Two-Handed Signs and Handedness: Phonological Implications for Sign Language Structure

Lisa Lepp, Mirella De Sisto, Dimitar Shterionov
{L.B.Lepp, M.DeSisto, D.Shterionov}@tilburguniversity.edu
Tilburg University
Warandelaan 1, 5037AB Tilburg

Abstract

Handedness —the use of one versus two hands in sign production— has traditionally been discussed in relation to dominance and symmetry conditions, yet it remains underrepresented in formal phonological models of sign languages. This paper argues that handedness constitutes a core phonological parameter that directly influences the structure and interaction of movement, handshape, location, and orientation. Building on hierarchical and dependency-based approaches, we propose an adapted phonological dependency model that explicitly integrates handedness in the representation of manual articulators. In one-handed signs, features are specified for a single active hand. In two-handed signs, feature distribution is constrained by symmetry and dominance conditions, which regulate whether the hands must share features or may differ in a structurally restricted way. This structural encoding accounts for variation phenomena such as weak add, weak prop, and weak drop as constrained adjustments within the phonological system. From a technical perspective, this refinement suggests more formal restrictiveness and empirical discriminability within the feature geometries, reduced representational ambiguity, and improved empirical testability across theoretical, corpus-based, and computational implementations, strengthening the interface between phonological theory and sign language technology.

Keywords: handedness, one- vs. two-handed signs, sign language phonology, sign language technology

1. Introduction

One of the most unique properties of sign languages (SLs) is the availability of two active manual articulators (Brentari, 1998; Crasborn and van der Kooij, 2013; Sandler, 2017; Van der Kooij, 2002). Lexical signs may be produced with one or two hands, and across SLs, both options are roughly equally represented in the lexicon[1] (Crasborn, 2011; McKee et al., 2024; Sandler, 2017). Despite this, the role of handedness in the phonological structure has not been included. Handedness itself is often treated as a derived aspect of lexical sign production. That is, handedness is not considered as an individual feature but rather as a side effect of the main hand.

In this paper, we take handedness as a starting point rather than as a secondary feature. From this perspective, handedness is not only about the number of involved articulators, but also about how phonological dependencies are distributed across them. With that respect, we investigate to what extent the choice between one-handed or two-handed signs formalizes the internal structure of signs. We treat handedness as the primary factor constraining the realization of other parameters. These parameters function as fundamental units of phonological structure, comparable to sublexical units in spoken languages. Thus, the contribution of this paper is to propose an adapted SL phonological hierarchy model where handedness is not a secondary property, but a structurally represented parameter.

The question whether a structural position for both manual articulators is needed in the phonological analysis of lexical signs is raised in earlier work of Van der Kooij (2002), as the involvement of one or two hands is potentially distinctive. Using variation provides evidence about the distribution and limits of phonological categories.

To analyze handedness as a phonological parameter and assess its place within established or new frameworks, we develop a hierarchical view of SL phonology. We argue that many well-known generalizations—such as dominance, symmetry, and patterns of weak-hand participation (Battison, 1978; Brentari, 1998; Crasborn and Van der Kooij, 2023; McKee et al., 2024) —are more naturally captured if handedness is represented explicitly within the phonological hierarchy of manual articulators. This addition does not require abandon-

[1] As Van der Kooij (2002) analyzed for the SignPhon database with 3084 signs, 54% of the signs were one-handed versus 46% of two-handed.

Proceedings of the 12th Workshop on the Representation and Processing of Sign Languages, pages 275–286
16 May 2026.

ing existing models; rather, it involves a small but consequential shift in perspective that makes the structural role of the second hand visible within the representation itself. That is, handedness gives a useful perspective for re-examining how phonological dependencies are organized in SLs.

This representational shift also has implications beyond theory, particularly for how structure is reflected in descriptive and corpus practices. If handedness is hierarchically encoded, annotation systems should capture not only whether one or two hands are involved, but also how phonological features are distributed across them. Not all corpora provide equal information for both hands, and some do not even annotate the weak hand (Sisto et al., 2022). We propose instead that each hand should be encoded as a distinct articulator with separate specifications for handshape, orientation, location, and movement. This would allow corpora to represent structured feature distribution across hands rather than reducing handedness to a binary distinction.

This paper is structured as follows: we start with a discussion of the evolution of phonological hierarchy models in SL linguistic theories in Section 2. Then, in Section 3, we describe the widely adopted manual phonological parameters, i.e., movement, handshape, orientation, and location. Section 4 is dedicated to motivating our choice to include the parameter *handedness* as a sixth parameter in future SL linguistics research (see Figure 4). We end with an explanation of the new adapted phonology dependence model in Section 5.

2. Phonological hierarchies in sign language phonology

Early work on SL phonology established the now-familiar view that lexical signs can be decomposed into a small number of discrete manual parameters. In the seminal model proposed by Stokoe (1980), handshape, location, and movement are introduced as abstract phonological units, laying the foundation for later parameter-based analyses. Subsequent work refined and expanded this inventory, adding orientation and location, while maintaining the assumption that phonological form is structured and systematic rather than holistic (Brentari, 1998; Sandler, 2014; Van der Kooij, 2002).

