

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

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# Introduction

- ▶ In a complex motion-event, an agent moves along a path with a manner<sup>1</sup>
- ▶ Languages have different ways of exponentiating manner and path

(1)



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<sup>1</sup> Talmy 1985; Benedicto et al. 2008; Özyürek et al. 2015; Supalla 1990



How do sign languages encode this?

# Introduction

## Observations for American Sign Language (ASL)<sup>2</sup>

- ▶ Restrictions on complex events
- ▶ Certain classifier handshapes (e.g., legs) require sequencing:

(2a)



Figure 6.3. "A person running zigzag uphill."



Manner



Figure 6.6. Verb sequence for figure 6.3.

Path

- ▶ Others conflate manner and path:

(2b) TWO-LEGGED-WALK-IN-A-CIRCLE

"A human agent walks in a circle"

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<sup>2</sup>Supalla 1990



# Introduction

- ▶ Possibility of a mixed form:<sup>3</sup>

(3) MAN HOUSE RUN.BPCL(ARMS) APPROACH.BPCL ENTER  
Manner Manner+Path

"A man runs into a house"

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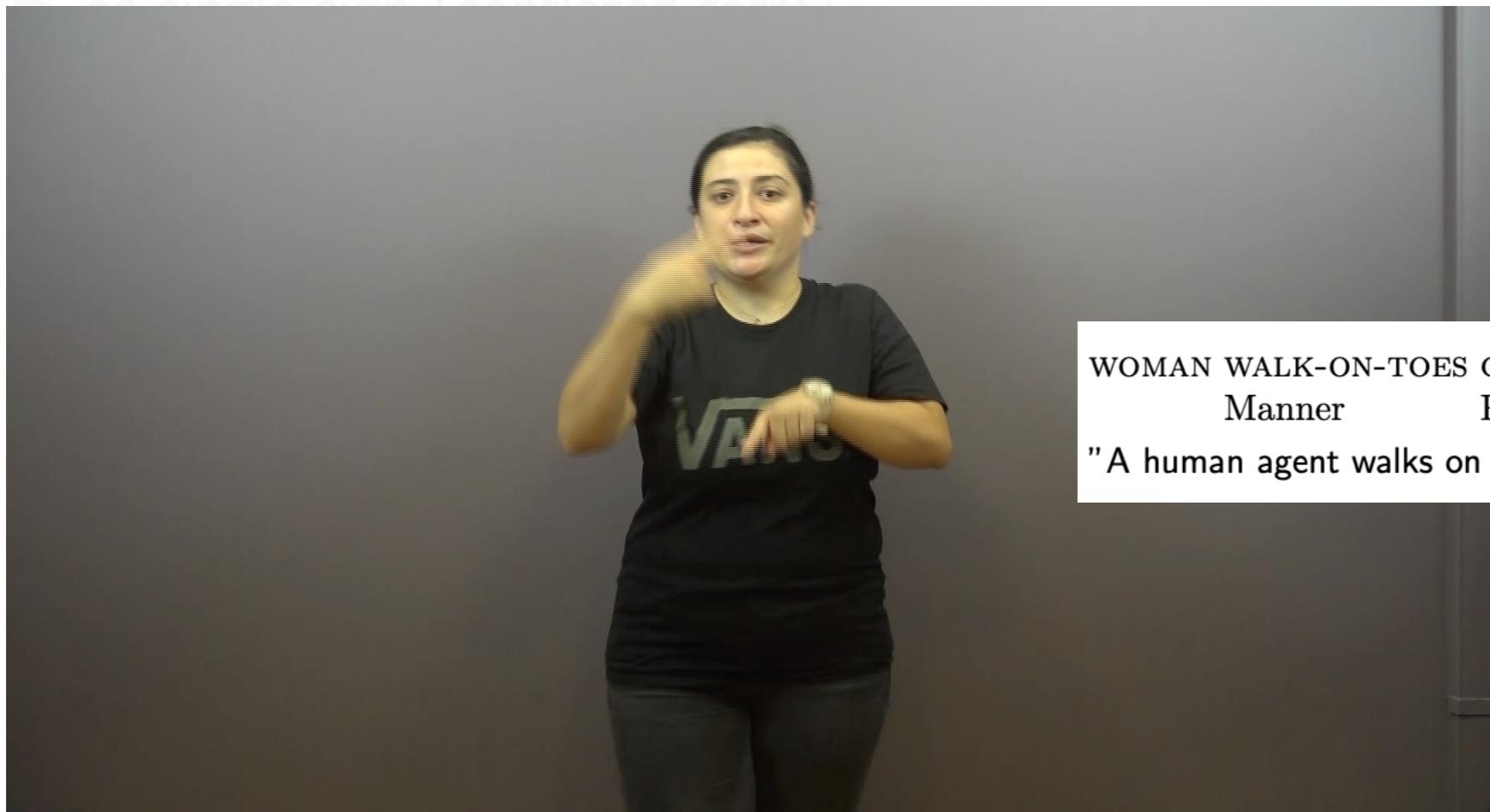
<sup>3</sup>Slobin and Hoiting 1994

# Introduction

Turkish Sign Language (TİD) signers use all these strategies:

- ▶ separate signs of manner and path (sequential form)

(4)



