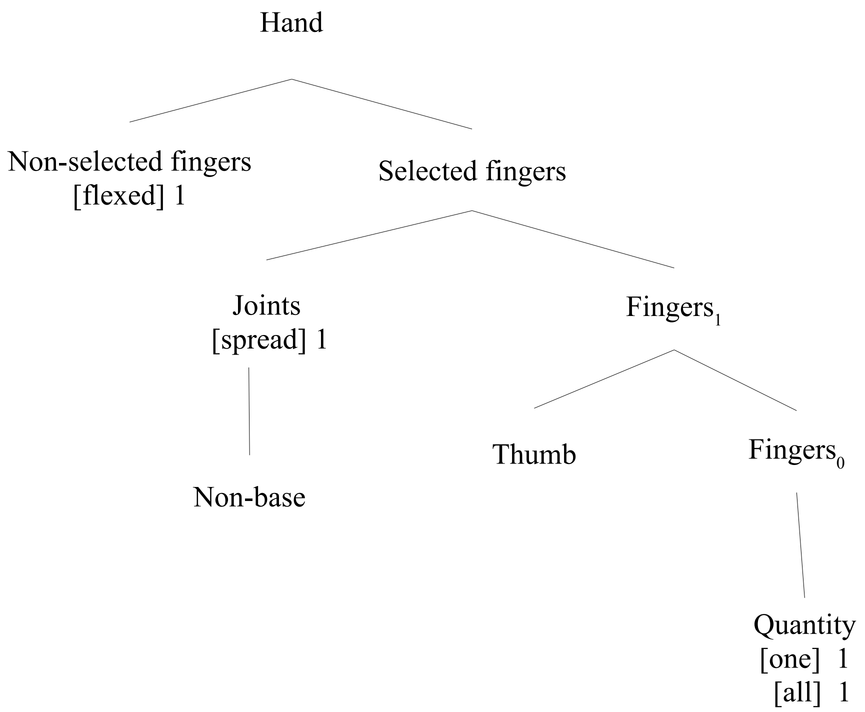
Point of reference
[middle] 1

Handshape: 2 curved = 7 & 11
Notes:



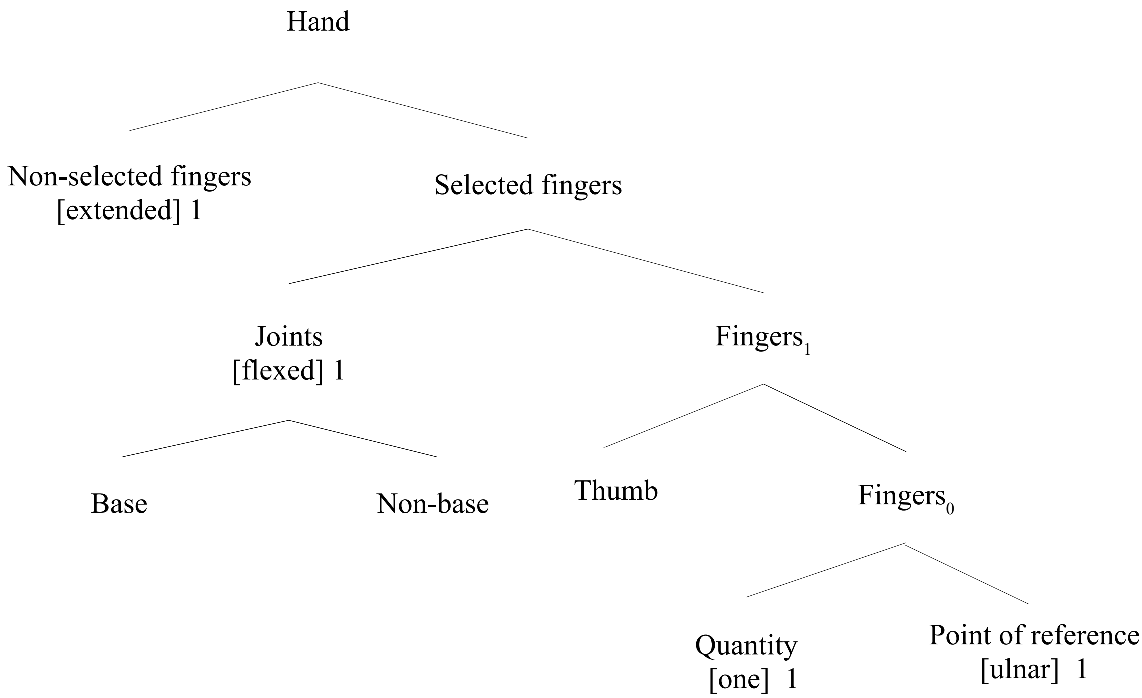
Handshape: 3 curved = 8 & 12

Notes:



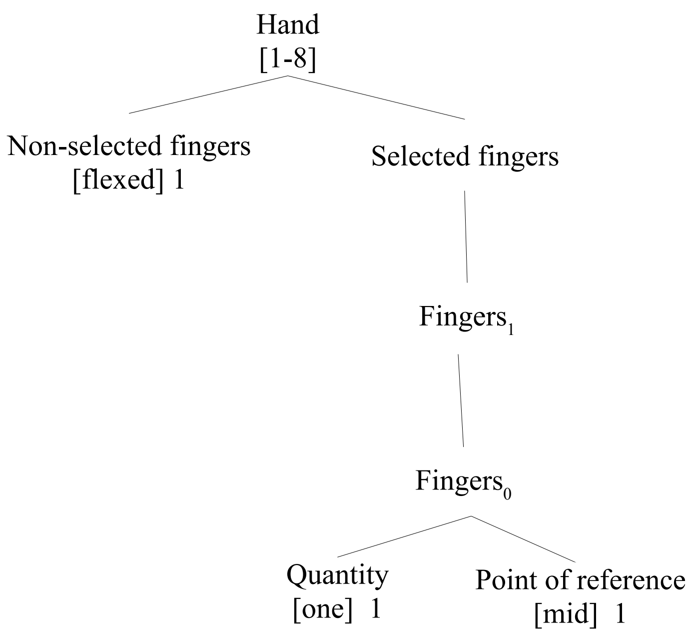
Handshape: W = 10 & 14

Notes:



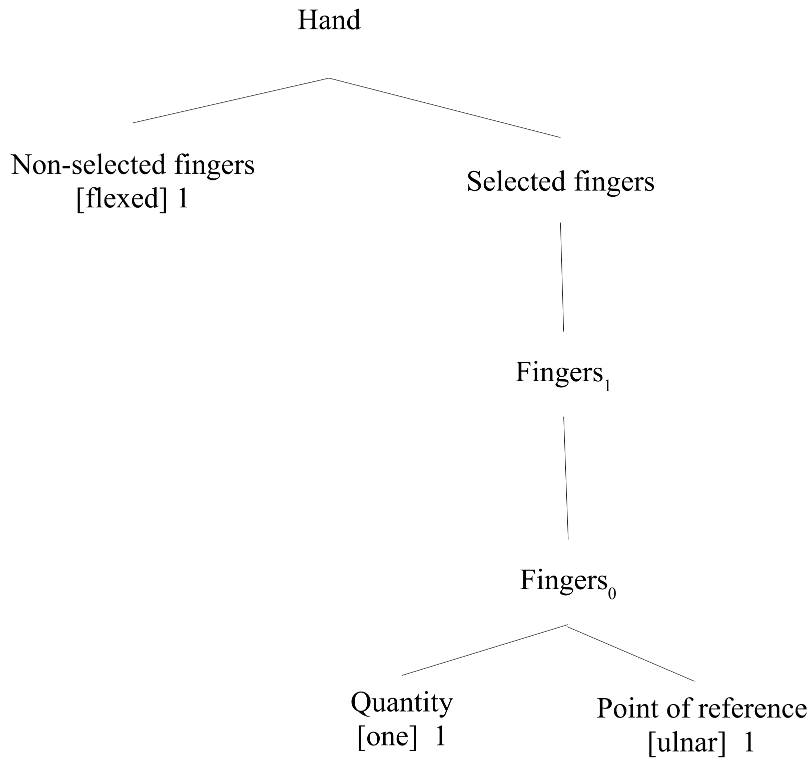
Handshape: MEDIUM = 6 & 9

Notes:



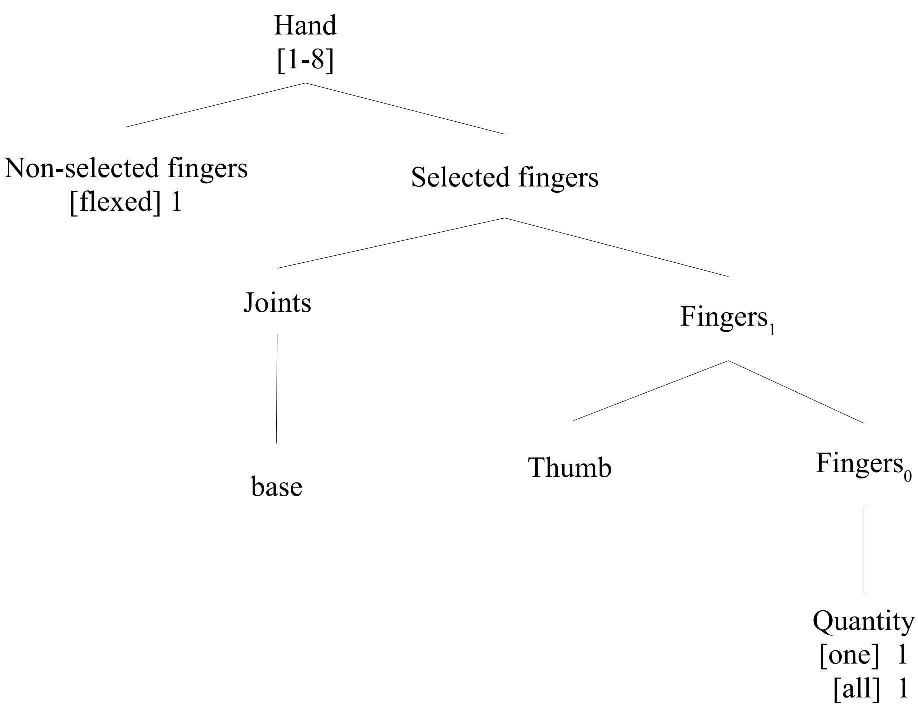
Handshape: I = 6 & 9

Notes:

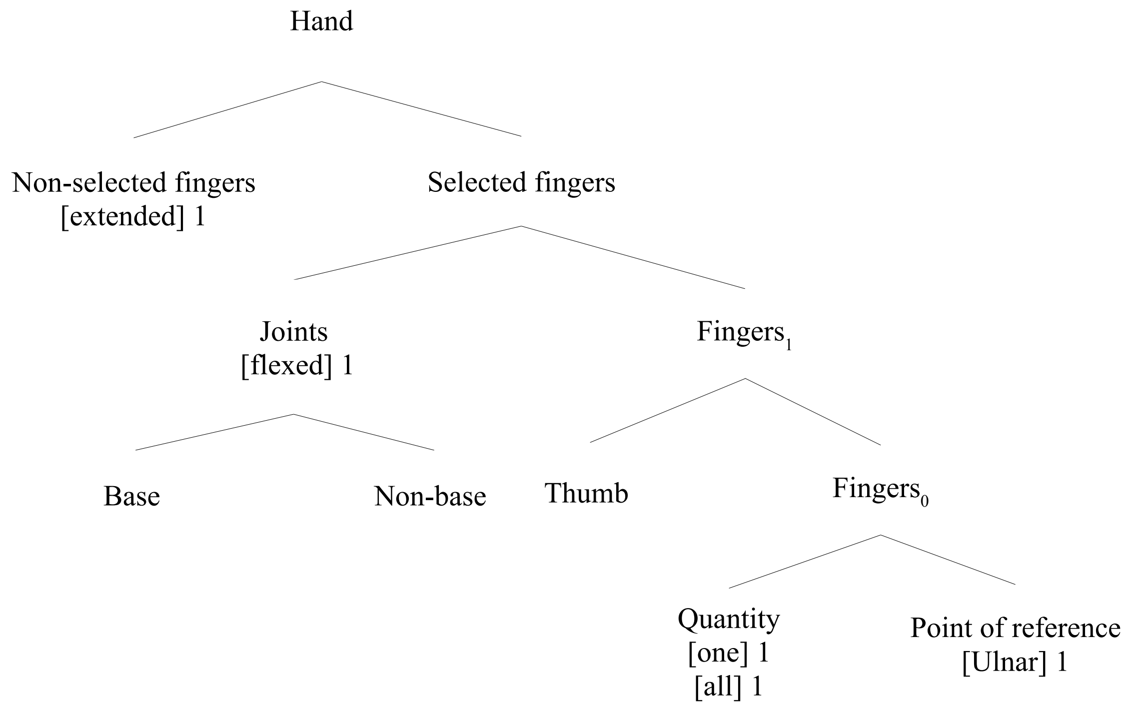


Handshape: H flat+thumb = 8 & 11

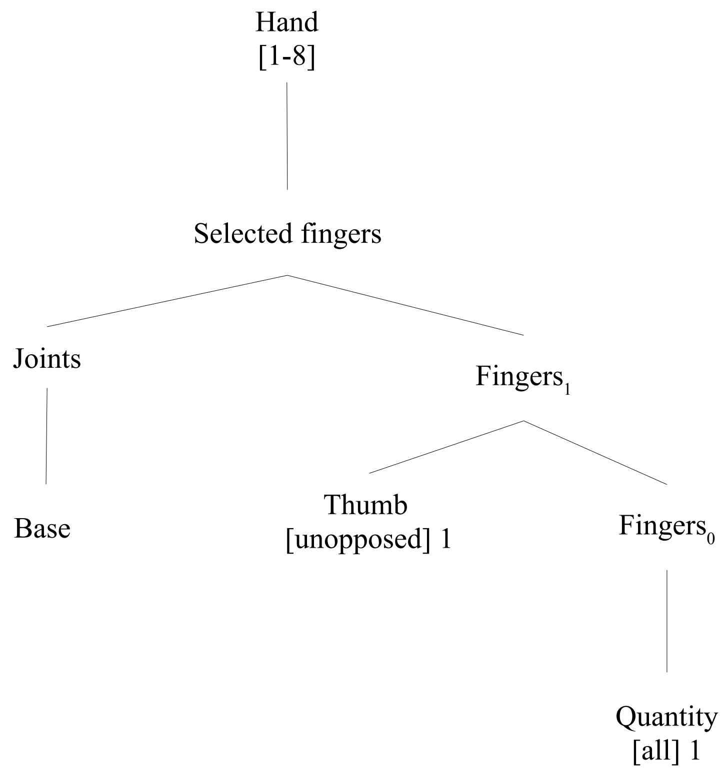
Notes:



Handshape: EXTENDED MEDIUM RING = 10 & 15
Notes:

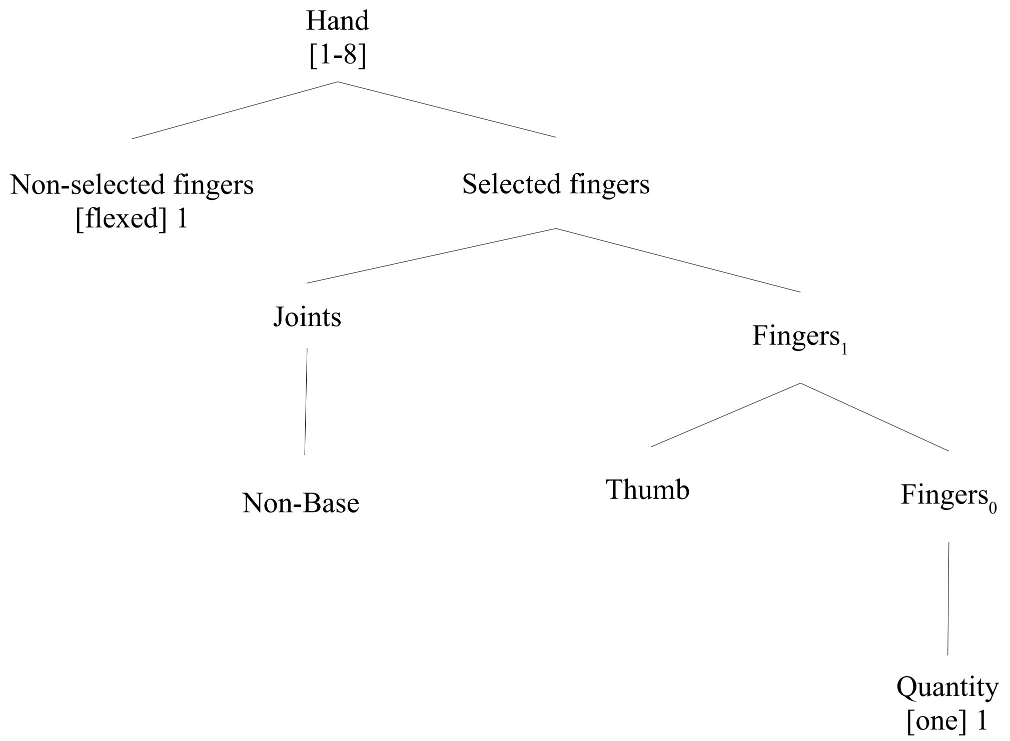


Handshape: B flat thumb = 7 & 9
Notes:



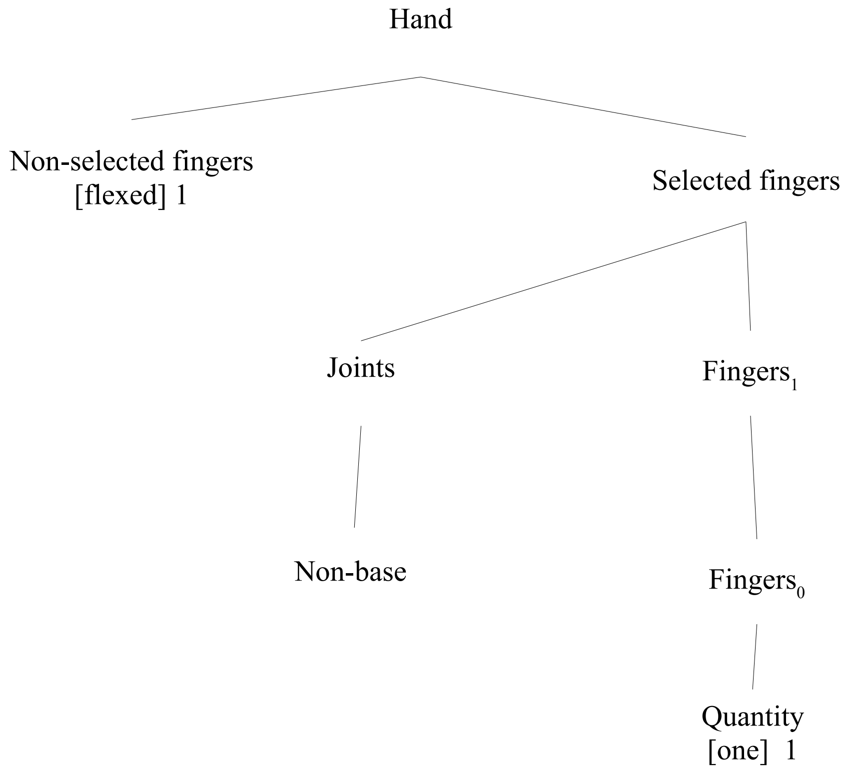
Handshape: L Curved = 8 & 10

Notes:

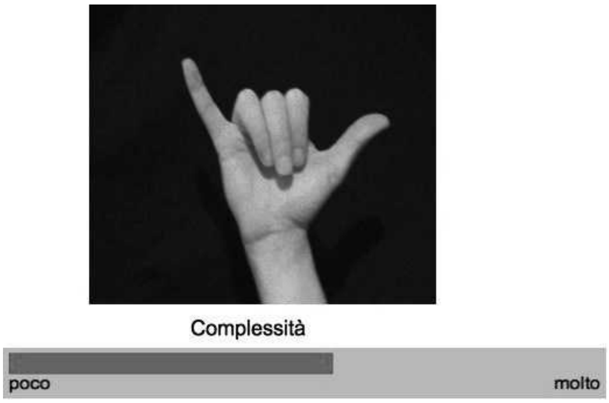


Handshape: 1 Curved = 7 & 9

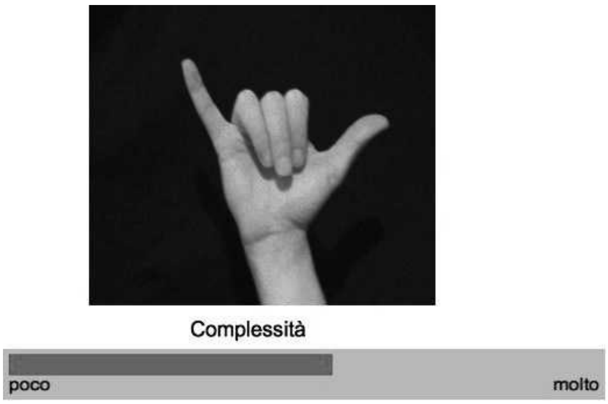
Notes:



B. Stimuli


Complessità
poco
molto


Complessità


Complessità
poco
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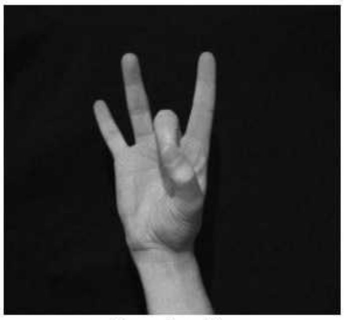

Complessità

Complessità

poco molto

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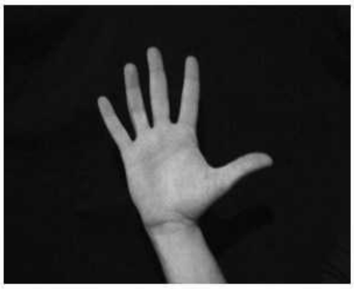

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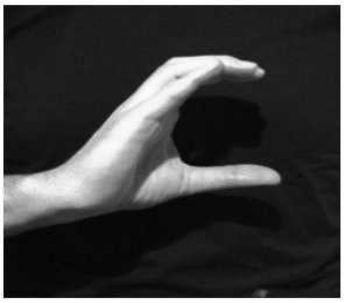

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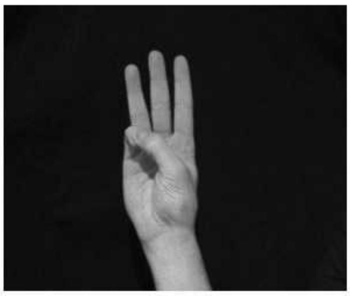
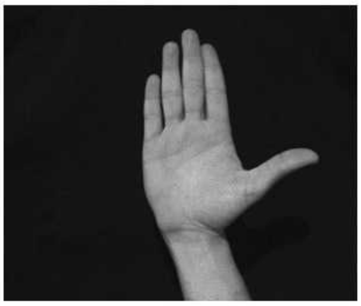


Complessità

Complessità

poco molto



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C. HTML code instruction

Here is how to prepare your items and insert them in your experiment

The simplest experiment

If the only thing you want to do is collect judgments for a few sentences presented in random order, here is how you should prepare your material:
[ ] Sentence 1
[ ] Sentence 2
[ ] Sentence 3
etc.
This will prompt for judgments for Sentence 1, Sentence 2 and Sentence 3, in random order.