While early parameter models primarily treated these units as co-equal components, later approaches increasingly emphasized hierarchical organization and dependency relations among phonological features (Brentari, 1998; Crasborn, 2001; Crasborn and van der Kooij, 2013; van der Hulst and van der Kooij, 2020). In this view, not all features in language systems are equally important. Some have a more prominent role of some features in comparison with others. In a hierarchical structure, there is a head feature and a dependent feature (Anderson and Ewen, 1987), leading to the proposal and establishment of hierarchical representations. Hierarchical representations are motivated by empirical patterns, such as markedness asymmetries, as well as by the need to model both simultaneous and sequential structure within a single representational framework. Many studies (Battison, 1974, 1978; Crasborn, 2001; Fenlon et al., 2017; Van der Kooij, 2002; McKee et al., 2024; Padden and Perlmutter, 1987; Sandler, 2014, 2017) among others, showed how the phonological manual structure of a lexical item is built up using this hierarchical description. Within these models, parameters such as handshape and movement are often treated as structurally prominent, as they trigger strong constraints on the realization of other features (Fenlon et al., 2017; van der Kooij and Crasborn, 2016; van der Kooij and van der Hulst, 2005). Orientation and location, in turn, are typically analyzed as dependent or relational parameters whose interpretation is conditioned by higher-level articulatory structure (Sandler, 2013; Fenlon et al., 2017)[2]. Despite the increasing formalization of hierarchical structure, handedness has not yet been systematically[3] incorporated into these representation structures. As handedness determines the organization of articulatory dominance, symmetry, and internal manual specification,the number of hands directly constrains the distribution and realization of other phonological parameters. If hierarchical models aim to capture asymmetries, dependency relations, and structural prominence, then arguably handedness constitutes a candidate for structural encoding rather than peripheral annotation.

[2]Non-manual parameters (NMP) such as eyebrow movement, cheek tension, tongue position, and body movement are not included in the scope of this article.

[3]By "systematically," we refer to the consistent and architecture-wide encoding of hierarchical relations between articulators. While some models do not incorporate such representations at all, others assume them in principle but implement them only in selected analyses, rather than as a general representational commitment.

3. Phonological parameters

The phonological structure of SLs can be described in terms of a limited set of manual parameters that jointly define lexical contrast, i.e., a small difference in one of the manual parameters can distinguish one sign from another[4]. Minimal pairs illustrate this contrast: they are pairs of signs that are identical in all parameters, except for one. The *Nederlandse Gebarentaal* (NGT), i.e., the sign language of the Netherlands, signs for DONDER (THUNDER) in Figure 1a, and BOOM (TREE) in Figure 1b illustrate this concept[5].

(a) An example of the one-handed sign THUNDER in NGT.

(b) An example of the two-handed sign TREE in NGT.

Figure 1: An example of a minimal pair in *NGT* illustrating contrast in handedness.

We first provide a brief description of the core parameters[6] (Anderson and Ewen, 1987; Battison, 1974, 1978; Crasborn, 2011; Crasborn et al., 2000; Crasborn and van der Kooij, 2013; Fenlon et al., 2017; Sandler, 1986, 2013, 2014; Stokoe, 1980; van der Kooij and Crasborn, 2016), and then discuss the new proposal.

[4]We acknowledge that Brentari (1998); Sandler (1996); Sandler and Lillo-Martin (2006) refer to parameters as classes and class nodes, but we have decided to follow the more general definition of parameters.

[5]Figures 1, 2, 3, and 5 are reproduced from the website of the Dutch Sign Language Centre (https://www.gebarencentrum.nl/)

[6]As noted by a reviewer, this paper does not discuss individual phonological features in detail; rather, it focuses on the classes of parameters and their specifications. The phonological features are mentioned implicitly throughout this article.

3.1. Movement

Movement is a defining property of SL-syllables[7]. In SLs, this organization can be expressed by the movement of the hand, or by the movement of only the fingers (Van der Kooij and Crasborn, 2008), and is phonologically obligatory (Brentari, 1998; Crasborn et al., 2000; Van der Kooij, 2002; Liddell and Johnson, 1989; Sandler, 2013, 2014). A distinction is made between *path movement* and *local movement*. Path movement (PM) involves a transition between two explicitly specified positions. Local movements are further categorized in hand-internal movement and orientation change (Van der Kooij, 2002; Sandler, 2014), with hand-internal movements referring specifically to the movement of the fingers and the wrist. Local movements therefore refer to lexical changes in finger position or changes in the orientation of the hand (Van der Kooij, 2002; van der Kooij and Crasborn, 2016; Sandler, 2013). A single syllable may contain at most one instance of each movement type, allowing simultaneous but constrained combinations (Crasborn and van der Kooij, 2013; van der Hulst and van der Kooij, 2020; van der Hulst, 1993; van der Kooij and Crasborn, 2016).

Distinguishing path and local movement is crucial for modeling the temporal structure of signs. By pairing two values of a setting (for example, [high] vs. [low], [contralateral] vs. [ipsilateral], or [proximal] vs. [distal]), the movement path can be precisely defined within a given location domain, without positing movement as an independent phonological primitive (van der Hulst and van der Kooij, 2020). In corpus annotation, for example, using ELAN, movement is typically encoded either on a single tier or through a set of defined labels, making explicit whether a sign involves path movement, local movement, or both. This distinction clarifies which movement features are obligatory or optional and how they interact with other parameters.

