The double identity of linguistic doubling

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Does knowledge of language consist of abstract principles, or is it fully embodied in the sensorimotor system? To address this question, we investigate the double identity of doubling (e.g., *slaflaf*, or generally, XX; where X stands for a phonological constituent). Across languages, doubling is known to elicit conflicting preferences at different levels of linguistic analysis (phonology vs. morphology). Here, we show that these preferences are active in the brains of individual speakers, and they are demonstrably distinct from sensorimotor pressures. We first demonstrate that doubling in novel English words elicits divergent percepts: Viewed as meaningless (phonological) forms, doubling is disliked (e.g., *slaflaf* < *slafmak*), but once doubling in form is systematically linked to meaning (e.g., *slaf* = ball, *slaflaf* = balls), the doubling aversion shifts into a reliable (morphological) preference. We next show that sign-naive speakers spontaneously project these principles to novel signs in American Sign Language, and their capacity to do so depends on the structure of their spoken language (English vs. Hebrew). These results demonstrate that linguistic preferences doubly dissociate from sensorimotor demands: A single stimulus can elicit diverse percepts, yet these percepts are invariant across stimulus modality—for speech and signs. These conclusions are in line with the possibility that some linguistic principles are abstract, and they apply broadly across language modality.

language universals | embodiment | phonology | morphology | sign language

Across languages, certain linguistic patterns are systematically preferred to others. English, for instance, allows *pots* and *pans* but not *boxs* and *buss* (from *box* and *bus*). Indeed, *boxs* and *buss* doubly engage the tongue blade, and doubling, generally, XX (where X stands for a phonological constituent) is avoided in the sound patterns of many languages (1, 2). Such (statistical) language universals are well documented (2). Their basis, however, is controversial.

One possibility is that language universals reflect abstract linguistic principles that are shared across languages (3). Alternatively, the restrictions on language structure could be fully embodied in the sensory and motor pressures on speech perception and production (4). The former "abstraction hypothesis" states that forms like *boxs* are banned because they violate abstract linguistic principles, whereas the alternative "embodiment hypothesis" asserts that *boxs* is avoided because it is difficult to perceive and articulate.

We note that these two alternatives represent extreme positions. And indeed, abstraction and embodiment could each play (distinct) roles at different components of the language system. For the sake of clarity, here, we deliberately focus on two extreme views that, by definition, are mutually exclusive, but we note that some forms of abstraction and embodiment could well coexist—a possibility we revisit in the *General Discussion*.

These rival hypotheses generate conflicting predictions concerning the link between the acceptability of a stimulus and its sensorimotor demands. The embodiment hypothesis predicts an association. Specifically, a single stimulus (A) should elicit invariant responses (as its sensorimotor demands are relatively invariant), whereas distinct stimuli (A and B) that exact different sensorimotor demands should elicit distinct responses. The abstraction hypothesis, by contrast, attributes response not to the stimulus (or its sensorimotor demands) but to its percept—that is, its mental representation. And because a single stimulus can elicit different representations, whereas different stimuli can be mapped to a single representation, responses to a stimulus (e.g., its acceptability) and its sensorimotor demands could doubly dissociate. That is, a single stimulus could elicit conflicting responses, whereas distinct stimuli that contrast on their sensorimotor demands could give rise to the same response (Fig. 1).

The following research demonstrates such dissociations. Our case study concerns the linguistic restrictions on doubling (e.g., *baba*, generally XX). Using novel English words, we first show that words with doubling give rise to two distinct percepts, depending on the linguistic level at which they are analyzed. Because the stimulus is unchanged, these two percepts must reflect competing cognitive principles rather than the sensorimotor demands imposed by the stimulus itself. We next show that English and Hebrew speakers without experience in sign language spontaneously project these principles to novel signs in American Sign Language (ASL). Furthermore, the interpretation of signs is modulated by the structure of participants' spoken language. Together, these results demonstrate that linguistic preferences doubly dissociate from stimulus sensorimotor demands: A single stimulus can elicit diverse percepts, yet these percepts remain invariant despite radical changes to stimulus modality—from speech to signs. These findings are in line with the possibility that some linguistic principles are abstract, and they apply broadly across language modality.

The Conflicting Parses of Doubling

Linguistic research suggests that doubling (e.g., *baba*, generally XX) is open to two conflicting interpretations (5). At the level of phonology, linguistic forms are patterns of meaningless elements. Here, doubling (e.g., *cocoa*) simply reflects identical elements—the whole (*cocoa*) bears no semantic relation to the parts (e.g., *co*), and phonological identity is generally avoided across languages (2). By contrast, the morphological level establishes systematic links between phonological forms and meaning. Doubling can signal such

Significance

Across languages, certain linguistic forms are systematically preferred to others (e.g., *blog* > *lbog*), but whether such preferences reflect abstract linguistic principles or the sensorimotor demands associated with the encoding of linguistic stimuli is unknown. To inform this debate, here we examine whether the preferences for linguistic forms can be disentangled from their sensorimotor characteristics. Our results demonstrate that people's linguistic preferences doubly dissociate from the demands exacted by the linguistic stimulus: A single stimulus can elicit diverse percepts, whereas each such percept can remain invariant despite radical changes to stimulus modality—speech and signs. These conclusions are in line with the possibility that linguistic principles are amodal and abstract.

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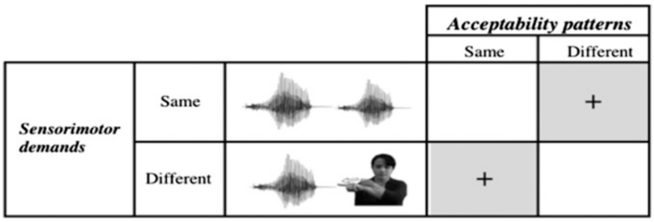

Fig. 1. The double dissociation between the sensorimotor properties of linguistic stimuli and their acceptability patterns, predicted by the abstraction hypothesis.

links. For example, in Hawaiian, the word *hoe* "to paddle" gives rise to *hoe-hoe* "to paddle continuously" (6); Ilocano (a language spoken in the Philippines) uses doubling to indicate plurality as in *púsa* "cat" → *puspúsa* "cats" (7). Morphological doubling is called reduplication, and unlike phonological identity, morphological reduplication is actively promoted across languages (8).

Summarizing, doubling presents a putative case of structural ambiguity (for a formal analysis, see *Supporting Information* and Table S1). Viewed as phonological identity, doubling is disliked, but when parsed as morphological reduplication, doubling is preferred. Our investigation tests this hypothesis.

