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Iconicity as an organizing principle of the lexicon

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The view that words are arbitrary is a foundational assumption about language, used to set human languages apart from nonhuman communication. We present here a study of the alignment between the semantic and phonological structure (systematicity) of American Sign Language (ASL), and for comparison, two spoken languages—English and Spanish. Across all three languages, words that are semantically related are more likely to be phonologically related, highlighting systematic alignment between word form and word meaning. Critically, there is a significant effect of iconicity (a perceived physical resemblance between word form and word meaning) on this alignment: words are most likely to be phonologically related when they are semantically related and iconic. This phenomenon is particularly widespread in ASL: half of the signs in the ASL lexicon are *iconically* related to other signs, i.e., there is a nonarbitrary relationship between form and meaning that is shared across signs. Taken together, the results reveal that iconicity can act as a driving force behind the alignment between the semantic and phonological structure of spoken and signed languages, but languages may differ in the extent that iconicity structures the lexicon. Theories of language must account for iconicity as a possible organizing principle of the lexicon.

language | iconicity | systematicity | phonological similarity | semantic associations

Significance

Contrary to the widely held assumption that words are arbitrary symbols for their meaning, this study shows that when words have similar meanings, they are also similar in phonological form. Further, we find that iconicity (a physical resemblance between word form and word meaning) influences this alignment in American Sign Language (ASL), English, and Spanish. Iconic systematicity is present in half of all ASL signs but rarer in the spoken languages studied. These results suggest that rather than a fringe phenomenon, motivated form–meaning associations can act as a fundamental organizing characteristic of human languages.

Until the 1970s, the field of Linguistics relied exclusively on investigations of spoken languages. As a consequence, linguistic properties that are pervasive in sign languages but limited in speech played a marginal role in linguistic theory. Perhaps the starkest example of this is iconicity, where the form of a word or sign can resemble its meaning. While sign languages have phonological structure (i.e., handshapes, locations, and movements are combined in rule-governed ways to create signs, just as speech sounds are combined to create words), signs can also resemble their meanings [e.g., the American Sign Language (ASL) sign STIR[*] bears a perceivable physical resemblance to the act of stirring]. Although a substantial proportion of sign language lexicons appear to contain some degree of iconicity, words in spoken languages are thought to be largely arbitrary—their pronunciations bear little to no perceivable relationship to their meaning [e.g., words meaning "to stir": *remuer* (French), *míchat* (Czech), *Khn* (Thai), etc.]. The historical bias for spoken language led to the assertion that arbitrariness is a defining feature of human language (1–3). The central idea was that because the forms of words are not tied in any way to their meaning, language serves as an abstraction from direct perceptual experience and allows humans to communicate infinite meanings in infinite contexts using only a finite set of speech sounds. This claim that languages are fundamentally arbitrary still holds a central position in linguistic theorizing, and popular linguistics textbooks still make claims like: "Despite occasional iconic characteristics, human language is essentially arbitrary" (4), and list arbitrariness as a defining property of human language (e.g., 5).

Unfortunately, the centrality of arbitrariness to early linguistic theory led researchers to ignore or, at best, downplay the ways in which form and meaning are in fact related in human language. The existence of onomatopoeia (words whose phonetic form mimics their referent's sound, e.g., "whoosh", "meow", "whack") and phonesthemes (sequences of sounds that semisystematically occur in words with particular semantic features e.g., /sn/- is used in words relating to noses: "snort", "sniff", "sneeze", "snout") has long been recognized in spoken languages (e.g., 6). However, despite their consistent cross-linguistic presence, these phenomena are often considered marginal exceptions to the rule: that words are arbitrary symbols.

In recent decades, however, research into the nonarbitrariness of language—both signed and spoken—has continued to grow. Across the literature "arbitrariness" is positioned as the opposite of two related but not identical constructs: iconicity and systematicity. We operationalize "iconicity" as a motivated, structured mapping between the perceptual properties of a person's phonological and semantic representation of a lexical item (7). For example, in ASL the motion and location of the two hands in the sign RECORD correspond to two

[*]In this paper, English glosses of signs are written in uppercase. For the convenience of the reader, we have provided links to videos depicting these signs.

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reels in a cassette or "reel-to-reel" player[†]. 'Systematicity' is when two or more lexical items share both meaning and some elements of phonology. For example, /gl/ appears across English words relating to light ("glimmer", "gleam", "glow"). In this paper, we explore both iconicity, systematicity, and the intersection of the two. Systematicity need not be iconic (e.g., /gl/ bears no resemblance to light), which we refer to as noniconic systematicity. In some cases, systematicity and iconicity co-occur (iconic systematicity), as in the cluster /sn/, (which includes a nasal sound and is used in words relating to noses: "snort", "sniff", "sneeze", "snout"; this particular mapping is common cross-linguistically; (8). See (9) for a detailed overview of the intersection of these phenomena. Studies have also demonstrated that iconicity plays an important role in language evolution, language acquisition, and language processing [see (10), for review]. Sign languages in particular exhibit sophisticated mechanisms of iconic form–meaning mapping, and recent work has demonstrated important cross-linguistic generalizations for how meaning may be expressed in sign-based phonology (e.g., 11–14). Collectively, the pervasiveness of these findings forcefully indicates that iconicity must be the subject of linguistic inquiry.

While much of what we know about iconicity has focused on the mapping between a single lexical form and a single meaning, a handful of studies have identified iconic mappings that occur systematically across the lexicon. These studies have generally proceeded in a top–down fashion where researchers identified a potential iconic vehicle and then collected data to adjudicate whether this relation was in fact borne out within or across languages. For example, (11) observed that signs for concepts that inherently include multiple entities (e.g., eyes, shoes, family) are frequently denoted by two-handed signs. Similarly, (15) examined signs in ASL and Libras (Brazilian Sign Language) that used a claw handshape, and found that across both languages convex/concave shapes were frequently denoted by signs using a claw handshape (such as BALL or BOWL in ASL). Studies of spoken languages also often examine researcher-identified associations between certain phonemes and meaning [e.g., /k/ with sharpness in the classic bouba/kiki effect; (16)].

The top–down approach exemplified by (11) (15) allows researchers to rigorously collect evidence for the existence of individual iconic mechanisms and has revealed important high-level patterns across languages (e.g., 14). However, a drawback of this approach is that it takes researcher-identified vehicles as its starting place and thus may miss subtler iconic form–meaning relationships in favor of ones that are highly salient or more readily perceivable. Second, this approach sometimes involves focusing on selected sets of signs (e.g., those that are conceptually plural), making it difficult to identify, describe, or quantify broader patterns across the lexicon. As a result, it remains unclear whether iconic systematicity is restricted to small pockets of the lexicon, or whether iconic systematicity is a pervasive pattern of form–meaning correspondence that exists across languages.