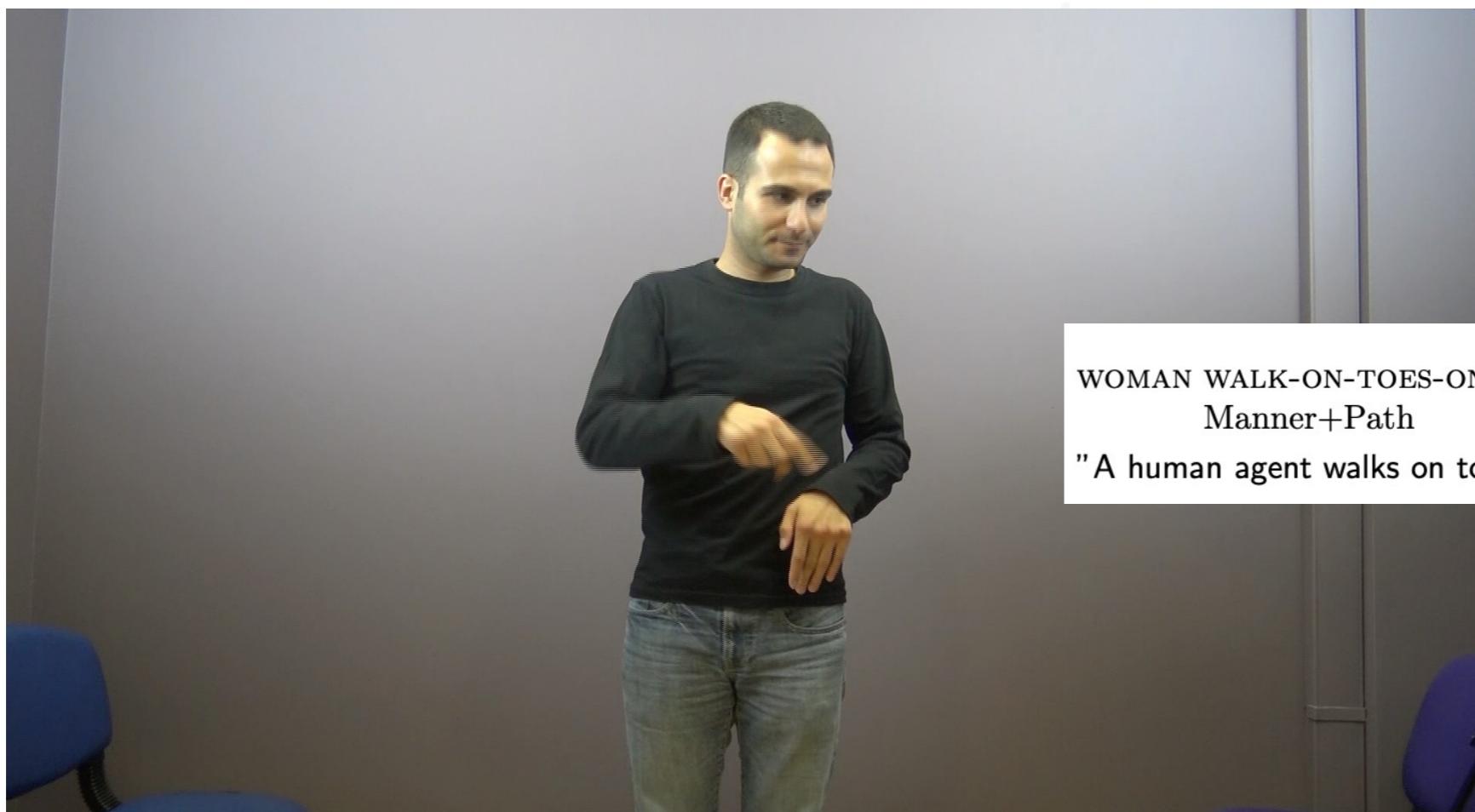
<sup>4</sup>This is what Slobin and Hoiting 1994 calls "path-focused (p. 493)"

# Introduction

Turkish Sign Language (TİD) signers use all these strategies:

- ▶ separate signs of manner and path (sequential form)
- ▶ as single sign (conflated form)

(5)



WOMAN WALK-ON-TOES-ON-A-CURVED-PATH  
Manner+Path  
"A human agent walks on toes on a curved path"

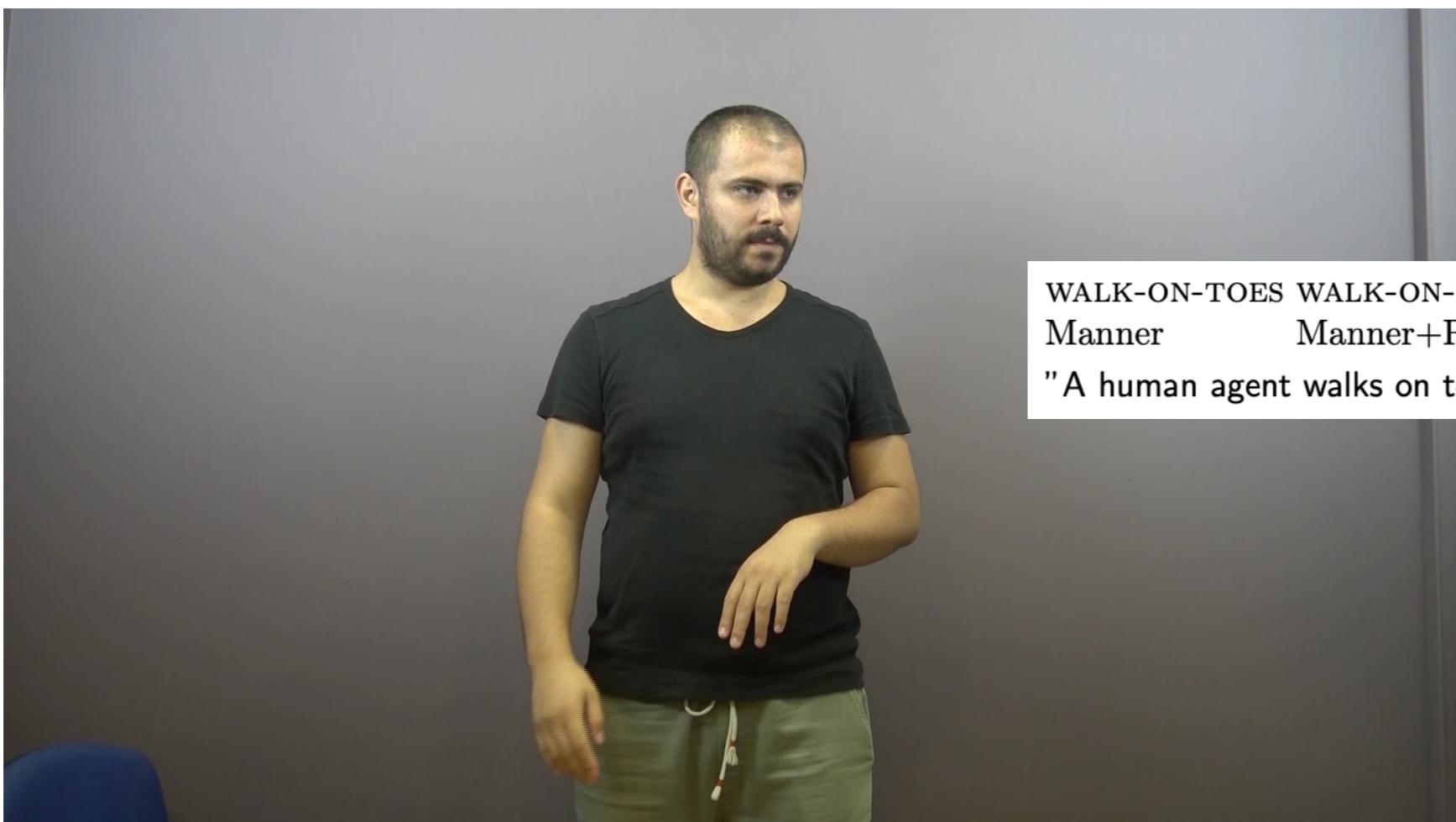
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# Introduction