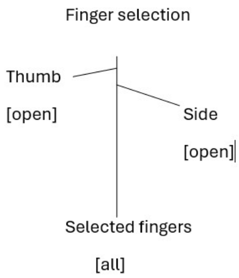
3.2. Handshape

Handshape is described as the form of the hands during the articulation of a sign, determined by the selection of fingers and their internal configuration (Brentari, 2011; Crasborn et al., 2000; Van der Kooij, 2002; Sandler, 2014). Finger se-

[7]Following Brentari (1998), a syllable in sign language is a prosodic unit organized around a movement nucleus, optionally preceded and/or followed by holds.

lection[8] distinguishes between foregrounded and back grounded fingers (Van der Kooij, 2002), while finger configuration specifies properties such as curve, width, aperture (Van der Kooij, 2002)[9]. The curve is the specification of the flexion of the fingers. Aperture specifies the open-close relationship between the thumb and the selected fingers, and width refers to the degree of spreading or opposition between them.
Simple handshapes, also called unmarked handshapes, involve minimal specification—for example, selecting all fingers in an open configuration, as shown in 2a, and in the phonological dependency hierarchy in Figure 2b.

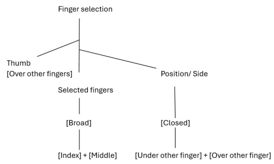
(a) Example of [all] selected fingers, thus a simple handshape.



(b) The phonological hierarchy model based on the 5-handshape in Figure 2a.

In contrast, complex handshapes, or marked handshapes[10], require multiple dependent features, as shown in Figure 3a and the related phonological hierarchy model in Figure 3b.

(a) Example of the R-handshape, thus a complex handshape.



(b) The phonological hierarchy model for the complex R-handshape in Figure 3a.

3.3. Orientation

Orientation encodes the facing of the hand palm with respect to space, the body, or another articulator. Previous research has approached the encoding of orientation from three complementary perspectives. The first approach, referred to as handshape-linked-orientation, defines the orientation via the direction of the palm of the handshape (Brentari, 2011; Crasborn and van der Kooij, 2013; Fenlon et al., 2017; Van der Kooij, 2002). In contrast, the movement-linked-orientation encodes which part of the hand faces the final location (Van der Kooij, 2002) and remains constant throughout the articulation of the sign. van der Hulst and van der Kooij (2020) suggests four types for the movement-linked-orientation: (i) Body – end contact; (ii) Weak hand – end contact; (iii) Space – path movement, and (iv) Body – continuous contact.

A third approach to orientation adopts a contact-based perspective. Fenlon et al. (2017) defines orientation as the relationship between the active hand and the place of articulation, specifying which side of the hand—most notably the radial (thumb) side—is involved. Orientation is often reduced to features such as [palm up] or [palm down], and defined relative to body, space, or another articulator.

3.4. Location

Location is the area of articulation (e.g., head, torso, arms, neutral space)[11]. It can be further divided into sub-locations that are contrastive (Van der Kooij, 2002). An empirical argument in favor of the distinctive locations is the *generalized double contact constraint*. This constraint indicates that if a sign involves two distinct contacts with the body, those contact points are restricted in their location (Van der Kooij, 2002). Evidence from NGT shows that this constraint is not limited to double contact movements, but also applies to continuous contact movements, which likewise remain within a single distinctive location (Van der Kooij, 2002). These constraints are part of a broader set of phonological rules, such as the symmetry and

[8] In Crasborn et al. (2000); Van der Kooij (2002); Sandler (2014), handshapes with either [one] or [all] features are discussed. However, in cases with [two], [three], or [four] selected fingers, the elements associated with [one] or [all] can combine and form dependency relations.

[9] Brentari (2011) describes fully open, bent (closed), flat-open, flat-closed, curved open, curved closed, and fully closed as seven options for joint configuration in ASL-handshapes.

[10] Markedness correlates with complexity, articulatory difficulty, frequency, order of acquisition, and other factors in the formalization of a handshape (van der Hulst and van der Kooij, 2020; Lepp, 2025; Sandler, 2014).

[11] Van der Kooij (2002) also calls Space and weak hand as areas.

dominance conditions, which will be discussed in the next section. Furthermore, signs may share the same phonological location while differing in the specific part of the hand that establishes contact, indicating that phonological location cannot be reduced to a single point in space (Mauk and Tyrone, 2012).

Location is distinguished from setting: location refers to the major articulatory area, while setting specifies finer-grained positional or movement-related distinctions within that area (e.g., high/low, ipsilateral/contralateral, proximal/distal, contact, and others) (Crasborn et al., 2000; van der Hulst and van der Kooij, 2020; Sandler, 1986) Some of the linked features are [radial], [back], [tips], [palmar], and [ulnar] (van der Kooij and Crasborn, 2016).

4. Handedness

As noted above, a defining characteristic of SLs is the availability of two manual articulators (van der Kooij and Crasborn, 2016; Crasborn, 2011; Sandler, 2017) which leads to the notion of handedness. Van der Kooij (2002) hypothesized that handedness may be lexically and phonologically specified and that one-handed and two-handed signs may exhibit distinct structural features. Following her idea, in this section, we introduce *handedness* as a new parameter in the existing model of phonological features in SLs. Building on these observations, we formally integrate handedness into the phonological hierarchy.