Briefly setting aside iconicity, bottom–up, lexicon-wide analyses have revealed that there is more systematicity than expected by chance in both spoken and sign languages (17, 18). Blasi et al. (8) documented patterns of sound-meaning associations in a set of 100 words *across* thousands of spoken languages. Using vector space models, Martinez del Rio et al. (18) showed that systematic form–meaning relationships are prevalent in the lexicons of ASL and British Sign Language (which are mutually unintelligible sign languages, unlike their countries' shared spoken language—English). While these studies speculated about iconicity as a possible mechanism underlying the observed systematicity, no studies to date have been able to document this phenomenon. Martinez del Rio et al. (18), for example, demonstrated systematic relationships in ASL and BSL but did not empirically test the role of iconicity in these relationships. Our study addresses this gap by explicitly examining the role of iconicity in systematicity across ASL, English, and Spanish, thereby providing a more comprehensive understanding of how iconicity contributes to lexical organization in both signed and spoken languages.

In the present project, we developed the largest lexical dataset of any sign language, allowing us to use a bottom–up approach to document iconic and noniconic systematicity across the lexicon of ASL. For comparison across languages and language modalities, we leveraged parallel datasets of spoken English and Spanish. As above, systematicity is defined as a systematic alignment between words' phonological and semantic properties, i.e., similarity in meaning is systematically associated with similarity in form. We determined semantic similarity using data from semantic association tasks (described more extensively in *Materials and Methods*), in which native users of each language were asked to provide the first three words that came to mind in response to a cue word. We then integrated semantic similarity with estimates of phonological similarity between the pairs. This approach enabled us to identify alignment between semantic and phonological relatedness in pairs of words in each language (using three large datasets). Finally, we obtained word-level iconicity ratings for each of the languages (7, 19–21). With these data, we asked: In each of the languages, does iconicity magnify the relationship between semantic and phonological similarity such that word pairs are most likely to be both phonologically and semantically related when they are iconic? (Fig. 1)

Results

Statistical Analysis. We conducted a mixed effects linear regression analysis that predicted the phonological distance between pairs of signs in ASL (measured in number of differing phonological features), based on the items' iconicity rating and semantic relatedness. The model included as predictors: semantic relatedness (related/a semantic associate, or unrelated/not an associate), summed iconicity ratings for the pair, and an interaction between semantic relatedness and iconicity. The models also included random intercepts of each word in the pair. To control for the role of morphology in driving systematicity, we focused our analyses on monomorphemic words. We found a significant main effect of semantic relatedness, such that semantically related sign pairs tended

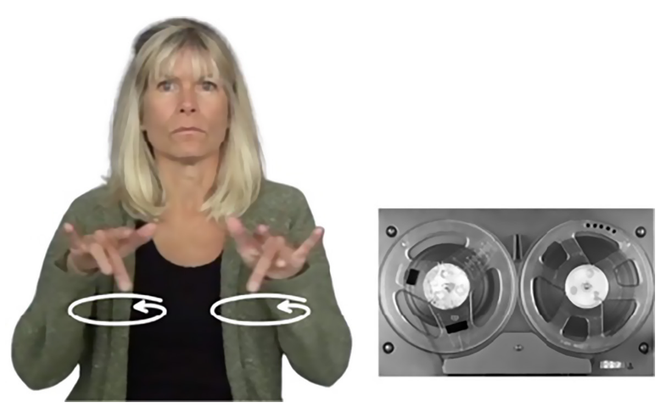

Fig. 1. The ASL sign RECORD and a reel-to-reel tape recorder.

[†]Iconicity is inherently subjective and depends on a person's perceived relationship between semantic and phonological representations (i.e., RECORD might not be iconic to a person who has only ever used it to refer to electronic recordings).

to be more phonologically similar than semantically unrelated pairs [β = −1.13 (−1.18 to −1.09), $P < 0.001$]. The model also contained a significant main effect of iconicity [β = −0.07 (−0.10 to −0.04), $P < 0.001$], wherein highly iconic pairs were more phonologically similar than less iconic pairs. Critically, there was also a significant interaction between semantic relatedness and iconicity [β = −0.16 (−0.20 to −0.11), $P < 0.001$]. Specifically, iconicity magnified the relationship between semantic associations and phonological similarity; the effect of semantic relatedness was stronger for more iconic signs; words were even more phonologically similar when they were semantically related and iconic (Fig. 2).

We follow up by asking whether this disproportionate effect of iconicity on form–meaning relationships is specific to the visuo-spatial nature of ASL, or whether iconicity plays a similar role in the lexica of spoken languages as in sign languages? We therefore fit two parallel models onto spoken languages, one for English and one for Spanish, where we predicted the phonological similarity between pairs of words (measured in number of differing phonemes) based on semantic similarity, iconicity, and an interaction between semantic relatedness and iconicity. Parallel to the ASL results, we found that semantically related word pairs tended to be more phonologically similar than semantically unrelated pairs [English: β = −0.16 (−0.16 to −0.16], $P < 0.001$; Spanish: β = −0.28 (−0.29 to −0.26), $P < 0.001$], and highly iconic pairs were more phonologically similar than less iconic pairs [English: β = −0.22 (−0.24 to −0.20], $P < 0.001$; Spanish: β = −0.03 (−0.06 to −0.00], $P = 0.026$]. Last, as in ASL, we additionally observed an interaction between iconicity and semantic relatedness wherein iconicity seemed to amplify the effect of semantic relatedness on phonological relatedness [English: β = −0.03 (−0.04 to −0.03), $P < 0.001$, Fig. 2; Spanish[‡]: β = −0.01 (−0.02 to 0.00), $P = 0.047$, Fig. 2]. Summaries of model results are provided in Fig. 2 and Tables 1–3.