Experiments 1–4 examine whether English speakers extend these conflicting parses to novel English forms. Having shown that a single stimulus can elicit distinct linguistic preferences, we next ask the converse—namely, whether linguistic preferences can remain invariant despite radical changes in the sensorimotor characteristics of linguistic forms. To this end, experiments 5–8 examine whether English speakers spontaneously extend the same principles to a novel linguistic modality—to sign languages. Experiments 9–12 establish the linguistic origins of these principles by showing that the interpretation of signs is informed by the morphological structure of participants' spoken language (English vs. Hebrew).

Doubling in Spoken Languages

We begin our investigation by examining whether English speakers spontaneously shift their responses to doubling depending on its level of analysis—the phonology or morphology. In our experiments, participants are asked to make a forced choice between a matched pair of novel English words exhibiting either doubling (e.g., *slaflaf*) or no doubling (e.g., *slafmak*).

Experiment 1 first elicited a choice among isolated words. Experiment 2 presented doubling as a morphological operation of plural formation. Our morphological manipulation proceeded in two steps: In the first step, people saw the base (e.g., *slaf*) paired with a single novel object (e.g., a ball-like toy). In the second step, people saw a set of objects of the same kind (several identical ball-like toys). Their task was to choose the word (e.g., *slaflaf* or *slafmak*) that forms the best name for that set. We predicted that, by default, English speakers will interpret doubling as phonological identity, and consequently, participants in experiment 1 should systematically disprefer novel forms with doubling (e.g., *slaflaf*) to controls (e.g., *slafmak*). In contrast, once a morphological context is invoked (in experiment 2), the doubling dislike should shift into a reliable preference.

Experiments 3 and 4 tested alternative nonmorphological explanations for this shift. To rule out the possibility that the doubling preference is simply due to the pairing of words with objects, in experiment 3, participants chose names for novel objects without first seeing the base (e.g., *slaf* = a ball). We predicted that, in the absence of a morphological context, people will now fail to parse *slaflaf* as reduplication, and no doubling preference will emerge.

To address the possibility that the doubling preference is only due to the introduction of the base (e.g., *slaf*), experiments 4a and 4b repeated the same manipulations in two conditions (intermixed). In both conditions, people were first presented with the base along with a single object (e.g., *slaf* = ball); participants next saw an object-set, and they were asked to name it (e.g., *slaflaf* or *slafmak*). In one condition, the set was homogeneous (e.g., three identical balls), whereas in the other, it was heterogeneous (e.g., a ball, a cup, and a pacifier). If the doubling preference reflects its interpretation as a morphological plural, then this preference should only emerge when the semantic conditions for plurality are met—that is, for sets of a single kind. Accordingly, the doubling preference should be obtained with homogeneous sets but not with heterogeneous ones.

Fig. 2 plots the doubling preference and illustrates the experimental manipulations. In this and all subsequent experiments, scatter plots present the doubling responses of individual participants, columns indicate the means, and chance level is marked by the dotted line. Statistical analyses test the proportion of doubling responses against chance (0.5) by means of mixed-effects logistic regression models. These models compare the intercept against 0 (chance, in log odds) using participants and item-pairs as random effects. Statistical tests for all experiments are reported in Table 1. Additional analyses using binomial tests yielded similar conclusions (for results, see Table S2).

Results show that when presented with isolated phonological forms, participants reliably disliked doubling (experiment 1). In contrast, once the form–meaning link between the base and doubling was explicitly established, the doubling dislike turned into a reliable preference (experiment 2).

The doubling preference is not due only to the pairing of complex linguistic forms with object sets, as when participants rated the same object–word pairs without seeing the base (experiment 3), the doubling aversion reappeared. Experiment 4 further demonstrates that neither the base nor the object set is sufficient to elicit the doubling preference. Specifically, when participants were presented with the same base followed by a heterogeneous set of objects (i.e., in violation of the semantic condition for morphological plurality), no doubling preference was obtained (experiment 4a). In contrast, once the same words were paired with homogeneous object sets, the doubling preference remerged (experiment 4b).

Taken as a whole, the results strongly suggest that the interpretation of doubling depends on its linguistic analysis. In the absence of explicit morphological links between form and meaning (when words are judged in isolation or when their meaning is not explicitly linked to the base), phonological doubling is disliked. But once this morphological link is established, the doubling dislike shifts into a preference.

Doubling in Sign Language

Experiments 1–4 show that a single (invariant) linguistic stimulus gives rise to variable preferences. We next asked whether these preferences can remain invariant despite radical changes to

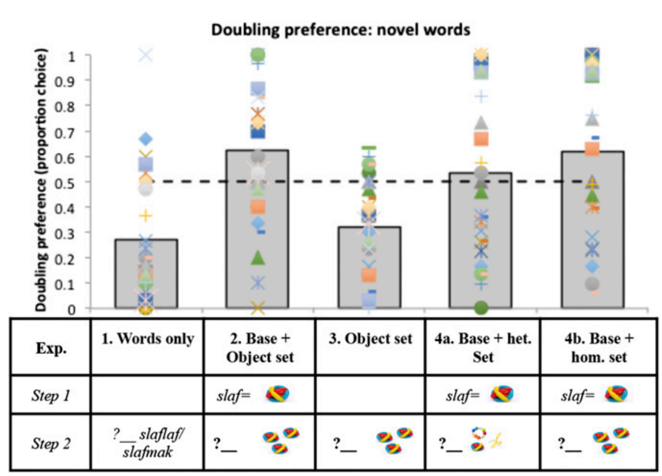

Fig. 2. Doubling preferences for novel English words. het., heterogeneous; hom., homogeneous.