Names and ordering

If you want to add names to your items or if you want to control their order of presentation, you can add these options as follows:
[*name* :: *position*] Sentence 1
Ordering: The position parameter specifies the relative order of presentation of the items (within their bloc or group, see below). An item with position number 3 will be presented before any item with position number 6. Items with the same position number will appear next to each other, in random order. Unless specified otherwise, position is set to 5.
Without the "::" sign, everything between the brackets is taken to be the name of the item.

Modification 1: Fixed order

If you want your items to appear in fixed order:
[:: 1] Sentence 1
[:: 2] Sentence 2
[:: 3] Sentence 3
etc.

Modification 2: Everything on one page

If you want all your items to appear on the same page, just add "[[ ]]" on top of your items (see the section about groups for more details):
[[ ]]
[ ] Sentence 1
[ ] Sentence 2
[ ] Sentence 3
etc.

Groups of items

If your sentences work by pairs (or triples...) and you want both members of the pairs to be presented together (e.g., to collect contrastive judgments, or to avoid similar things to be read several times), then simply "group" them by pairs (the double brackets [[ ]] introduce groups of items):
[[ ]]
[ ] Sentence 1a
[ ] Sentence 1b
[[ ]]
[ ] Sentence 2a
[ ] Sentence 2b
etc.

Options for groups

Here are the options you may specify for groups:
[[*name* :: *position*]] *Common prompt*
The optional arguments in italics are:
name: the name of the group
position: the relative order of presentation of the group
Common prompt: A message printed on top of the items in the group, e.g., a general context for these items.

Blocs of items/groups

You can also specify "blocs" of items/groups. This mainly serves to control the order of presentation of your items (or groups). Typically, you might do the following:

[[[Training :: 1]]]
[ ] Training sentence 1
[ ] Training sentence 1
[[[A]]] Answer as quickly as possible.
[ ] Sentence A-1
[ ] Sentence A-2
[ ] Sentence A-3
[[[B]]] Answer carefully.
[ ] Sentence B-1
[ ] Sentence B-2
[ ] Sentence B-3
Here is how this pseudo-example works. The sentences in the bloc "Training" will be presented first (this is because for the two other blocs defined here, the position parameter takes the default value "5").
Then, the sentences from either bloc "A" or bloc "B" are presented, one by one, in pseudo-random order. Then we move to the other bloc.
In other words, we first launch the warming up examples, and then two series of examples which are not intertwined.
Note: You may add groups within blocs (instead of simple items, or you can have simple items).

Options for blocs

[[[*name* :: *position*]]] *Top of page*
The optional arguments in italics are:
name: the name of the bloc
position: the relative order of presentation of the bloc
Top of page: A message printed on top of each page displayed within this bloc.

Full syntax

You can specify blocs (triple brackets), groups (double brackets) and items (simple brackets). Groups and blocs are never mandatory, the arguments in italics are optional. The full syntax is the following.
[[[*name of bloc* :: *position of bloc*]]] *Top of page*
[[*name of group* :: *position of group*]] *Common prompt for the group*
[*name of item* :: *position of item*] Sentence