Data Visualization. In order to explore phonological and semantic relationships between word pairs, we next present network visualizations of systematicity for each language. In these networks (Figs. 3–5), each node represents a word. We first filtered each dataset to word pairs that were systematically related to each other, as defined by 1) they shared at least half of their phonemes with each other and were freely associated by at least 2 participants—word pairs that met these criteria were connected by an edge. We then excluded words that did not share at least one edge with another word. Note that this definition of semantic relatedness is stricter than in the statistical analysis (e.g., we require that at least two versus one person associated the items, excluding words that were not related to any other words)—this is because more aggressive pruning helped to simplify the network visualization. While the pruned network is more interpretable, it is based on an arbitrary cut-off for whether pairs are systematically related, and thus does not include the full continuum of possible systematic relationships. We then organized the networks using the Fruchterman–Reingold algorithm, which is a force-directed algorithm that attempts to identify an equilibrium in a network such that nodes are generally repelled from one another, but nodes that share an edge are drawn toward one another. For each network, we measured the percentage of words that were connected to at least one other word, the average number of connections for each node (mean degree), and the percentage of nodes in the network that formed part of the largest connected component (giant component). Within the giant component, we also measured the shortest path between each word and each other word in the component (mean path length) and whether a word's associates shared direct connections with one another (clustering coefficient). To view these networks, see Figs. 3–5, and see Table 2 for network measurements. Additionally, to examine the network structures of high- and low-iconicity words, we filtered the nodes in the networks using a within-language median split on iconicity. We then recomputed network statistics for the high-iconicity and low-iconicity words. For these filtered networks, see *SI Appendix*, Figs. S1–S6.

What we observe in the network plots is that the ASL lexicon is rife with systematicity. Based on our criteria for systematicity (word pairs semantically associated by at least two people and share at least half of their phonological features), 54% of the ASL signs ($n_{systematic/total}$ = 1,334/2,461 words) were included in the ASL systematicity network. The ASL network was characterized by relatively long chains of sparsely connected signs (Mean path length = 13.5; 22% of nodes appeared in the giant component), and signs tended to be systematically related to multiple other signs (Mean degree = 0.966).

Visualizing the data in this way showcases clusters of signs that share elements of form and meaning. For example, the ASL systematicity network (Fig. 3) includes a cluster of iconic signs that related to food and are produced near the mouth [e.g., EAT, DRINK, SPICY, as described in (12) and a cluster of signs that relate to family and are produced on the head [e.g., as expected,

[‡]For transparency, in an earlier version of the manuscript, when polymorphemic words were included in the analyses, the effects of semantic relatedness and iconicity in Spanish were additive, rather than interacting. Results of these earlier models are included in the *SI Appendix*.

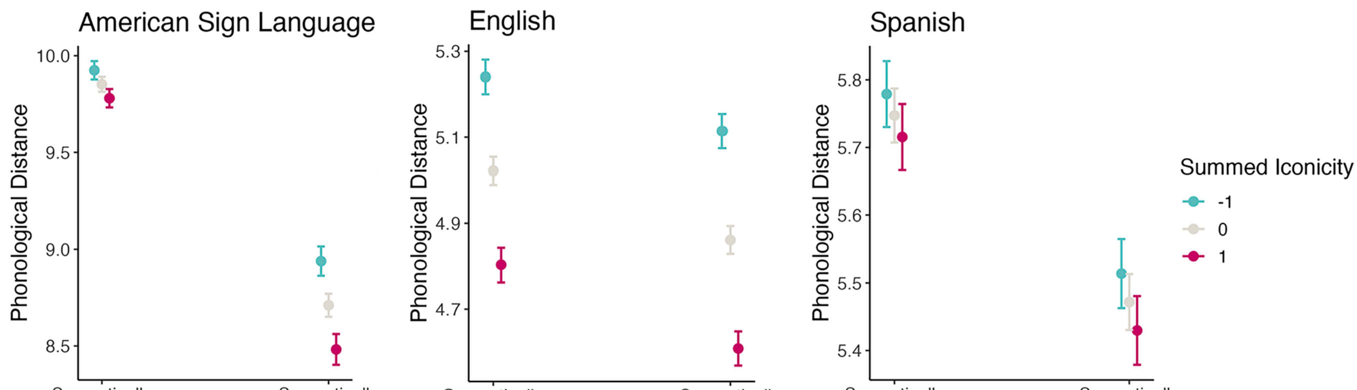

Fig. 2. Interaction effects between semantic relatedness and iconicity on the phonological distance for (*Left*) American Sign Language, (*Middle*) English, and (*Right*) Spanish. Error bars show SD around the mean.

Table 1. Effect of semantic relationships and summed iconicity on the number of differing phonological features in American Sign Language

	Phonological distance		
Predictors	*Estimates*	*CI*	*P*
(Intercept)	9.86	9.82 to 9.90	<0.001
Semantic relationship [related]	−1.13	−1.18 to −1.09	<0.001
Summed iconicity	−0.07	−0.10 to −0.04	<0.001
Semantic relationships [related] * summed iconicity	−0.16	−0.20 to −0.11	<0.001
Random effects			
σ^2		4.94	
$\tau_{00\ \mathrm{Source}}$		0.48	
$\tau_{00\ \mathrm{Target}}$		0.48	
ICC		0.16	
N_{Source}		2,461	
N_{Target}		2,461	
Observations		6,045,640	
Marginal R^2/conditional R^2		0.001/0.165	

based on (18): FATHER, MOTHER, GRANDFATHER]. That our network plots highlight known clusters of systematically related signs lends confidence to our visualization approach. Our networks also identified neighborhoods of systematically related signs that, to our knowledge, have not been previously described in the literature: including a group of noniconic signs related to emptiness that use the same middle-finger-extended handshape (e.g., EMPTY, INVISIBLE, VANISH, NAKED), iconic signs that relate to weather produced with two hands in neutral space with all fingers selected (e.g., WIND, CLOUD, RAIN), and iconic signs that relate to exercise are produced with two closed hands (e.g., GYM, EXERCISE, STRETCH). We note that the systematicity in the ASL network is often, but not always, iconic (Table 4).

Table 2. Effect of semantic relationships and summed iconicity on the Levenshtein distance between phoneme strings in English

	Phonological distance		
Predictors	*Estimates*	*CI*	*P*
(Intercept)	5.02	4.99 to 5.05	<0.001
Semantic relationship [related]	−0.16	−0.16 to −0.16	<0.001
Summed iconicity	−0.22	−0.24 to −0.20	<0.001
Semantic relationships [related] * summed iconicity	−0.03	−0.04 to −0.03	<0.001
Random effects			
σ^2		0.64	
$\tau_{00\ \mathrm{response}}$		0.77	
$\tau_{00\ \mathrm{cue}}$		0.67	
ICC		0.69	
N_{cue}		4,829	
N_{response}		5,554	
Observations		26,820,266	
Marginal R^2/conditional R^2		0.023/0.697	

Table 3. Effect of semantic relationships and summed iconicity on the Levenshtein distance between phoneme strings in Spanish

