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Form with no substance: Substance-Free Phonology and amodal grammars

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Substance-free approaches to phonology hold that phonological representations contain no information about their physical realization. If this is right, phonology should require no modality-specific machinery, and what spoken and signed languages share should abstract away from the channel through which either is externalized. This article asks what, exactly, is shared, and what neuroscientific evidence could bear on the answer. The answer is not a set of features. If features are individuated by their relations within a system, and if the inventories emerging in the two modalities differ in size, dimensionality, and organization, then there is no way to ask if a signer and a speaker possess the same feature. What is shared is the combinatorial architecture that generates phonological structure, the range of oppositions a contrastive system makes available, and the principles by which inventories are acquired. The inventories are modality- and language-specific, though substance-free; the mapping to phonetic exponence is acquired, modality-specific, and lies outside the grammar. It is argued that a feature specified in terms of one channel is uninterpretable to a learner acquiring a language in another. Neural evidence cannot settle whether two modalities share features, since no linking hypothesis connects features to neural objects. It can address whether the relations among representations correspond where their contents do not. That comparison is available through representational similarity analysis in bimodal bilinguals, and has not yet been attempted.

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1 Introduction

In substance-free approaches to phonology (see Hale & Reiss 2008; Chabot 2026), phonological representations do not contain substantive information about their physical realization. A segment such as /b/ may be specified by a feature like [+labial] in phonology which marks a natural class and distinguishes the segment from non-labials, but this feature does not import labiality as a physical property into the representational system. Rather, it functions as an abstract symbol whose phonetic interpretation is determined at an interface between phonological cognition and the sensory-motor system.

It is a fundamental assumption in the substance-free program that features do not contain phonetic substance, but there is disagreement concerning where features come from (see Chabot 2022 for discussion). Following a long tradition (Chomsky & Halle 1965), some substance-free theories hold that the inventory of such units is innate and universal (Volenec & Reiss 2017; 2020; 2022). Others hold that it emerges under acquisition (Chabot 2021; Dresher 2014; Odden 2022; Scheer 2022). §2.1.3 returns to this.

This paper proposes a discussion of this question in the light of the signed modality. An innate inventory with fixed phonetic correlates must be available to every learner independently of the channel they will acquire a language in, and a primitive specified in terms of one channel is not merely unused by a learner acquiring a language in the other—it is uninterpretable, there being, in most cases, nothing in the input to which it could apply. An emergent, language-specific inventory, however, has no such commitment. If representations are substance-free in this way, then a theory of phonology should require no modality-specific representational machinery, and what is common to spoken and signed languages should be something that abstracts away from the channel through which they are externalized. The question is what, exactly, is common to them in phonological terms. This article is an attempt to state that question precisely enough that it can be asked of cognitive neuroscience, and to work out what the answers would look like.

The argument is not that spoken and signed language share their phonological representations. Instead, it is assumed that features are individuated by their relations within a system (Sapir 1925), and if the inventories that emerge in the modalities differ in size, dimensionality, and organization, then there is no sense in which a signer and a speaker possess the same feature. Thus, what is common to modalities is not a stock of primitives, but rather the architecture that generates structure over them. That is to say, the combinatorial and contrastive machinery, the range of relations a contrastive system makes available, and the principles by which inventories are acquired. This is a distinction between the computational and the representational, and it is critical to the discussion here.

This article argues at three levels. The first is what is amodal: the capacity for constructing categories, the principles organizing them, and the range of oppositions available to a system

of contrasts. The second is modality- and language-specific but substance-free: the feature inventories that emerge in acquisition, which differ across languages and across modalities without thereby containing phonetic content. The third is modality-specific and lies outside the grammar: the mapping from phonological categories to their phonetic exponence, which is acquired alongside the system it serves.

The first level has been described before. van der Hulst (2000), and subsequently van der Hulst (2020), argues that the innate abilities underlying phonology are specific neither to phonology nor to spoken language, while the phonologies built from them are specific to a language and to a modality. The argument here is largely compatible with that view, but further argues that substance may constrain what a learner arrives at, but it may not enter into the categories that result. Berent (2026) makes a related claim, arguing that sign-naive adults parse signed syllables and extend restrictions on doubling to novel signs, and sign-naive infants extract reduplicative patterns from them. This is taken as evidence that phonology is amodal in a representational sense. A participant with no experience of a signed language has no inventory in that modality, so what is brought to the signed stimuli is at least the capacity to detect identity over units and to parse a signal into constituents.

Finally, it argues that the units of linguistic theory and those of neurobiological description are of different orders and may not describe the same kinds of object at all, meaning that whether a signer and a speaker possess the same feature is not the best question to ask. Rather, it is more appropriate to ask whether the relations among their representations correspond, by comparing the relational structure across the two modalities in bimodal bilinguals, at the level of phonological organization.

This article is not, as such, a complete survey of sign language phonology, nor does it compare representational frameworks comprehensively (see Brentari 2019; Fenlon et al. 2018; van der Hulst & van de Kooij 2020; Sandler 2014 for recent overviews). Further, it takes no position on long-standing debates within sign language scholarship, such as whether sign representations are best understood as segments or as syllables (Brentari 1993; Corina & Sandler 1993; van der Hulst 1993; Perlmutter 1992). For present purposes it suffices that sign representations are decomposable into atomic isolates which are meaningless by themselves but linguistically significant in their combinatorial relations.

The remainder of the article proceeds as follows. §2.1 sets out the architectural commitments of sign phonology, showing that sign exhibits a combinatorial, contrastive organization in which complex forms are built from meaningless atomic units. §2.2 examines representational models of sign and argues that their hierarchies are organized around the articulatory apparatus in a way that makes them modality-specific by construction. §2.3 develops the positive account, including the argument that amodality requires substance-freeness (§2.3.2), the evidence that phonetic exponence in sign is systematically non-transparent (§2.3.3), and the interface that the resulting

picture requires (§2.3.4). §3 asks what neuroscientific evidence could bear on the account, what the available evidence establishes, and what would challenge it.

2 Sign language phonology

Despite their substantially different sensory-motor implementation, sign languages exhibit many of the structural hallmarks traditionally associated with phonology in the vocal-auditory modality: discreteness, combinatoriality, contrast, and rule-governed patterning. Thus, at an appropriate level of abstraction, the phonological structure of sign languages can be meaningfully compared to spoken language phonology, despite the obvious difference in articulatory and perceptual systems used in each modality (Sandler 2006). This cross-modal commonality, in so far as it reflects something real about the structure of human brains and cognition, suggests the possibility of an amodal phonological architecture, since the shared properties are abstract and must be distinguished from non-linguistic sensory-motor effects in language production.

To say that two systems are unified is not to say that they share every property. A system that merges A with B and a system that merges X with Y are unified with respect to the operation MERGE, whatever the relation between the objects merged. The claim defended here is that phonological primitives have no content beyond their position in a system of contrasts. Thus, whether a signer and a speaker possess the same feature is not a question that can be asked independent of a correspondence between their systems as wholes. Since the inventories that emerge in the two modalities differ in size, dimensionality, and organization, no such correspondence is determined. What sign and speech share is the combinatorial and contrastive architecture that generates phonological structure, together with the acquisition principles by which inventories emerge. What differs is the structure of the inventories those principles yield. This is a distinction between the computational and the representational, and much of the difficulty in discussions of cross-modal unification follows from letting the two run together.