Table 1. **Statistical tests of doubling preferences in experiments 1–12**

Stimuli	Experiment	Manipulation	Language	M	*N*	Intercept	*SE*	*z*	*P*
English	1	Words only	English	0.27	30	−1.48	0.36	4.61	0.0001
	2	Base + object set (homogeneous)	English	0.62	30	0.83	0.36	2.28	0.023
	3	Object set (no base)	English	0.32	29	−0.91	0.20	−4.54	0.0001
	4a	Base + object set (heterogeneous)	English	0.53	29	0.46	0.46	0.99	0.322
	4b	Base + object set (homogeneous)	English	0.61	29	1.04	0.45	2.29	0.0218
ASL	5	Single object	English	0.37	16	−0.53	0.12	−4.56	0.0001
	6a	Base + set (homogeneous)	English	0.65	16	0.75	0.27	2.83	0.0047
	6b	Base + set (heterogeneous)	English	0.18	16	−2.68	0.64	−4.20	0.0001
	7a	Object set (homogeneous): no base	English	0.46	16	−0.18	0.13	−1.34	0.18
	7b	Object set (heterogeneous): no base	English	0.45	16	−0.22	0.19	−1.16	0.247
	8a	Base + set (heterogeneous): mixed	English	0.52	46	0.11	0.18	0.58	0.56
	8b	Base + set (Homogeneous): mixed	English	0.67	46	0.99	0.21	4.70	0.0001
	8a	Base + set (heterogeneous): no ASL	English	0.51	38	0.04	0.21	0.20	0.843
	8b	Base + set (homogeneous): no ASL	English	0.68	38	1.08	0.24	4.48	0.0001
ASL	9	Signs only	Hebrew	0.47	14	−0.06	0.61	−0.10	0.922
	10a	Base + object set (Licit)	Hebrew	0.48	15	−0.09	0.22	−0.42	0.677
	11a	Base + diminutive (Licit)	Hebrew	0.61	17	0.64	0.39	1.64	0.101
	6a*	Base + object set (Licit)	English	0.65	16	0.75	0.27	2.83	0.0047
	12a	Base + diminutive (Licit)	English	0.52	17	0.14	0.31	0.46	0.648
	10b	Base + object set (Illicit)	Hebrew	0.38	15	−0.59	0.25	−2.36	0.0182
	11b	Base + diminutive (Illicit)	Hebrew	0.33	17	−1.03	0.36	−2.87	0.00408
	6b*	Base + object set (Illicit)	English	0.18	16	−2.68	0.64	−4.20	0.0001
	12b	Base + diminutive (Illicit)	English	0.41	17	−0.43	0.28	−1.50	0.133

*The results of experiments 6a and 6b are reproduced for comparison with experiments 10a and 10b.

stimulus modality. To this end, we turn to examine doubling in sign language.

Like spoken languages, many sign languages rely on reduplication in a variety of morphological functions, including nominalization (9) and the formation of plural nouns (10). Our past research (11) has shown that signers prefer doubling, as they favor isolated novel XX signs (where X is a single syllable) to matched XY controls (where X and Y are distinct syllables), in both rating and online lexical decision experiments. Remarkably, nonsigners (English speakers) exhibited a reliable doubling dispreference. The contrast between signers and nonsigners could have emerged because, unlike signers, nonsigners only rely on nonlinguistic principles. Alternatively, both signers and nonsigners could parse the signs linguistically, albeit at different levels: Signers might parse XX signs as morphological reduplication, whereas nonsigners (English speakers) might encode them as phonological identity. Experiments 5–8 seek to adjudicate between these possibilities.

The procedure closely follows the design of experiments 1–4. In each experiment, English speakers with little to no experience with a sign language were presented with a picture of a novel object (or an object set) along with a matched pair of novel disyllabic signs. One such sign exhibited reduplication (XX), whereas the other had no reduplication (XY). Participants were asked to choose the sign that presents the better name for the object(s). Of interest is whether speakers' choices depend on the analysis of the XX form as morphologically related to the X base (i.e., as reduplication).

If the doubling dislike of nonsigners only stems from nonlinguistic, visual pressures, then this bias should be maintained, irrespective of the links between form and meaning. In contrast, if English speakers rely on abstract linguistic principles, then these principles could conceivably apply to signs, mirroring the outcomes with English words. Thus, in the absence of any morphological context, people should interpret the signs as purely phonological forms, and consequently, doubling (viewed as phonological identity) should be disliked. But once doubling is parsed as a morphological operation, its dislike should shift to a reliable preference.

To gauge people's baseline preferences, in the absence of any morphological information, experiment 5 first asked participants to select a name for a single object. We found that English speakers reliably disfavored XX signs to XY controls (Fig. 3; for statistical tests, see Table 1). Their aversion replicates our previous results with nonsigners, and it sharply contrasts with signers' doubling preferences (11).

The contrast between the two groups (signers and nonsigners) could reflect either the reliance on different mechanisms (linguistic, for signers; nonlinguistic, for nonsigners) or different levels of analysis within the language system itself—morphological reduplication, for signers, versus phonological identity, for nonsigners.

To adjudicate between these possibilities, experiment 6a presented the same signs as morphological plurals. Following the design of experiment 2, participants first saw the monosyllabic base (X) with a single novel object (e.g., a ball). Next, they were presented with a set of objects of the same kind (e.g., four balls), along with the two disyllabic options (XX and XY). Finally, participants were asked to choose the sign that makes the best name for the set (XX or XY). Results showed that, once a morphological context was established, nonsigners shifted their behavior, resulting in a significant preference for XX signs.

Subsequent experiments demonstrated that the doubling preference is only obtained when a morphological interpretation is viable. Experiment 6b showed that merely linking XX forms and the base (X) is insufficient to elicit the doubling preference, as no such preference is obtained when the signs were paired with heterogeneous sets (in line with experiment 4a).

Experiment 7 showed that the pairing of signs with appropriate plural semantics is not sufficient to trigger the reduplication preference either. The procedure followed the final two steps of experiments 6a and 6b, except the first critical step (i.e., the pairing of the base X with a single object) was eliminated. Thus, people saw either a homogeneous (in experiment 7a) or a heterogeneous (in experiment 7b) set of objects, along with two novel signs (XX and XY), and they were asked to choose the best name for that set. No reduplication preference was obtained (replicating experiment 3).

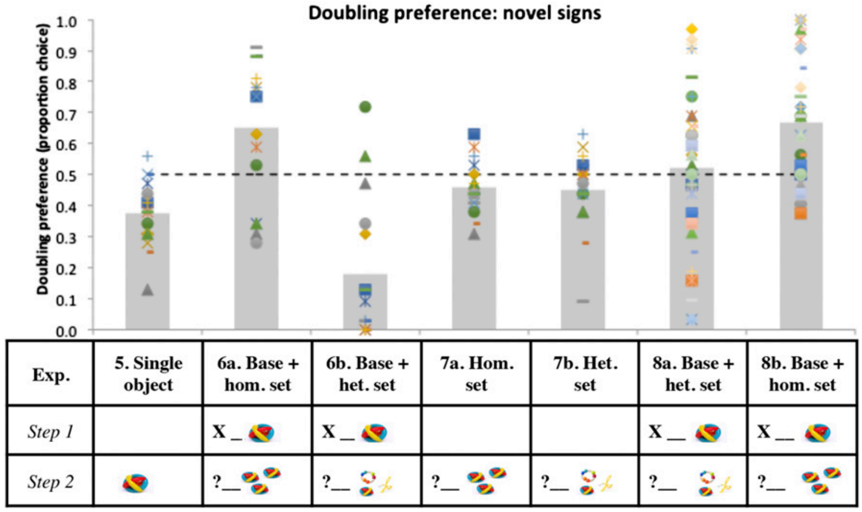

Fig. 3. Doubling preferences for novel ASL signs. het., heterogeneous; hom., homogeneous.

