Articulatory and perceptual patterns in sign language lexicons

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work done partially in collaboration
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Roadmap of the talk

1. Background
2. The effect of reactive effort on the lexicon
3. The effect of perception on the lexicon
4. Summary

Background

Sign language phonetics

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Sign language phonetics

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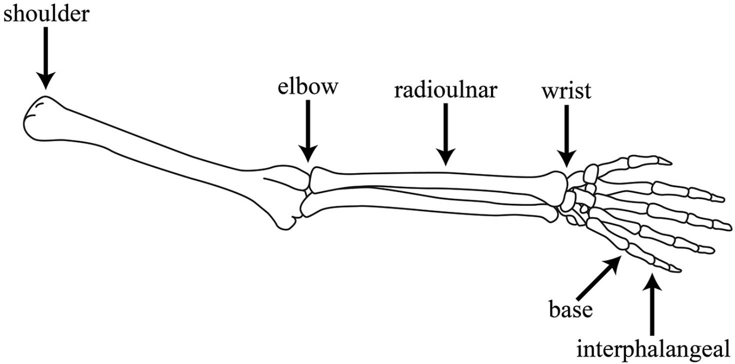
- *phonetics* < Greek *φωνή (phōnē)* 'sound'
- *language* < Latin *lingua* 'tongue'
- but despite etymology, *language* refers to any language, regardless of its modality (i.e. both sign and speech)
- similarly, despite etymology, *phonetics* refers to the physical properties of any language, regardless of its modality

Sign language articulators

manual: arms, hands, fingers, thumbs

nonmanual: eyebrows, nostrils, lips, tongue, head, torso

Manual joints



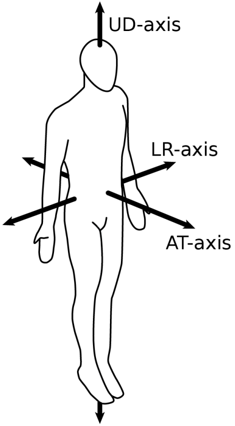
Manual movement

path: at the shoulder or elbow (e.g. ASL STAY and SAME)

local: at the radioulnar, wrist, base, or interphalangeal (e.g. ASL YES and YELLOW)

Axes of movement

Sanders and Napoli (2016a) introduce notation for three cardinal axes of movement (**away-toward (AT)**, **up-down (UD)**, **left-right (LR)**), and for two-handed signs, the relative direction of the hands: $+$ for the same direction, $-$ for the opposite direction, and 0 for no movement.



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

Signs like these, in which movement occurs along only one axis, are called **monoaxial**.

Axes of movement

Signs can also be **multiaxial.** For example, PACK in ASL would be notated as

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The effect of reactive effort on the lexicon

Articulatory effort

There is a 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.).

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.

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

Articulatory effort

Strategies for reducing articulatory effort:

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

Effort reduction in spoken languages

- **reduce number of moving articulators:** e.g. simplification of labiovelars to velars

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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 mass moved:** e.g. joint freezing (ASL RELAX can be articulated with both the shoulders and elbows or with just the elbows, freezing the shoulders)
- **reduce isometric (stabilizing) forces: stay tuned!**

Reactive effort and torso stability

Reactive effort, first identified by Sanders and Napoli (2016a) (extending Kirchner 1998, 2004), is a type of articulatory effort distinct from active effort, which is the effort used within an articulator to move it (the traditional conception of what articulatory effort is).

Reactive effort and torso stability

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Sanders and Napoli (2016a) define reactive effort as the effort used to isometrically resist incidental movement of one part of the body caused by movement elsewhere in the body.

Reactive effort and torso stability

For manual movement in a sign language, reactive effort is the effort needed to prevent the manual articulators from destabilizing (twisting or rocking) the torso, which we resist by engaging the abdominals, back muscles, obliques, etc.

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But the manual articulators are much more massive and can easily cause incidental movement of the torso, especially when they have path movement.

Reactive effort and torso stability

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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)

Reactive effort and torso stability

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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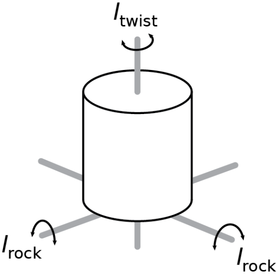
Thus, torso stability is a crucial concern for humans in general, but especially within the context of sign language communication.