Turkish Sign Language (TİD) signers use all these strategies:

- ▶ separate signs of manner and path (sequential form)
- ▶ as single sign (conflated form)
- ▶ or a combination of both (mixed form)<sup>4</sup>

(6)



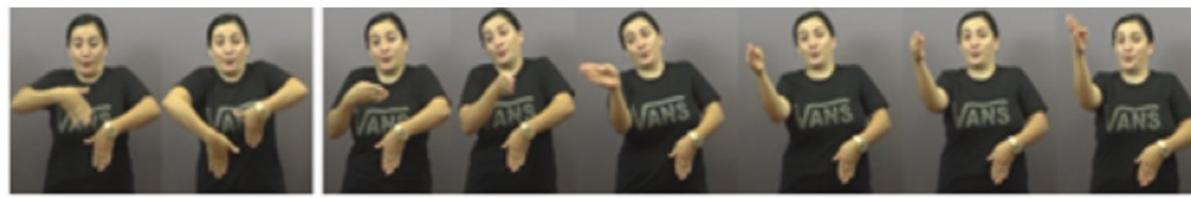
WALK-ON-TOES WALK-ON-TOES-ON-A-CURVED-PATH  
Manner Manner+Path  
"A human agent walks on toes on a curved path"

<sup>4</sup>This is what Slobin and Hoiting 1994 calls “path-focused (p. 493)”

# Introduction

## (7) Sample expressions for Walking on Toes on a Curved Path

Sequenced:



Mixed:



Conflated:



# Background

Turkish homesigners conflated manner with path more frequently than sequencing manner and path separately or a mixed form

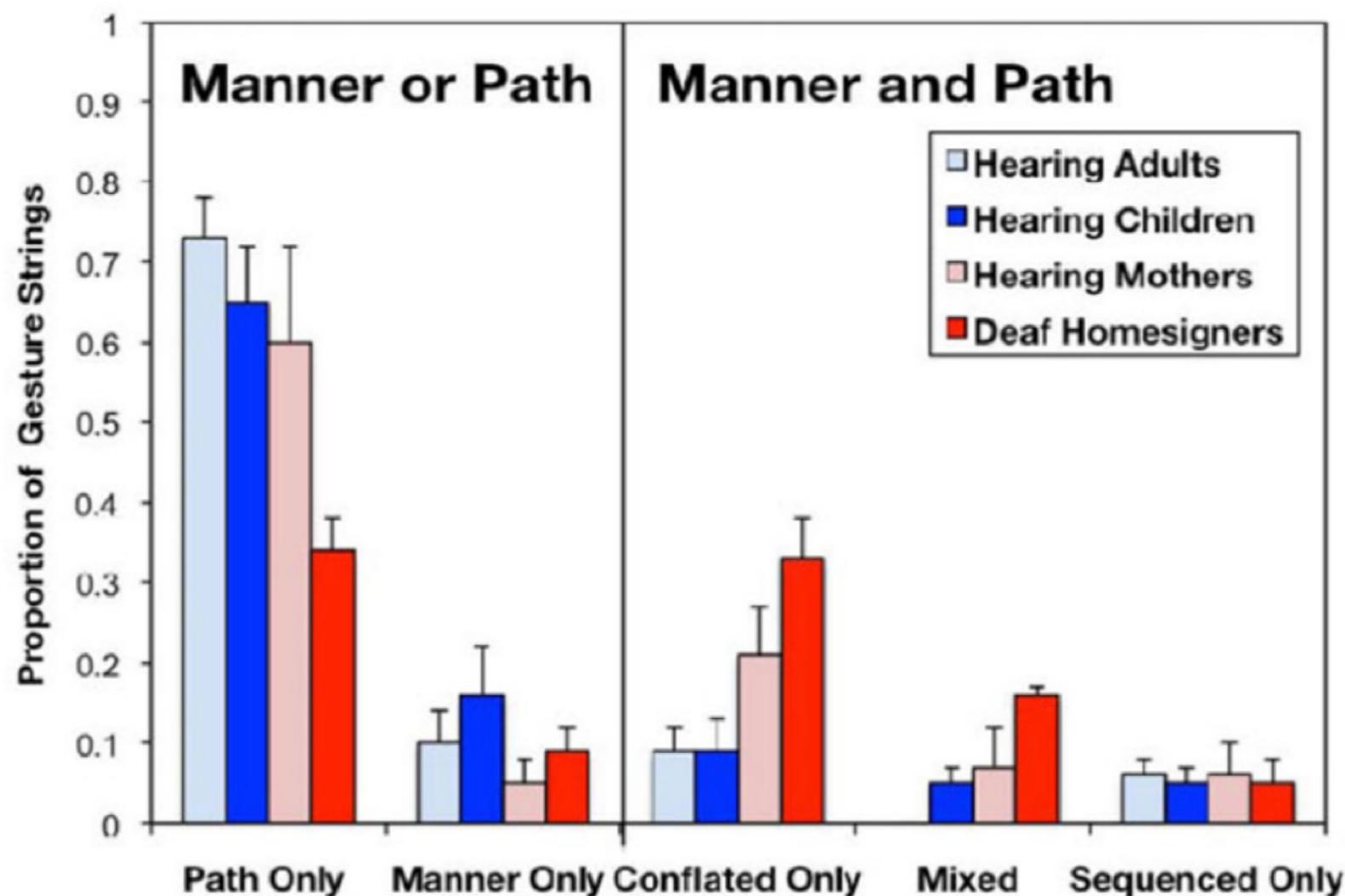


Figure 2: Özyürek et al. 2015



# Background

## Age of Acquisition (AoA) Effects

- ▶ 90 percent of all Deaf are late signers (i.e., born into hearing & non-signing parents<sup>5</sup>)
- ▶ Late signers receive frequent & regular language exposure after infancy starting from age 4 and onward<sup>6</sup>