2.1 Compositional structure in sign phonology

Much early work in linguistics did not recognize any kind of systematic structure in sign language. For example, among the design features of language identified by Hockett (1960), was the “vocal auditory” channel, considered to be a basic property of language. This normative view which gives primacy to the vocal-auditory modality leaves sign language outside the bounds of human language (cf. Sapir 1921: 21). Indeed, in the view of Hockett, the vocal-auditory channel provided a distinct advantage in that the organs of speech and audition could be used for language while the hands and the rest of the body were free for other tasks during the production of speech.

However, the foundational work of Stokoe (1960 [2005]) demonstrated that sign language is characterized by another of Hockett’s design features: “duality of patterning”. This refers to the distinct levels of linguistic structure, including meaningful morphology and smaller, discrete

elements which carried no meanings themselves but could be combined at higher levels to produce meaning. Stokoe provided a strong argument that the vocal-auditory channel was just one modality by which human language can be expressed. Stokoe elaborated an analysis of American Sign Language in which morphemes are built from isolates, individual contrastive units built from configuration (handshape), position (place of articulation), and motion (of the articulators). Later work expanded on Stokoe's set of basic contrastive units, adding orientation (Battison 1978), and a variety of non-manual articulations at the face and mouth (Crasborn & van der Kooij 2013; Liddell 1980; Pfau & Quer 2010).

A minimal pair makes the contrastive status of these isolates concrete. In ASL, the signs commonly glossed APPLE and ONION are identical in handshape, orientation, and movement, differing only in place of articulation—the cheek versus the temple (Figure 1). The relationship between them is the same kind of relationship that holds between English *pat* and *bat*: two lexical items distinguished by a single contrastive specification along a single dimension, where the dimension itself defines a class of items that pattern together. What the labial/dorsal opposition does for English obstruents, the place opposition does here.

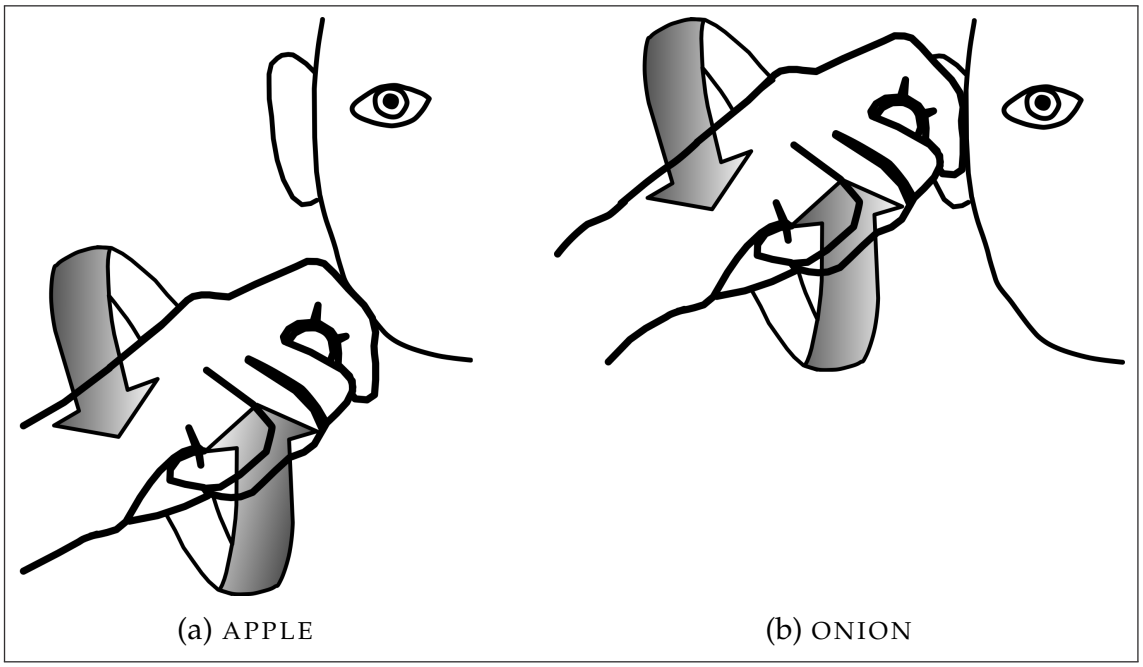


Figure 1: A minimal pair in ASL. Both signs share the same handshape (bent index) and movement (double wrist rotation). The difference is only in place of articulation: at the side of the mouth in **(a)** and at the temple in **(b)**.

In addition to the basic isolates just discussed, sign-language phonology makes a distinction between selected and unselected fingers (Brentari 1998; Mandel 1981). Selected fingers are

actively specified and constitute the contrastive articulatory set that defines a handshape, while unselected fingers are not contrastively specified and typically remain passive, constrained by default hand configurations. The distinction between selected and unselected fingers is the basis for further structure in signs, which are made in a set of joint-configuration features (Brentari 1998; Corina 1990; Eccarius 2008; van der Hulst 1995b). The selected/unselected distinction is functionally comparable to the notion of a designated or active articulator in models of spoken language, where a subset of the available articulatory structures is contrastively specified for a given segment and the remainder is either predictable or free (Halle 1995; Sagey 1986). In both modalities the point is not that the unspecified structures are absent from the physical event, but that they are absent from the representation.

Each of these individual isolates carries no meaning by itself,[1] but can be combined with other isolates to build morphemes and further higher-order structure. Since these isolates are categorical and compositional, substituting one for another yields a different lexical item, in just the way that distinctive features compose the speech segments stored in the lexicon in the vocal-auditory modality. Thus, at a basic level the compositional nature of contrastive isolates has an analogous functional role with the segmental features long used in theories of representation in the vocal-auditory modality. There are also organizational principles at work above these "segmental" features, as Stokoe (1960 [2005]) argues for suprasegmental features in sign language, manifest in facial expression and other non-manual cues which mark emphasis and prosodic boundaries.

2.1.1 Allochers and natural classes

Points of cross-modal comparison are not limited to static representations, but can also be extended to the interactions across signs during language production. Stokoe (1960 [2005]) identified *allochers* in sign—contextually conditioned variants of signs in complementary distribution. For example, during the production of a sign the index finger may pass near the tip of the nose, yet signers interpret the sign as being located at the eyes when the handshape and outward motion match patterns associated with vision-related signs. In this way, the combination of handshape and motion contextually guides the perceived location at the eyes, even though the physical point of contact may actually be the nose. Such examples of variations in non-contrastive location are allochers of the same underlying location: nothing in the representation changes, and the variation arises in the mapping to articulation.

Further research, both on adult use and acquisition of sign in children, has demonstrated the use of natural class and feature variation in ASL handshapes (Corina & Sandler 1993; Brentari 1998; van der Hulst 1995a; Sandler 2012; Whitworth 2011). Feature-based transcription systems

[1] This is compatible with the greater degree of iconicity that sign languages exhibit relative to spoken ones (see Bellugi & Klima 1976; Frishberg 1975; Pleyer et al. 2026). Iconic motivation may hold of a sign as a whole without holding of the isolates from which it is composed, and it is the latter that the argument here concerns.

decompose handshapes into properties such as finger selection and joint configuration, making it possible to identify contrastive units and natural classes of signs that share phonological features (Liddell & Johnson 1989). The phonological organization of signs, thus, is apparent in structured variation in sign and through natural class behavior defined over feature bundles.

2.1.2 Modality-specific temporal organization

These striking similarities are belied by the obvious physical, or phonetic differences between the signed modality and the vocal-auditory modality, in particular in its temporal organization. Representations in the vocal-auditory modality are frequently characterized as linear, where morphemes are built out of sequences of segments which line up one after the other like beads on a string. This conception is about mental representation rather than articulation, where speech gestures overlap extensively both within and across segments. Speech additionally carries tone, pitch accent, and intonation, none of which is linearly ordered with respect to the segmental string. The linearity at issue is a property of the phonological object, rather than any acoustic or articulatory event.