Reactive effort and torso stability

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



Reactive effort and torso stability

The formulas for these two moments of inertia are:

$$I_{\text{twist}} = \frac{mr^2}{2} \qquad I_{\text{rock}} = \frac{m(3r^2 + 4h^2)}{12}$$

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This inequality means that the torso has less inherent resistance to twisting, requiring us to expend more reactive effort to resist it than we would need to expend to resist rocking.

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Thus, we expect that:

- **destabilizing** signs (those which induce either twisting or rocking) should be **dispreferred to stable** signs (which induce no torso movement)
- signs that induce **twisting** (which has a lower moment of inertia and thus, less inherent resistance to offer) should be **dispreferred to signs that induce rocking**

Donna Jo Napoli and I tested these predictions, in a preliminary study of 3 languages (Sanders and Napoli 2016a) followed up by a larger study of 24 languages (Sanders and Napoli 2016b).

Sanders and Napoli 2016a, 2016b

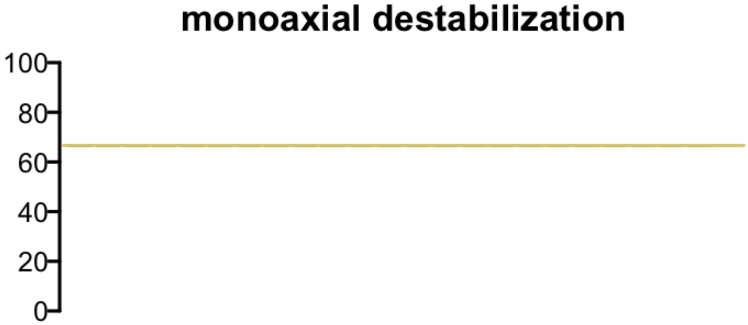
We compiled signs with **free, single or retraced two-handed path movement**.

In our original study, we looked at the lexicons of Italian Sign Language (Romeo 1991), Sri Lankan Sign Language (Sri Lanka Central Federation of the Deaf 2007), and Al-Sayyid Bedouin Sign Language (Meir et al. 2012).

The results were solid and suggestive, so we followed up with 24 languages from the online database Spreadthesign (2012). I report those results here.

destabilizing stable

$+$AT, $-$AT, $-$UD, $+$LR $<$ $+$UD, $-$LR



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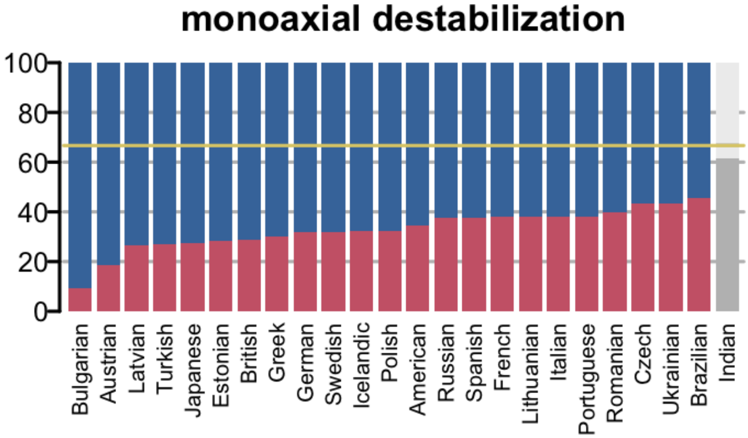
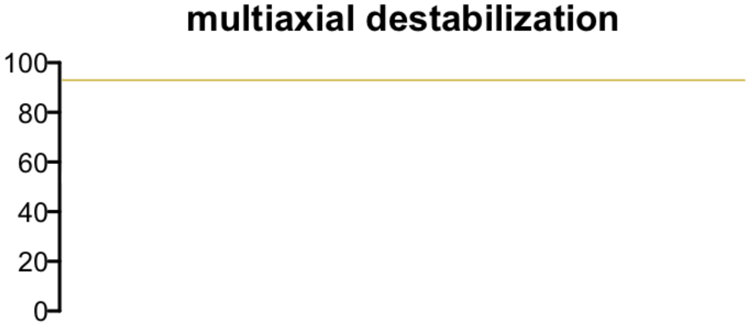


