Active and reactive effort in sign language phonetics

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Roadmap of the talk

1. Articulatory effort
2. Sign language phonetics
3. Active effort
4. Reactive effort
5. Summary

Articulatory effort

Background

Long tradition of functional work recognizing the importance of reducing articulatory effort in (spoken) language:

Passy 1891, Jespersen 1894, Martinet 1952, 1955, Kiparsky 1968, King 1969, Lindblom and Maddieson 1988, Lindblom 1990, Vennemann 1993, Willerman 1994, Flemming 1995, Boersma 1998, Hayes 1999, etc.

Defining articulatory effort

Kirchner 1998, 2004: Sum of all articulatory forces involved throughout the duration of the articulation, both those which result in movement and those which isometrically hold an articulator in place.

$$\text{total articulatory effort} = \int_{t_i}^{t_j} |\mathbf{F}(t)|\, \mathrm{d}t$$

Strategies for effort reduction

- reduce number of moving articulators
- reduce distance moved
- reduce mass moved
- reduce isometric (stabilizing) forces
- and probably others

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- **reduce distance moved:** e.g. place assimilation
- **reduce mass moved:** e.g. shift of palatals to coronals
- **reduce isometric (stabilizing) forces:** Kirchner's explanation for why lenition results in non-strident, rather than strident, continuants

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- **reduce distance moved:** e.g. location undershoot (ASL KNOW is sometimes articulated under the eye)
- **reduce mass moved:** stay tuned!
- **reduce isometric (stabilizing) forces:** stay tuned!

Sign language phonetics

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- despite etymology, *language* refers to any language, regardless of its modality (i.e. both sign and spoken)
- similarly, despite etymology, *phonetics* refers to (the study of) the physical properties of any language, regardless of its modality

Sign language articulators

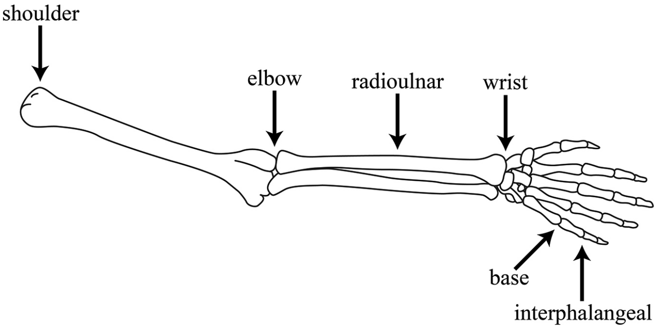
manual

arms, hands, fingers, thumbs

nonmanual

eyebrows, nostrils, lips, tongue, head, torso

Manual joints



Manual movement

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Active effort

Definition of active effort

Active effort: The effort used to move or stabilize an articulator itself. This is the usual understanding of articulatory effort. For manual movement in a sign language, this would be the effort needed to move the manual articulator, by engaging the biceps, triceps, etc.

Joint proximity and active effort

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In Napoli et al. 2014, we tested these predictions.

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- recruited two native ASL signers in their 30s, one male (from Austin TX) and one female (from Philadelphia), asked to sign the list as if in casual conversation
- coded signs for movement of the six joints, both for citation form and for each speaker's casual version(s)

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First prediction fulfilled! Freezing preferred to grafting.

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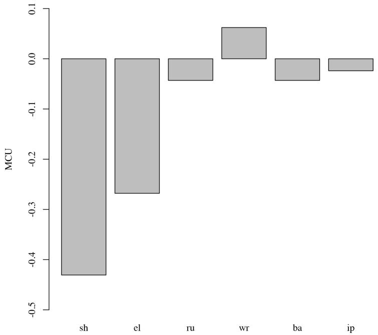
We also found that the mean change in usage (MCU) of a joint corresponded to its proximity (with a caveat):



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Reactive effort

Definition of reactive effort

Reactive effort: The effort used to isometrically resist destabilization caused by active effort elsewhere in the body. For manual movement in a sign language, this would be the effort needed to prevent the manual articulators from twisting or rocking the torso, by engaging the abdominals, back muscles, etc.

Definition of reactive effort

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As far as we know, we are the first to look at reactive effort!