Together, experiments 5–7 show that neither a formal analysis of the reduplicative sign nor its link with plural semantics suffice to elicit a reduplicative preference. To bolster our contention that it is morphology—the link between form and meaning—that is critical for establishing the reduplicative preference, experiment 8 contrasted the homogeneous and heterogeneous conditions presented intermixed, in a single block of trials. The results confirm that pairing the base and an object set only yields a reduplication preference when the semantic conditions for morphological plurality are met, with homogenous sets but not with heterogeneous ones. To ensure that these findings are not due to the handful of participants who had (minimal) sign language experience, we reanalyzed the data after excluding these participants—the results (Table 1, no ASL) remained unchanged.

The Role of Linguistic Experience

Experiments 1–8 demonstrate that the interpretation of linguistic doubling is constrained by principles that operate across language modalities—for spoken and signed language. In the absence of a morphological context, nonsigners parse XX signs phonologically, so doubling is dispreferred. But once a systematic link between form and meaning is established, the doubling dislike shifts into a preference. This shift is readily explained by the hypothesis that speakers project their linguistic knowledge to signs, and they assign doubling distinct linguistic interpretations—as phonological identity versus morphological reduplication.

To further evaluate the linguistic basis of this phenomenon, we next asked whether the preferences for XX signs depend on the morphological system of participants' spoken language. We suggest that speakers bootstrap the morphological analysis of signs from their semantics, and this bootstrapping process is informed by the form-meaning links in their spoken language. We thus expect that speakers should be more likely to assign XX signs a morphological interpretation if their native language (*a*) provides positive evidence that the semantics of XX signs can be expressed by the morphology and (*b*) offers no negative evidence that XX semantics cannot be expressed by reduplication. And because morphological doubling is preferred, we expect this morphological experience with spoken language (per *a* and *b* above) to elicit a preference for XX signs relative to XY controls.

To test this hypothesis, we next compared the analysis of XX signs that were linked with two different semantic interpretations—plurals versus diminutives. Our participants comprised speakers of two languages with two different morphological systems —English and Hebrew.

English morphology marks nouns for semantic plurality (albeit not with reduplication), and it lacks productive diminutives (forms like *booklet*, *piglet* are attested, but the *-let* suffix is not productive). In contrast, Hebrew uses reduplication in a variety of morphological functions, and one function, the diminutive (e.g., *kelev* "dog"—*klavlav* "puppy"), is partly productive (12). Although Hebrew also marks plurals (by suffixes, e.g., *shir* "song"—*shirim* "songs"), plurality is never marked by reduplication. Furthermore, the semantics of reduplicative nouns often denotes diminution and attenuation but never augmentation or plurality.

If the morphological interpretation of XX signs is informed by participants' spoken language, then Hebrew speakers should assign a morphological parse (hence, exhibit a doubling preference) when XX signs are presented as diminutives but not as plurals. English speakers should exhibit the opposite pattern. That is, the fact that English morphology marks nouns for plurality but does not productively mark diminutives should boost the preference of English speakers for XX plurals but not for diminutives.

Experiments 9–12 compare the preferences of Hebrew and English speakers for reduplicative signs presented as either morphological diminutives or plurals. As a phonological baseline, in experiment 9, we first asked Hebrew speakers to rate XX–XY sign pairs presented in isolation—that is, as phonological identity—to compare with English speakers (11). Experiments 10–12 next compared the preferences of Hebrew and English speakers for signs using the two-step procedure. The first step paired the base sign (X) with a single novel object. The second step presented either an object set or a diminutive object, and participants were asked to choose which member of the sign pair (XX or XY) is the best name for that object/object set. We administered this procedure in two conditions. In the *licit* condition, the base and the disyllabic forms (XX/XY) were paired with objects of the same kind (e.g., if X is a ball, then XX/XY is either a set of balls or a diminutive ball, for the plural and diminutive conditions, respectively). The *illicit* condition paired the base and disyllabic forms with objects of different kinds (e.g., if X is a ball, then XX/XY is either a ball, rattle, and pacifier or a diminutive rattle, for the plural and diminutive conditions). We predict that experience with the relevant morphological operation will selectively increase the doubling preference in the licit but not the illicit condition.

Table 1 presents the mean doubling preference in experiments 9–12. Results from experiment 9 show that, like their English counterparts, Hebrew speakers exhibited no doubling preference when signs were presented in isolation. We next asked whether this pattern would shift when signs are given a morphological analysis and whether their interpretation depends on participants' spoken language. Fig. 4 illustrates the effect of linguistic experience (with Hebrew vs. English) on the doubling preference for plural sets/diminutives in the morphological licit condition (i.e., with objects of the same kind as the base) and the illicit morphological condition (i.e., with objects of a different kind to the base). To interpret the plural preferences of Hebrew speakers, we plot them against the previous results from English speakers (in experiment 6).

When XX signs denoted plurality, we found doubling preference only with English speakers (experiment 6a) but not with Hebrew speakers (experiment 10a). The diminutive condition elicited the opposite pattern. Here, Hebrew speakers favored XX over XY forms (experiment 11a), whereas no such preference was obtained with English speakers (experiment 12a). A comparison of the two languages in the licit plural and licit diminutive conditions via a mixed-effects logistic regression model (using sum coding) yielded a reliable interaction of Language (Hebrew/English) × Meaning (Plural/Diminutive) ($\beta = -0.338$, SE = 0.0799, $z = -4.24$, $P < 0.0001$). Thus, English speakers prefer doubling with plurals (but not diminutives), whereas Hebrew speakers prefer doubling for diminutives (but not plurals).

The contrasting preferences of Hebrew and English speakers in the licit condition (experiments 10a–12a) suggest that the interpretation of doubling in signs is constrained by the transfer of knowledge from spoken language, and this transfer can acquire both positive and negative forms. Considering positive transfer, the experience of Hebrew speakers with diminutive morphology encouraged the parse of XX signs as reduplicative diminutives. Although this preference was significant only when items were entered as the sole random effect ($M = 0.447$, SE = 0.10, $z = 4.53$, $P < 0.0001$, probably due to the limited productivity of reduplicative diminutives in Hebrew), it clearly differed from the responses of English speakers, whose language exhibits no productive morphological diminutives. Experience with spoken language, however, can also block incongruent morphological parses for signs. Such negative transfer explains why Hebrew speakers were less likely to extend the doubling preference for licit plurals than English speakers. Indeed, Hebrew reduplicative nouns often indicate diminution or attenuation (e.g., *vradrad* "pinkish" is of a weaker *varod* "pink"; *gvarvar* "macho" indicates a young *gever* "man" trying to act as a grownup, etc.) but never plurality. The negative transfer from Hebrew prevented Hebrew participants from extending the doubling preference to signed XX plurals.

