Some issues in the perceptual phonetics of sign language: Motion-in-depth and the horizontal-vertical illusion

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Abstract. Although the human body's biomechanics and visual system are fairly well understood in general, our knowledge of their relationship specific to sign language is rather weak, especially in comparison to the extensive knowledge we have of the analogous articulatory and auditory phonetics of speech. Some work has been done on the articulatory phonetics of sign, but the perceptual phonetics are still greatly understudied.

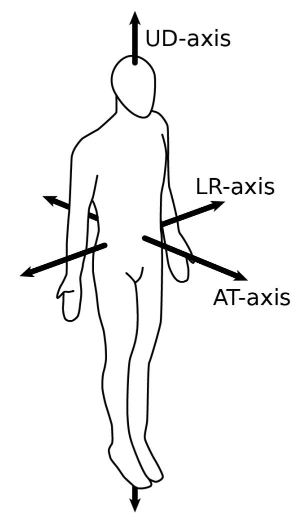
In this research, I consider two properties of visual perception that may be relevant to sign: (i) the difficulty in perceiving motion-in-depth, which causes horizontal and vertical motion to be easier to perceive than motion towards or away from the viewer; and (ii) the horizontal-vertical illusion, in which vertical motion is perceived as longer (and thus, more salient) than horizontal motion. These two factors predict that motion-in-depth should be the most perceptually marked in sign language and that vertical motion should be the least.

I test these predictions by looking at the frequency of the three types of motion in signs with two-handed path movement in the lexicons of 24 sign languages. I find some evidence for a crosslinguistic bias against motion-in-depth but no evidence of a crosslinguistic preference for vertical motion, suggesting that path movement in sign may indeed be sensitive to the difficulty of perceiving motion-in-depth but perhaps not to the horizontal-vertical illusion. I conclude with some ideas on how the horizontal-vertical illusion may yet still play a role in the structure of sign languages.

1 Background

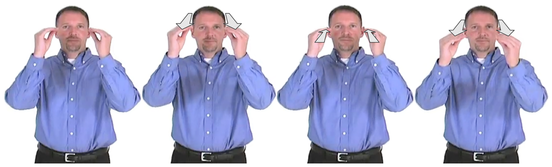
Sanders and Napoli (2016a) developed a framework for analyzing bimanual movement in sign languages, categorizing signs based on how the two hands move in three dimensions, as defined by three axes: **away-toward (AT)**, **up-down (UD)**, and **left-right (LR)** (1).

(1)

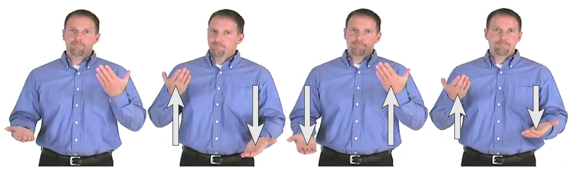


Signs are categorized for each axis based on whether the hands move parallel to that axis in the same direction (+), in opposite directions (−), or not at all (0), as in (2–5). Signs are further categorized by whether they are **monoaxial** (moving parallel to only one axis, as in (2) and (3)) or **multiaxial** (moving parallel to two or three axes, as in (4) and (5)).

(2) monoaxial TEACH in ASL, +AT 0UD 0LR (+AT for short)[1]

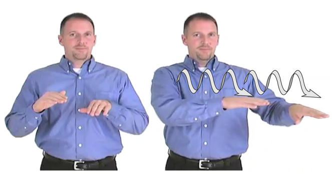


(3) monoaxial MAYBE in ASL, 0AT −UD 0LR (−UD for short)



(4) multiaxial BICYCLE in ASL, −AT −UD 0LR

(5) multiaxial WAVE in ASL, +AT +UD +LR



Sanders and Napoli (2016b) used this framework to analyze signs from 24 sign languages in the online database Spreadthesign (2012). The signs Sanders and Napoli collected and analyzed are bimanual, have path movement (requiring shoulder or elbow movement), and have both hands unconnected for at least some portion of the path. In addition, the paths in question are relatively simple: straight lines without angles, circles, etc.

[1]Example signs from American Sign Language (ASL) are annotated stills taken from video from Signing Savvy (2009/2017).