Sanders and Napoli 2016a, 2016b

destabilizing		stable
all others	$<$	0AT +UD −LR



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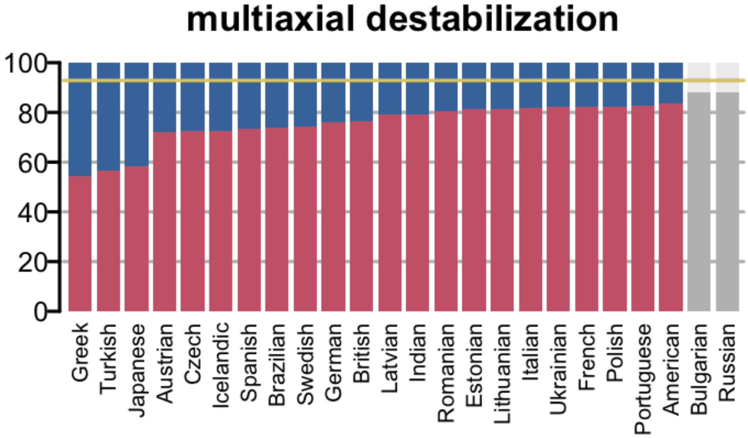
destabilizing — stable

all others $<$ 0AT $+$UD $-$LR

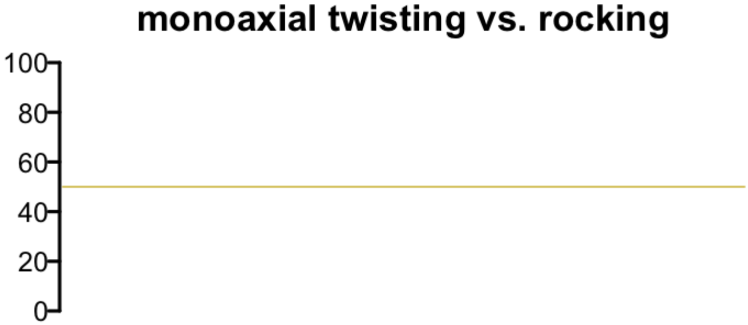


Sanders and Napoli 2016a, 2016b

We find that for both monoaxial and multiaxial signs, in all languages, destabilizing signs are less common than would be expected by chance frequency (nearly all comparisons, 45 out of 48, are statistically significant). First prediction fulfilled!

Furthermore, in both cases, the languages are statistically indistinguishable from each other (except Greek and Turkish in the multiaxial comparison), which points to a **cross-linguistic universal**.

twisting rocking
$-$AT, $+$LR $<$ $+$AT, $-$UD



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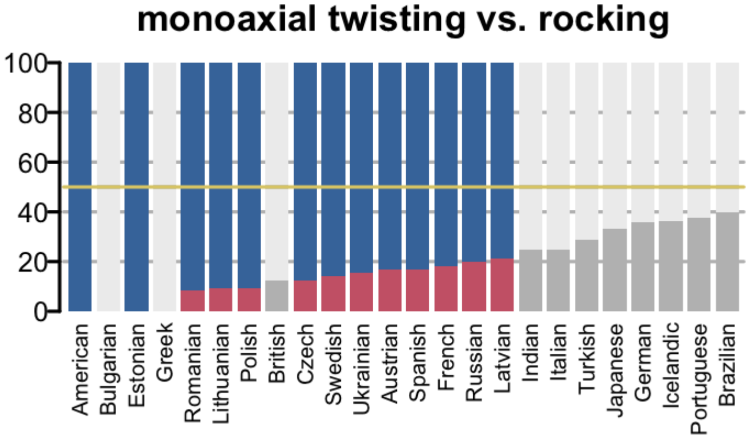

Sanders and Napoli 2016a, 2016b

We find that for destabilizing monoaxial signs, in all languages, twisting signs are less common than would be expected by chance frequency (about half of the comparisons, 13 out of 24, are statistically significant). Second prediction fulfilled!

Again, the languages are statistically indistinguishable from each other, which points to a **cross-linguistic universal**.

The effect of perception on the lexicon

Motion in depth

Motion in depth (movement along the AT-axis) is more difficult to perceive than vertical (UD) or horizontal (LR) movement (Regan et al. 1986, Regan and Kaushal 1994).

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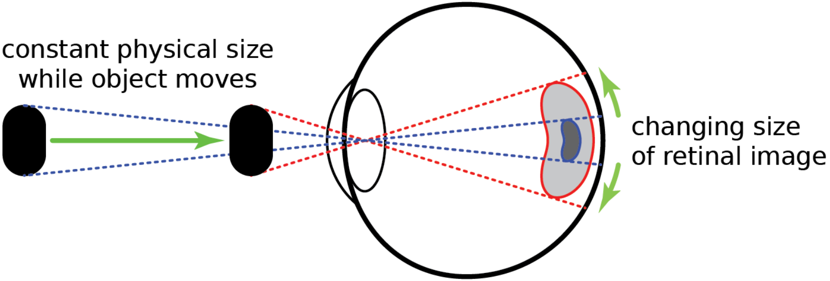
This is because, unlike UD and LR, we do not view AT movement directly, but must instead infer it from indirect cues.