Regardless of its direction—positive or negative—the transfer from participants' spoken language suggests that the interpretation of signs depends on linguistic experience. Further support for the role of linguistic knowledge is presented by the finding that participants' doubling preferences for signs were critically modulated by the semantic legality of form–meaning links. Both groups only showed preferences for XX signs in the licit condition—when the base and the plural set/diminutive were paired with objects of the same kind. But when the base and plural/diminutive were paired with different kinds of objects (i.e., in the illicit condition; in experiments 10b–12b), the doubling preference shifted into an aversion. These findings are line with the possibility that the interpretation of doubling is shaped by abstract linguistic principles that operate across language modalities.

General Discussion

This research asked whether linguistic preferences originate from abstract principles or from the sensorimotor demands exacted by the sensorimotor encoding of linguistic stimuli. To address this question, we examined whether the acceptability of a linguistic stimulus could be doubly dissociated from its sensorimotor characteristics.

Using spoken language, experiments 1–4 first showed that responses to a single novel linguistic stimulus (e.g., *slaflaf*) shift dramatically depending on the level of its linguistic analysis. Viewed as a phonological form, doubling is disliked, but once the same form is presented as a morphological operation of plural formation, the doubling dislike shifts into a reliable preference. These results demonstrate that an invariant linguistic stimulus can elicit diverse percepts. Experiments 5–8 next showed that this linguistic percept remains invariant despite radical change in stimulus modality—from spoken language to manual signs. Regardless of linguistic modality, speakers disliked forms with identical phonological elements, but their aversion shifted to a preference if (and only if) a morphological parse was viable. The double dissociation between linguistic preferences and the stimulus sensorimotor characteristics is in line with an abstract linguistic origin; the application of the same abstract principles to spoken and sign language further suggests that they are amodal. Finally, experiments 9–12 demonstrate that the application of these principles depends on participants' linguistic experience. English speakers showed a reliable preference for XX signs only when presented as plurals (but not as diminutives), whereas Hebrew speakers favored XX signs for diminutives (but not for plurals). The correspondence between the doubling preference and participants' linguistic experience, on the one hand, and the convergence with the linguistic regularities concerning doubling (1, 2, 5), on the other, suggest that participants' preferences were informed (at least in part) by tacit linguistic knowledge. This knowledge includes principles that (*a*) ban identity at the phonological level and (*b*) favor reduplication (XX) to the affixation of unrelated material (XY) in morphological forms (e.g., plurals, diminutives).

These conclusions challenge the hypotheses that grammatical linguistic preferences are constrained exclusively by direct sensorimotor

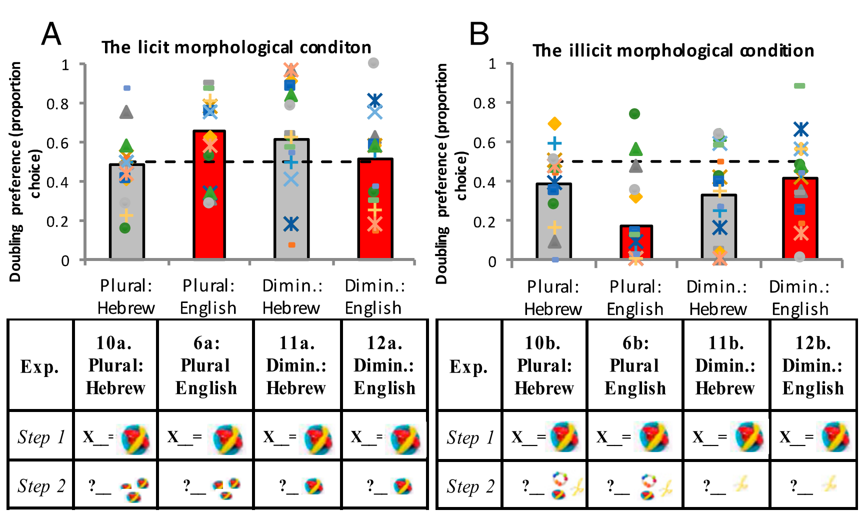

Fig. 4. Doubling preferences for novel signs in morphological (*A*) licit and (*B*) illicit conditions.

restrictions. As noted in the beginning of this article, however, the hypothesis of "embodiment only" and "abstraction only" each represents an extreme position. An intermediate view might assert that abstraction and embodiment each plays a role at different levels of analysis within the language system. For example, embodiment could mediate early levels of phonetic processing, whereas grammatical computations might rely on principles that are abstract. Similarly, the conclusion that grammatical linguistic preferences are irreducible to direct sensorimotor constraints that operate in online processing is compatible with a more nuanced account that links linguistic knowledge to functional constraints indirectly. In this proposal, functional (e.g., sensorimotor) constraints shape the language system off-line, in ontogeny and phylogeny. These constraints conspire to produce universal linguistic constraints that optimize sensorimotor pressures. However, the optimization is attained only indirectly, by favoring the evolution of abstract (algebraic) linguistic principles that are functionally "sensible" [i.e., the *algebraic optimization* hypothesis (13)]. This proposal nicely explains the apparent contradiction between the abstraction of linguistic structure (3, 8), on the one hand, and its grounding in the sensorimotor system, on the other. Our present results do not directly speak to the evolution of the language faculty, but they do suggest that it includes principles that are amodal and abstract.

Methods

Experiments 1–4.

Participants. Participants were native English speakers who were reportedly free of any language or reading disorders (for sample sizes in all experiments, see Table 1). Five additional participants were excluded because of inattention to the task (as described under *Materials*, below). All participants gave their written informed consent according to the procedures approved by the Institutional Review Boards at Northeastern University and the Western Galilee College.

Materials. Materials consisted of 30 pairs of novel disyllabic English words (see *Appendix 1*). Pair members shared the same base, which was a novel $C_1C_2VC_3$ syllable (e.g., *traf*). One pair member partly reduplicated the base by affixing a C_2VC_3 constituent (e.g., *trafraf*), whereas the control paired it with an unrelated C_4VC_5 (e.g., *trafkam*). Experiments 2–4 further included pictures of a novel object and/or a set of 3–5 novel objects—either homogeneous (e.g., three ball-like objects) or heterogeneous (e.g., a ball-like object, a rattle-like object, and a pipe-like object). All sets included the object paired with the base.

Procedure. Experiments 1–4 were conducted online, via Amazon Mechanical Turk. Each experiment elicited a forced-choice among pairs of novel words (balanced for order). Participants were asked to sound out each word (to ensure its phonological decoding) before making their response. Experiment 1 only presented those novel words; experiment 3 presented each word pair with a homogeneous set of novel objects (3–5 objects per set) and asked participants to choose the word that makes a better name for that set. Experiments 2 and 4a and 4b used a two-step procedure. First, people saw the base (e.g., *traf*) along with a single novel object, and they were asked to silently sound out the base, memorize it, and then type it into the computer. Next, they were presented with a pair of novel words, along with an object set, either homogeneous (in Experiments 2 and 4b) or heterogeneous (in Experiment 4a). Participants were asked to indicate the word that makes the better name for the objects set (for instructions to all experiments, see *Appendix 2: Instructions in Experiments 1–12*; for illustrations, see Figs. S1–S3). Experiments 1–3 presented each pair once (30 trials each); experiment 4 presented each pair in both the homogeneous and heterogeneous conditions (a total of 60 trials). To ensure that participants attended to the task, each experiment included attention checks, requiring participants to click on either the left or right object. Inattentive participants ($M \leqq 80\%$) were excluded.