Communication normally involves at least two interlocutors, one to produce a message and one to receive it, and each participant puts in effort. Ideally, both types of effort would be reduced, but there is no perfect balance (generally, reducing articulatory effort results in increasing perceptual effort, etc.). But both concerns play a role in shaping language, so we see the effects of both.

Sanders and Napoli (2016a,b) show that articulatory effort is a factor that affects which types of movement are more or less common, so I focus here on perception, with the underlying premise that the more perceptually salient a movement is, the more common it should be.

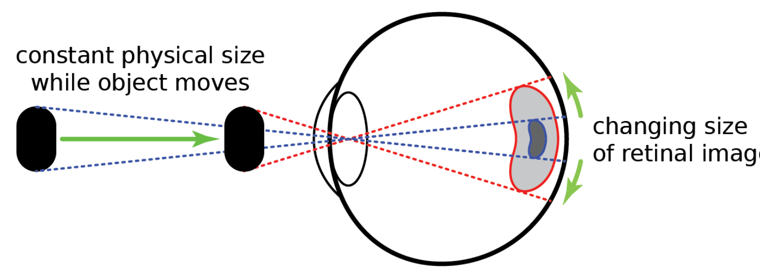
Although articulatory effort in spoken languages and sign languages operates on the same basic principles (muscles, energy, etc.; see Napoli et al. 2014 for discussion and references), just with different articulators, perception differs drastically between the two modalities, because the auditory and visual systems function very differently.

2 The difficulty of perceiving motion-in-depth

In order to understand perceptual salience in sign, we need to understand the peculiarities of the visual system. I focus first on the perception of motion-in-depth, that is, motion along the AT-axis.

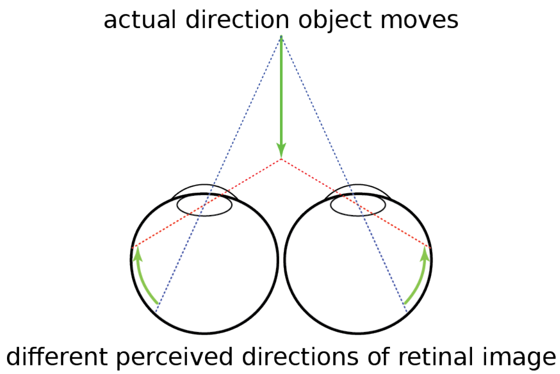
When we view a moving object, we can see UD and LR movement directly, but AT movement is more complicated and must be inferred by other aspects of what we see (Regan et al. 1986, Regan and Kaushal 1994). For example, when objects move closer to us, their image on our retina gets larger (6). Thus, a change in the apparent size of an object is a cue to AT movement.

(6)



Another cue to AT movement is parallax, which is the different views our individual eyes have (7). In particular, when we view AT movement, our left eye sees leftward movement, while our right eye sees rightward movement. The discrepancy is resolved by our visual system and reinterpreted (along with change in image size) as AT movement.

(7)



Because AT movement must be inferred by these and other indirect cues, it (likely) requires more perceptual effort than UD or LR movement, since they are viewed directly and do not need to be computed by extra visual processing. This suggests the scale in (8) for perceptual salience (which should apply to both monoaxial and multiaxial signs):

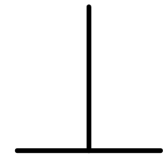
(8)

more salient		less salient
UD and LR (directly observed)	>	AT (indirectly observed)

3 The horizontal-vertical illusion

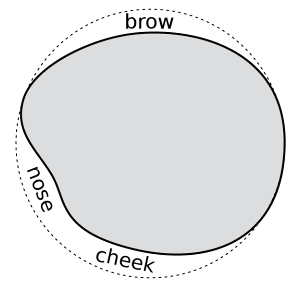
Although they are directly observed, UD and LR movement are also perceived slightly differently. One example of this is the horizontal-vertical illusion (demonstrated by the inverted T in (9)), in which UD distances and movements appear longer than LR distances and movements of the same physical size (Fick 1851, Bailey and Scerbo 2002). In (9), the horizontal-vertical illusions causes the vertical leg to appear longer than the base.