In the signed modality, the temporal distribution over time is not as linear; Stokoe (1960 [2005]) showed that handshape is typically constant across the duration of a sign, with meaning emerging from the co-occurrence of multiple contrastive dimensions rather than linear concatenation. For example, a single sign may use a movement to change location, while the handshape stays constant throughout these other changes, in particular in the dominant hand. Though handshape generally remains stable in the dominant hand while it executes a movement, the hand may exhibit limited internal sequences, such as changes in spatial position or directional movement over time (Liddell 1984; Liddell & Johnson 1989; Sandler 1989; Sandler & Lillo-Martin 2006).

Stokoe treated handshape, movement, and location as analogous to phonemes, with the difference between modalities being whether or not the basic units are linearly ordered. However, the major classes of spoken language—laryngeal, manner, place—are not linearly ordered with respect to one another either. Compared to a single segment rather than to a word, the sign structure is not anomalous. The difference between the modalities is therefore not the presence or absence of linear order, but that monomorphemic signs appear to be monosegmental where spoken words are typically polysegmental (van der Hulst 2000; 2020). Thus, simultaneity in sign is like the simultaneity internal to a segment in a system where a single segment often constitutes an entire sign.

This yields a phonological system in which paradigmatic organization takes precedence over syntagmatic organization, while still allowing for temporal structure within individual parameters. Signs are therefore best analyzed not as fully segmentalized objects, but as aspectual units composed of co-occurring structural components, some of which may unfold dynamically

(Brentari 1998). That is, signs are not interpreted holistically, but rather as an integrated system of internal temporal and spatial features. Though this quality of simultaneity is not as salient in the vocal-auditory modality, at an appropriately high level of abstraction, the temporal organization of sign languages is defined by structural relations rather than by modality-specific temporal primitives (see Idsardi 2025).

Thus, we have in sign a system which presents many common points with the abstract system governing the organization of language in the vocal-auditory modality, but which differs in the relative priority it assigns to paradigmatic and syntagmatic structure. One way of resolving this tension is to assume that the modality-specific aspects of externalization are not a part of the phonological grammar, and instead to impute them to acquisition unfolding in the context of a particular modality.

Stokoe noted that the very notion of time-span does not have the same perceptual salience in the visual channel as it does in the auditory channel. If the beads-on-a-string metaphor is appropriate for the linear order of segments in the vocal-auditory modality, then a snapshot metaphor may be more appropriate for the visual modality, which allows for a more immediate and holistic perception of sign. The simultaneous or paradigmatic organization of signs is made possible by the visual sensory-motor system and three-dimensional space, while the syntagmatic mode of the vocal tract makes this impossible in the vocal-auditory modality. In this view, the structure of sign phonology and of vocal-auditory speech are both governed by the human faculty of language, but the way that structure is externalized is determined by the language-specific experience of learners, and is not part of the representational vocabulary used by the grammar.

2.1.3 Where features come from

In this interpretation, modality-specific effects are imposed by physical constraints on the channel, not by the grammar. For example, the vocal-auditory modality has no equivalent to the “dual articulator” available in the signed modality (Sandler 2006), and so the temporality of speech is imposed on it by the machinery of the vocal apparatus. In turn, the mapping between representation and physical externality is not fixed in the grammar itself: an articulator is not bound by grammar to do one role and one role only. Instead, phonological features are substance free, emerging on a language-specific basis rather than in some immutable fashion determined by the genome (Dresher 2014; Odden 2022).

The commitment to emergent features is not shared across the substance-free program, however. Hale & Reiss (2003) argue that learning can only combine primitives already innately available, since parsing an input requires assigning it a representation, and that acquisition therefore proceeds by narrowing from a highly specified initial state rather than by adding contrasts to an impoverished one. Since at least Chomsky & Halle (1965) that inventory has been assumed to be innate and universal, and recent work in substance-free phonology from the

Concordia school has argued for the same ontology (Volenec & Reiss 2017; 2020; 2022), though features carry no substantive content. The disagreement is therefore not about whether phonology has innate structure or whether phonological objects encode substance, but about whether the inventory of features itself is determined by the genome and thus universal.

This article adopts the emergentist position, and investigates the signed modality in that light. In this view, what comes from the universal human endowment are the principles by which features can be organized synchronically and their valency manipulated, and constraints on well-formed syllable structure. This is compatible with the position developed by Berent (2026), who argues that the universal restrictions on syllable structure are abstract and algebraic rather than derived from articulatory or auditory pressure. What is argued to be acquired is the inventory of features itself.

The argument, developed in §2.3.2, is that an inventory fixed in advance of experience must be specifiable without reference to any particular channel, since the learner who will acquire a signed language is not distinguishable in advance from the learner who will acquire a spoken one. A primitive defined over vocal-tract configurations is not merely unused by a learner of a signed language, but is uninterpretable, since there is nothing in the input to which it could apply. The universalist position is thus presented with a dilemma. Either the innate primitives are contentful enough to be channel-specific, in which case they fail for one modality; or they are abstract enough to be channel-neutral, in which case it becomes unclear what work remains for innateness to do, since the inventory that emerges must still be fixed by experience.

2.2 Representational theories of sign language

As discussed in §2.1, the earliest work in the structure of sign language phonology split signs into basic isolates which co-occurred as mostly simultaneous units, rather than internally structured sequences (Stokoe 1960 [2005]). However, later work further developed this view, showing that isolates in the signed modality are subject to organizational principles which circumscribe the configurational possibilities. Sign demonstrates a clear hierarchy of available features, with dependencies that are quite familiar from models of feature geometry (cf. Clements 1985; Sagey 1986). One example comes from orientation. Early accounts of orientation treated it as a property of the palm (e.g., [up], [in], [prone], [contra]; see Liddell & Johnson 1989; Sandler 1989), but later work refined this to specify the orientation of one of eight parts of the hand relative to a place of articulation (Brentari 1998; Crasborn & van der Kooij 2013).

Another example of this kind of internal structure of signs is demonstrated by contrasts made at the joints, which depend on the distinction between selected and unselected fingers (Sandler 1989). Certain joint-configuration contrasts are available only on selected fingers, while being neutralized on unselected ones, a dependency relationship that motivates a hierarchical organization of features. The same kind of hierarchical relationship holds for the number of hands

used in a sign: many signs use both hands, rather than one, and the non-dominant hand may serve as a place of articulation (van der Hulst 1993; Sandler 1989; 2006; Sandler & Lillo-Martin 2006).

There are also implicational relationships between hands, demonstrated by the generalization that signs in which both hands move independently must use the same handshape on both hands (Sandler 2006). Finally, when finger shape is contrastive, as for example in the difference between extended versus curved fingers, this specification depends on the handshape allowing for open fingers (van der Kooij & van der Hulst 2005).

The discussion thus far has been intended to demonstrate that sign language phonology is built from distinct categories, each of them with a comparable functional role, but also with their own unique properties. Handshape and movement, for example, are both contrastive units, but work in slightly different ways and interact with each other in a way that is not strictly linear. The question for phonological theory, then, is how to represent these distinct, but interacting contrastive isolates.

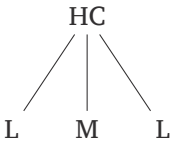
2.2.1 Hierarchical models of feature organization

Two architectural properties recur in representational models of sign. The first is autosegmental: phonological categories are distributed across tiers, so that a specification may be held constant while others change, and association between tiers can be built, dissolved, and relinked. The second is the dependency hierarchy of feature geometry: features are organized under class nodes, so that the availability of one specification is conditioned on another. The models examined below make use of both, but the representation in (1) illustrates only the first.