	Phonological distance		
Predictors	*Estimates*	*CI*	*P*
(Intercept)	5.75	5.71 to 5.79	<0.001
Semantic relationship [related]	−0.28	−0.29 to −0.26	<0.001
Summed iconicity	−0.03	−0.06 to −0.00	0.026
Semantic relationships [related] * summed iconicity	−0.01	−0.02 to 0.00	0.047
Random effects			
σ^2		0.80	
$\tau_{00\ \mathrm{cue}}$		0.50	
$\tau_{00\ \mathrm{response}}$		0.48	
ICC		0.55	
N_{cue}		2,078	
N_{response}		2,689	
Observations		5,585,757	
Marginal R^2/conditional R^2		0.001/0.550	

Turning to the spoken language networks, 39% of the English words ($n_{\mathrm{systematic/total}}$ = 1,867/4,829 words; Fig. 4), and 24% of the Spanish words ($n_{\mathrm{systematic/total}}$ = 504/2078 words; Fig. 5) were determined to be systematically related to other words and thus appeared as nodes in the respective networks. Descriptively, words in the English and Spanish systematicity networks tended to occur in pairs or triplets rather than long chains (English mean path length = 5.19, Spanish mean path length = 2.5), and words in the spoken language networks tended to be connected to just one other word, if any (English mean degree: 0.832, Spanish mean degree: 0.698). Still, the English network highlights a chain of iconic words related to short, well-defined sounds (bleep–beep–bop–pop), a cluster of words for vocalization of distress (squeal–squeak–squawk), and a cluster of words related to bouncy, back-and-forth movement (wiggle–jiggle–giggle). Also visible are several previously described phonesthemes (the /sn/ in sniff–snuff, the /sh/ in mush–mash–smash; Hutchins, 1998). In Spanish, we observed a few pairs of auditorily iconic word pairs (pam "bam"–pum "boom"; tic "tick"–tac "tock") and some pairs that lacked a clear motivation, but nevertheless shared a high degree of form and meaning (peso "weight"–obeso "obese"), but that many word pairs or clusters could be attributed to etymology (nada "nothing"–nadie "nobody"; noviembre "November"–diciembre "December"; suspiro "sigh"–respiro "respite").

Discussion

In this study, we took a data-driven, bottom–up approach to measure iconicity as a possible driver of systematicity in the lexicons of ASL, English, and Spanish. In order to uncover patterns of systematicity—neighborhoods of words in the lexicon where words are phonologically and semantically related—we combined information about the semantic structure of the lexicon (from semantic free association tasks) with information about their phonological structure (shared phonological features). Replicating earlier work, we found evidence for systematicity across all three languages: words that are closer in meaning tend to have more

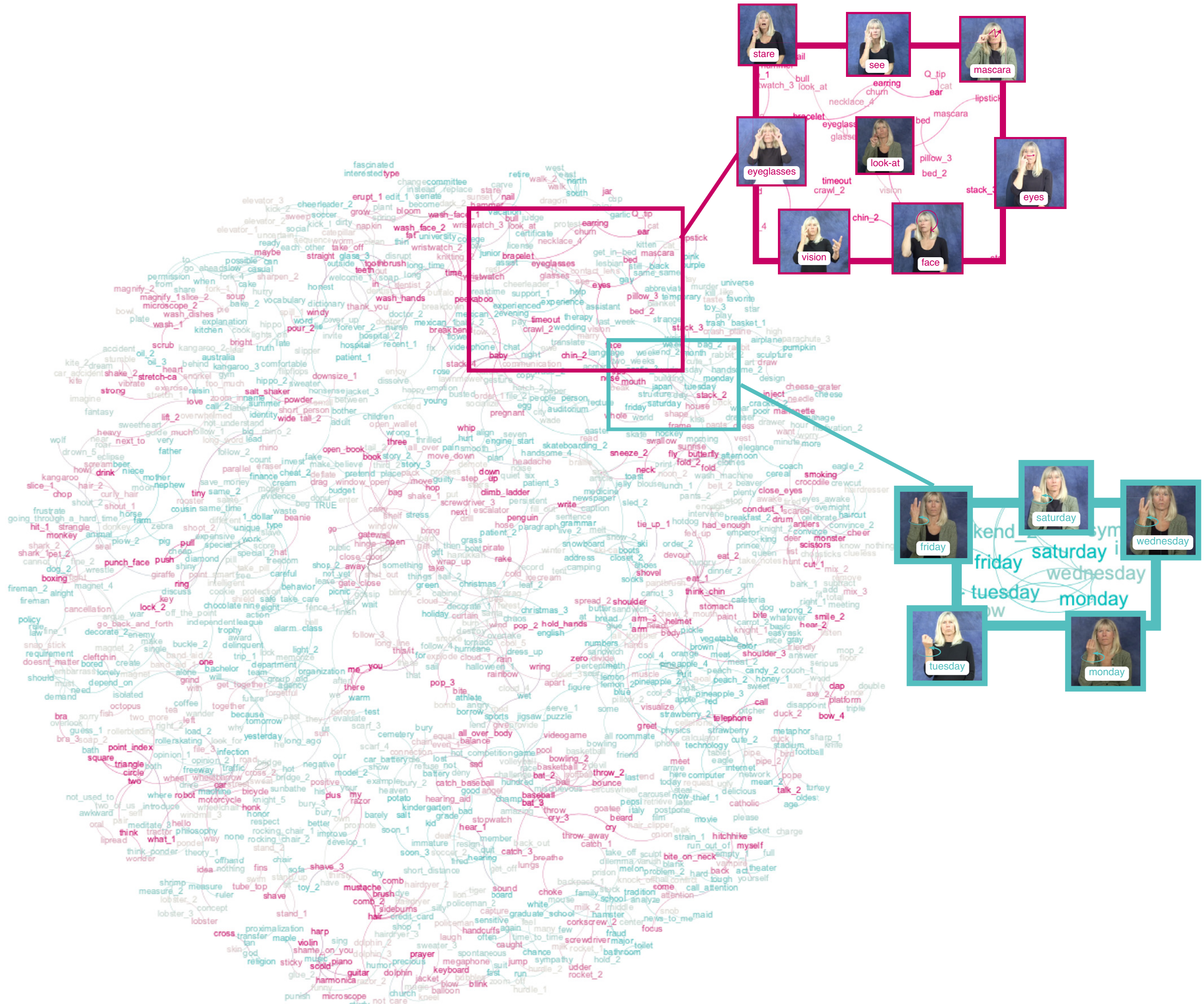

Fig. 3. Systematicity in ASL: signs pairs that were semantically associated by at least two people, shared more than eight phonological features. Iconicity is encoded by color, with more iconic signs in magenta and less iconic signs in teal. Two clusters of interrelated signs are highlighted by cut-outs. Videos of all of these signs can be found at https://asl-lex.org/.

similar word forms. We then explored iconicity among words that were both phonologically and semantically related. This bottom–up approach to identifying iconic systematicity freed us from the need to rely on researcher-identified iconic motivations. In all three languages, iconicity predicted phonological similarity, suggesting that iconic motivations might be best expressed with some common phonological features. Crucially, we observed that in ASL, English, and Spanish, there was a significant interaction such that the relationship between semantic and phonological similarity was magnified for iconic pairs. Taken together, this work shows that iconicity is not simply a rudimentary use of the body to mimic the meaning of a single word, rather iconicity occurs in highly patterned ways across the lexicon. These results implicate iconic systematicity as a defining characteristic of the lexicon regardless of language modality. These findings thereby challenge the long-standing notion that word forms are inherently arbitrary (1–3).