(9)



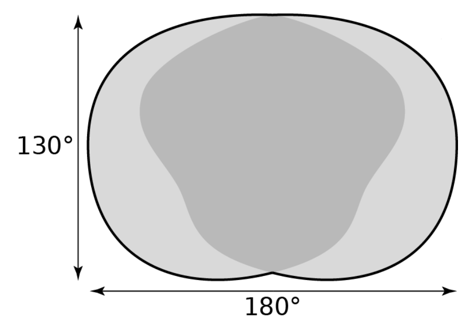
The horizontal-vertical illusion can be explained by the geometry of our visual field (Künnapas 1957). Each individual eye has a roughly circular visual field, with portions blocked off due to the brow, nose, and cheek, as shown by the approximation of the right eye's monocular visual field in (10) (based on Webb 1964, Parker and West 1973).

(10)



Our ambinocular visual field is the result of both monocular fields of view combined: the binocular (stereoscopic) overlap plus the monocular (far peripheral) edges (11).

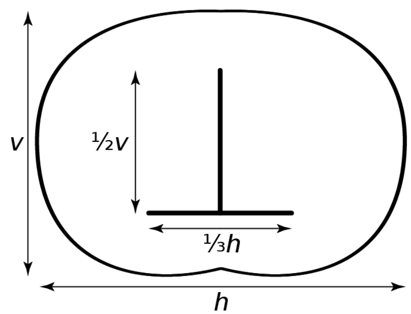
(11)



Because our eyes are set apart horizontally, our overall ambinocular visual field is roughly elliptical and is slightly wider than it is tall: our horizontal ambinocular visual angle is about 180° (which means the very edges of our far peripheral vision when staring straight ahead are to our direct right and left), while our vertical ambinocular visual angle is only about 130°.

Distances or movements in this elliptical visual field take up different amounts of space, depending on whether they are oriented vertically or horizontally. For example, in (12), though the two lines of the inverted T are physically the same size, the vertical line takes up relatively half of the vertical dimension of the visual field, while the horizontal line takes up only about one-third of the horizontal dimension.

(12)



Given this illusion, UD movements naturally appear larger, and thus, are easier to see; alternatively, we can think of the physical effort involved: more articulatory effort is needed for UD movements in order to compensate for the horizontal-vertical illusion. Either way, this gives of the scale of perceptual salience in (13).

(13)

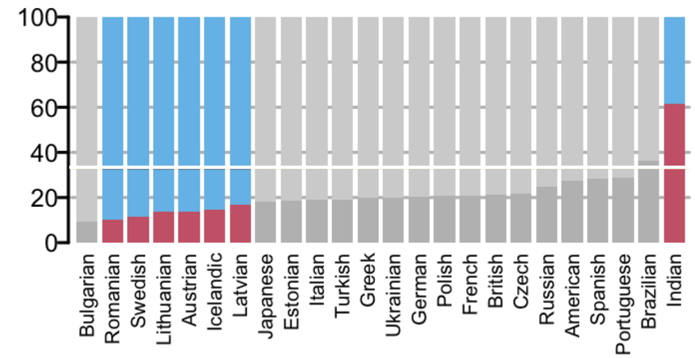
more salient		less salient
UD (looks larger)	>	LR (looks smaller)

4 Results from 24 languages

To test the two predicted scales of perceptual salience, I matched them to the distribution of signs in each of the individual 24 languages in the Sanders and Napoli (2016b) dataset, for both monoaxial and multiaxial signs. First is the predicted amount of AT movement (motion-in-depth) in comparison to UD and LR movement. If these movements are distributed uniformly, we expect that AT movement should make up about one-third of all movements, so any deviation from that indicates some bias for or against AT movement.

For monoaxial signs, there is evidence that languages tend to disprefer AT movement, as predicted. In (14), the uniform distribution (the null hypothesis) is shown by the white horizontal line, with the proportion of AT movement graphed from the bottom up (darker bars indicate statistical significance).