4.1. Handedness in existing models

A long-standing question in sign language phonology concerns how the two manual articulators should be represented in the phonological structure. Van der Kooij (2002) explicitly raised the issue of whether handedness should receive a structural position in the hierarchy, noting that earlier hierarchical models (Brentari, 1990; van der Hulst, 1996; Sandler, 1986) risk over-generalization if both hands are fully specified at the lexical level. Subsequent work, including (Padden and Perlmutter, 1987) and more recently (Crasborn and Van der Kooij, 2023), further examined the role of the non-dominant hand in discourse and questioned whether two independent structural positions are always required, or whether a single underlying representation might suffice in some cases. These authors do not treat handedness as a fully formalized phonological parameter. Rather, they identify a representational tension: some two-handed configurations appear lexically stored, while others arise through morphological or post-lexical processes. To address this, Crasborn and Van der Kooij (2023) propose a three-level architecture consisting of (i) a lexical level, (ii) a surface (spelled-out) level, and (iii) a post-lexical level. According to their view, the lexical representation alone cannot account for phenomena that span multiple lexical items or depend on signer-specific dominance[12]. An intermediate surface level is therefore required to determine which hand is dominant and to specify the distribution of features such as finger selection, orientation, and position of the non-dominant hand. Only at the post-lexical level are the left and right hands fully specified separately, allowing the model to capture processes in which one hand, or specific features, persists longer than the other.

This discussion directly motivates our proposal. The need for multiple representational levels and for mechanisms that determine dominance and feature distribution across articulators indicates that handedness is not a marginal or purely phonetic property. Previous accounts treat handedness as an architectural issue rather than a formal parameter; we integrate it directly into the phonological hierarchy. In doing so, we maintain the need for multiple representational levels, avoid lexical overgeneralization, and capture the distribution of features across articulators within the core phonological system.

4.2. Handedness and asymmetry

A functional asymmetry is observed between the dominant (strong) hand and the non-dominant (weak) hand (Crasborn, 2011; Padden and Perlmutter, 1987). The dominant hand typically serves as the active articulator, while the non-dominant hand functions as a passive articulator or a place of articulation (Brentari, 2011; Crasborn and Van der Kooij, 2023; Van der Kooij, 2002; McKee et al., 2024).

These asymmetrical signs are subject to two well-established phonological constraints: the symmetry constraint and the dominance constraint (Battison, 1978; van der Kooij and Crasborn, 2016; Sandler, 2013). The symmetry constraint requires

[12]Signers may be right- or left-hand dominant; thus, "dominant" is relative to the individual signer (McKee et al., 2024).

that if both hands are active, they share handshape, movement, and location. The dominance constraint applies when one hand is passive: if the non-dominant hand serves as a place of articulation, it must either have an unmarked handshape or share the handshape of the dominant hand (Van der Kooij, 2002). These constraints suggest that handedness concerns not only the number of articulators, but also the distribution of phonological dependencies across them. Such restrictions are difficult to explain if handedness is treated only as a surface realization choice; instead, Crasborn and Van der Kooij (2023) points to a structurally constrained role for the second hand within the phonological system.

4.3. Handedness configurations

Because handedness varies in constrained ways, it must be represented as a phonological parameter. This interpretation is further supported by the recent work of McKee et al. (2024), who show that handedness is systematically manipulated in phonetic and discourse-driven contexts[13]. As they show for New Zealand SL, signs may undergo several specifications, such as:

1. Weak add: A weak hand is added to a one-handed sign.
2. Weak prop: The non-dominant hand partially or fully copies the handshape and movement of the dominant hand, consistent with the dominance constraint (Frishberg, 1975)
3. Weak drop: The weak hand of a lexically two-handed sign is omitted.
4. Doubling: A one-handed sign becomes a symmetrical two-handed sign.
5. Echo articulation and mirroring: The weak hand participates incompletely or at a reduced level (Sandler, 1993; McKee et al., 2024).

These manipulations of the non-dominant hand respect phonological constraints such as the dominance constraint and the symmetry constraint, showing that handedness interacts systematically with the phonological system. This supports the claim that handedness is a manipulable phonological parameter rather than a fixed lexical property.

[13]The focus of their research analyzed specific communicative functions that are socially conventionalized and reflected in grammar and lexicon over time (McKee et al., 2024).

5. Adapted phonological dependency model

The previous sections outlined the manual phonological parameters and their interaction with handedness. While previous work addressed only specific aspects—for instance, Sandler (2014) focused on hand configuration, and Van der Kooij (2002) did not incorporate the newer parameter handedness—a comprehensive account remained lacking. Building on these hierarchical approaches (Van der Kooij, 2002; Sandler, 2014, 2017), the present section formalizes the interactions among manual articulators within a phonological dependency model, incorporating hierarchical organization and head-dependent relations (Battison, 1974, 1978; Fenlon et al., 2017; Crasborn, 2001; McKee et al., 2024; Padden and Perlmutter, 1987). Morgan (2022) discusses the theoretical distinction between dominant and non-dominant hand features (often expressed as [1H] and [2H]) within phonological analyses of Kenyan Sign Language. However, this work does not present a fully implemented dependency model that incorporates these features. The present paper develops exactly such a formalization.

5.1. Model description

The present model extends earlier work in two main ways. First, it introduces handedness as an explicit structural node within the hierarchy–shown in green letters in Figure 4. Second, it formalizes the asymmetric distribution of phonological specifications across the two hands–shown via the dashed lines. In contrast to previous accounts[14], handedness is not treated as an implicit or peripheral factor, but is integrated directly under the manual articulator node. This constitutes a key innovation of the model. Because the hands are asymmetrical, the non-dominant hand may carry independent specifications for movement, handshape, orientation, and location. Although the model does not explicitly encode temporal structure, it is not intended to represent the sequential organization of signs, which is instead assumed to emerge at the level of articulatory realization.

For the research community, this provides a concrete framework for analyzing cross-linguistic differences in one- and two-handed signs, un-

[14]The extent to which the weak hand is phonologically independent has been widely debated in Brentari (1993).

