

# Natural Language Processing for Signed Languages

Kayo Yin



Berkeley NLP



BERKELEY ARTIFICIAL INTELLIGENCE RESEARCH

Berkeley AI Research

# Signed languages



- Fully-fledged natural languages
- Independent of spoken languages

# Signed languages



- 200 signed languages
- ~70m deaf people

# American Sign Language



- Areas where ASL or a dialect/derivative thereof is the national sign language
- Areas where ASL is in significant use alongside another sign language

- Predominant in the US and anglophone Canada
- Often used as a lingua franca

# American Sign Language



Gallaudet memorial

Emerged in early 19th century in the American School for the Deaf

# American Sign Language



1880 Milan Conference

- Only 30-40% of English speech can be understood with lipreading
- Cochlear implants doesn't always work
- Integral to Deaf culture

# Phonology

Handshape



Hand orientation



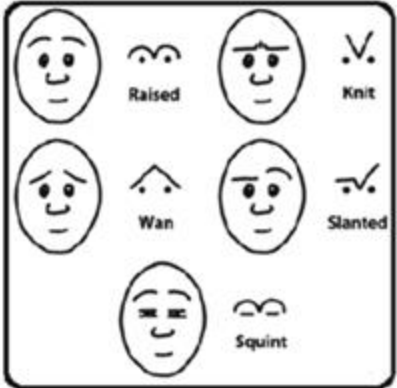
Location



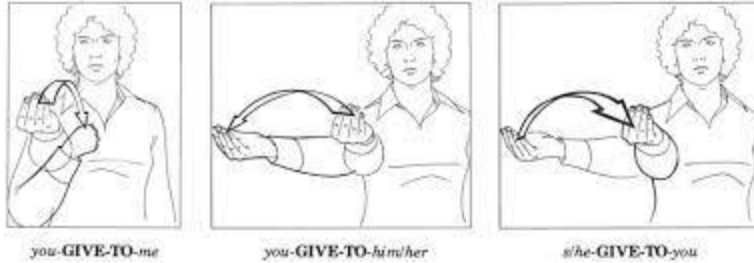
Movement



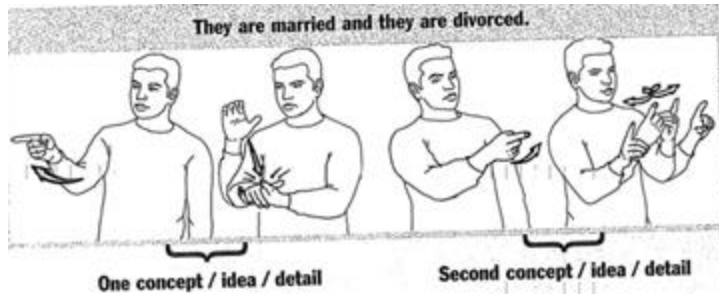
Non-manual



# Spatial organization

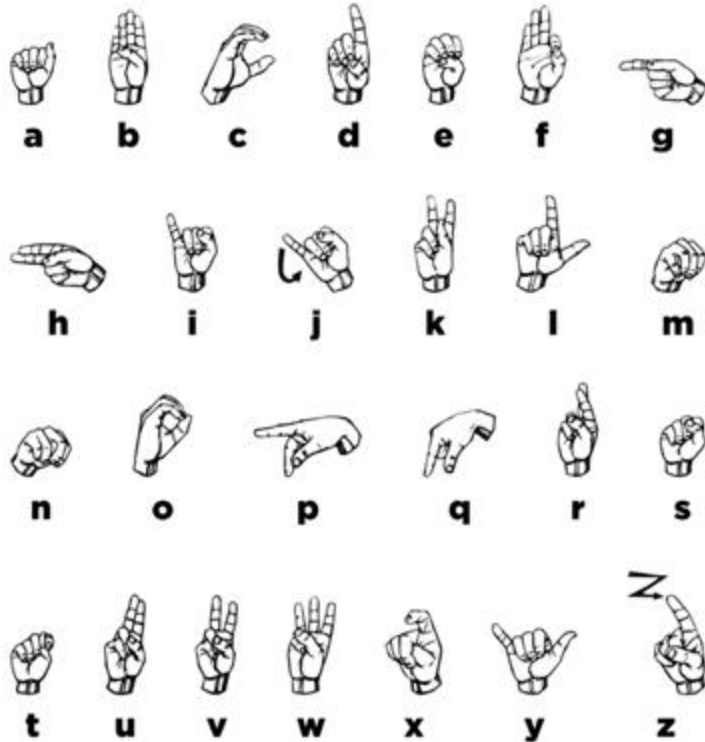


- Referencing (pointing, eye gaze, head tilt)
- Directional verbs
- Shoulder shift
- Role shift