These architectural properties motivate theoretical models of representations in sign language phonology, of which I will briefly examine three: the Hand Tier (HT) model (Sandler 1989; Sandler & Lillo-Martin 2006), the Prosodic Model (Brentari 1998), and the Dependency Model (van der Hulst 1995b; van der Hulst & van de Kooij 2020; van der Kooij 2002).

The HT model (Sandler 1989; Sandler & Lillo-Martin 2006) represents hand configuration on a separate tier from location and movement, since hand configuration can be "held steady" over changes in movement and location in a single sign. In this model, then, hand configuration is an isolate at a higher tier than movement and location.

(1)



The model in (1) places movement—for example, [straight]—between two locations while the same hand configuration is realized over the entire movement sequence, and the locations at the start and end of the sign. Location, in turn, dominates place and other features which depend

on it, while features like selected fingers and joint configuration depend on the HC node. As in autosegmental theories, nodes are connected through association lines, which can be dissolved, relinked, and otherwise built to formalize the relationship between features and tiers to capture effects such as assimilation during the production of sign.

Other models of feature organization in sign differ in their details (see van der Kooij & van der Hulst 2005 and Sandler 2012 for informed overviews)—including which features they ascribe linguistic significance to—but the representation in (1) demonstrates the basic insight behind them all. For example, the Dependency Model (DM) (van der Hulst 1995b; van der Hulst & van de Kooij 2020; van der Kooij 2002) also builds a hierarchy of feature dependencies, though it uses a different set of basic isolates, removing movement and setting up dependencies between feature categories based on a couple of principles inherited from Dependency Phonology (Anderson & Durand 1986; van der Hulst & van de Weijer 2018). The DM also unifies temporal features by bringing in the familiar skeletal timing positions of autosegmental phonology to represent aspects of sign which are sequential.

The Prosodic Model (PM) is a further variant of the basic hierarchical architecture of the HT and DM representations (Brentari 1998). It makes use of some of the same feature categories in both, and incorporates the skeletal tier from the DM. However, the principal motivation behind the organization of features in the PM is the notion that movement features play a fundamentally prosodic role in signs. As a consequence, this model posits a root node which dominates two sets of features. The first set, known as Inherent features, includes the features at the dominant hand and selected fingers. The second set are Prosodic features, and include all features related to movement. These distinct tiers, being dominated by a single root node, are thus coordinated in their representation, but behave in different ways.

In the application of Radical CV Phonology to sign in van der Hulst (2020: 353ff.), the structure of signs requires an articulator node in addition to a place node, whereas models of spoken segments conflate the two—and the justification offered for the conflation is anatomical, namely that the relation between active articulator and location in the vocal tract is largely predictable, with many combinations impossible or too difficult to occur (van der Hulst 2020: 358f.). The number of class nodes is thus derived from facts about the body rather than from phonological patterning. A comparable point applies to the assignment of head status within the hierarchy, which in that model is fixed by the relative perceptual salience of the phonetic correlates (van der Hulst 2020: 364). Finally, in two-handed signs the articulator node is elaborated into strong and weak hands (van der Hulst 2020: 373), with a branching node because signers have two of them.

The logic of sign feature hierarchies in these models is easy to understand and provides a great deal of empirical coverage and explanatory power. These theories differ in their

formal details, and indeed the kinds of explanation they provide, but share some core insights concerning the hierarchical organization of features. These models are organized around the articulatory apparatus of sign, and in this they are like the feature geometries developed for spoken language, where the constituent structure recapitulates the vocal tract: the laryngeal and supralaryngeal nodes partition it, the articulator nodes are the active articulators, and features depend on the node whose articulator realizes them, so that [voice] falls under Laryngeal and the coronal features under Coronal (Clements 1985; Sagey 1986). The sign models reviewed above organize features in the same way over a different anatomy, with joint configuration depending on the selected fingers and orientation on the hand. In this way, they recapitulate the articulatory apparatus of the hand, arm, body, and other articulators in the structure of the representations. These models are thus modality specific, with a geometry shaped by articulatory and perceptual substance.

As a consequence, there is a tension here between descriptive and explanatory adequacy. The models discussed here account for restrictions on possible signs through their dependencies, in the same way as the vocal-tract geometries they are modeled on. These generalizations are about what can be articulated in a particular channel, and encoding them in the representations renders the system modality specific, excluding a computational architecture shared across modalities. The argument in §2.3 is that the restrictions are properties of the mapping to articulation rather than the objects mapped.

2.3 Towards an amodal phonology

2.3.1 Phonological representations as structural elements

The basic structural observations made by Stokoe (1960 [2005]) and expanded on by others demonstrate the fully linguistic nature of sign language, which uses a contrastive phonology, combinatorially generated from simultaneously realized parameters. Conceptually, if features are abstract symbols in a system of contrasts and indexes for natural-class definition, then the difference between the signed and vocal-auditory modalities need not be imputed to underlying linguistic competence, but solely to externalization. The vocal-auditory modality appears to maximize temporal sequencing and make minimal use of spatial specifications because of constraints inherent in the sensory-motor domain in which it operates. Likewise, signed languages exploit spatial relations and are not as strictly linear precisely because the modality makes such relationships possible (though see Idsardi 2025 for discussion of the special spatial relationships inherent in some movement in the signed modality).

That both sign and vocal-auditory phonological systems have a substantially shared computational architecture is not explained by models built on substantive primitives, because these must necessarily be modality specific, no matter how much other formal structure might be shared between them. Since the time of Saussure (1916 [1967]) and the structuralists, it has been

argued that phonological representations can be understood as part of a system of relationships, rather than in terms of their raw physical properties. What is relevant to the grammar in English /p t k/ versus /b d g/, for example, is not details of aspiration or voicing, but rather the fact that these obstruents stand in the same kind of relationship relative to each other as /f s/ and /v z/, and pattern together phonotactically and as a class for phenomena such as plural allomorph selection. That is, representational isolates are relational objects, defined by what they share and how they differ from other units in the system.

Sapir (1925) viewed phonemes as symbolically utilizable counters—abstract representations that organize speech sounds into paradigmatic and relational systems. What matters to this organizational scheme is not the precise phonetic detail of any given utterance, but the contrastive patterning of units in a language. The content of phonological representations is defined positionally, within the system and relative to other symbolic counters. If isolates are individuated in this way, their identity is fixed by the whole system in which they occur, and comparison across systems is correspondingly constrained. Two languages whose contrastive structures are isomorphic are, at the level of grammatical representation, indistinguishable since whatever differences hold between them are differences in how their categories are realized, not in the categories themselves. Whether a signer and a speaker possess the same feature is a question of the same kind, and it has no answer independent of a correspondence between their systems taken as wholes. The inventories that emerge in the two modalities differ in size, dimensionality, and organization, so no correspondence between individual features is determined.

Trubetzkoy (1969) classified oppositions by their type—privative, gradual, equipollent; bilateral or multilateral; proportional or isolated—in a way that requires each system to be described on its own terms while allowing systems to be compared by the kinds of contrast they employ. In this way, even cross-modal representations may be compared: what is shared across modalities is the range of relations available to a contrastive system, not the terms that stand in them. Modality shapes what emerges, since the categories a learner arrives at are constrained by the perceptual space in which contrast is available; and it is where the resulting categories are mapped to articulation, in an implementation that is acquired separately and lies outside the grammar (§2.3.3).