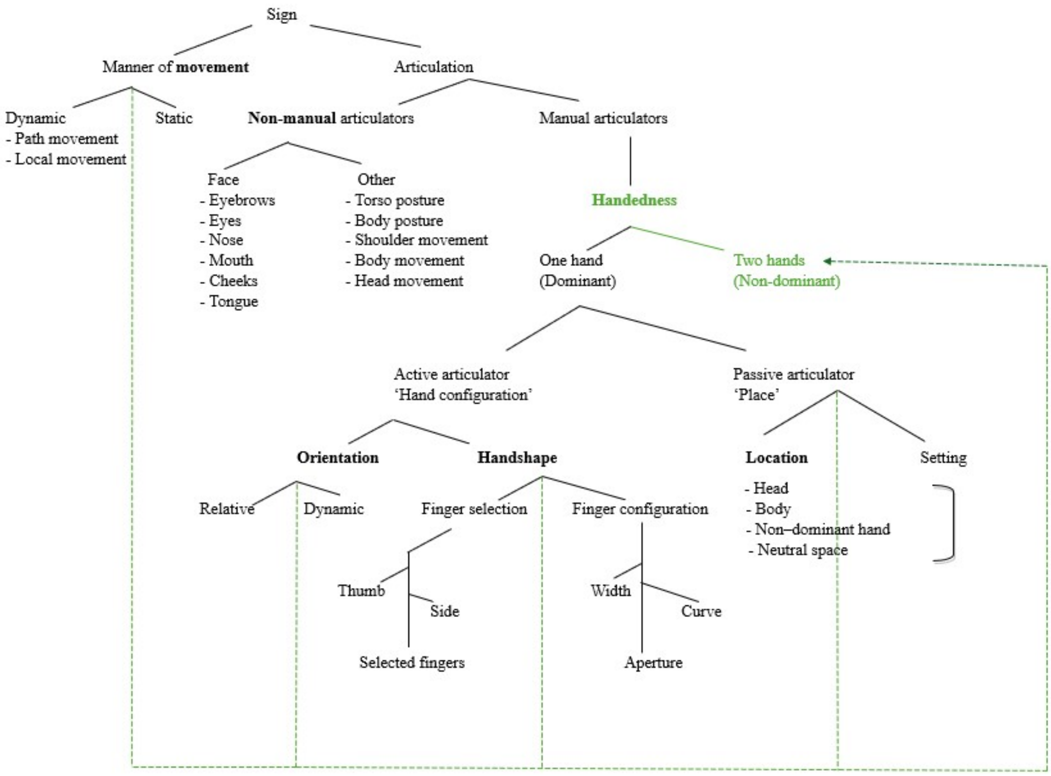


Figure 4: Adapted phonological hierarchy dependency model

derstanding constraint interactions, and exploring the interface between phonology and articulation in SLs. It also offers a practical tool for formal modeling, corpus annotation, and computational applications where handedness must be represented explicitly. While the Global Sign Bank (https://signbank.cls.ru.nl/) already distinguishes between one- and two-handed signs -and the handshapes-, the proposed model refines this distinction further by encoding the dependency relations between the hands. In corpus annotation terms, for example in ELAN (2025), an additional tier could be introduced to encode whether the non-dominant hand carries independent specifications, and, if so, which phonological parameters are specified independently.

5.2. Model interpretation

The adapted phonological hierarchy dependency model builds on earlier hierarchical accounts of sign language phonology, in which manual and non-manual components are organized across tiers. In the present model, this structure is retained but extended with a bidirectional interpretation. Specifically, the model can be interpreted in two directions: (1) bottom-up, or (2) top-down. Each of these directions corresponds to two modes of processing: the first reflects the production phase, whereas the second represents the comprehension phase. From the production perspective, during the production of a lexical item, the movement patterns and articulators, together with their associated subcomponents, serve to formalize the sign's linguistic content. Viewed from the comprehension perspective, sign recognition begins with the perception of finger selection and handshape configuration, which provide the earliest and most salient cues for lexical access (Brentari, 1998; Emmorey and Corina, 1990; Mauk and Tyrone, 2012). In contrast to previous accounts, however, the present model explicitly formalizes how these early cues are mapped onto the hierarchical structure. These cues inform the reconstruction of the hand configuration, which in turn supports the interpretation of the manual-articulator tier (with non-manuals as its sister tier), the movement tier as a parallel branch, and, ultimately, the sign as a whole.

To illustrate how these parameters are captured within a unified single phonological hierarchy dependency model, we analyze the one-handed sign THUNDER (Figure 1a), shown in Appendix A, and the two-handed sign TREE (Figure 1b), shown in Appendix B. For each sign, two representations are provided: an original hierarchy (Figure 5 and 7), and a revised hierarchy (Figure 6 and 8)[15].

THUNDER (Figures 5 and 6) is characterized by a zigzag, downwards (path) movement. It is produced with a single articulator in neutral space, starting from a high position and moving downwards (indicated by '–>'). The handshape consists of a closed palm oriented toward neutral space, with the thumb bent across the fingers and one selected finger fully extended. As the second hand does not give any information in this sign, the notation in the new hierarchy contains as features 'X', e.g., no information available.

TREE (Figures 7 and 8), on the other hand, has two active articulators. This sign is produced with symmetrical parameters, with the same underlying representations, and thus both hands have the same orientation, handshape, location, and orientation. Both hands produce a zigzag, downward movement.