The way we have defined form–meaning systematicity allows us to identify sublexical units of form and meaning that occur across lexical items, and one might reasonably wonder what the difference is, if any, between form–meaning systematicity and morphology. Even though we filtered our analyses to monomorphemic words, many of the systematic relationships we see shared across the lexicon look almost morphological in nature. For example, the ASL network identified noun–verb pairs in which the noun is a reduplicated form of the verb (e.g., OPEN_BOOK and BOOK, GATE_CLOSE and GATE) and initialized signs (meaning the signs are formed the same way except the handshape relates to a letter of the manual alphabet; e.g., M for MONDAY, T for TUESDAY, etc.). However, in other cases, the shared elements are not discrete and/or productive, e.g., DRAGON, SPICY (related by an iconic or metaphoric depiction of flames at the mouth), or FIANCE, RING (related by metonymy). In some cases, pairs encode syntactic information (e.g., the ASL noun–verb pairs), but in many cases they do not. Some theories of morphology account for these facts more readily as they do not require morphemes to have discreteness, productivity, or syntax (e.g., 22), whereas other theories of morphology [e.g., Lexeme-Morpheme Base Phonology; (23)] may find more friction. And conversely, some descriptions of systematicity include morphology (alongside iconicity and etymology) as drivers of systematic form–meaning relationships (24).

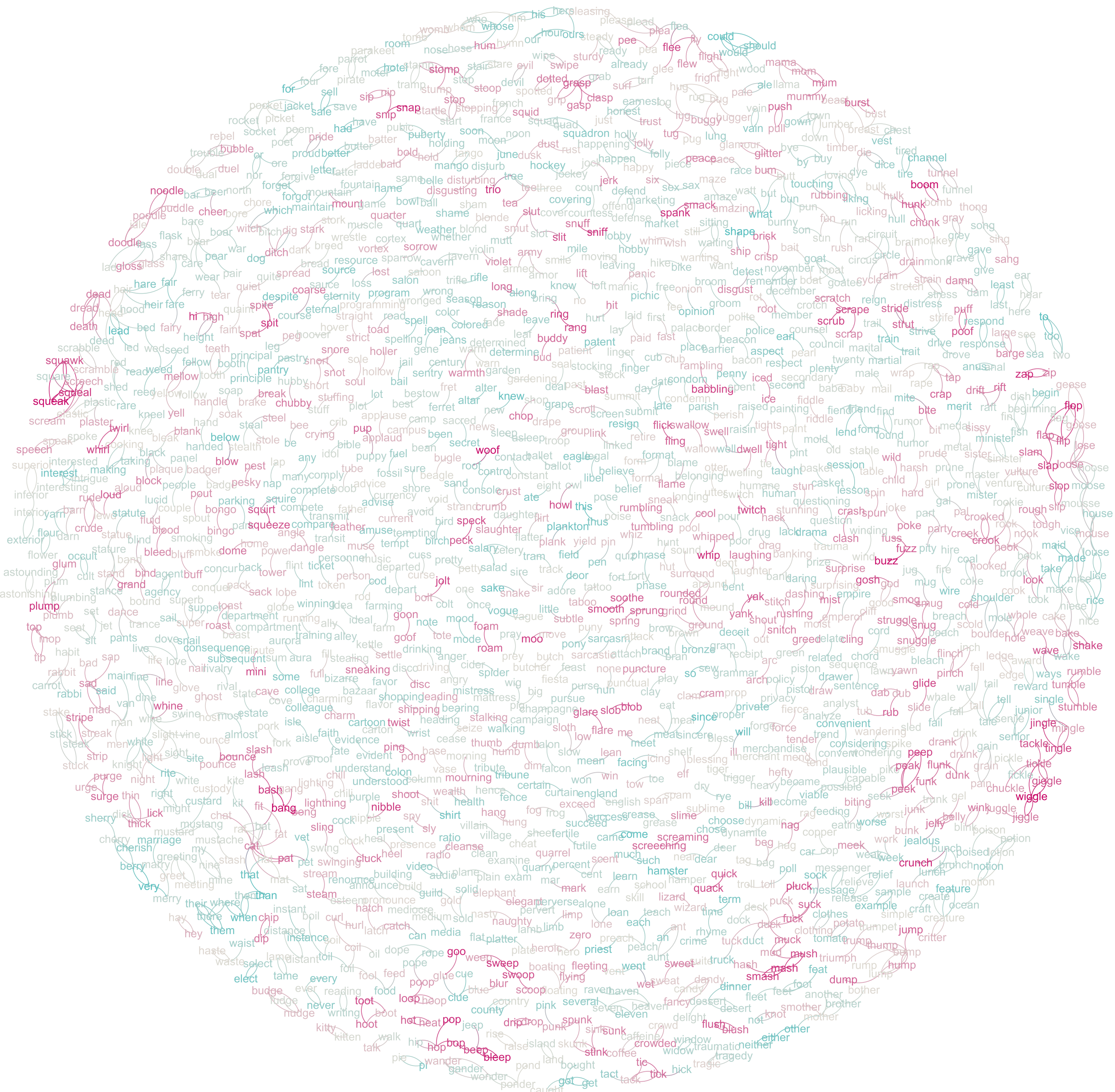

Fig. 4. Systematicity in English. Word pairs are connected by an edge if they share at least half of their phonemes with one another and they were associated by at least two participants in SWOW. Iconicity is encoded by color, with more iconic words in magenta and less iconic words in teal.