This presages the contemporary view that phonological representations are abstract, and is compatible with a view of phonological competence that is independent of sensory-motor systems. Put another way, a structural understanding of representations is compatible with an effort to unify the *computational* systems of the sign and vocal-auditory modalities: phonological representations in sign language need not encode modality-specific phonetic detail. As with spoken language, what is crucial is the system of contrasts and relationships, not the physical instantiation of each unit.

Categorization operates over a structured perceptual space, and groupings that correspond to no coherent region of that space are not learnable: the feature that would group initial *p* with final *t*, and exclude initial *t* and final *p*, is excluded not because it is ill-formed but because nothing in the input would lead a learner to it (Chomsky & Halle 1965: fn. 24). Substance does this work without entering the grammar, and the categories that result are individuated by their relations alone, while the computational system has no access to the space that shaped them. The emergentist model of van der Hulst (2000; 2020), allows perceptual salience to fix head status within phonological structure itself; on the view taken here, substance may constrain what a learner arrives at, but it may not appear among the relations that individuate the result.

2.3.2 What amodality requires

An amodal language faculty requires that phonological primitives be specifiable without reference to any particular channel. Suppose the faculty of language is amodal in the sense that a single acquisition mechanism constructs a grammar from whatever perceptual input is available, and suppose further that the mechanism has no advance knowledge of which channel it will be applied to. Then any representational primitive it manipulates must be specifiable without reference to a channel, for a primitive defined in terms of vocal-tract configuration is uninterpretable to a learner acquiring a signed language, and one defined in terms of manual configuration is uninterpretable to a learner acquiring a spoken one.

An innate inventory containing both is possible in principle, but it requires the learner to be endowed with representational machinery that will, for the overwhelming majority of learners, never be used. The alternative is that the primitives are contentless: their identity is exhausted by their position in a system of contrasts, and the channel enters only when the system is mapped to articulation. On this view substance-freeness is not an independent stipulation about representations, but a consequence of amodality itself.

This point is illustrated further by tactile sign languages, attested both as adaptations of an existing visual sign language, as when deafblind signers of Italian Sign Language transition to a tactile variety (Checchetto et al. 2018), and as systems conventionalizing in communities where touch is the primary channel from the outset (Edwards & Brentari 2020). Phonological structure emerges in these systems as it does elsewhere, over a perceptual space that is neither auditory nor visual. An innate inventory adequate to this would have to be specifiable in terms of three channels rather than two. Whatever the number of channels a phonology may be realized in, the learner cannot be assumed to know in advance which of them applies.

2.3.3 Representations in sign are phonetically underspecified

As suggested at the end of §2.1, it may be appropriate to assume that the mapping between representations and their physical correlates is not fixed in the grammar itself. That is, phonology

and phonetics cannot be derived one from the other (Sandler 2006). The composition of sign presents direct evidence in support of this view, in that there are strong arguments to be made that sign features do not need to encode anything about their physical correlates.

The work by Stokoe (1960 [2005]) and others shows that not only are sign isolates compositional, they are defined in relational terms, as part of a system. Further, the relationship between a sign feature and its physical realization is not one-to-one in either direction: the same physical configuration can serve contrasts of different classes depending on where it occurs. For example, [position] is signaled by proximity of the moving hand to places of articulation on the signer's body (e.g. temple, chin, and trunk). However, position can also be marked by the non-moving hand, in which case it is signaled through the configuration of that hand rather than the actual physical location. Thus, [configuration] (an extended index finger for example) marks contrasts along one articulatory dimension on the moving hand, and another on the non-moving hand, where an extended index finger can represent a contrast usually spelled out as [position]. Put another way, there is no substantive relationship between the physical configuration of the hand and its structural role as the [position] isolate.

A similar mismatch between the phonetics and phonology of sign is demonstrated by the split between the dominant hand and the non-dominant hand. During the production of a sign, the dominant hand is typically the locus for handshape features, but the non-dominant hand is still available to effect a contrast. However, the non-dominant hand contrast is part of the place of articulation paradigm, in a class with other body parts where place is used contrastively (generally the body and parts of the face). This means that hands can mark contrasts which are of entirely different classes, even though they are objectively the "same" articulator.

van der Hulst (2020) proposes to accommodate the two fundamentally different roles of the other hand by elaborating the articulator node into strong and weak hands, adopting that structure even for signs in which the other hand functions as the place. In this view, the weak hand remains a dependent of the articulatory node, while serving in the place paradigm. Typically, the strong hand is the signer's dominant hand, meaning that the grammatical distinction is between a head and its dependent, yet which physical hand realizes the head is not fixed by the grammar.

A similar point may also be made concerning the major class of motion features. For Stokoe (1960 [2005]), the motion isolate consists both of spatial displacement and of changes in configuration without displacement. Stokoe classifies both of these kinds of changes as motion because they serve the same structural function within the language, even though there is a kind of phonetic opaqueness in that it is not restricted to literal movement through space. Idsardi (2025) argues that movement with spatial displacement is indeed a special property of sign language, because it must contain two locations at two different times. Motion as a phonological notion, then, is not just interpreted as its phonetic cues, but rather as its phonological behavior (cf. Kaye 2005), as well as abstract relational properties.

These examples demonstrate that sign-language phonology groups an irregular set of phonetic cues under a single category, meaning that the mapping between phonology and phonetics is not transparent. Such mismatches between phonetic realization and phonological function are not peculiar to the signed modality (see Hamann 2014). For example, in the laryngeal domain, a single articulatory continuum modulates pitch gradiently, and that modulation is phonologized as categorically distinct objects—tone in one language, register in another—in ways that are not recoverable from the phonetics (Chabot to appear). Sign phonology, then, is organized around abstract, relational categories rather than modality-specific articulatory primitives, and in this it is no different from spoken phonology. The two modalities share an organizational system in which phonological identity is a function of the system, and is recoverable neither from its phonetic cue nor from the inventory of any other language.

2.3.4 Phonetic exponence requires an interface

If the content of representations, in any modality, is defined relationally within a phonological system, then there must be some way for the cognitive system to externalize them (Cohn 1998; Keating 1988; Kingston 2007; Hamann 2011; Reiss 2007; Scobbie 2007). This interface must be a mapping between phonology and phonetics which interprets between phonological symbols and instructions to the musculo-skeletal system and phonetic cues. If phonology is amodal, and representations are substance free, they must be language-specific and acquired through individual experience (Boersma 1998; Chabot 2022; Cowper & Hall 2015; Dresher 2014; Kingston & Diehl 1994; Odden 2022; Scheer 2022). On the other hand, if the feature system is innate and universal, a single invariant transducer which dispenses with language-specific interpretation is possible, since a given feature can be given a universal phonetic correlate (Volenec & Reiss 2017; 2020; 2022).

The mismatches between phonetics and phonology across modalities suggest that there is no universal, fixed interpretation of phonological categories. In sign, one physical configuration may serve contrasts of different classes depending on which hand carries it—one category is realized now by proximity to a body location and now by the configuration of the non-moving hand. Further, motion groups spatial displacement together with changes of configuration in place. What the interface does, then, is interpret. It translates between vocabularies at the two levels of description, performing no computation of its own, inserting and removing nothing, and altering no structure. It is exactly this property of the interface which makes it possible to confine modality-specific properties to it, and phonological structure to be united across modalities without the representations themselves being shared (Samuels et al. 2022).

This view must still account for well-known differences in the temporal organization of representations across modalities, most notably the extensive simultaneity characteristic of sign languages. However, if phonological representations are substance-free and relational, such

differences need not be encoded in the representational primitives themselves. Instead, they may emerge from the constraints that the sensory-motor systems impose on externalization. On this view, phonology need not posit modality-specific representational machinery to account for simultaneity in sign; rather, simultaneity can be understood as a property of the mapping from a shared computational architecture to a visual-manual articulatory channel.