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<sup>5</sup>Mitchell and Karchmer 2004

<sup>6</sup>Mayberry 2007; Mayberry et al. 2011



# Background

## Late signers may exhibit AoA effects on:

- ▶ morphosyntax and sentential processing<sup>7</sup>
- ▶ lexicon<sup>8</sup>
- ▶ pragmatic abilities<sup>9</sup>
- ▶ and possibly on spatial language development<sup>10</sup>

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<sup>7</sup>Sevgi and Gökgöz 2023; Kayabaşı and Gökgöz 2013; Cheng and Mayberry 2019;  
Newport 1990

<sup>8</sup>Keleş et al. 2022; Sehyr et al. 2018

<sup>9</sup>Keleş et al. 2023; Cormier et al. 2013

<sup>10</sup>Karadöller et al.

## Research Questions

- ▶ How are complex motion events expressed in Turkish Sign Language (TİD)?
- ▶ Can we estimate the energy spent during the articulation of these complex events with computer vision?
- ▶ Do native and late signers differ in the energy spent on the expression of complex motion events in TİD?

# Stimuli

- ▶ 54 items: 9 Manners (Running, Walking-on-Toes, etc.) with 6 Paths each (Curved, Circle, Zigzag, etc.) adapted from<sup>11</sup>

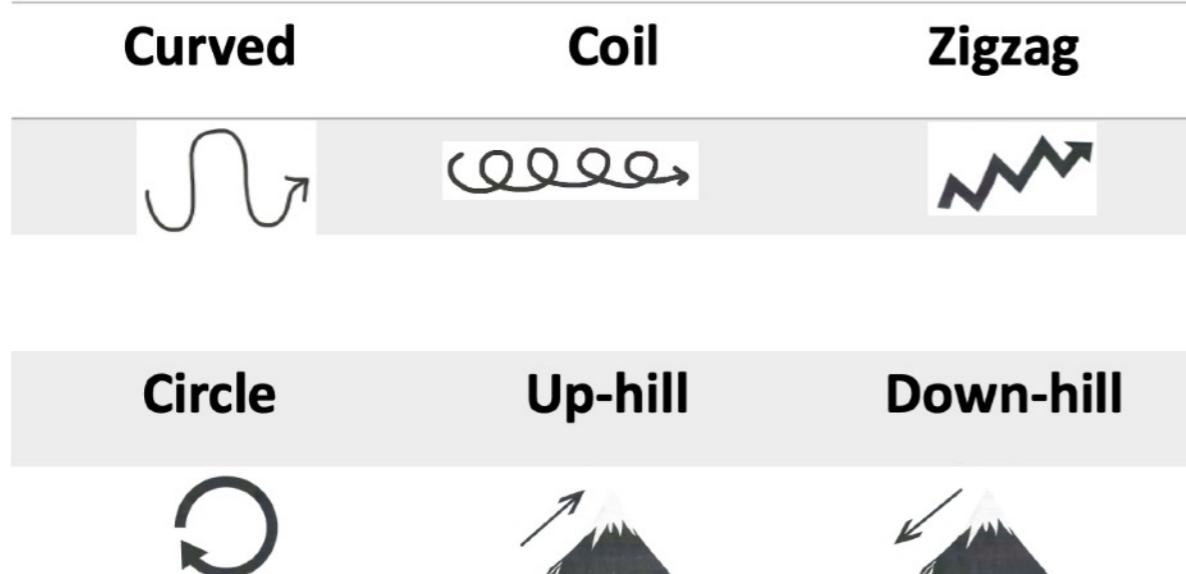


Figure 3: Path Stimuli

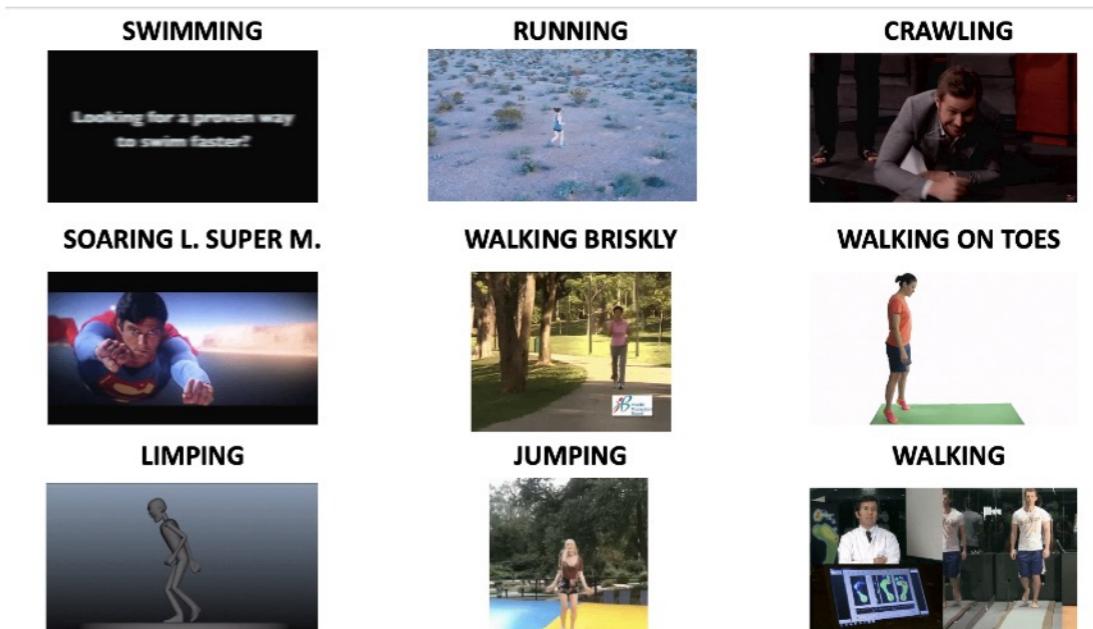


Figure 4: Manner Stimuli

<sup>11</sup>Supalla 1990

# Participants

## 10 adult native signers

- ▶ 6 females; 4 males, all right-handed
- ▶ All have deaf parents
- ▶ Exposed to TID from birth
- ▶ Age range at testing: 18-35 (mean age: 27.6)