# Fingerspelling



- Proper nouns
- Technical terms / missing signs
- Loan words
- Grammatical/stylistic choice (e.g. emphasis)
- ~8.7% of casual ASL

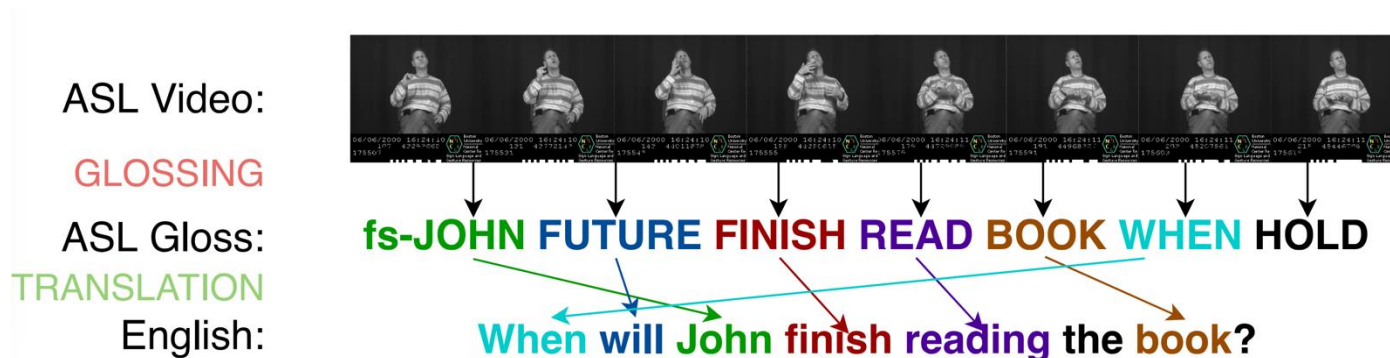
# Current progress in AI for signed languages

# Current progress in AI for signed languages

- 101 papers between 2021-2023 (Desai et al., [2024](#))

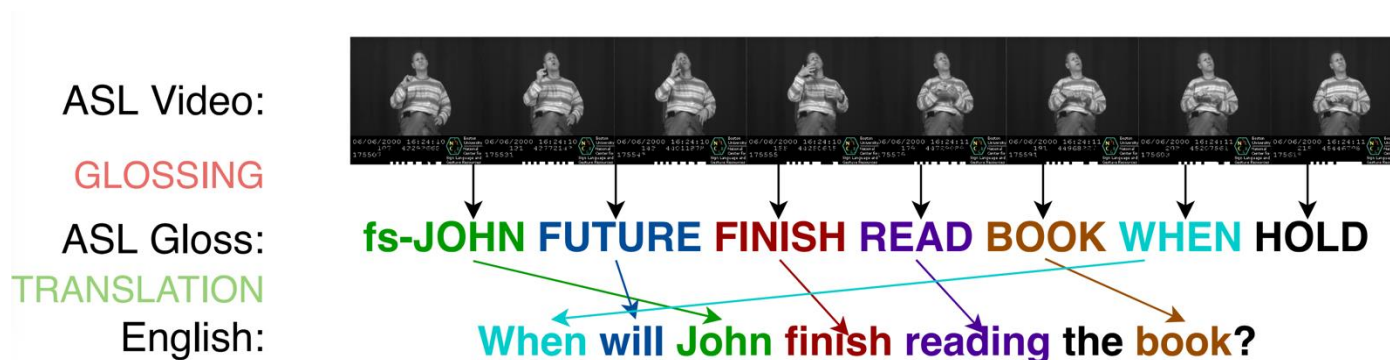
# Current progress in AI for signed languages

- 101 papers between 2021-2023 (Desai et al., [2024](#))
  - o Most focus solely on sign language recognition / translation



# Current progress in AI for signed languages

- 101 papers between 2021-2023 (Desai et al., [2024](#))
  - o Most focus solely on sign language recognition / translation
- Misinformed representations
  - o “Tyranny of glossing” (Hochgesang, [2022](#))



# Current progress in AI for signed languages

- 101 papers between 2021-2023 (Desai et al., [2024](#))
  - o Most focus solely on sign language recognition / translation
- Misinformed representations
  - o “Tyranny of glossing” (Hochgesang, [2022](#))
- ~ 40 public datasets