Because the feature inventories that emerge are modality- and language-specific, the account does not predict that a signer and a speaker share phonological representations. What it predicts is that they share the computational machinery that operates over them: the combinatorial and contrastive architecture, and the principles by which inventories are acquired. The prediction is therefore not simply that the two modalities recruit overlapping cortical territory—overlapping activation is compatible with two distinct systems converging on similar implementation—but that the shared organization should be found at the level of computation while representational codes diverge. The following section is a brief overview of related neuroscientific literature, and some specific ways to test the representational distinctions made here.

3 Modalities in the brain

3.1 What the account predicts

The preceding section argued that sign and speech share the combinatorial machinery that generates phonological structure and the principles by which contrastive inventories are acquired. The argument in this section is that what amodal phonological grammars share is the computational architecture and the range of relations available to a contrastive system. The assignment of particular features to particular positions within that system, however, is not shared. The result is two systems whose internal organization is alike, while their contents are not. The claim is not about where phonological processing occurs but about the relations among its representations: what should correspond across modalities is the structure of the representational space, not the positions within it. I return to this question in §3.4.

That phonological processing in the two modalities should recruit overlapping cortical territory is what one would expect if a single system served both. It is also what one would expect if two distinct systems happened to converge on similar implementation, which is unsurprising given that both must interface with working memory, sequencing, lexical access, and so on. A finding compatible with both hypotheses is of no use in adjudicating between them. Nor does the observation that a region is active during a task establish that the computation associated with that region in other contexts is the one being performed, a difficulty known as the problem of reverse inference (Poldrack 2011).

The question is not new, and a survey of what neurophysiological work has established about phonological abstraction in the vocal-auditory modality is given by Monahan et al. (2026). They

point out that the datasets required to reveal language-particular abstract entities do not yet exist: what is needed is comprehensive multi-language material collected under shared experimental designs, since a representation that is specific to a language cannot be identified from work on one language alone. The same reasoning extends across modalities; if inventories are language- and modality-specific while the architecture generating them is not, then neither a single language nor a single modality will suffice to distinguish the two, and the comparison has to be made where the systems differ.

3.1.1 Granularity mismatches and incommensurability

As Poeppel & Embick (2005) point out, there are two major issues concerning linking hypotheses between linguistic theory and neurobiology. The first, known as the Granularity Mismatch Problem (GMP), is about size: linguistic computation involves fine-grained distinctions and explicit operations, while neuroscientific approaches to language operate in terms of considerably broader conceptual distinctions. For example, it does not follow that some active brain region encodes a category such as manner or place, since these are clusters of features and the encoding recovered from cortical responses is coarser than the phonological description that the question presupposes.[2]

The second is known as the Ontological Incommensurability Problem (OIP), and is about kind: the units of linguistic computation and the units of neurological computation are incommensurable. Within each domain the relations between objects and operations are principled—a distinctive feature and the operation of spreading belong to the same ontology, as do a dendrite and long-term potentiation—but the relations across the two domains are essentially arbitrary, since the two ontologies were developed independently and to capture generalizations of quite different kinds.

The GMP is in principle a soluble problem, since it is a matter of finer instruments and more explicit theory. The OIP is more thorny, since it is possible that no mapping between the two vocabularies is available. Whether a signer and a speaker possess the "same" feature is not a question suitable for neurocognitive inquiry, since there is no neural object for a feature to be comparable to. This does not mean that no correspondence between phonological and neural objects could ever be established, but that establishing one would require a linking hypothesis specifying what it would take for a neural state to count as a feature, and no such hypothesis is currently available.

[2] This bears on how the literature on the neural encoding of speech should be understood. Studies reporting tuning to manner, place, and voicing are detecting robust and systematic regularities (see Monahan 2026 for a useful overview). Correia et al. (2015) train a classifier to discriminate place of articulation within stops and find that it generalizes to fricatives, indicating that what is recovered is not the acoustic form itself. What generalizes is an articulatory code, available even in passive listening, and there is no expectation that the categories recovered should correspond to the phonological primitives of any particular language.

If features are individuated by their relations within a system, then a feature is not the sort of object that could be identified with a population of neurons, however precisely characterized. Two populations alike in every intrinsic respect would instantiate different features if the systems containing them were differently organized. What would have to be compared, even under ideal conditions, is not the states but the structures relating them. Further, Monahan et al. (2026) argue that the findings of the past decade support the existence of abstract phonological representations in auditory cortex. They also note that auditory, phonetic, and phonological properties are so closely correlated that no single experiment is likely to disentangle them, so that evidence must accrue across many experiments and many languages.

3.1.2 Integrated neurolinguistics and the amodal computational architecture

Poeppel & Embick (2005) propose that the appropriate connection between the two domains is at the level of computation, in models explicit enough that their primitives and operations are both plausibly executable by assemblies of neurons and plausibly constitutive of linguistic computation. A question is tractable, on this view, to the extent that it concerns an operation rather than an object, and a relation rather than a term. In that light, the prediction is that there is a shared architecture that generates structure over representations, along with a range of relations a contrastive system makes available. What is different is the assignment of particular categories to positions within that structure.

Embick & Poeppel (2015) distinguish three grades of connection between computational-representational theories and neurobiology. In *correlational* neurolinguistics, a theory of language is used to explore the brain, and the outcome is knowledge of what neural structures correspond to the representations and operations the theory posits. In *integrated* neurolinguistics, neurobiological evidence bears on the choice between competing theories. In *explanatory* neurolinguistics, properties of neurobiological structure account for why a theory of language involves the particular computations it does. Much work on the neurobiology of language remains at the first of these (Poeppel et al. 2012).

The discussion here is of the second kind. Confronted with two competing accounts of feature acquisition—one innate and universal, the other emergent and language-specific—neuroscience could potentially be used to adjudicate between them. Findings that a region is recruited during phonological processing in both modalities are correlational by construction, and do not adjudicate between theories that agree about which computations are performed. What would count is evidence about whether the same operations are carried out over inventories that differ, and whether the relations among representations are alike where their contents are not (see also Chabot et al. 2026).

3.2 Lesion evidence

The earliest evidence for domain-specific functional cortical anatomy comes from the work of Broca and Wernicke, who linked canonical left-hemisphere trauma to specific aphasia syndromes. Work on the signed modality established a parallelism: damage to left temporal regions produces characteristic patterns of aphasic dysfunction closely analogous to spoken aphasia (Hickok et al. 1996; Poizner et al. 1987; 1990). Across clinical studies, impairments in sign language comprehension and production are associated primarily with left-hemisphere damage, particularly to frontal and temporal regions traditionally implicated in language (Atkinson et al. 2005; Hickok et al. 2002). Critically, these deficits cannot be reduced to low-level visual, motor, or praxis impairments (Hickok et al. 1996).

Right-hemisphere damage in signers produces marked deficits in non-linguistic spatial cognition—fragmented drawing and figure copying, often with hemispatial neglect—while the core linguistic abilities are largely spared, and the converse pattern holds of left-hemisphere damage (Hickok et al. 1996; Poizner et al. 1987). Thus, the linguistic and non-linguistic uses of space do come apart, indicating that what the left-hemisphere network handles in signers is not spatial processing as such, and that signed languages engage the language system rather than a general visuomotor one (Klima & Bellugi 1979).

