Morpho-phonology and Articulatory Energy in Expressing Complex Motion Events in Turkish Sign Language (TİD) and Age of Acquisition Effects

Introduction: In a complex motion-event, an agent moves along a path with a manner [2][4][6]. We analyze the expression of these complex events, offer an estimation of articulatory energy with pose estimation, and discuss differences between native and late signers.

Stimuli: 54 items: 9 Manners (Running, Walking-on-Toes etc.) with 6 Paths each (Curved, Circle, Zigzag etc.) adapted from [6].
Participants: 10 adult native signers (deaf-of-deaf) and 10 adult late signers (deaf-of-hearing), all right-handed.

Expression-Coding: Following [4], we coded *Sequenced* (separate manner and path), *Conflated* (simultaneous manner and path), and *Mixed* (at least one separate manner or path, followed/preceded by a conflated form), examples in (1).
Calculating estimated articulatory energy: For pose estimation, we took a set of screenshots from each movement and processed the images in OpenPose library [3] in Python by marking the torso, shoulder, elbow, wrist and fingers (Figure-1). To calculate a value for the estimated energy spent on a movement within an expression we assigned relative values to joints according to the body-mass moved by each factoring in the duration of active joints (2). We calculated total and average values for each expression. We measured the Right and Left side of the body separately.

Results: Both groups produced all expression types but native signers used more sequenced expressions whereas late signers used more conflation (Figure-2). We fit two Poisson regression models using lme4 [1] in R to expression types. One had the group as a predictor and the other didn't, and we used a likelihood ratio test to compare both models. The nested model without the group was a worse fit ($p<0.001$). For the articulatory energy, we fit a linear mixed regression model with group, dominant side, and expression type as fixed effects, and participant and processed frame as random effects. Figure-3 shows that being a late signer versus a native signer increased articulatory energy spent. Signers spent less articulatory energy with the non-dominant side of their body than their dominant side. Furthermore, signers used less articulatory energy when they conflated manner with path as opposed to when they sequenced manner and path, which increased estimated energy spent compared to the reference level (the mixed expressions). The results also revealed a two-way interaction between group and side. Late signers spent significantly more energy with non-dominant (i.e., left) side of their bodies than native signers.

Discussion: The results suggest two age-of-acquisition effects on the production of complex motion-events in TİD.
Morpho-phonological expression: late signers produce more conflated forms, (simultaneous manner and path) whereas native signers produce more sequenced forms (manner and path separately). This suggests that morpho-phonological sequencing of physically-simultaneous events is sensitive to age-of-acquisition in TİD (see [4] for a similar finding in Turkish homesigners).
Estimated articulatory energy: overall late signers spent more energy. However, a strong age-of-acquisition effect is present for the non-dominant side, suggesting that while native signers do not use the non-dominant side when it is not required, possibly due to an articulatory inhibition strategy [5], late signers less frequently employ this inhibition strategy.
500 words

(1) Sample expressions for Walking on Toes on a Curved Path.

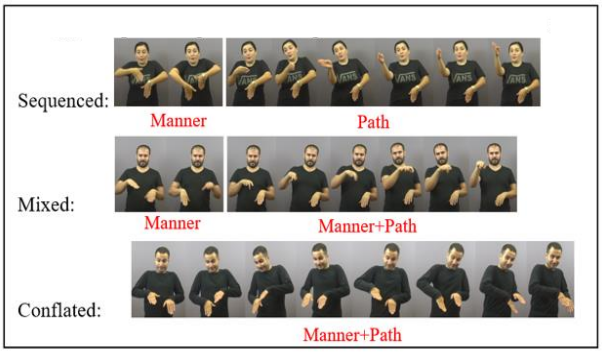
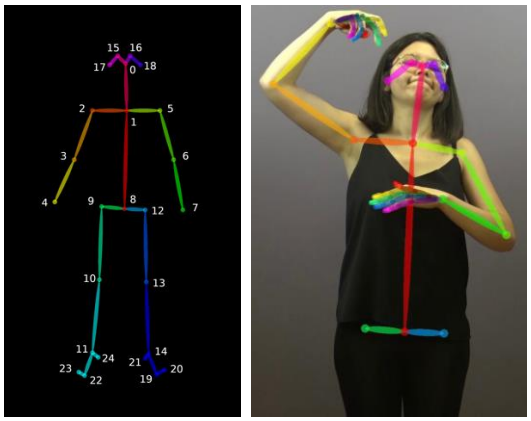