Experiments 5–8.

Participants. Participants were all native English speakers, either students at Northeastern University (in experiments 5–7) or participants from Amazon Mechanical Turk (in experiment 8). Most participants reported no knowledge of sign language; some participants reported familiarity with a few signs only (n = 3, 6, 6, and 11 in experiments 5–8, respectively).

Materials. The materials consisted of 32 pairs of novel disyllabic signs: One member had identical syllables (XX, where X stands for a syllable), whereas the other paired the same X syllable with a nonidentical syllable (i.e., XY). All items were phonotactically legal in ASL (see *Appendix 3: Illustrations of the Displays in the Novel Word and Novel Sign Tasks*). They were recorded by a deaf, native signer and used in our past research, where they are described in detail (11).

Experiments 5–8 presented each such pair (counterbalanced for order) with a picture featuring either one object or an object set. Participants were asked to choose the sign that makes the best name for that object(s) in ASL. In experiment 5, the signs were paired with a single object, whereas in experiment 7 they were paired with a set of 3–5 novel objects, either homogeneous (experiment 7a), or heterogeneous (experiment 7b). Experiments 6 and 8 used a two-step procedure. Participants were first presented the base sign (X), paired with a single novel object. They were next presented with the XX and XY sign pair, along with a set of 3–5 novel objects, either homogenous (experiments 6a and 8b) or heterogeneous (experiments 6b and 8a). All sets invariably included the object associated with the base. Experiments 6 and 7 presented the homogeneous condition followed by the heterogeneous condition; experiment 8 presented them intermixed. Experiment 5 had 32 trials; experiments 6–8 each had 64 trials.

Experiments 9–12.

Participants. Participants in experiments 9–11 were native Hebrew speakers, students at the Western Galilee College, who had no sign language experience. Participants in experiment 12 were native English speakers and students at Northeastern University. Most participants reported no knowledge of sign language; some reported familiarity with a few signs only (n = 2). All participants took part in the experiments in partial fulfillment of a course credit.

Materials and procedure. Experiments 9–12 used the same signs from experiments 5–8, and they likewise elicited a forced choice between matched XX versus XY signs. Experiment 9 elicited judgment of signs in isolation; experiments 10a–12a paired the signs with images of novel objects. Participants were first presented the base sign X, paired with a single object; they next saw either a set of objects (identical to the base, in experiment 10a) or its diminutive version (in experiments 11a–12a). Experiments 10b–12b followed the same procedure as experiments 10a–12a, respectively, except that the objects in steps 1 and 2 were of different kinds, and consequently, the plural and diminutive interpretations were illicit. Each participant first took part in the licit condition (e.g., experiment 10a) followed by the corresponding illicit condition (e.g., experiment 10b). Experiment 9 had 32 trials; experiments 10–12 each had 64 trials.

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Supporting Information

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The Conflicting Parses of Doubling: A Linguistic Analysis

Doubling (generally, XX, where X stands for a phonological constituent) presents a case of structural ambiguity.* At the phonological level, doubling (e.g., *cocoa*) is encoded as repeated phonological elements—that is, as phonological identity (XX). But when the same input is parsed as morphological reduplication (e.g., in the Ilocano word *hoe-hoe*, to paddle continuously, from *hoe*, to paddle), doubling is encoded as a single constituent, X, and its copy "X_c" (*hoe*$_c$, where subscript "c" stands for copy) (8) or, generally, as XX_c.

These different parses each violates distinct constraints within the grammar. In what follows, we adopt an optimality theoretic view of the grammar as a ranked set of (universal) violable constraints (3, 8). Although every linguistic input violates some constraint, inputs differ in the severity of violations, depending on the ranking of the constraints and the number of violations. The severity of violation, in turn, determines the (relative) well-formedness of the form in the language. Phonological identity and morphological reduplication differ on that respect.

Phonological identity, XX, (e.g., *cocoa*), violates a putatively universal ban on identical elements (i.e., the Obligatory Contour Principle, OCP) (1), and consequently, phonological identity is worse-formed than no-identity controls (e.g., *cocoa* < *copo*)† Viewed as morphological reduplication (e.g., *hoe-hoe*), however, doubling is represented as a single constituent *hoe* and its copy (*hoe*$_{c,}$) (8), akin to a person and her image in a mirror, so the phonological ban on identity is inapplicable. In fact, morphological reduplicative forms are superior to the nonreduplicative alternative (e.g., *hoe-po*) inasmuch as they add no new material to the base [i.e., in line with the constraint DEP (short for dependency), which requires the output to be faithful to the input] (3). The phonological and morphological parses of doubling and their respective constraint violations are described in Table S1.

Additional Statistical Analyses

To further evaluate the statistical significance of our findings, we submitted the results to binomial tests, comparing the proportion of doubling response in each experiment against chance (0.5). Results (Table S2) closely aligned with the outcome of the mixed-effect logistic regression.

Appendix 1

For appendix 1, see Table S3.

Appendix 2: Instructions in Experiments 1–12

Experiment 1 (Words Only).

In this experiment, we ask you to judge novel words. In each question, you will be presented with two different novel words. Please sound out each word in your head. Then, please pick which word sounds better in English.

*In the theory of prosodic morphology (8), reduplicative material (X_c, where "c" indicates a copy) is a prosodic constituent, filled with segmental material from the base (X). Accordingly, the structural ambiguity in the interpretation of XX (as identity, XX, vs. reduplication, XX_c) only arises when a reduplicative parse is viable—that is, when X is a prosodic constituent. We note, however, that phonological identity can also arise at smaller phonological domains (e.g., a feature), but our discussion here only concerns doubling of prosodic constituents.

†Our present analysis assumes that the OCP operates within a morpheme. We note, however, that the OCP could apply either within or across morphemes and its effects in the two cases could differ.

Experiment 2 (Base + Homogeneous Set).

In this experiment, we ask you to select a name for novel objects. In each question, you will be presented with a picture of a novel object along with its name. Please sound it out in your head and memorize it. Next, you will see a set of related objects, along with two possible names for the set. Again, please sound out each name in your head. Then, please pick which word is the best name for that object.

Experiment 3 (Picture Set, No Base).