Evidence of this kind is correlational in the sense of §3.1: it identifies neural structures corresponding to the representations and operations a theory of language posits, without bearing on the choice between theories that agree about which computations are performed. Sign aphasia establishes that the left-hemisphere network is recruited for language in both modalities, and the parallelism of the syndromes indicates that it is recruited for structurally comparable purposes—morphological and syntactic composition anteriorly, lexical and phonological selection posteriorly. What it cannot show is whether the operations performed at those sites are the same operations. That a signer and a speaker with posterior lesions both make selection errors at the sublexical level is consistent with one system handling two inventories, and equally consistent with two systems whose breakdown profiles converge because both must select from a contrastive inventory under damage.

3.3 Neuroimaging and the shared fronto-temporal network

Neuroimaging offers more fine-grained inquiry into functional architecture. Across modalities, comprehension recruits a partially overlapping fronto-temporal network centered on the left inferior frontal gyrus (Brodmann areas 44/45) and posterior temporal cortex (STS/STG, often including BA22), regions implicated in abstract linguistic processing (Campbell et al. 2008; Emmorey 2006; 2015; Newman et al. 2015; Petitto et al. 2000). Meta-analyses of sign-language neuroimaging converge on left-lateralized frontal and temporal regions, mirroring functional asymmetries observed in spoken language (Trettenbrein et al. 2021). This shared network is

complemented by modality-specific sensory cortices supporting lower-level perceptual analysis in the auditory or visual domain, a division of labor consistent with a distinction between core linguistic computation and peripheral input systems (Buchweitz et al. 2009; Hagoort 2014; 2017; Friederici et al. 2017; Price 2010).

Petitto et al. (2000) found that deaf signers viewing meaningless but linguistically organized sign-phonetic and syllabic units, as well as real signs, showed bilateral activation in the planum temporale, where hearing controls viewing the identical stimuli did not, suggesting that this region is specialized not for speech sounds as such but for properties of linguistic patterning that can be realized in more than one modality. The cross-modal comparison in that study is direct at the lexical level, where signed and spoken verb generation elicited closely similar left inferior frontal activation, while at the sublexical level it rests on the independently established role of the same region in speech. Neural evidence on the tactile case remains sparse (Obretenova et al. 2010), though it is worth noting that basal temporal-occipital cortex, engaged during signed and spoken production alike, is also engaged during tactile reading by blind subjects (Crone et al. 2001).

That this shared network reflects linguistic rather than manual or praxic organization is shown by comparisons with non-linguistic gesture. Emmorey et al. (2011a) had deaf native signers generate ASL verbs and hearing non-signers produce pantomimes for the same objects, including ASL handling verbs which closely resemble the corresponding pantomime; verb generation engaged left inferior frontal cortex, while pantomime for the same objects produced no frontal activation, and both groups instead recruited left parietal cortex. Sign constructions that superficially resemble gesture therefore engage the left-lateralized language network rather than regions associated with praxis or spatial imagery (Newman et al. 2015). Sublexical processing can be isolated more directly using pseudosigns, possible but non-occurring forms conforming to the phonotactic constraints of ASL. These elicit greater activation in left posterior STS for deaf signers than for hearing non-signers, and for signers produce greater activation than known signs in left posterior STG, as in the pattern reported for spoken pseudowords (Emmorey et al. 2011b).

In Trettenbrein et al. (2024), functional regions of interest in left posterior inferior frontal gyrus and left posterior middle temporal gyrus and superior temporal sulcus were defined meta-analytically from a large dataset of syntactic processing in hearing non-signers. Deaf native signers of German Sign Language were then tested on stimuli systematically varying the presence of syntactic and lexical-semantic information. Those same regions were recruited for computing grammatical relations in sign. The two regions showed distinct response profiles—left pIFG responded specifically to the participants' native language, while left pMTG/STS also responded to signs unknown to them—mirroring a functional differentiation reported for spoken and written language. In this study, regions individuated by their function in one population are shown to serve the same function in another whose language differs in modality. That is a

comparison of organization rather than of location, and suggests that the shared network is modality-independent.

This kind of work is largely correlational: it establishes which structures correspond to the operations a theory posits, without adjudicating between theories that agree about the operations. As van der Burght et al. (2023) argue, any conclusion drawn from an experiment depends on a chain of auxiliary assumptions, theoretical and methodological, and where the theoretical commitments are left implicit the chain from result to interpretation cannot be evaluated. Establishing the neural basis of the abstract principles underlying language will need data from sign languages, from tactile sign languages, and from typologically diverse spoken languages, since operations assumed to be universal must be tested against representations that are language-specific (Trettenbrein 2025).

3.4 From networks to representational codes

The studies surveyed above establish that the two modalities recruit a common network, but they do not establish what is shared within it. The prediction is that the codes should differ even where the organization does not, and testing this requires methods that examine the pattern of activity across many voxels together, rather than to whether particular regions are engaged. Multivariate pattern analysis asks whether a distributed pattern of activity carries information sufficient to distinguish one condition from another (Norman et al. 2006), and so bears on whether signed and spoken representations are distinguishable at all. That such methods can operate at sufficient resolution is not obvious in advance, but Correia et al. (2015) train a classifier on place of articulation within stop syllables and find that it generalizes to fricatives, recovering structure that survives a change in the acoustic form. Feature-level organization is therefore not in principle beyond the resolution of the technique, though the generalization demonstrated there is across stimulus classes within one listener's system rather than across two.

The most directly relevant intracranial evidence comes from two case studies. Crone et al. (2001) recorded electrocorticographic gamma activity from subdural electrodes in a hearing interpreter who had acquired ASL in adulthood, producing words in both English and ASL across naming, reading, and repetition tasks. Spoken and signed production engaged many of the same regions, particularly those handling input processing, but diverged along somatotopic lines in sensorimotor cortex, with speech engaging tongue representations and signing engaging hand representations. Signing additionally recruited parietal sites where stimulation disrupted signed production—suggesting the interface to the manual channel makes demands beyond the articulators themselves, plausibly the integration of linguistic structure with visuospatial representations of the gestures that realize it. Leonard et al. (2020) recorded high-density electrocorticographic activity from a subdural grid over sensorimotor cortex in a profoundly deaf signer with early ASL exposure, and found activity there organized along dimensions defined

by ASL phonology: location and handshape are separably encoded, with a temporal hierarchy in which location classification peaks before movement onset and handshape shortly after. What these studies suggest is a division of the kind discussed in §2.3, with convergence where computation is shared, and divergence where articulation is not.

Representational similarity analysis is a statistical technique used to ask if two representations carry information that is organized in the same way (see Kriegeskorte et al. 2008a; b). Kriegeskorte et al. (2008a) observe that the units of a computational model and the channels of a brain-activity measurement cannot in general be placed in one-to-one correspondence, and that where no such mapping exists, attempting to define one is ill-motivated. They propose instead abstracting from the activity patterns themselves to representational dissimilarity matrices, which characterize the information a representation carries rather than the states that carry it. This is one remedy to the incommensurability problem raised in §3.1.1: rather than attempting a unit-to-unit mapping, it compares structures across vocabularies. This is offered as a way of relating representations across measurement modalities, across subjects, and even across species. As such, it does not require that a feature be identified with a neural object, and yet offers a concrete way to compare organization.

Using representational similarity analysis with hearing early sign-speech bilinguals, Evans et al. (2019) compared neural patterns evoked by the same concepts presented in spoken English and in British Sign Language. In left posterior middle and inferior temporal gyrus, individual items and semantic categories were both encoded within a modality, but across modalities only categories were, with item-level encoding significantly stronger within than across. In modality-specific regions the coding was item-based and retained sensitivity to auditory and visual features, which the authors interpret as evidence of word and sign form representations situated in auditory and visual cortices respectively. Put another way, the terms of comparison are different, but their organization corresponds, and what is modality-specific is not in any common cortical geography, but rather in the systems that transduce.