## 10 adult late signers

- ▶ 4 females; 6 males, all right-handed
- ▶ All have hearing parents
- ▶ Delayed exposure to TID
- ▶ TID learning starts with enrollment in a deaf school
- ▶ Age range at testing: 25-51 (mean age: 37.6)
- ▶ Mean number of years TID used: 30.7

# Coding

## We coded the string types as

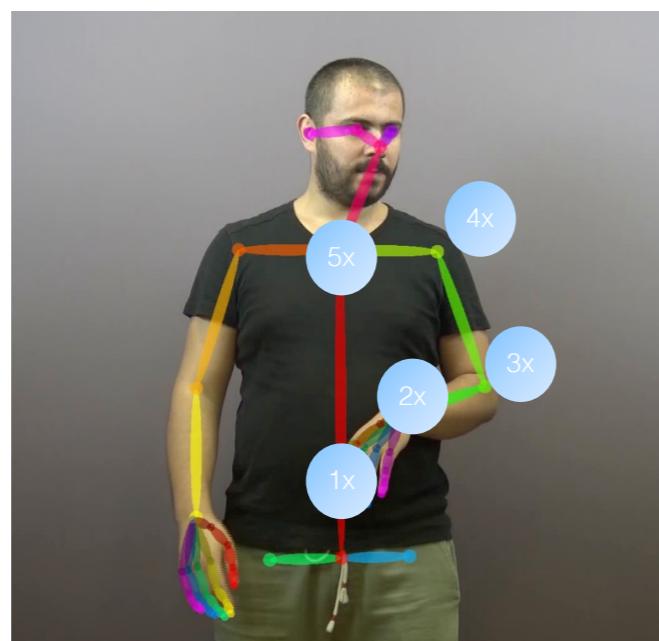
- ▶ Sequenced (separate manner and path)
- ▶ Conflated (simultaneous manner and path)
- ▶ Mixed (at least one separate manner or path, followed/preceded by a conflated form)

### (7) Sample expressions for Walking on Toes on a Curved Path



# Pose Estimation and Estimate Energy Calculation

## (8) Joint reference numbers and an example output

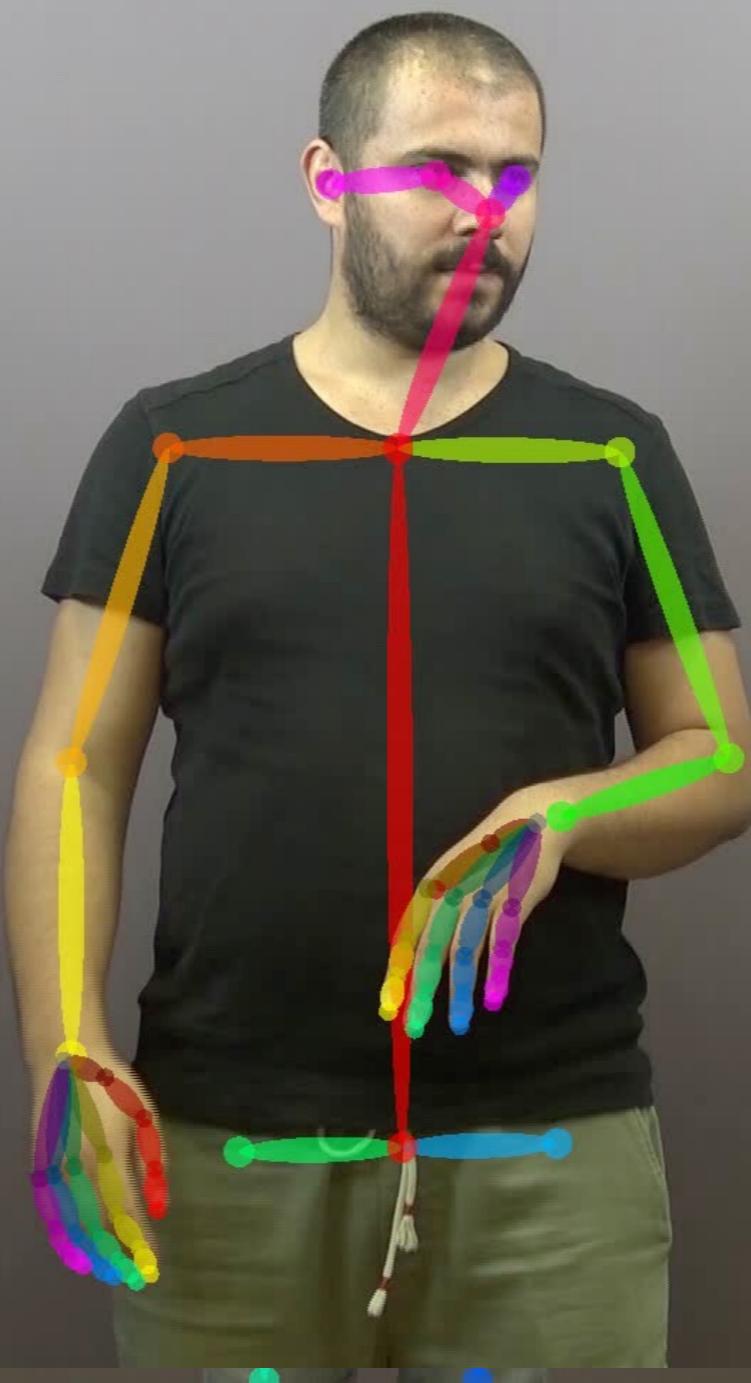


- ▶ Step 1: Extract 8 frames from the videos per second
- ▶ Step 2: Run OpenPose on each frame and get the coordinates of the joints for Left and Right separately
- ▶ Step 3: Then, calculate the Euclid distance of each joint between the consecutive frames to calculate estimated energy