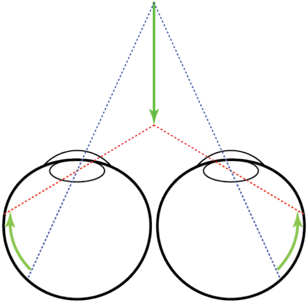
Motion in depth

One such cue is change in apparent size of an object as it moves along the AT-axis.



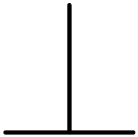
Motion in depth

Another cue to AT movement is parallax, in which AT movement results in different movements on the two retinas, which must be integrated and reinterpreted.



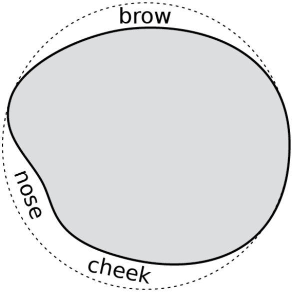
The horizontal-vertical illusion

Although they are directly observed, UD and LR movement are perceived slightly differently, as in the **horizontal-vertical illusion** (Fick 1851, Bailey and Scerbo 2002):



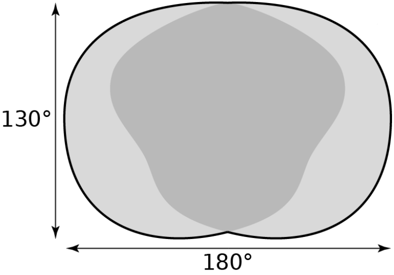
The horizontal-vertical illusion

This illusion can be explained by the geometry of our visual field (Künnapas 1957). Each individual eye has a roughly circular visual field (Webb 1964, Parker and West 1973):



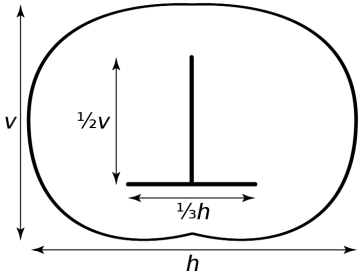
The horizontal-vertical illusion

Our ambinocular visual field is the result of both monocular fields of view combined, which is roughly elliptical because of the horizontal placement of the eyes:



The horizontal-vertical illusion

Distances or movements take up different proportions of the visual field, depending on whether they are oriented vertically or horizontally, with vertical appearing larger:



Predictions

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Given consideration of perceptual distinctiveness of movement, we expect that:

- **AT** movements (which require extra cues and extra cognitive processing to perceive) should be **dispreferred to UD and LR**
- **LR** movements should be **dispreferred to UD** because of the horizontal-vertical illusion

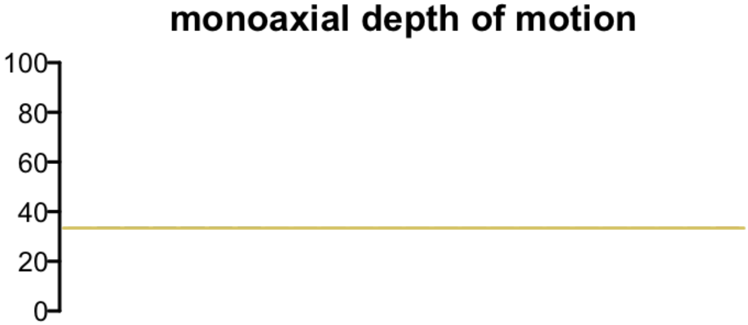
Preliminary results

I tested these predictions against the same data from the 24 languages in Sanders and Napoli (2016b).