In this experiment, we ask you to select a name for novel objects. In each question, you will be presented with a picture of a set of novel objects, along with two possible names for the set. Please sound out each name in your head. Then, please pick which word is the best name for that object.

Experiment 4 (Base + Object Set, Mixed).

In this experiment, we ask you to select a name for novel objects. In each question, you will be presented with a picture of a novel object along with its name. Please sound it out in your head and memorize it. Next, you will see a set of related objects, along with two possible names for the set. Again, please sound out each name in your head. Then, please pick which word is the best name for that object.

Experiment 5 (Signs + Single Object).

In this experiment, you will see a picture of a novel object. After carefully viewing the object, you will see two novel American Sign Language signs. Your task is to determine which ASL sign makes a better name for the novel object. To select the video on the left, please press "7." To select the video on the right, please press "8." We know this is a difficult task without knowing any ASL. But please try your best and go with your gut feeling. You may view the signs as many times as necessary by clicking on them with the mouse.

Any questions?

Experiment 6 (Picture + Object Set).

In this experiment you will first see a novel object along with its name in American Sign Language. Please carefully view this object and its name. Next, you will next see a group of objects, related to the initial object you had observed, along with two names for these objects in American Sign Language. Your task is to determine which sign makes a better name for the group of objects. To select the video on the left, please press "7." To select the video on the right, please press "8."

None of these signs are currently used in ASL, but we believe these could be possible signs. We know this is a hard task without knowing any American Sign Language. Please try your best and go with your gut feeling. You may repeat the videos as many times as necessary by clicking on them with the mouse.

Experiment 7 (Picture Sign, No Base).

Block 1: Identical objects. In this experiment you will see a group of identical objects, along with two novel signs in American Sign Language. Your task is to determine which sign makes a better name for the objects depicted. To select the video on the left, please press "7." To select the video on the right, please press "8." We know this is a hard task without knowing any American Sign Language. Please try your best and go with your gut feeling. You may repeat the videos as many times as necessary by clicking on them with the mouse.

Block 2: Nonidentical objects. In the next part of this experiment, you will see a group of distinct objects, along with two novel signs in American Sign Language. Your task is to determine which sign makes a better name for the objects depicted. To select the video on the left, please press "7." To select the video on the right, please press "8." We know this is a hard task without knowing any American Sign Language. Please try your best and go with your gut feeling. You may repeat the videos as many times as necessary by clicking on them with the mouse.

Experiment 8 (Base + Set).

In this experiment, we ask you to name novel objects using a sign language. In each question, you will be presented with a novel object along with its name in American Sign Language. Please carefully view this object and its name. You may replay the signs as many times as you want. Next, you will see a group of objects, related to the initial object you observed, along with two names for these objects in American Sign Language. Then, you will choose which sign makes a better name for the group of objects.

Experiment 12 (Base + Set, Diminutive).

In this experiment you will first see an image of a novel object along with its name in American Sign Language. Please carefully view this object and its name. Next, you will see an image of another object, related to the one you had just observed, along with two possible names for that object in ASL. Your task is to determine which sign makes a better name for that object. To select the video on the left, please press "7." To select the video on the right, please press "8."

None of these signs are currently used in ASL, but we believe these could be possible signs. We know this is a hard task without knowing any American Sign Language. Please try your best and go with your gut feeling. You may repeat the videos as many times as necessary by clicking on them with the mouse. Any questions? Please press 'Y' to begin.

Appendix 3: Illustrations of the Displays in the Novel Word and Novel Sign Tasks

Please refer to Figs. S1–S3.

Appendix 4

Please see Table S4.

Fig. S1. An illustration of the display in experiment 2 (base and a homogeneous object set). In this condition, the base and plural set were presented in two successive displays.

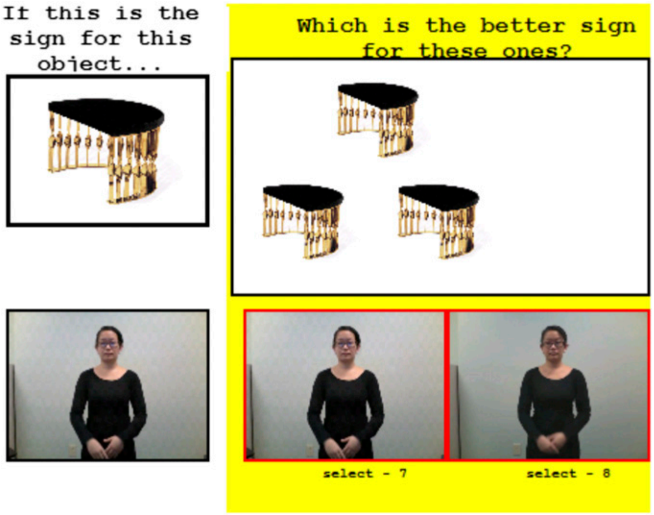

Fig. S2. An illustration of the display in experiment 6a (a base and a homogeneous object set). In this condition, the base and plural set were presented together, in a single display.

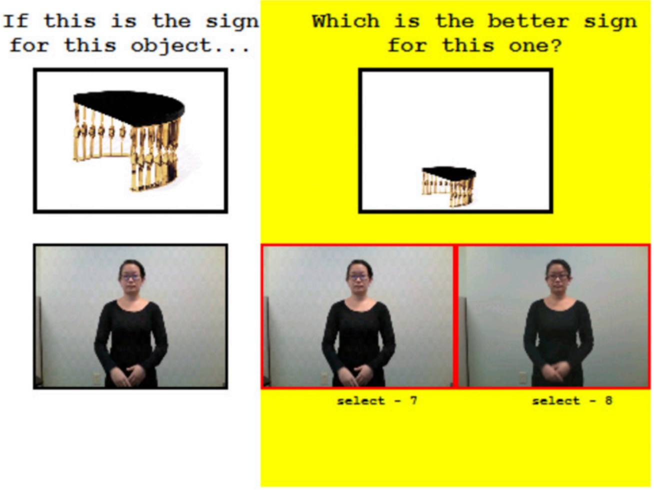

Fig. S3. An illustration of the display in experiment 12a (a base and a diminutive object of the same kind). In this condition, the base and the diminutive were presented together, in a single display.

Table S1. Constraint violation at the phonological and morphological levels

Level	Example	Structure	OCP	DEP
Phonology:	*cocoa*	XX	*	
	copo	XY	✓	
Morphology:	*hoe-hoe*$_c$	XX_c		✓
	hoe-po	XY		*

*Violation; forms that abide by the constraints are marked by ✓.