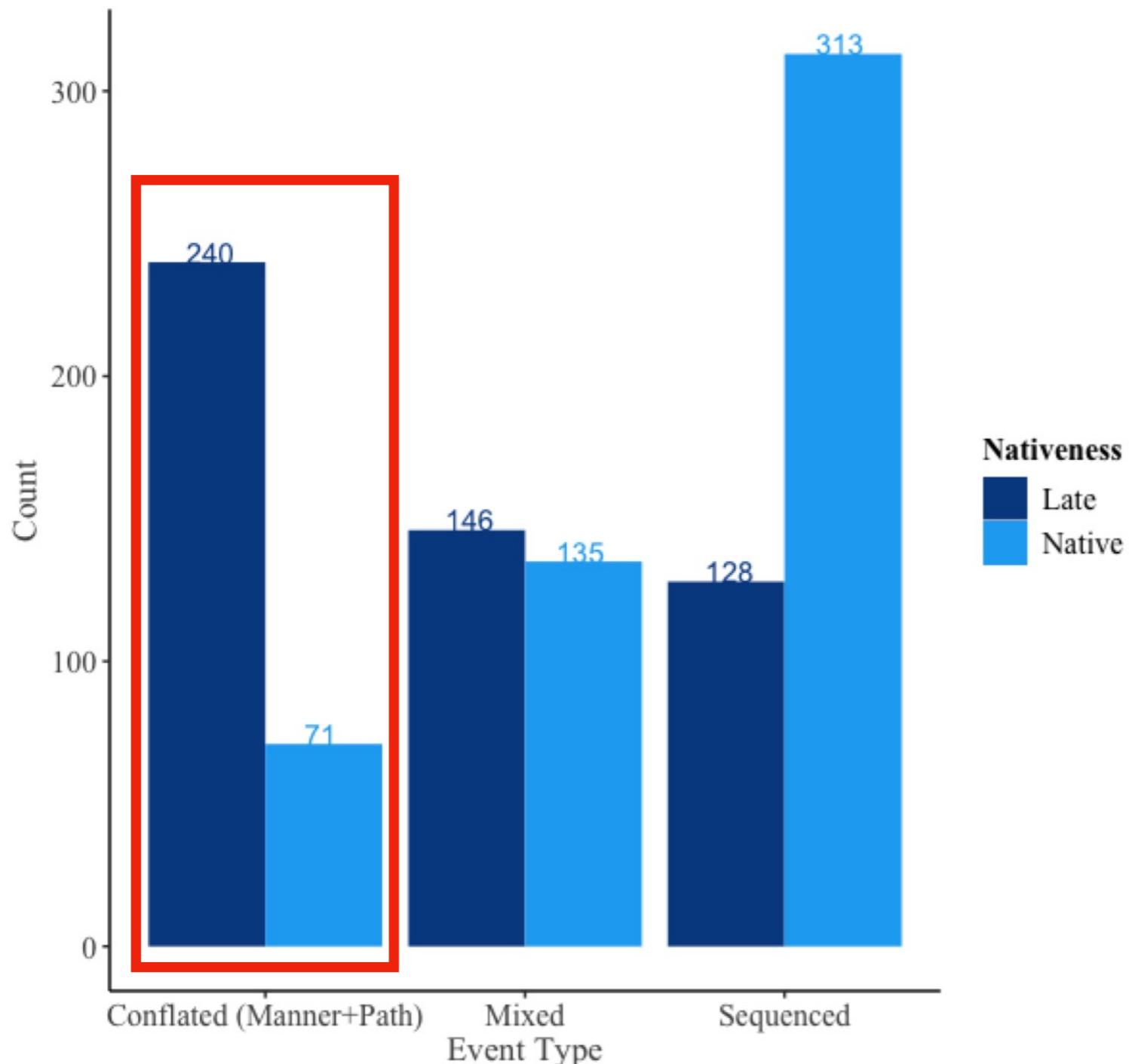
## (9) Formula

$$\text{Energy} = \sum_{i=1}^5 \frac{\text{Movement of active joint/point } i}{\text{Movement of entire sign}} \times \text{Relative value of joint/point } i$$