In the ASL data, we found that many ostensibly noniconic signs do not bear an obvious physical resemblance to their meaning, but in the context of other signs with similar forms and meanings, the shared elements reveal possible iconic mappings. For example, in our networks, we observed a group of signs related to employment status and are produced with the index and middle finger extended and moving relative to a closed fist (JOIN, QUIT, RESIGN). While in isolation, the sign QUIT may not strongly iconically evoke the act of quitting, together, the signs JOIN, QUIT, and RESIGN could be seen as depicting a person with two legs moving toward or away from an entity or organization. These patterns point to an even *larger* role of iconicity in the lexicon than estimated by our present approach – perhaps more subtle and less readily perceivable by people. In the ASL analysis, our iconicity ratings came from participants who did not know the language; iconicity ratings from fluent signers may be more influenced by systematicity. Our sense from the present analysis is that most of the systematic relationships in ASL could be analyzed as being iconically motivated.

Interestingly, the converse was true for English and Spanish. That is, there was a striking lack of iconic motivations shared between words that are systematically related. Instead, systematically related words often appear as etymologically related pairs (e.g., junior–senior, brother–mother, hotel–motel, nada–nadie), or binomials that are frequently collocated in speech (e.g., flip–flop, nature–nurture). As pointed out by a reviewer, while languages may all exploit iconic systematicity, the configuration of the iconic networks is more similar in English and Spanish (small pockets of two or three related words) as compared to ASL (larger, more interconnected neighborhoods). This lack of

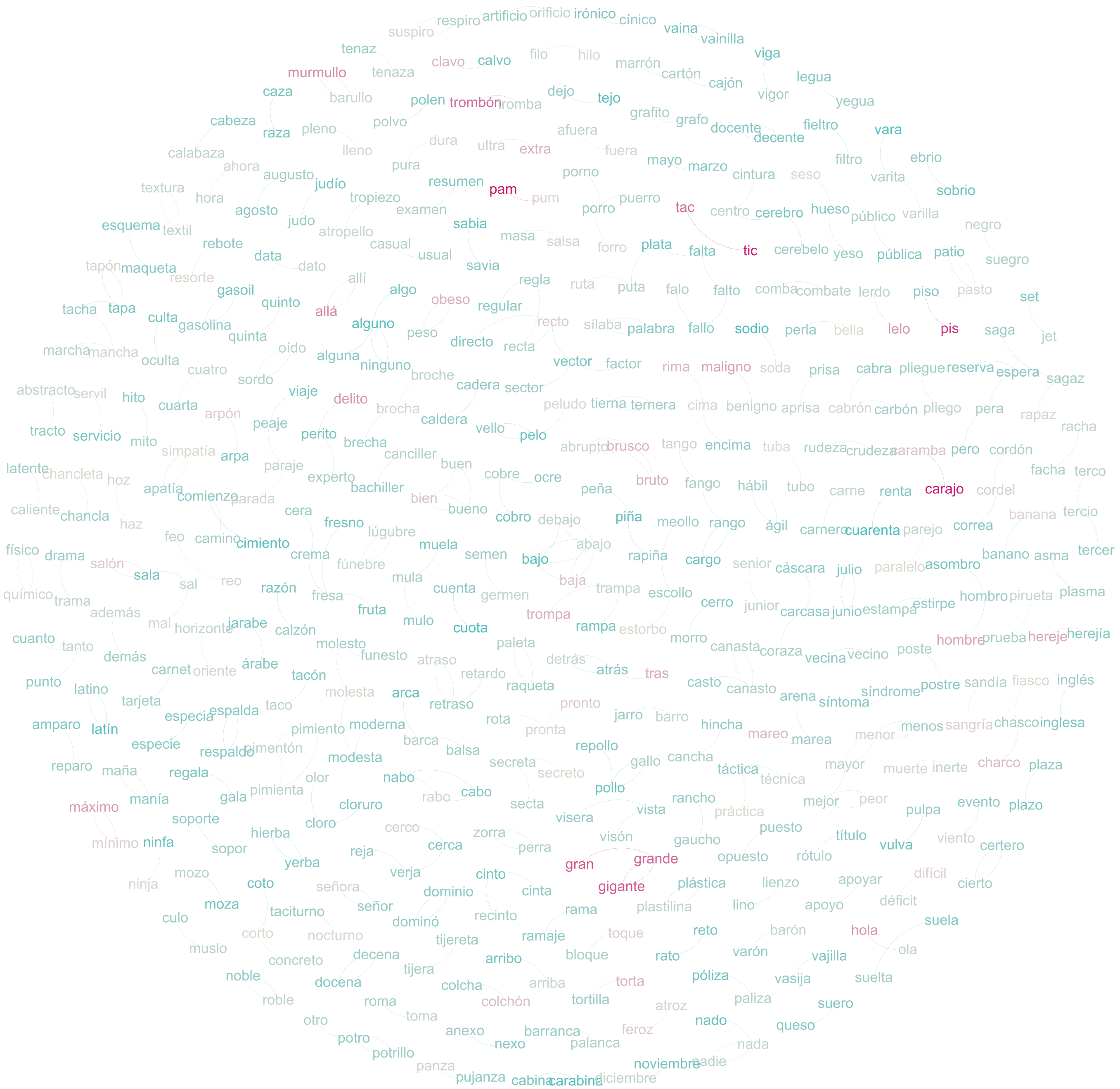

Fig. 5. Systematicity in Spanish. Word pairs are connected by an edge if they share at least half of their phonemes with one another and they were associated by at least two participants in SWOW. Iconicity is encoded by color, with more iconic words in magenta and less iconic words in teal.

shared iconic motivation across systematically related words was borne out statistically in a modest interaction between iconicity and semantic relatedness on phonological similarity in English and Spanish. Primarily, our modeling approach highlighted relationships between iconicity and phonological form, showing that word pairs that are more iconic are more phonologically similar (e.g., bang–boom, whoosh–swish). This result might reflect that certain speech sounds are used more often than others to depict auditory phenomenon (e.g., the "sh" sound to depict friction through air; plosive sounds like "b" to depict explosion) (25).

Such iconic motivations might be shared not only within languages but across languages. Blasi et al. (8) show that many spoken languages, even unrelated spoken languages, share commonalities in patterns of sound symbolism, and here, we show that within some languages, iconicity can explain much systematicity. Perhaps some iconic motivations are useful enough that multiple languages converge on the same phonological form; these motivations may then be conventionalized systematically in the language. For example, food signs might be systematically produced at the mouth across signs not only within a language but across sign languages. Evidence from emerging sign languages suggests that signers converge on which aspect to represent iconically before converging on the phonological form (26, 27). For instance, over time, sign languages generally converge on representing objects either by depicting their shape or by depicting how the object is handled (14, 28). Since languages generally share the same articulators (the hands and/or the vocal tract), a combination of iconic motivation and constraints on articulation and perception may result in cross-linguistic similarities in iconic systematicity.