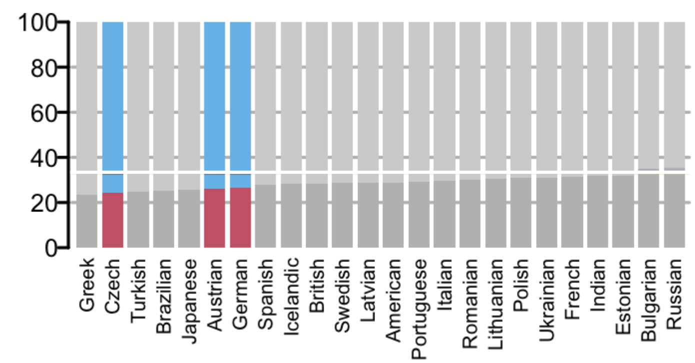
(14)



AT movement vs. UD/LR movement in monoaxial signs

Multiaxial signs pattern similarly, though the evidence is a bit weaker (15).

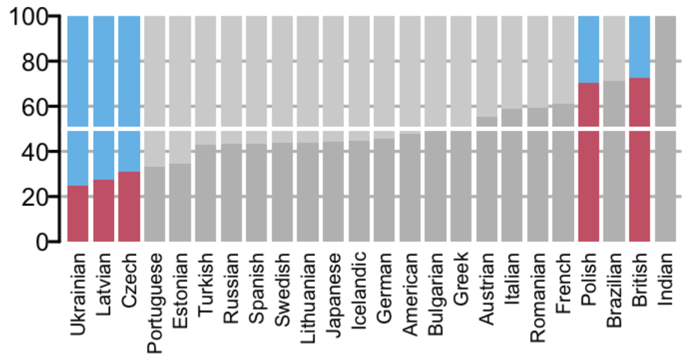
(15)



AT movement vs. UD/LR movement in multiaxial signs

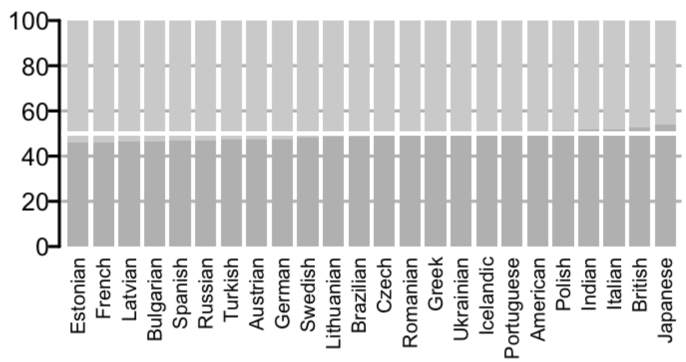
However, for the horizontal-vertical illusion, there appears to be no crosslinguistic effect on the distribution of LR versus UD movement, for either monoaxial signs (16) or multiaxial signs (17). In both cases, the LR movement is predicted to be disprefered because it is perceptually less salient, but there is little crosslinguistic difference in the amount of LR movement in comparison to UD.

(16)



LR movement vs. UD movement in monoaxial signs

(17)



LR movement vs. UD movement in multiaxial signs

5 Summary

Humans have difficulty perceiving motion-in-depth (AT movement) because it is perceived indirectly and must be inferred by other perceptual cues. This indirect inferential processing seems to have some crosslinguistic effect on the distribution of path movements among two-handed signs in the lexicon, with both monoaxial and multiaxial signs having less AT movement than would ordinarily be expected by random chance.

Additionally, horizontal motion (LR movement) is less perceptually salient than vertical motion (UD movement), due to the shape of the visual field and the resulting horizontal-vertical illusion. However, this does not seem to have a crosslinguistic effect on the path movements among two-handed signs in the lexicon, with no consistent deviation in the amount of LR versus UD movement from what would be expected by random chance.

But perhaps the horizontal-vertical illusion could be rescued. It (and maybe also motion-in-depth) may play a role in the distribution of smaller fingers movements rather than path movement. The data to test this has not been collected yet but is on my agenda!

In addition, I need to do more work in teasing apart the effects of articulatory effort reduction (as in Sanders and Napoli 2016a,b) versus the effects of perceptual salience. How much of the distribution of movement can be attributed to considerations of articulatory effort or perceptual salience alone? Is it possible that the effects of articulation and perception are synergistic?

Finally, there are many ways these effects might show up in sign languages besides frequency within the lexicon. Perhaps there are effects on grammatical structure, conversational frequency, change over time, acquisition, etc.

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