# Pose Estimation and Energy Calculation



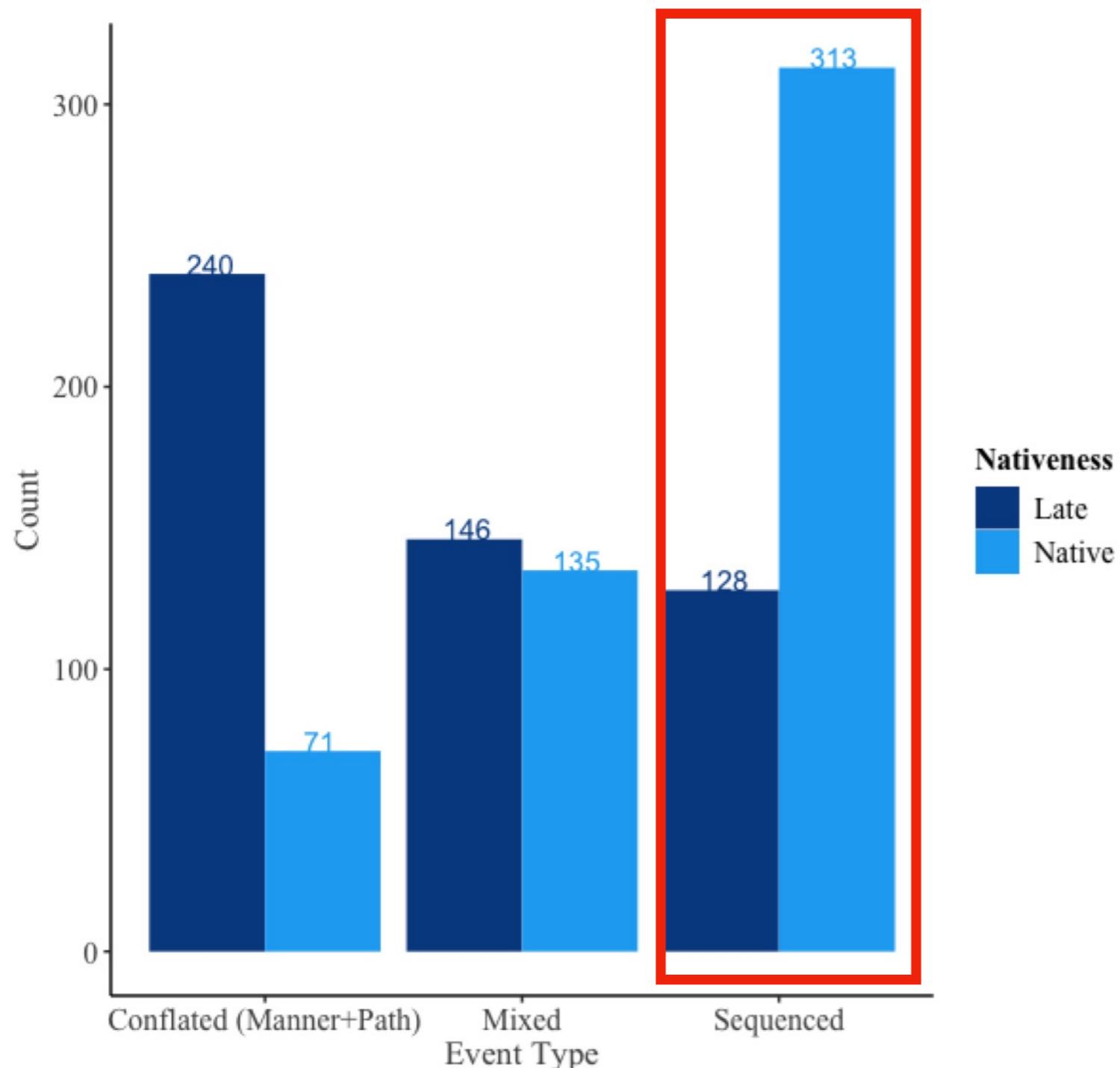
# Results



- ▶ Late signers use conflated forms more than native signers
- ▶ Native signers use sequenced forms more than native signers

**Figure 5:** Production of Complex Motion Events by Event Type and Nativeness

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**Figure 5:** Production of Complex Motion Events by Event Type and Nativeness

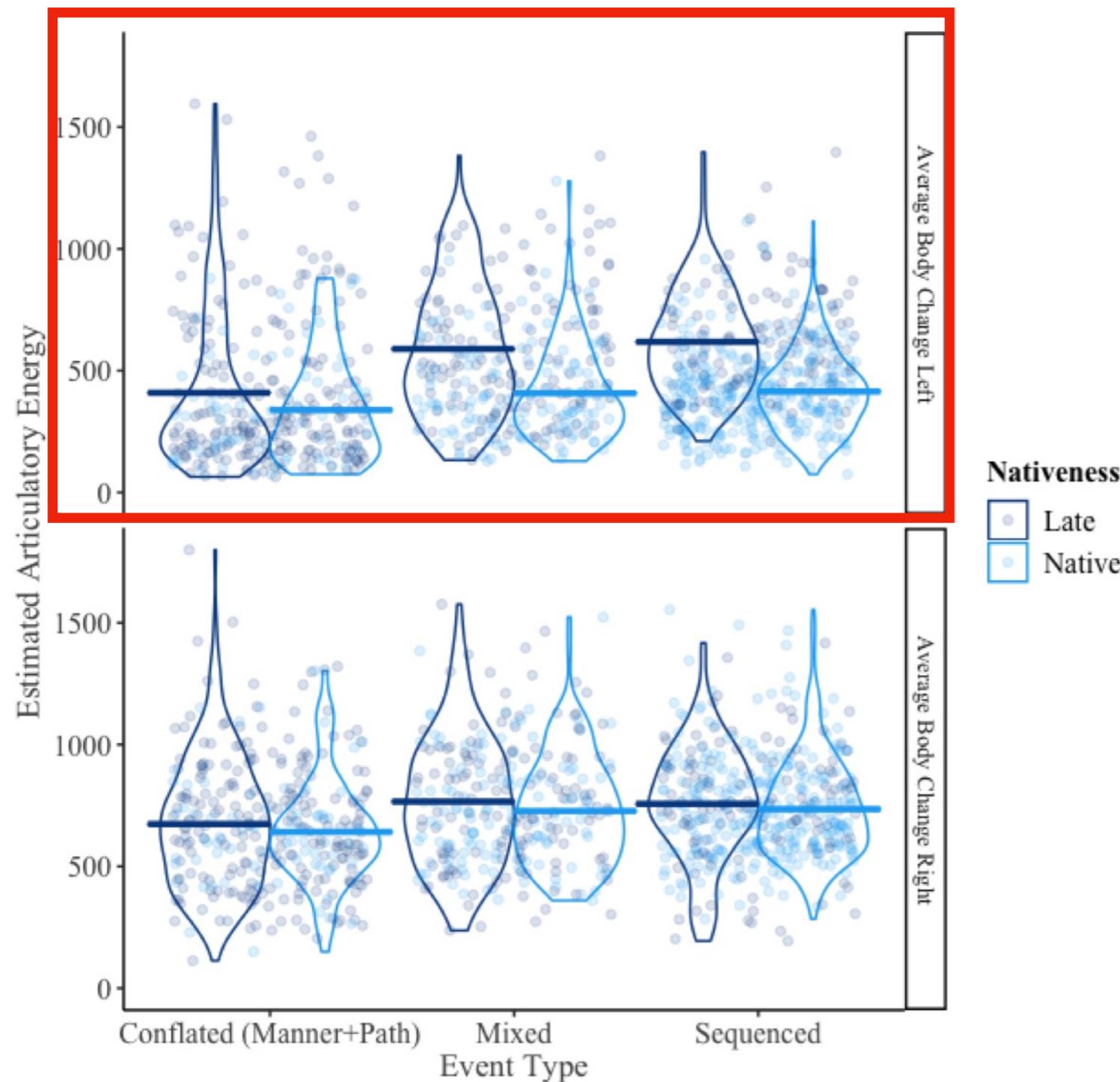
# Results

<i>Predictors</i>	Number		
	<i>Incidence Rate Ratios</i>	<i>CI</i>	<i>p</i>
Intercept	15.13	14.11 – 16.19	<b>&lt;0.001</b>
Conflated	0.74	0.60 – 0.91	<b>0.005</b>
Sequenced	1.75	1.46 – 2.10	<b>&lt;0.001</b>
Late	1.10	0.96 – 1.26	0.174
Conflated*Late	9.44	6.30 – 14.35	<b>&lt;0.001</b>
Sequenced*Late	0.14	0.10 – 0.20	<b>&lt;0.001</b>
Observations	60		
R <sup>2</sup> Nagelkerke	0.980		