Table 4. Network measurements of systematicity graphs in ASL, English, and Spanish

	ASL			English			Spanish		
	Overall	High iconicity	Low iconicity	Overall	High iconicity	Low iconicity	Overall	High iconicity	Low iconicity
% Words in network	54%	54.2%	54.8%	38.6%	42.9%	35.9%	24.25%	12.46%	12.17%
Mean degree	0.966	0.628	0.631	0.832	0.574	0.423	0.698	0.394	0.25
% Nodes in giant component	22.45%	24.47%	20.45%	1.93%	1.21%	1.13%	1.59%	1.16%	0.81%
Mean path length	13.5	3.11	2.92	5.19	3.45	3.06	2.5	1.5	1
Mean clustering coefficient	0.097	0.053	0.121	0	0	0	0.02	0.462	0

The Overall networks include all words that were systematically related (share at least half of their phonemes and were associated by at least 2 participants) to at least one other word. High-iconicity and low-iconicity subnetworks were determined by a median split on each language's iconicity ratings. Mean Degree refers to the mean number of edges each node in the network has. Mean Path Length is the mean number of steps in the shortest path between connected nodes in the giant component.

This work illustrates that there is variability across languages in the degree and the form of how iconic systematicity plays out. Some factors we might expect to influence the manifestation of iconic systematicity include: languages' iconicity, phonological inventory, and age. For instance, we hypothesize that languages with a higher degree of iconicity in their lexicons will show more iconic systematicity. Investigating languages like Japanese, Siwu, and Pastaza Quechua, which have been described as having rich onomatopoetic or ideophonic vocabularies (29), may shed some light on whether spoken languages ever show iconic systematicity to a similar degree as ASL does here. Additionally, if iconic systematicity plays a role in word creation and transmission, we would expect newer languages to have a high degree of iconicity that may or may not be systematic. As language users converge on operators of iconicity (14, 26–28), we would hypothesize that older languages may show increasingly systematic iconicity.

Another reason the patterns may differ across languages in this study is the number of phonological features that contribute to iconicity. The iconicity ratings we use in the present study ostensibly reflect perceived iconicity of the entire word, but across languages, these ratings might be driven by different phonological features. In spoken languages, often, only a single phoneme or phonological feature that participates in the iconic mapping (e.g., in "poke", the action appears to be depicted by the stop manner of the consonants, but not their voicing or place, nor anything about the vowel). While onomatopoeias and ideophones—some of the most salient examples of spoken language iconicity—tend to make iconic use of many of a word's sounds [e.g., "splash"; (30), these words are relatively rare in most languages. Conversely, in ASL many features often participate simultaneously in the structure mapping (e.g., the handshape and movement of the hands in RECORD]. Building off the structure mapping theories of refs. 31 and 32, analogies are stronger when there are multiple connections between the target domain (e.g., phonology) and the source domain (e.g., meaning). When only one aspect of a word's phonology participates in form–meaning mappings, as is commonly the case in spoken language, iconicity may not be able to support strong systematic mappings across multiple lexical items. We suggest that the strength of iconic structure mapping (i.e., the number of phonological features that can map to semantic features) is a useful property on which to structure lexical relationships. It may also be harder to detect examples of iconic systematicity in languages where the form–meaning unit only makes up a small portion of the word.

Another source of variability in iconic systematicity may be the degree of iconicity: It subjectively appears that the "highly-iconic" signs in ASL are more iconic than the "highly-iconic" words in the spoken languages, but it is not readily clear how to operationalize cross-linguistic differences in lexical iconicity [but c.f. (33)]. Linguistic theories may need to accommodate variation in the prevalence of iconic systematicity by considering other ways that systematicity may be instantiated (e.g., via morphology or etymology).

Additionally, an open question remains whether iconic systematicity is inherent to all sign languages, or whether ASL is unique in its lexical organization. Data are not yet available to test these patterns across the lexica of other sign languages (semantic association data in particular are needed) but based on linguistic descriptions of pockets of the lexica of other sign languages, we hypothesize that iconicity might often drive systematic alignment between phonology and semantics. For example, in many sign languages of the world, signs with semantic plurality tend to be produced with two hands (13, 34). In Swedish Sign Language (alongside other sign languages), signs relating to certain concepts tend to be articulated in the iconically relevant location [e.g., signs related to cognition produced at the head; (13, 35)]. In French Sign Language, signs referring to semantically plural events are often characterized by movement reduplication (an iconic relation wherein events that are repeated are depicted by articulations that are repeated) (36). In Kata Kolok, an isolated sign language from Indonesia, many place names are formed as iconic depictions of representative landmarks of the city/region, articulated on the upper chest of the signer (37). Indeed, many sign languages of the world are rife with examples of how iconicity is employed in phonologically patterned ways across semantically related signs. Here, we show that these patterns are not limited to small semantic pockets, but rather iconic systematicity can be observed at the level of the whole lexicon.

The multiply layered relationships inherent to iconic systematicity, in particular, has consequences for psycholinguistic theories of how words are organized and retrieved from the mental lexicon. To date, psycholinguistic studies of iconicity in recognition and production have largely focused on the iconicity of individual signs (e.g., 38–40), what we refer to as "sign-specific iconicity." These studies ask questions about the extent to which signers are sensitive to iconicity in sign perception and production, for example. The effects of sign-specific iconicity on sign production and recognition have been quite mixed, and it is yet unknown whether and how lexicon-wide patterns of iconicity affect language processing. For instance, spreading activation has long been considered a factor in how individuals access and retrieve words in semantic memory (41), whereby during word retrieval, other closely connected words in the network also become active. Much of the spreading activation literature focuses on semantic and phonological organization of the network, but the role of iconicity has not been accounted for in possible patterns of spreading activation (e.g., are iconically related lexical items more likely to become active during lexical access due to overlapping phonological and semantic properties?). Considering systematic iconicity in addition to or instead of sign-specific iconicity may help clarify the role of iconicity in sign processing.