Figure 1. Joint reference numbers and an example output



(2) a. Relative values assigned to the joints:
Body-midline = 5, Shoulder = 4, Elbow = 3, Wrist = 2, Fingers = 1

b. Formula for calculating estimated energy spent for each movement

$$\text{Sum of } \left(\left(\frac{\text{Duration of active involvement of an articulator}}{\text{Duration of the entire sign}} \right) \text{X} \quad \text{Relative value of the joint} \right)$$

Figure 2. Articulatory Energy by Expression Type and Nativeness

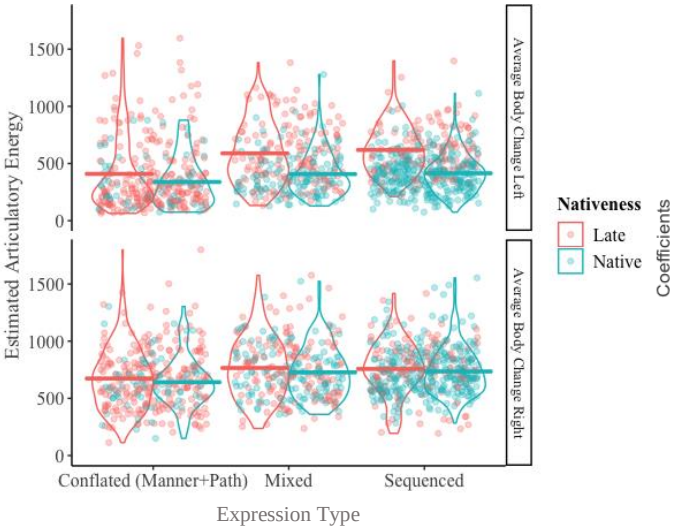
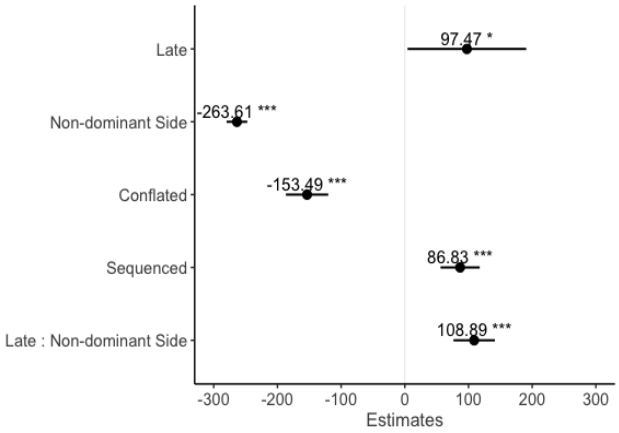


Figure 3. Regression Model of Articulatory Energy by Nativeness, Dominant Side and Event Type



Note. * indicates $p < 0.05$ and *** indicates $p < 0.001$. The white vertical line shows the intercept or the grand mean.

References. [1] Bates, D., Mächler, M., Bolker, B, and Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software, 67*(1), 1–48. doi:10.18637/jss.v067.i01. **[2] Benedicto, E., Cvejanov, S., & Quer, J. (2008).** "The morphosyntax of verbs of motion in serial constructions: a crosslinguistic study in three signed languages," I Signs of the Time. Selected Papers from TISLR 8, ed J. Quer. Hamburg: Signum, 111-132. **[3] Cao, Z., Hidalgo Martinez, G., Simon, T., Wei, S., & Sheikh, Y. A. (2019).** OpenPose: Realtime Multi-Person 2D Pose Estimation using Part Affinity Fields. IEEE Transactions on Pattern Analysis and Machine Intelligence. **[4] Özyürek, A., Furman, R., & Goldin-Meadow, S. (2015).** On the way to language: Event segmentation in homesign and gesture. *Journal of child language*, *42*(1), 64. **[5] Sanders, N., & Napoli, D. J. (2016).** Reactive effort as a factor that shapes sign language lexicons. *Language*, *92*(2), 275-297. **[6] Supalla, T. (1990).** Serial verbs of motion in ASL. *Theoretical issues in sign language research*, *1*, 127-152.