A comparison of THUNDER and TREE highlights two key differences between the original and revised hierarchies. First, while the original model does not systematically encode the distribution of features across articulators, the revised model explicitly distinguishes between active and non-active articulators. This is reflected in the extra specification of the non-active hand in THUNDER versus the full specification of both hands in TREE. Second, the revised hierarchy captures the parallelism in symmetrical two-handed signs by representing shared feature structures across articulators, rather than duplicating independent specifications.

Taken together, these differences demonstrate that the revised model more transparently encodes handedness and articulator activity within a single hierarchical structure, while maintaining a consistent representation of shared phonological parameters such as movement. This supports the claim that handedness is not an external annotation, but an integral part of the phonological representation.

[15]One of the reviewers requested two fully worked examples of signs represented under both an existing model and the adapted model as we suggested to make the structural role of handedness more concrete. This was actually a very good suggestion, which we thus adopted.

6. Conclusion

This paper proposes a new hierarchical model of SL phonology. We have argued that handedness should be represented as a structurally encoded phonological parameter within a proposed hierarchical model of sign language structure. By integrating handedness directly under the manual articulator node, the model makes explicit how phonological features are distributed across articulators and how variation shows where the boundaries within the system are. Our next step is to validate this approach with automated tools and with linguists.

Encoding these distinctions in annotation also brings technical benefits. Hierarchical articulator structure enables more precise corpus searches, improves dataset interoperability, and supports computational modeling. Distinguishing lexical weak-hand features from gradient or discourse-driven variation helps automated systems separate stable contrasts from performance effects, strengthening reproducibility and integration with technological applications.

Bibliographical References

John M. Anderson and Colin J. Ewen. 1987. *Principles of Dependency Phonology*. Cambridge University Press.

Robbin Battison. 1974. Phonological deletion in American Sign Language. *Sign Language Studies*, 5:5–19.

Robbin Battison. 1978. *Lexical Borrowing in American Sign Language*. Linstok Press, Silver Spring, MD, USA. Discusses lexical borrowing and phonological constraints in ASL.

Diane Brentari. 1990. *Theoretical Foundations of American Sign Language Phonology*. Ph.D. thesis, University of Chicago, Chicago.

Diane Brentari. 1993. *Current Issues in ASL Phonology*. Academic Press, San Diego.

Diane Brentari. 1998. *A Prosodic Model of Sign Language Phonology*. Cambridge University Press, Cambridge, UK.

Diane Brentari. 2011. Handshape in Sign Language Phonology. In Marc van Oostendorp, Colin J. Ewen, Elizabeth Hume, and Keren Rice, editors, *The Blackwell Companion to Phonology*, pages 195–222. Wiley-Blackwell, Malden, MA.

Onno Crasborn. 2011. The other hand in sign language phonology. In Marc van Oostendorp, Colin J. Ewen, Elizabeth Hume, and Keren Rice, editors, *The Blackwell Companion to Phonology*, pages 223–240. Wiley-Blackwell, Malden, MA.

Onno Crasborn, Harry van der Hulst, and Els van de Kooij. 2000. Phonetic and phonological distinctions in sign languages. Intersign Introduction Chapter (draft).

Onno Crasborn and Els van der Kooij. 2013. The phonology of focus in Sign Language of the Netherlands. *Journal of Linguistics*, 49(3):515–565. Published online 11 April 2013.

Onno Crasborn and Els Van der Kooij. 2023. *The Emergence of the Second Hand in Sign Language Phonology: From Underlying to Surface Representations*, pages 319–344. Cambridge University Press, Cambridge.

Onno A. Crasborn. 2001. *Phonetic Implementation of Phonological Categories in Sign Language of the Netherlands*. Phd thesis, Universiteit Leiden, Leiden, The Netherlands. Promotoren: Colin Ewen & Harry van der Hulst.

ELAN. 2025. Computer software version 7.0. Technical report, Max Planck Institute for Psycholinguistics, The Language Archive, Nijmegen, The Netherlands.

Karen Emmorey and David Corina. 1990. Lexical recognition in sign language: Effects of phonetic structure and morphology. *Perceptual and Motor Skills*, 71(3 Suppl.):1227–1252.

jordan Fenlon, Diane Brentari, and Kearsy Cormier. 2017. *The Phonology of Sign Languages*.

Nancy Frishberg. 1975. Arbitrariness and iconicity: Historical change in American Sign Language. *Language*, 51(3):696–719.

Lisa Lepp. 2025. *Lexical Acquisition of Sign Language of the Netherlands by Deaf Refugee Children: A Study of Phonological Complexity*, pages 315–344.

Scott K. Liddell and Robert E. Johnson. 1989. American Sign Language: The phonological base. *Sign Language Studies*, 64:195–278.

E. Mauk and Martha E. Tyrone. 2012. Location in ASL: Insights from phonetic variation. *Sign Language & Linguistics*, 15(1):128–146.

Rachel McKee, Mireille Vale, George Major, Sara Pivac Alexander, and Miriam Meyerhoff. 2024. Two hands are powerful. Handedness variation and genre in New Zealand Sign Language. *Language & Communication*, 100.

Hope E. Morgan. 2022. *A Phonological Grammar of Kenyan Sign Language*. De Gruyter Mouton, Berlin/Boston.

Carol Padden and David M. Perlmutter. 1987. American Sign Language and the architecture of phonological theory. *Natural Language & Linguistic Theory*, 5:335–375.

Wendy Sandler. 1986. The spreading hand autosegment of American Sign Language. *Sign Language Studies*, (50):1–28.