- ▶ Two Poisson GLMMs (one with Nativeness as predictor and other without this predictor) were fitted to the data
- ▶ The model with Nativeness as predictor was found to be a better fit for the data

Figure 6: Poisson GLM Results

# Results



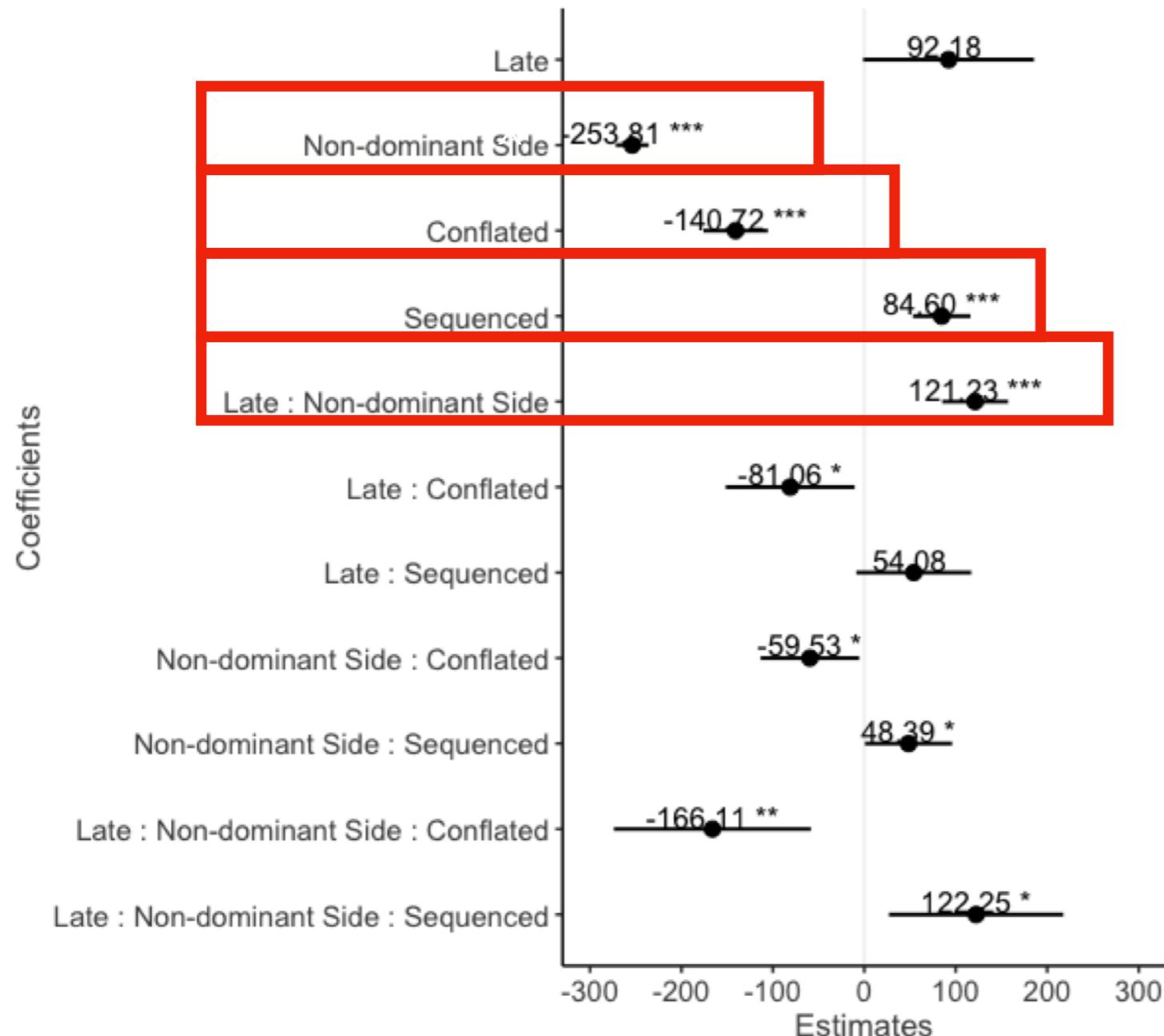
**Energy spent on a complex motion event increases with**

- ▶ Late acquisition
- ▶ Using a sequenced form
- ▶ Using the dominant side

**Age of Acquisition Effects**  
If a signer is a late acquirer, more energy use on the non-dominant side (i.e., "left side of the body")

**Figure 7:** Articulatory Energy by Event Type and Nativeness

# Results



- ▶ LME model fitted to Energy values with Nativeness, Body Dominance and Event Type as Fixed Effects
- ▶ Participants and Frames as Random Effects
- ▶ Two-way interaction between Nativeness and Body Dominance

Figure 8: Mixed effects model results

# Discussion

## Summary of Results

- ▶ Late signers use conflated forms more, similar to home signers<sup>a</sup>
- ▶ Native signers used more sequenced forms than late signers
- ▶ Similar frequency of mixed forms in both groups
- ▶ Although conflated forms decreased the use of energy, late signers used more energy overall than native signers
- ▶ Dominance x Nativeness interaction: Late signers used more energy on the non-dominant side

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<sup>a</sup>Özyürek et al. 2015



# Discussion

## Implications

- ▶ Sequential exponence is the default strategy for natives<sup>a</sup>
- ▶ Age-sensitivity in complex motion event production
- ▶ Less inhibition of the non-dominant side in late signers
- ▶ The idea of Reactive Effort<sup>b</sup>

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<sup>a</sup>Supalla 1990

<sup>b</sup>Sanders and Napoli



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