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- bipedal locomotion induces twisting, which is destabilizing, but the human muscles evolved differently from other great apes to resist this twisting (the other great apes rock side to side to stabilize themselves) (Lovejoy 1988)
- humans use eye gaze for nonverbal communication, and a fixed torso position helps (Kobayashi and Kohshima 2001)

Avoidance of torso movement

An upright, forward-facing torso orientation is also specifically preferred in signing, because torso movement often carries a linguistic function, such as surprise (Sze 2008), marking topic boundaries (Winston and Monikowski 2003), role shifting (Engberg-Pedersen 1993), etc. So extraneous torso movement could be misinterpreted by the addressee as meaningful.

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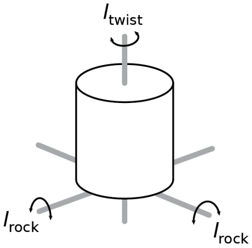
Thus, torso stability is a crucial concern for humans in general and especially within the context of signing.

Avoidance of torso movement

Rotational inertia is how much an object resists being rotated (roughly speaking, the rotational equivalent of mass). Approximating the torso as a cylinder, we have:



Avoidance of torso movement

The formulas for these two moments of inertia are:

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This means that twisting is more easily induced than rocking, because the torso offers less inherent resistance to twisting, requiring us to expend more reactive effort to resist it.

Predictions

Since articulatory ease is a factor in synchronic casual variation, which can lead to diachronic change, we predict to see bias in the lexicon, such that:

- **stable** signs (which induce no torso movement) should be more common than by chance frequency, and thus, **destabilizing** signs (those which induce either twisting or rocking), should be less common

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- **stable** signs (which induce no torso movement) should be more common than by chance frequency, and thus, **destabilizing** signs (those which induce either twisting or rocking), should be less common
- signs that induce rocking (which has a higher moment of inertia) should be more common than signs that induce twisting

Our second study: Design

- compiled signs with **free, single or retraced two-handed path movement** for Italian Sign Language (LIS; Romeo 1991), Sri Lankan Sign Language (SLSL; Sri Lanka Central Federation of the Deaf 2007), and Al-Sayyid Bedouin Sign Language (ASBSL; Meir et al. 2012)

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- coded those signs for six types of movement, along three cardinal axes (away-toward, left-right, up-down) and two relative directions between the hands (the same or opposite direction)

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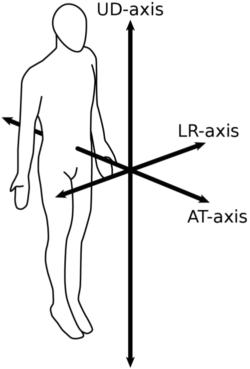

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For example, ACTIVITY in ASL would be coded as +LR, since the hands move in the same direction along the LR-axis, while ALLIGATOR in ASL would be coded as −UD.

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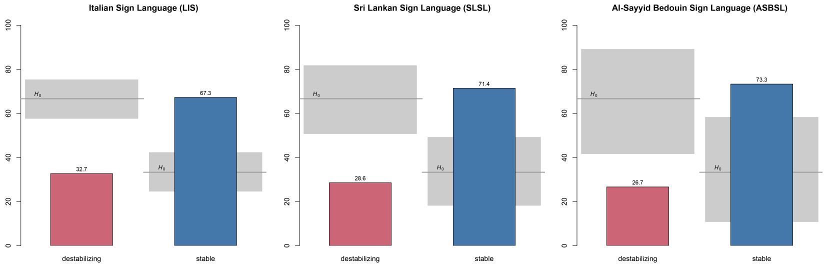
Signs can be multiaxial. For example, PACK in ASL would be coded at +LR and −UD.

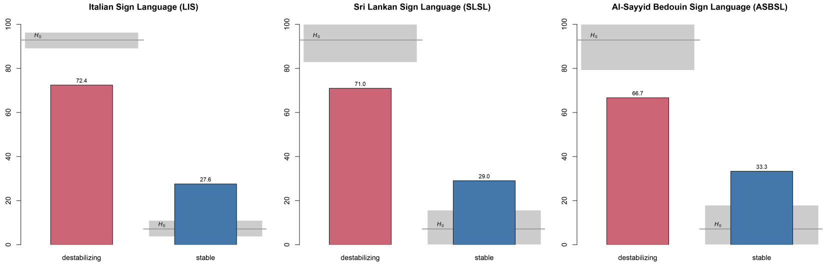
Our second study: Results

Monoaxial signs: four destabilizing movements (+LR, −AT, +AT, −UD) and two stable movements (+UD, −LR)