Iconic systematicity may also play a role in how people learn words. There are robust effects of iconicity on early vocabulary acquisition in both spoken and signed languages (e.g., (42–44)), but the mechanisms underpinning these effects remain elusive. While children might observe an analogy between the form of a new sign and its meaning (e.g., the perceptual similarity between trees and TREE) in ways that could make it easier to learn the sign, it is unclear whether this type of analogical reasoning can fully explain effects of iconicity that are detected during infancy (45). However, the prior studies of iconicity in word learning have focused exclusively on iconicity at the level of individual signs. It is possible that the effects of iconicity that have been documented are better attributed to iconic systematicity. By hypothesis, children might leverage iconic mappings between form and meaning in signs they *already* know to help them build new lexical representations of novel, iconically related signs. For example, a child might more easily learn a novel sign related to eating that is produced at the mouth (e.g., DEVOUR, TASTE) if they already know other eating-related signs that are also produced at the mouth (EAT). In English, effects of systematicity on words' age of acquisition have recently been documented (46): words whose phonology better conforms to English's systematic form–meaning relationships tend to be learned earlier. Perhaps the effect of systematicity on age of acquisition is stronger in languages, such as ASL, that have more robust patterns of systematicity. How then might iconicity and systematicity interact in children's acquisition of words, and does this change across languages that differ in the extent to which iconicity drives systematicity?

Limitations. The methods used to identify systematicity in this study represent just one out of many possible approaches. Semantic similarity might alternatively be measured by weighting according to the number of people who associated the pair, or with a different measure of semantic relatedness altogether (e.g., collocation in a corpus). Phonological similarity might be alternatively measured over a different set of features or by weighting features according to their position in a feature geometry. Perhaps because of how similarity was defined, the networks presented here may include patterns that others might not ascribe to systematicity (e.g., morphological relationships), and/or exclude real examples of systematicity. Signs may be related, but not meet our stringent criteria (e.g., eight shared phonological features, semantically associated by at least two people). In contrast, the methods used to identify iconic systematicity might have been overly inclusive, capturing sign pairs that are phonologically and semantically related and are iconic, but the iconic motivation for each member of the pair is unrelated (e.g., PULL depicts a person pulling a rope, and MAGNET depicts two small objects being drawn toward one another). Understanding how different operationalizations of phonological and semantic relatedness impact observed systematicity may further illuminate the structure of form and meaning correspondence in the lexicon.

Conclusion. In sum, we found evidence that challenges the idea that relationships between word form and word meaning are necessarily arbitrary; systematicity is evident across languages, and iconic systematicity in particular is pervasive in ASL. This work makes clear that linguistic theorizing must consider iconicity and systematicity as possible organizing principles of the lexicon and should be accounted for in psycholinguistic theories of how the lexicon is structured, used, and learned.

Materials and Methods

For the ASL analysis, we combined information about the phonological and iconic properties of 2,461 signs from the ASL-LEX database with recent data on semantic associations between signs. In the following section we briefly explain how these data were collected, but see (19, 20, 47) for more exhaustive details. To replicate these analyses in two spoken languages, English and Spanish, we drew on data from existing word-level iconicity ratings, phonetic transcriptions, and semantic association datasets. For each of the more than 7 million pairs of signs in ASL-LEX, 26 million English pairs, and 5.5 million Spanish pairs, we quantified iconicity, phonological associations, and semantic associations, using the procedures described below.

Summed Iconicity. For ASL, each of the 2,461 signs in ASL-LEX was evaluated by approximately 30 hearing nonsigners, who determined how much the sign resembled its meaning. For example, they watched a video of the sign CAT and reported how much the sign resembled a cat on a scale of 1 to 7. These ratings were aggregated to determine the average iconicity rating for each sign. In the following analysis, for all pairwise combinations of signs in ASL-LEX, we added the average iconicity of the two signs in order to determine the summed iconicity of the pair. For English and Spanish, iconicity ratings were drawn from Winter (7), and Hinojosa et al. (21), respectively. In these studies, native speakers of the languages (on average, $N_{English} = 10$, $N_{Spanish} = 22.6$ raters per word) were presented with words and asked to rate the extent to which words sounded like what they mean. As with the ASL data, the iconicity of word pairs was averaged across raters per word and then these averaged iconicity ratings were summed across word pairs. This variable was scaled for all analyses.

Phonological Associations. For ASL, using a phonological transcription scheme guided by Brentari's Prosodic Model (48), trained, fluent-signing linguists annotated phonological features of each sign in ASL-LEX: location, movement, whether each finger was extended and/or flexed, and sign type (one-handed, two-handed symmetrical, or two-handed asymmetrical). Further details on phonological transcription can be found in (19). Cases where there were multiple sequential units (e.g., compounds, fingerspelled signs; n = 262) were excluded to control for the role of sequential morphology in systematicity. Each possible pair of signs in the lexicon was then matched to determine how many phonological features the pair shared vs. diverged on, out of a maximum of 16. In the network analyses, we binned phonological relatedness by labeling pairs that shared more than eight phonological features as "phonologically related." For the spoken languages, phonetic transcriptions of the words were drawn from LexOPS [English (49)] and EsPal [Spanish (50)]. The Levenshtein edit distance in phonemes was then calculated for each word pair.

Semantic Associations. For ASL, we used semantic associations from a large-scale dataset of semantic associations between signs (47). In this dataset, deaf ASL signers saw each of the 2,723 signs in the ASL-LEX database (19, 20, and were filmed producing the first three signs that came to mind. Up to 15 participants responded to each cue sign, yielding up to 45 associations per sign. The average age of first exposure to ASL was 2.44 y, (*Mdn* = 0, SD = 4.63, Range = 0 to 19). The complete ASL dataset included 113,883 semantic associations. For the following analyses, we removed responses that were impossibly short (<500 ms, n = 909 responses excluded) or long (>6,000 ms, n = 714 responses excluded), had a corrupted video file, were multimorphemic signs, or the response did not match a sign in ASL-LEX. For the statistical analysis, for every possible pair of signs in ASL-LEX, we determined whether the pairs were semantically related (i.e., at least one person freely associated the pair, n = 9,400) or not semantically related (n = 6,087,812).

For the two spoken languages, semantic associations were drawn from the Small World of Words (SWOW) project via their large-scale, crowd-sourced word association task. For these norms, participants were presented with cue words (over 13,000 per language) and asked to type the first three words that sprung to mind. Data collection procedures are described in more detail in (51) (English), and (52) (Spanish). For each of the possible word pairs given the cue words, each word pair freely associated by at least one of the participants was considered semantically related. For English, this resulted in n = 292,514 semantically related pairs and n = 26,527,752 semantically unrelated pairs. For Spanish, the final dataset included n = 27,564 semantically related pairs and n = 5,558,193 semantically unrelated pairs.

Data, Materials, and Software Availability. Dataset have been deposited in OSF: Iconicity as an Organizing Principle of the Lexicon (https://osf.io/5y6s4/) (53).

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