The methods from Kriegeskorte et al. (2008a) applied to a population like that of Evans et al. (2019) could be adapted for inquiry into phonology across modalities. Bimodal bilinguals hold the learner constant while the modality varies; representational similarity analysis compares organization without requiring that any feature be identified with a neural object. Such a design would allow for a direct question: do the relations between a signer's phonological categories correspond to the relations among a speaker's, despite disparate kinds of categories themselves.

3.5 What non-confirmation would look like

In §3.1, I suggested that there is no shared representational code across modalities, and that instead features are substance-free and emerge during acquisition in a language-specific fashion. If a single acquisition mechanism must construct a grammar from whatever channel is available,

the primitives it manipulates cannot be specified in terms of a channel. This hypothesis makes predictions that could be shown to be inadequate in several ways.

The first concerns the inventory. If the representational codes recruited by a signer and by a speaker were found to correspond at the level of individual categories rather than only in their relational organization, the case for an innate and universal feature inventory would be considerably stronger than anything argued here. The design able to establish this is the multivariate comparison within bimodal bilinguals described in §3.4, where the learner is held constant and the modality varies. Evans et al. (2019) report the opposite pattern for conceptual representations, with item-level encoding significantly stronger within than across modality. If the corresponding question were asked at the level of phonological structure instead, a result showing item-level correspondence would constitute an argument in favor of the universalist position.

The second concerns the architecture. The claim that the combinatorial machinery is amodal rests on evidence that the same network is engaged for structure-building in both modalities. Were that network to split under finer analysis into modality-dedicated subnetworks—if what seemed to be a common region proved, at the resolution of multivariate methods, to comprise separable populations for signed and spoken structure—then the appearance of a shared architecture would be an artifact of spatial resolution, and the convergence would be the convergent implementation of two systems rather than the operation of one.

The third concerns the interface. In this account, modality-specific detail is placed in the mapping to articulation and perception, outside the grammar. Evidence that feature-level encoding in sign is found in the core language network rather than close to the systems that transduce it, where Leonard et al. (2020) found it, would threaten this account, since the modality-specific information would then be located where the account says only amodal computation occurs.

Finally, a class of potentially confirmatory neural results can also be identified. Within bimodal bilinguals, neural patterns whose similarity structure for signed phonological categories matches that for spoken ones. This is the same kind of comparison made by Evans et al. (2019), where category structure corresponded across modality and item-level encoding did not, transposed to a level at which the competing accounts of the inventory actually differ. A similar result, showing that the two systems are organized alike but their contents are not would be in line with an amodal architecture operating over emergent, modality-specific inventories.

In order to use techniques from cognitive neuroscience, it is necessary to formulate questions which can actually be specified and answered. For example, whether representational codes correspond across modalities at the level of individual categories or only in their organization; whether the network that appears shared at the resolution of current designs remains shared under multivariate analysis; and whether feature-level encoding in each modality is situated near the systems that transduce it. These are questions the universalist and the emergentist should

both want answered, since the accounts make different predictions about each. That they can be posed at all is a consequence of having specified the representational commitments first.

3.6 Summary

The evidence surveyed here bears on the computational half of the architecture and is largely silent on the representational half. The vocal-auditory and signed modalities recruit a largely overlapping, left-lateralized network centered on inferior frontal and posterior temporal regions, with modality-specific sensory and motor cortices engaged at the periphery, and the lesion literature converges with the imaging literature. Functional regions defined by their role in syntactic processing in hearing non-signers are recruited for the same purpose by deaf signers (Trettenbrein et al. 2024), and infants with no exposure to any signed language bring to signed stimuli a rule system they also bring to speech (Berent et al. 2021). The latter establishes a channel-neutral operation in a design where shared representations are excluded by construction.

The intracranial evidence points the same way at the level of the interface, with articulatory and phonological organization appearing close to the systems that transduce it in both modalities (Crone et al. 2001; Leonard et al. 2020), though both are single cases and neither was designed to compare codes. Correlational findings do not adjudicate between theories that agree about which computations are performed. The multivariate study by Evans et al. (2019) showed a correspondence in organization with a concurrent divergence in the terms. Though this study was done on conceptual structure, rather than phonological, it proposes the right design to ask the question.

4 Conclusion

This article set out to ask what signed languages suggest about the neural correlates of phonological activity, and to ask it in the light of a specific set of commitments about what phonological representations contain. Among those commitments, the article argued that phonological features have no inherent phonetic content. The inventories in which they figure emerge during acquisition and are language- and modality-specific. What is common across modalities is not the inventories but the architecture that generates structure over them, together with the range of relations a contrastive system makes available. The mapping from categories to their phonetic exponence is acquired, modality-specific, and lies outside the grammar.

Sign language is the empirical basis of two arguments in this paper. §2.3.2 is an argument that a mechanism that builds a grammar from whatever channel is available cannot manipulate primitives specified in terms of a channel, since such primitives are uninterpretable to a learner acquiring a language in the other one. §2.3.3 argues that the mapping between phonological category and phonetic cue in sign is systematically non-transparent, with one

physical configuration serving contrasts of different classes and one category realized in unrelated ways depending on where it occurs.

The models surveyed in §2.2 all achieve a great deal of generalizing power by using a system of dependencies and nodes which recapitulate anatomy. They have the additional virtue of encoding restrictions on possible signs. The argument here is that those restrictions belong to mapping to articulation rather than the representations. Locating the anatomy in the representations is what makes the resulting systems modality-specific, thereby precluding unification.

§3 is a discussion of cognitive neuroscience investigations into sign and its neural foundation. I argue that whether a signer and a speaker possess the same feature is not a question neural evidence can decisively settle, since there is no neural object for a feature to be compared to, and no linking hypothesis specifying what it would take for a neural state to count as one. Evidence that both modalities recruit overlapping cortical geography is reviewed, but this evidence is of limited use in adjudicating between one phonological system serving both or two phonological systems converging on similar implementation. What can be fruitfully asked is whether the relations among representations correspond across modalities where their contents do not—a question about organization rather than content.

The available evidence is mostly relevant to the computational wing of the grammatical system. The two modalities recruit a common fronto-temporal network (Trettenbrein et al. 2021), and functional regions individuated by their role in syntactic processing in hearing non-signers and deaf signers (Trettenbrein et al. 2024). Infants with no exposure to any signed language bring to signed stimuli a rule system they also bring to speech (Berent et al. 2021), in a design where shared representations are excluded by construction. One study to have compared representational structure across modalities in the required design reports the anticipated pattern—correspondence in organization, divergence in the terms—but for conceptual rather than phonological structure (Evans et al. 2019). The comparison that would discriminate the competing accounts of phonological features and inventories has not been made at the level where they differ.

This article has tried to specify what is required for answerable questions to be asked. Within Substance-Free Phonology, the universalist and emergentist accounts of features make different predictions, but both have the virtue of having specified their representational commitments. Establishing the neural basis of the abstract principles underlying language will require evidence from signed languages, from tactile signed languages, and from typologically diverse spoken languages (Trettenbrein 2025), where computational operations that are assumed to be universal can be tested against representations that are not.

Competing interests

The author has no competing interests to declare.

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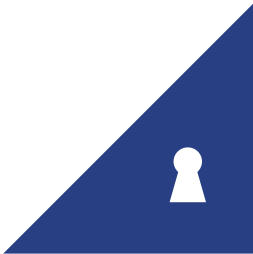
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