Our second study: Results

Multiaxial signs: thirteen destabilizing movements and one stable movement (we ignore cognitively difficult movements with AT and UD having opposite signs)

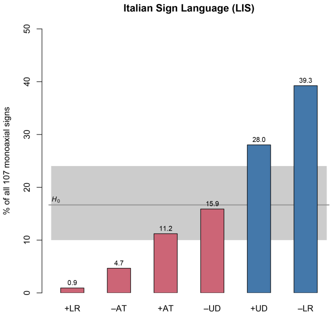


Our second study: Results

We find that for both monoaxial and multiaxial signs, in all three languages, stable signs are more common than would be expected by chance frequency, and thus, destablizing signs are less common than would be expected by chance frequency.
First prediction confirmed!

Our second study: Results

Rough analysis for LIS suggests that monoaxial movements that induce torso rocking (+AT and −UD) are more common than those that induce torso twisting (+LR and −AT).



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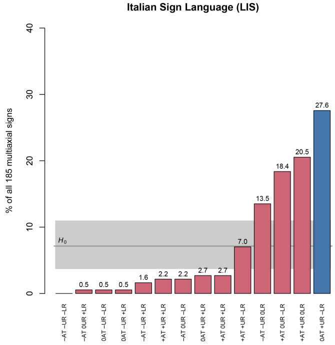
Multiaxial signs are rather complicated. . .



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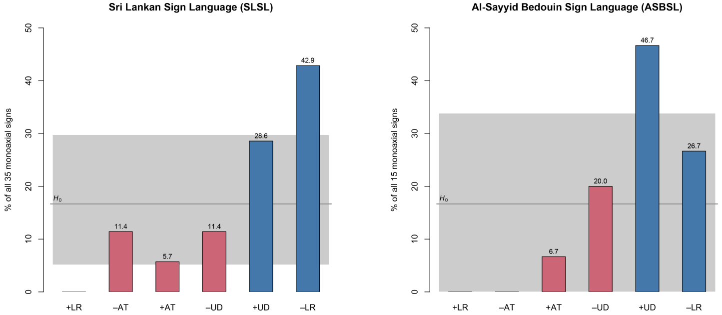
SLSL and ASBSL have too few signs to get solid results. . .



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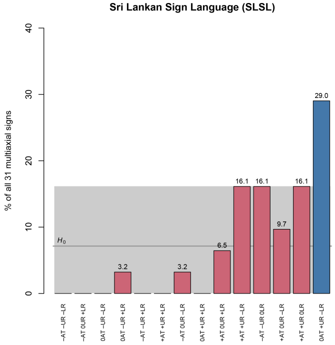

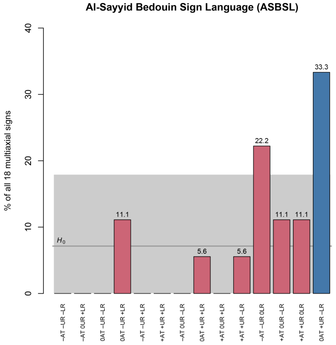

Summary

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- number of joints decreases
- average amount of freezing versus grafting of a joint (MCU) depends on joint proximity to torso (and thus, amount of mass being moved): shoulder freezes most and grafts least, then the elbow, then the radiolunar, then the wrist
- base and interphalangeal get a pass, because they are also used for handshape

Reactive effort is a previously unstudied facet of articulatory effort that needs to be distinguished from active effort and can really only be studied by looking at sign languages. It is reduced in the lexicons of LIS, SLSL, and ASBSL (which suggests a cross-linguistic pattern):

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- stable movements are more common — and destablizing movements less common — than would be expected by random chance
- rocking movements may be more common than twisting movement, but more data is needed

Thank you!

References I

Boersma, Paul. 1998. *Functional Phonology: Formalizing the Interactions Between Articulatory and Perceptual Drives*. The Hague: Holland Academic Graphics.

Engberg-Pedersen, Elisabeth. 1993. *Space in Danish Sign Language: The Semantics and Morphosyntax of the Use of Space in a Visual Language*. Hamburg: Signum.