# Current progress in AI for signed languages

- 101 papers between 2021-2023 (Desai et al., [2024](#))
  - o Most focus solely on sign language recognition / translation
- Misinformed representations
  - o “Tyranny of glossing” (Hochgesang, [2022](#))
- ~ 40 public datasets
  - o Gap between training data and target users



BOBSL dataset  
(Albanie et al., 2021)

# Need for Deaf leadership

April 12, 2016

## UW undergraduate team wins \$10,000 Lemelson-MIT Student Prize for gloves that translate sign language



## Wearable-tech glove translates sign language into speech in real time

The device is inexpensive, flexible and highly durable, UCLA bioengineers say

**Matthew Chin**

June 29, 2020

## Hand-ear co-ordination: Interactive glove translates sign language into speech

Infinity Glove, a Lebanon-based start-up, seeks to help translate sign-language into speech by using a high tech glove solution. Cody Combs / The National



**Cody Combs**

Feb 21, 2024



Listen In English



Listen in Ar

Powered by automated trans



# Need for Deaf leadership

## Why Sign-Language Gloves Don't Help Deaf People

Wearable technologies that claim to translate ASL overlook the intricacies of the language, as well as the needs of signers.

By Michael Erard

NOVEMBER 9, 2017

SHARE  SAVE



## Sign Language Translating Devices Are Cool. But Are They Useful?



Emily Matchar

Innovation Correspondent

February 26, 2019

News & Views | Published: 15 July 2020

WEARABLE TECHNOLOGY

## Do deaf communities actually want sign language gloves?

[Joseph Hill](#) 

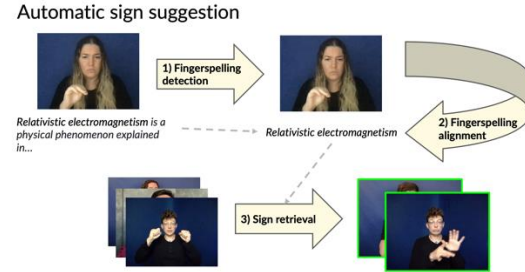
# My research

2 projects:

# My research

2 projects:

- AI tools to support deaf education

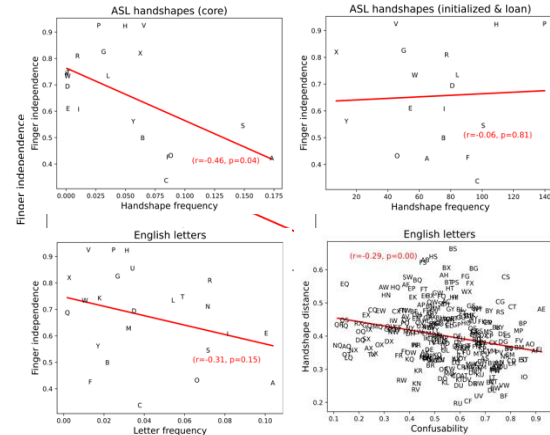
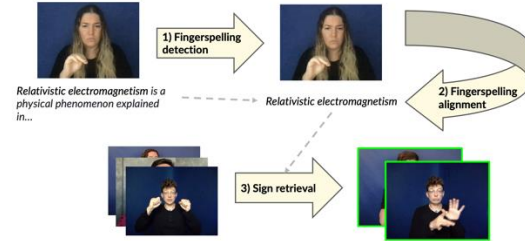


# My research

2 projects:

- AI tools to support deaf education
- NLP to test linguistic theories

## Automatic sign suggestion



# ASL STEMpedia

## Dataset and Benchmark for Interpreting STEM Articles



Kayo  
Yin



Hal  
Daumé III



Cyril  
Zhang



Alex  
Lu



Danielle  
Bragg

# Barriers to STEM education for DHH students

- Lack of **early exposure** to sign language -> **delays** in literacy and education

# Barriers to STEM education for DHH students

- Lack of **early exposure** to sign language -> **delays** in literacy and education
- STEM resources in ASL are **scarce**