Preliminary results

motion in depth — all others

+AT, −AT < +UD, −UD, +LR, −LR



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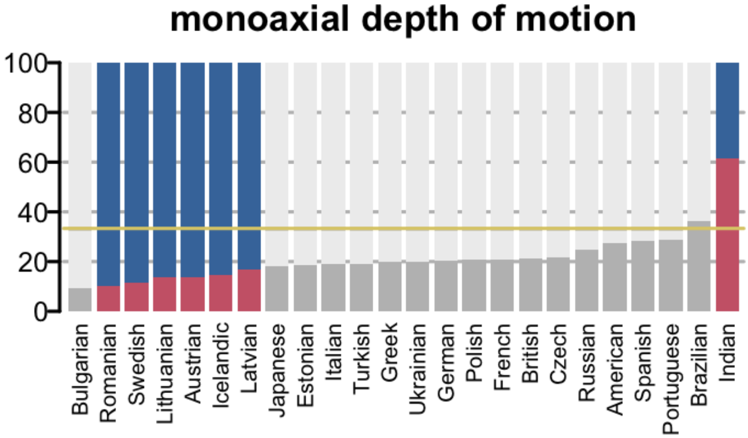

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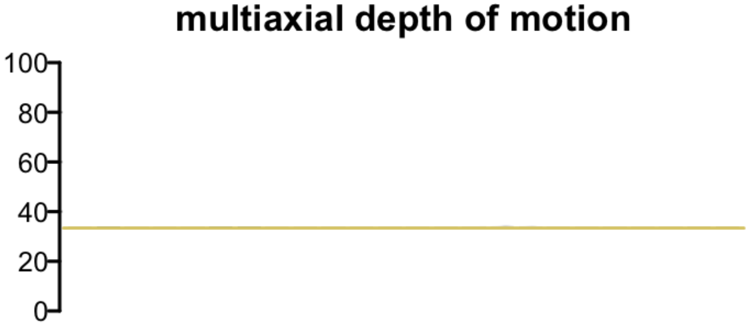

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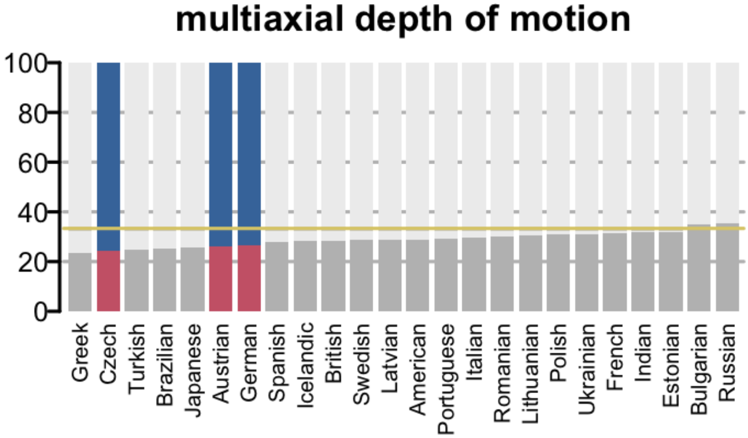


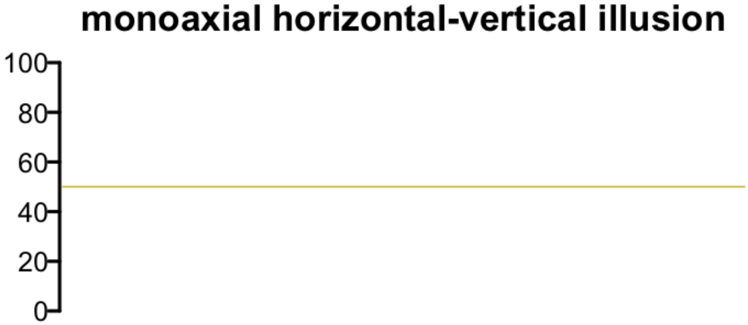
Preliminary results

I find that for both monoaxial and multiaxial signs, in nearly all languages (22 out of 24 for each case), AT movement is less common than would be expected by chance frequency (though only 10 out of 48 comparisons are statistically significant, one of which contradicts the prediction). First prediction fulfilled?

Furthermore, in both cases, the languages are statistically indistinguishable from each other, which points to a possible **cross-linguistic universal**.