Flemming, Edward. 1995. *Auditory Representations in Phonology*. Doctoral dissertation. University of California, Los Angeles.

Hayes, Bruce. 1999. Phonetically driven phonology: The role of Optimality Theory and inductive grounding. In Michael Darnell, Edith Moravscik, Michael Noonan, Frederick Newmeyer, and Kathleen Wheatly, eds. *Functionalism and Formalism in Linguistics. Volume I: General Papers*. Amsterdam: John Benjamins. 243–285.

References II

Jespersen, Otto. 1894. *Progress in Language with Special Reference to English*. London: Swan Sonnenschein.

King, Robert D. 1969. *Historical Linguistics and Generative Grammar*. Englewood Cliffs, NJ: Prentice-Hall.

Kiparsky, Paul. 1968. Linguistic universals and language change. In Emmond Bach and Robert T. Harms, eds. *Universals in Linguistic Theory*. New York: Holt, Rinehart, and Winston. 170–202.

Kirchner, Robert. 1998. *An Effort-Based Approach to Lenition*. Doctoral dissertation. University of California. Los Angeles.

——. 2004. Consonant lenition. In Bruce Hayes, Robert Kirchner, and Donca Steriade, eds. *Phonetically Based Phonology*. Oxford: Oxford University Press. 313–345.

References III

Kobayashi, Hiromi and Shiro Kohshima. 2001. Unique morphology of the human eye and its adaptive meaning: Comparative studies on external morphology of the primate eye. *Journal of Human Evolution* 40:419–435.

Lindblom, Björn. 1990. Explaining phonetic variation: A sketch of the H&H theory. In William J. Hardcastle and Alain Marchal, eds. *Speech Production and Speech Modeling*. Dordrecht: Kluwer Publishers. 403–439.

Lindblom, Björn and Ian Maddieson. 1988. Phonetic universals in consonant systems. In Larry M. Hyman and Charles N. Li, eds. *Language, Speech, and Mind: Studies in Honour of Victoria A. Fromkin*. London: Routledge. 62–78.

Lovejoy, C. Owen. 1988. Evolution of human walking. *Scientific American* 259:118–125.

Martinet, André. 1952. Function, structure, and sound change. *Word* 8:1–32.

References IV

——. 1955. *Économie des changements phonétiques: Traité de phonologie diachronique*. Bern: Francke Verlag.

Meir, Irit, Wendy Sandler, Carol Padden, and Mark Aronoff. 2012. *Al-Sayyid Bedouin Sign Language Dictionary*. Haifa, Israel, and Chicago: University of Haifa and University of Chicago.

Napoli, Donna Jo, Nathan Sanders, and Rebecaa Wright. 2014. On the linguistic effects of articulatory ease, with a focus on sign languages. *Language* 90:424–456.

Passy, Paul. 1891. *Étude sur les changements phonétiques et leurs caractères généreaux*. Paris: Libraire Firmin-Didot.

Romeo, Orazio. 1991. *Dizionario dei segni*. Zanichelli.

Signing Savvy. 2014. <http://www.signingsavvy.com/>.

Sri Lanka Central Federation of the Deaf. 2007. *Sri Lanka sign dictionary*. Colombo, Sri Lanka: Graphitec.

References V

Sze, Felix. 2008. Blinks and intonational phrasing in Hong Kong Sign Language. In Josep Quer, ed. *Signs of the Time: Selected Papers from TISLR 2004 (International Studies on Sign Language and Communication of the Deaf 51*. Hamburg: Signum.

Vennemann, Theo. 1993. Language change as language improvement. In Charles Jones, ed. *Historical Linguistics: Problems and Perspectives*. London: Longman. 319–344.

Willerman, Raquel. 1994. *The Phonetics of Pronouns: Articulatory Bases of Markedness*. Doctoral dissertation. University of Texas at Austin. Austin, TX.

Winston, Elizabeth and Christine Monikowski. 2003. Marking topic boundaries. In Melanie Metzger, Steven D. Collins, Valerie Dively, and Risa Shaw, eds. *From Topic Boundaries to Omission: New Research on Interpretation 1*. Washington, DC: Gallaudet University Press. 187–227.