Wendy Sandler. 1993. Hand in hand: The roles of the nondominant hand in sign language phonology. *The Linguistic Review*, 10(4):337–390.

Wendy Sandler. 1996. The prosodic model of sign language phonology. *Sign Language & Linguistics*, 1(1):1–36.

Wendy Sandler. 2013. The phonological organization of sign languages. *Linguistics and Language Compass*, 6(3):162–182.

Wendy Sandler. 2014. The emergence of phonetic and phonological features in sign language. *Nordlyd*, 41(2):183–212.

Wendy Sandler. 2017. The challenge of sign language phonology. *Annual Review of Linguistics*, 3:43–63.

Wendy Sandler and Diane Lillo-Martin. 2006. *Sign Language and Linguistic Universals*. Cambridge University Press.

Mirella De Sisto, Vincent Vandeghinste, Santiago Egea Gómez, Mathieu De Coster, Dimitar Shterionov, and Horacio Saggion. 2022. Challenges with sign language datasets for sign language recognition and translation. In *Proceedings of the 13th Conference on Language Resources and Evaluation (LREC 2022)*.

William C. Stokoe. 1980. Sign language structure. *Annual Review of Anthropology*, 9:365–390.

Harry van der Hulst. 1993. Units in the analysis of signs. *Phonology*, 10(2):209–241.

Harry van der Hulst. 1996. On the other hand. *Lingua*, 98:121–143.

Harry van der Hulst and Els van der Kooij. 2020. Sign language phonology – theoretical perspectives. In Josep Quer, Roland Pfau, and Annika Herrmann, editors, *The Routledge Handbook of Theoretical and Experimental Sign Language Research*, pages 1–25. Routledge, London / New York.

Els Van der Kooij. 2002. *Phonological Categories in Sign Language of the Netherlands: The Role of Phonetic Implementation and Iconicity*. Ph.D. thesis, Leiden University / LOT Netherlands Graduate School of Linguistics, Utrecht, The Netherlands. PhD thesis on phonological representation and the role of iconicity in NGT sign phonology.

Els Van der Kooij and Onno Crasborn. 2008. Syllables and the word-prosodic system in Sign Language of the Netherlands. *Lingua*, 118(9):1307–1327.

Els van der Kooij and Onno Crasborn. 2016. Phonology.

Els van der Kooij and Harry van der Hulst. 2005. On the internal and external organization of sign language segments: Some modality-specific properties. In Marc Van Oostendorp and Jeroen van de Weijer, editors, *The Internal Organization of Phonological Segments*, volume 89 of *Studies in Generative Grammar*, pages 153–180. Mouton de Gruyter, Berlin / New York.

A. The phonological hierarchy dependency models for THUNDER

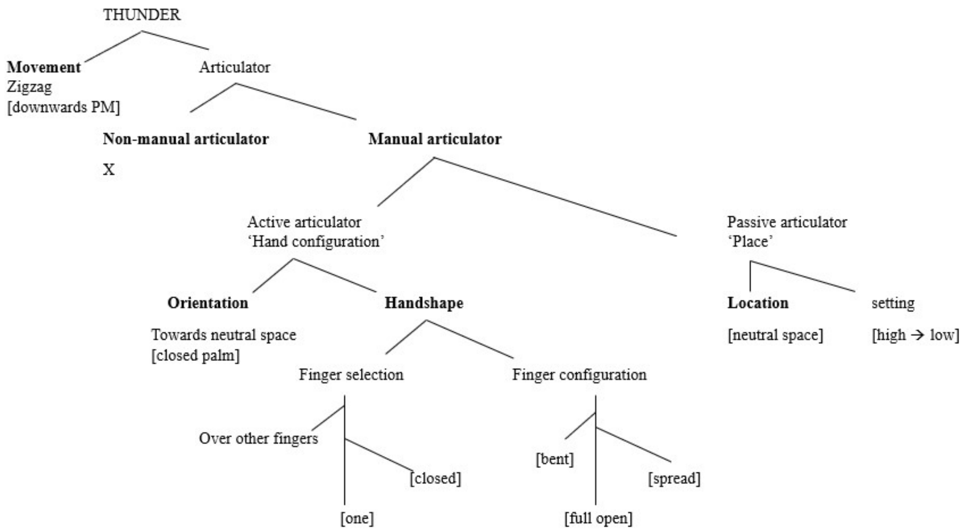


Figure 5: The old phonological hierarchy dependency model for the one-handed sign THUNDER