Table S2. **Binomial tests of the observed proportion of doubling responses**

Experiment	Manipulation	Language	Mean	*N* participants	K, doubling response	*N* trials	SD	*z*	*P*
1	Words only	English	0.27	30	244	900	15.00	−13.70	0.00000
2	Base + object set (hom.)	English	0.62	30	561	902	15.02	7.29	0.00000
3	Object set (no base)	English	0.32	29	280	870	14.75	−10.48	0.00000
4a	Base + object set (het)	English	0.53	29	459	870	14.75	1.59	0.11184
4b	Base + object set (hom.)	English	0.61	29	530	870	14.75	6.41	0.00000
5	Single object	English	0.37	16	191	512	11.31	−5.70	0.00000
6a	Base + set (hom.)	English	0.65	16	334	512	11.31	6.85	0.00000
6b	Base + set (het.)	English	0.18	16	91	512	11.31	−14.54	0.00000
7a	Object set (hom.); no base	English	0.46	16	235	512	11.31	−1.81	0.07030
7b	Object set (het.); no base	English	0.45	16	232	512	11.31	−2.08	0.03753
8a	Base + set (het.): mixed	English	0.52	46	769	1,472	19.18	1.69	0.09103
8b	Base + set (Hom.): mixed	English	0.67	46	979	1,472	19.18	12.64	0.00000
8a	Base + set (het.): no ASL	English	0.51	38	636	1,248	17.66	0.65	0.51569
8b	Base + set (hom.): no ASL	English	0.68	38	846	1,248	17.66	12.54	0.00000
9	Signs only	Hebrew	0.47	14	413	884	14.87	−1.92	0.05486
10a	Base + object set (licit)	Hebrew	0.48	15	230	482	10.98	−0.96	0.33706
11a	Base + diminutive (licit)	Hebrew	0.61	17	331	554	11.77	4.55	0.00001
6a*	Base + object set (licit)	English	0.65	16	334	512	11.31	6.85	0.00000
12a	Base + diminutive (licit)	English	0.52	17	267	512	11.31	0.93	0.35237
10b	Base + object set (illicit)	Hebrew	0.38	15	183	482	10.98	−5.24	0.00000
11b	Base + diminutive (illicit)	Hebrew	0.33	17	180	544	11.66	−7.85	0.00000
6b*	Base + object set (illicit)	English	0.18	16	91	512	11.31	−14.54	0.00000
12b	Base + diminutive (illicit)	English	0.41	17	214	514	11.34	−3.75	0.00018

Mean indicates the proportion of doubling responses; "*N* participants" indicates the number of participants in each experiment; "K, doubling responses" indicates the total number of doubling responses across all trials; "*N* trials" indicates the total number of trials. het., heterogeneous; hom., homogeneous.

*The results of experiments 6a and 6b are reproduced for comparison with experiments 10a and 10b.

Table S3. Materials in experiments 1–4

Doubling	Control
slaflaf	slafmak
drakrak	drakmav
glanlan	glanvap
gravrav	gravlat
drafraf	drafpag
flaslas	flaspar
glatlat	glatrab
dravrav	dravkam
bravrav	bravgat
smafmaf	smafkal
blavlav	blavmar
plaflaf	plafsav
smarmar	smarvak
snavnav	snavmak
brafraf	brafgat
blaflaf	blaftak
klaflaf	klafpar
prafraf	praftak
travrav	travgam
smalmal	smalgar
kravrav	kravlan
smavmav	smavgar
slanlan	slanvak
snafnaf	snafgab
trafraf	trafkam
slavlav	slavnag
fralral	fralgad
snarnar	snarkal
frasras	frasmal
glavlav	glavdap

Table S4. Novel signs used in experiments 5–12

Item	Syllable	Handshape		Palm orientation		Location	Movement
		Dominant	Nondominant	Dominant	Nondominant		
1	X			Down	Down	H2	Path
	Y			In		Chest	Path
2	X			In		Face	Path
	Y			Down		Neutral	Bent wrist
3	X			Up	Up	Neutral	Path
	Y			Side		Neutral	Path (up)
4	X			Side	Side	H2	Path
	Y			In		Head	Path
5	X			In		Face	Path
					Side	Neutral	Arch
6	X			Side		Neutral	Twist
	Y			In		Neutral	Path
7	X			Down		Shoulder	Path
	Y			Down		Neutral	Path
8	X			Out		Neutral	Closing
	Y			Side		Neutral	Path
9	X			Side		Forehead	Path
	Y			Side		Neutral	Path
10	X			Side	Down	H2	Path
	Y			Side		Chest	Path
11	X			Side		Neutral	Path
	Y			Side		Neutral	Path
12	X			Side		Chest	Path
	Y			Side		Neutral	Arch
13	X			Down	Side	H2	Path
	Y			Down		Neutral	Path
14	X			Out		Head	Path
	Y			Side		Chest	Path
15	X			Side		Chin	Path
	Y			Side		Chest	Path
16	X			In	Down	H2	Path
	Y			Side		Neutral	Path (up)
17	X	OI		Down	Down	H2	Path
	Y			In		Chest	Path

Table S4. Cont.

Item	Syllable	Handshape		Palm orientation		Location	Movement
		Dominant	Nondominant	Dominant	Nondominant		
18	X	OI		In		Face	Path
	Y			Down		Neutral	Bent wrist
19	X	OI	OI	Up	Up	Neutral	Path
	Y			Side		Neutral	Path (up)
20	X	OI	OI	Side	Side	H2	Path
	Y			In		Head	Path
21	X	EE		In		Face	Path
	Y			Side		Neutral	Arch
22	X	EE		Side		Neutral	Twist
	Y			In		Neutral	Path
23	X	EE		Down		Shoulder	Path
	Y			Down		Neutral	Path
24	X	EE		Out		Neutral	Closing
	Y			Side		Neutral	Path
25	X	V*		Side		Forehead	Path
	Y			Side		Neutral	Path
26	X	V*		Side	Down	H2	Path
	Y			Side		Chest	Path
27	X	V*		Side		Neutral	Path
	Y			Side		Neutral	Path
28	X	V*		Side		Chest	Path
	Y			Side		Neutral	Arch
29	X	Claw*		Down	Side	H2	Path
	Y			Down		Neutral	Path
30	X	Claw*		Out		Head	Path
	Y			Side		Chest	Path
31	X	Claw*		Side		Chin	Path
	Y			Side		Chest	Path
32	X	Claw*		In	Down	H2	Path
	Y			Side		Neutral	Path (up)

Shown are the matched X and Y syllable in each item pair. Pair members were generated by either reduplicating the X syllable (in reduplicated signs) or concatenating the X and Y syllables (in nonreduplicated signs). Claw*, OI, EE, and V* indicate possible handshapes that are non-native to ASL (detailed in fig. 4 of ref. 11); H2 indicates the location of the non-dominant hand.

Other Supporting Information Files

Dataset S1 (XLSX)