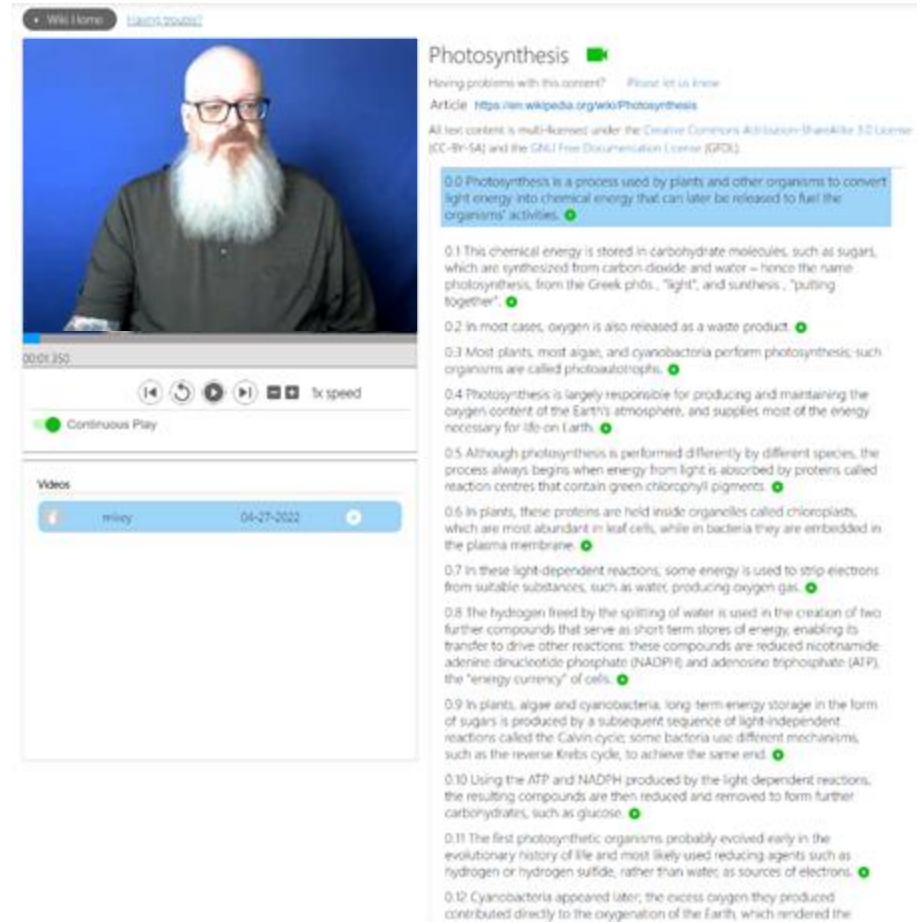
# Barriers to STEM education for DHH students

- Lack of **early exposure** to sign language -> **delays** in literacy and education
- STEM resources in ASL are **scarce**
- Lack of **standardized ASL signs** for technical words



# ASL Wikipedia

- 254 Wikipedia articles
  - Science, technology, mathematics, medicine, geography
- 300+ hours
- 37 ASL interpreters



The image shows a screenshot of a Wikipedia article titled "Photosynthesis" with an ASL video player overlay. The video player features a video of a man with a long white beard and glasses, wearing a dark shirt, against a blue background. The player includes a progress bar at 00:01:35, playback controls (play, stop, next, previous, full screen), a volume icon, and a "1x speed" setting. Below the video player, there is a "Videos" section with a video thumbnail from "mivy" dated "01-27-2022".

**Photosynthesis** 🟢

Having problems with this content? [Please let us know](#)

Article <https://en.wikipedia.org/wiki/Photosynthesis>

All text content is multi-licensed under the [Creative Commons Attribution-ShareAlike 3.0 License](#) (CC-BY-SA) and the [GNU Free Documentation License](#) (GFDL).

**0.0** Photosynthesis is a process used by plants and other organisms to convert light energy into chemical energy that can later be released to fuel the organisms' activities. 🟢

**0.1** This chemical energy is stored in carbohydrate molecules, such as sugars, which are synthesized from carbon dioxide and water – hence the name photosynthesis, from the Greek *phōs*, "light", and *synthesis*, "putting together". 🟢

**0.2** In most cases, oxygen is also released as a waste product. 🟢

**0.3** Most plants, most algae, and cyanobacteria perform photosynthesis; such organisms are called photoautotrophs. 🟢

**0.4** Photosynthesis is largely responsible for producing and maintaining the oxygen content of the Earth's atmosphere, and supplies most of the energy necessary for life on Earth. 🟢

**0.5** Although photosynthesis is performed differently by different species, the process always begins when energy from light is absorbed by proteins called reaction centres that contain green chlorophyll pigments. 🟢

**0.6** In plants, these proteins are held inside organelles called chloroplasts, which are most abundant in leaf cells, while in bacteria they are embedded in the plasma membrane. 🟢