D. HTML experiment code

<p>
Benvenuto sul nostro sito internet!
<p>
Grazie di partecipare a quest'esperimento.
<p>
In questo messaggio ti verrà spiegato quello che dovrai fare.
<p>
Quando il test inizia sarnno caricate due immagini una sopra l'altra.
<p>
L'immagine in alto è la foto di una mano ed ha sempre la stessa forma.
<p>
Sotto questa immagine c'è una barra che indica il livello di complessità della forma della mano rappresentata nella foto.
<p>
La seconda immagine contiene la foto di una mano che ogni volta assume forme diverse.
<p>
Il tuo compito è stabilire il livello di complessità della forma della mano della foto in basso considerando il livello di complessità assegnato alla forma della mano nella foto in alto.
<p>
Per fare questo devi usare la barra che sta sotto la foto in basso.
<p>
La barra mostra i valori da "poco" a "molto".
<p>
I valori che si avvicinano a "poco" indicano che la forma della mano che stai valutando è meno complessa rispetto a quella in alto.
<p>
I valori che si avvicinano a "molto" indicano che la forma della mano che stai valutando è più complessa rispetto a quella in alto.
<p>
Fai attenzione a cliccare solo sulla barra e non in altre parti dello schermo!
<p>
Dopo che hai cliccato e quindi risposto, passerai alla coppia di immagini successiva.
<p>
Attenzione!!! Non usare il tasto torna in dietro!
<p>
Se hai cambiato idea sulla risposta non puoi tornare indietro e cambiarla. Non importa continua ad andare avanti lo stesso, perché per noi è importante che tu finisca il test.
<p>
In questo test non ci sono risposte giuste o risposte sbagliate, vogliamo sapere soltanto la tua opinione su alcune forme della mano.
<p>
Prima del test ci sarà una fase di allenamento, alla fine dell'allenamento comincia il test vero è proprio.
<p>
Complessivamente il test dura circa 10 mintuti. Alla fine del test dovrai rispondere ad un brevissimo questionario.
<p>

Se è tutto chiaro puoi iniziare il test facendo clic su START!
</p>

[[[::1]]]
[[ ]]
[Y_5]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_5.jpg">
[[]]

[Y_MediumRingOpen]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_MediumRingOpen.jpg">
[[]]

[Y_1Curved]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_1Curved.jpg">
[[]]

[[[::2]]]
[[]]
[]
… adesso è finito l'allenamento! Per cominciare il test clicca sulla barra qui sotto!
[[]]

[[[::3]]]
[[]]
[Y_1]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_1.jpg">
[[ ]]

[Y_2]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_2.jpg">
[[ ]]

[Y_2Curved]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_2Curved.jpg">
[[ ]]

[Y_3]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_3.jpg">
[[ ]]

[Y_3Curved]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_3Curved.jpg">
[[ ]]

[Y_4]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_4.jpg">
[[ ]]

[Y_5Curved]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_5Curved.jpg">

[[ ]]

[Y_5Medium]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_5Medium.jpg">
[[ ]]

[Y_A]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_A.jpg">
[[ ]]

[Y_Bflat]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_Bflat.jpg">
[[ ]]

[Y_BflatThumb]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_BflatThumb.jpg">
[[ ]]

[Y_Bthumb]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_Bthumb.jpg">
[[ ]]

[Y_C]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_C.jpg">
[[ ]]

[Y_F]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_F.jpg">
[[ ]]

[Y_G]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_G.jpg">
[[ ]]

[Y_H]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_H.jpg">
[[ ]]

[Y_HbentThumb]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_HbentThumb.jpg">
[[ ]]

[Y_I]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_I.jpg"
[[ ]]

[Y_IndexPinkyOpen]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_IndexPinkyOpen.jpg">
[[ ]]

[Y_L]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_L.jpg">
[[ ]]

[Y_LCurved]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_Lcurved.jpg">
[[ ]]

[Y_Medium]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_Medium.jpg">
[[ ]]

[Y_MediumThumbClosed]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_MediumThumbClosed.jpg">
[[ ]]

[Y_O]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_O.jpg">
[[ ]]

[Y_RThumbRing]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_RThumbRing.jpg">
[[ ]]

[Y_S]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_S.jpg">
[[ ]]

[Y_W]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_W.jpg">
[[ ]]

[Y_T]
<img src="https://dl.dropbox.com/u/19192123/Perception/Y_T.jpg">
[[ ]]

<p>
L'esperimento è finito.
Adesso ti chiediamo di rispondere ad alcune brevi domande
</p>

<p>
Adesso hai veramente finito!
Grazie per aver partecipato.
<p>

</p>
Se sei interessato a saperne di più puoi contattarci
per email e fissare un appuntamento via skype
Carlo Geraci: carlo.geraci76@gmail.com
Valentina Aristodemo: aris81@hotmail.it
</p>

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