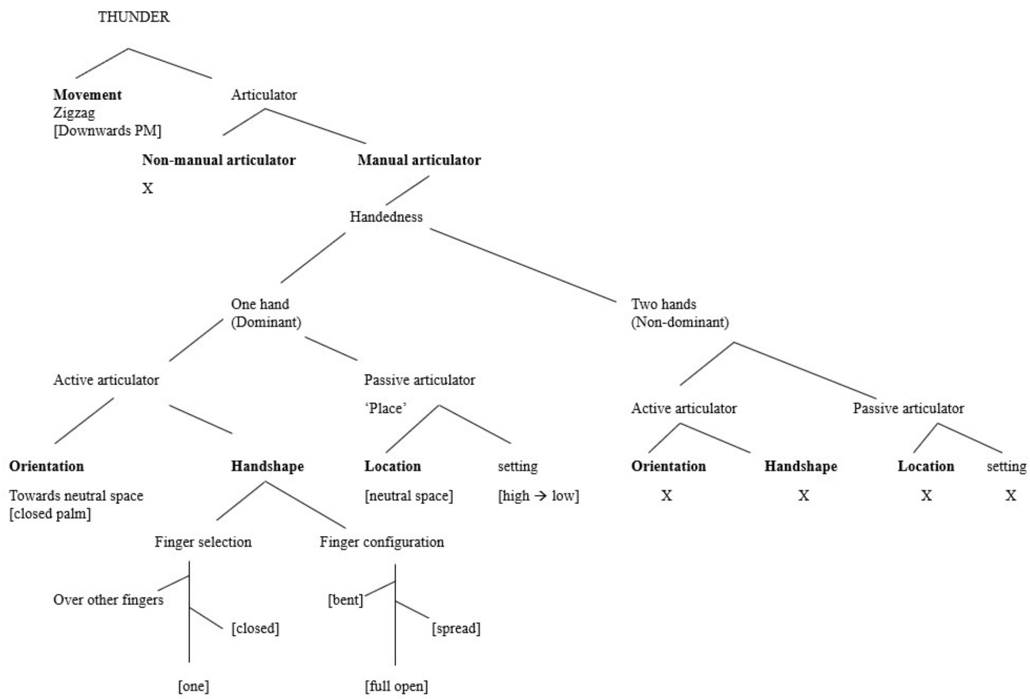


Figure 6: The new phonological hierarchy dependency model for the one-handed sign THUNDER

B. The phonological hierarchy dependency models for TREE

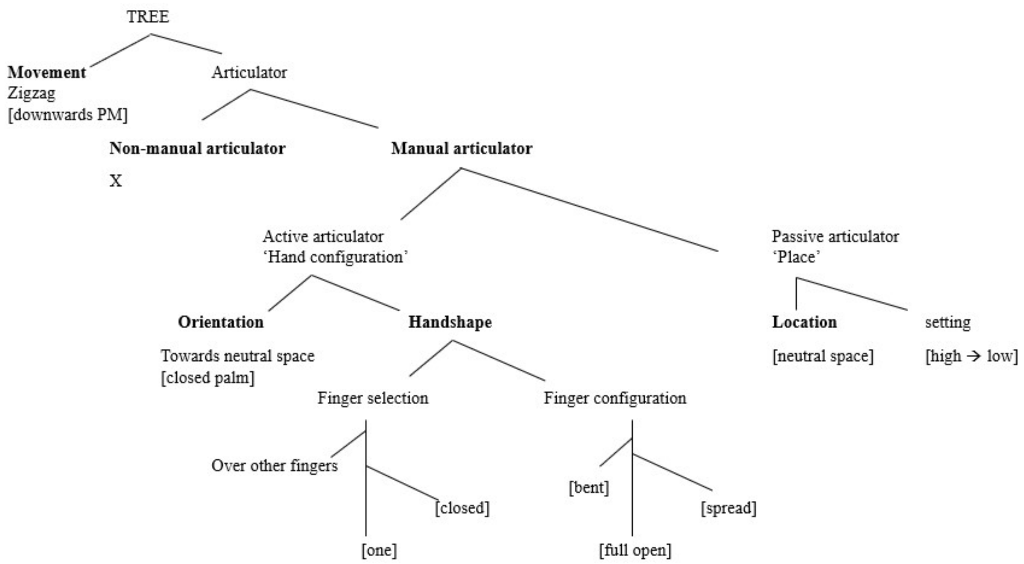


Figure 7: The old phonological hierarchy model for the two-handed sign TREE

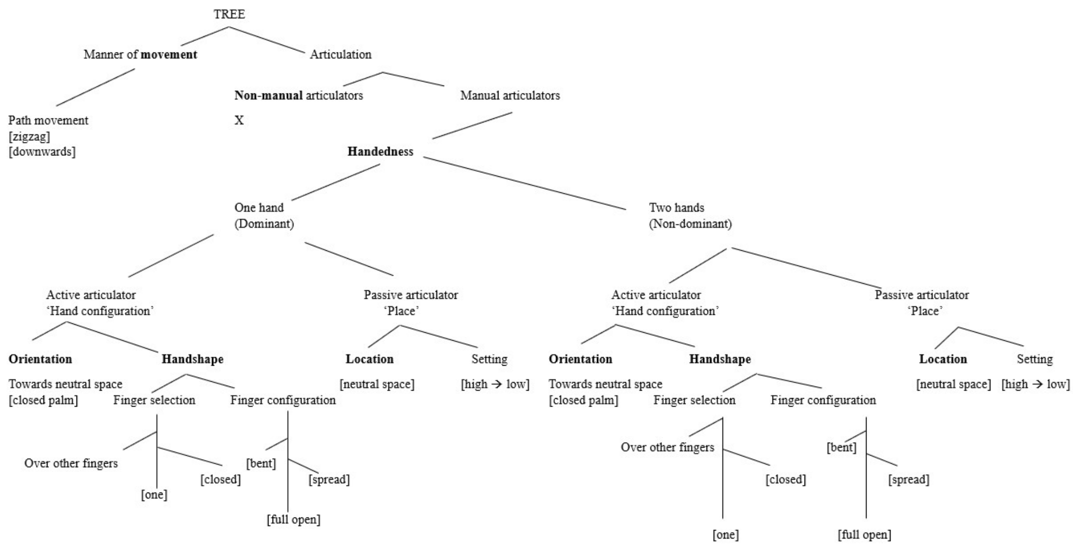


Figure 8: The new phonological hierarchy model for the two-handed sign TREE