Preliminary results

horizontal vertical
$+\text{LR}, -\text{LR} < +\text{UD}, -\text{UD}$



Preliminary results

horizontal vertical

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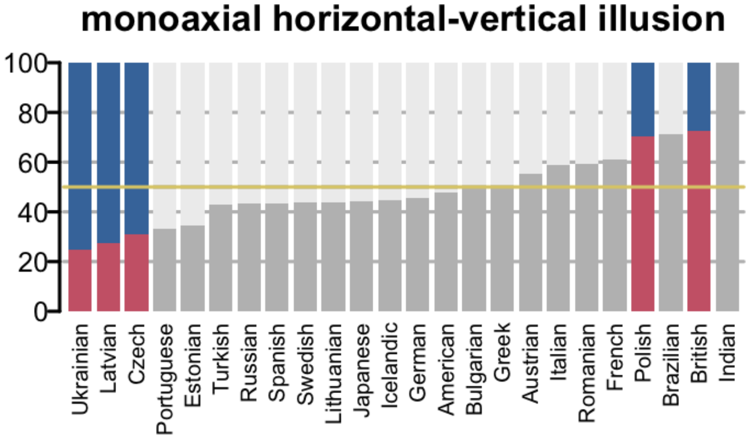

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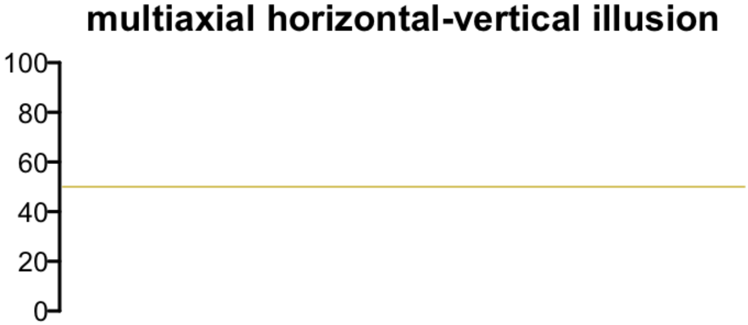

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horizontal vertical

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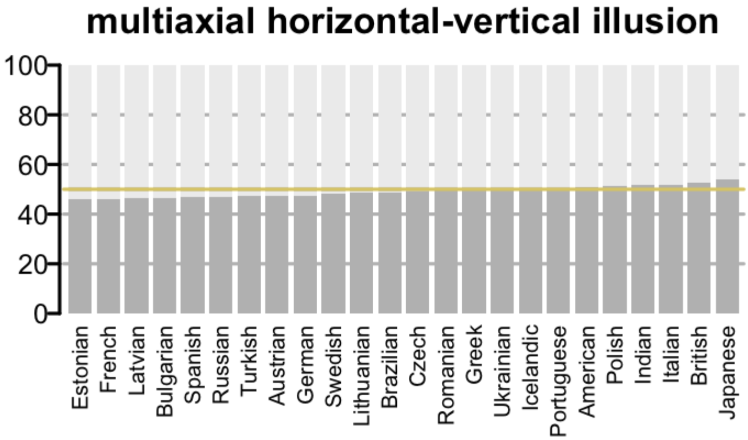

Preliminary results

I find that for both monoaxial and multiaxial signs, in only about half of the languages (14 and 10 out of 24 for each case), LR movement is less common than would be expected by chance frequency (though only 5 out of 48 comparisons are statistically significant, two of which contradict the prediction). Second prediction fails?

Summary

Reactive effort results

Reactive effort is a previously unstudied facet of articulatory effort that needs to be distinguished from active effort. It is reduced in various ways in the lexicons of 24 languages, following essentially the same mathematical pattern across languages (which suggests a cross-linguistic universal):

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Reactive effort results

Reactive effort is a previously unstudied facet of articulatory effort that needs to be distinguished from active effort. It is reduced in various ways in the lexicons of 24 languages, following essentially the same mathematical pattern across languages (which suggests a cross-linguistic universal):

- among both monoaxial and multiaxial signs, destabilizing movements are less common than would be expected by random chance
- among monoaxial signs, twisting movements are less common than rocking movements than would be expected by random chance

Perceptual distinctiveness results

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Perceptual distinctiveness was not nearly as strongly apparent as reduction of reactive effort:

- among both monoaxial and multiaxial signs, motion in depth was moderately less common than horizontal and vertical movement than would be expected by random chance
- among monoaxial and multiaxial signs, the horizontal-vertical illusion seems irrelevant, with horizontal and vertical movement being about equally likely

What’s next?

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- find evidence for reduction of reactive effort in spoken languages
- use effort reduction to look at other aspects of sign: frequency in conversation, order of acquisition, etc.

What's next?

- in particular, use effort reduction to help do historical reconstruction on sign languages (currently ongoing work with Donna Jo)

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- compare path movement to local movement; perhaps path movement is more sensitive to articulatory effort (bigger masses are harder to move), while local movement is more sensitive to perceptual effort (smaller movements are harder to see) (my next project)

Thank you!

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