**0.7** In these light-dependent reactions, some energy is used to strip electrons from suitable substances, such as water, producing oxygen gas. 🟢

**0.8** The hydrogen freed by the splitting of water is used in the creation of two further compounds that serve as short term stores of energy, enabling its transfer to drive other reactions: these compounds are reduced nicotinamide adenine dinucleotide phosphate (NADPH) and adenosine triphosphate (ATP), the "energy currency" of cells. 🟢

**0.9** In plants, algae and cyanobacteria, long term energy storage in the form of sugars is produced by a subsequent sequence of light-independent reactions called the Calvin cycle; some bacteria use different mechanisms, such as the reverse Krebs cycle, to achieve the same end. 🟢

**0.10** Using the ATP and NADPH produced by the light dependent reactions, the resulting compounds are then reduced and removed to form further carbohydrates, such as glucose. 🟢

**0.11** The first photosynthetic organisms probably evolved early in the evolutionary history of life and most likely used reducing agents such as hydrogen or hydrogen sulfide, rather than water, as sources of electrons. 🟢

**0.12** Cyanobacteria appeared later; the excess oxygen they produced contributed directly to the oxygenation of the Earth, which rendered the

# Interpreting STEM articles is hard

- Fingerspelling in place of ASL sign



*“relativistic electromagnetism”*

# Interpreting STEM articles is hard

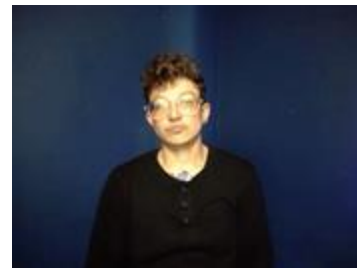
- Fingerspelling in place of ASL sign
- Inconsistent technical signs



*“relativistic electromagnetism”*

# Interpreting STEM articles is hard

- Fingerspelling in place of ASL sign
- Inconsistent technical signs
- Translationese
- Expanded context / added meanings
- ...



*“relativistic electromagnetism”*

# Interpreting STEM articles is hard

- Fingerspelling in place of ASL sign

“[Deaf] students prefer that terms either be signed in ASL, or signed and fingerspelled, as opposed to just fingerspelled.”

Development of American Sign Language Guidelines for K-12 Academic Assessments



*“relativistic electromagnetism”*

# Automatic sign suggestion



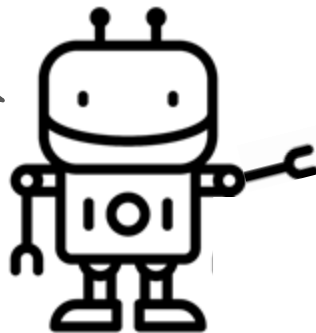
User

# Automatic sign suggestion



User

Here are other ways  
people sign  
"relativistic  
electromagnetism"



# Automatic sign suggestion



*Relativistic electromagnetism is a physical phenomenon explained in...*



# Automatic sign suggestion



1) Fingerspelling  
detection



*Relativistic electromagnetism is a  
physical phenomenon explained  
in...*

# Automatic sign suggestion



1) Fingerspelling  
detection



*Relativistic electromagnetism is a  
physical phenomenon explained  
in...*

*Relativistic electromagnetism*

2) Fingerspelling  
alignment

# Automatic sign suggestion



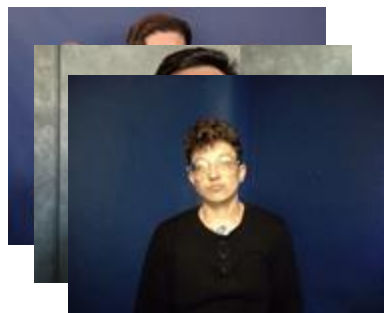
1) Fingerspelling  
detection



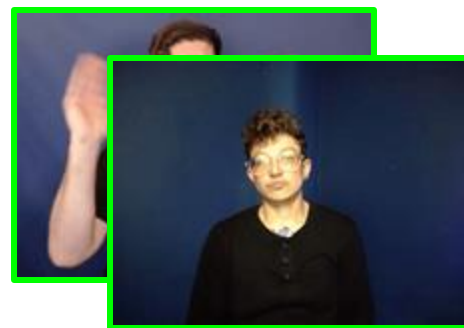
*Relativistic electromagnetism is a  
physical phenomenon explained  
in...*

*Relativistic electromagnetism*

2) Fingerspelling  
alignment



3) Sign retrieval

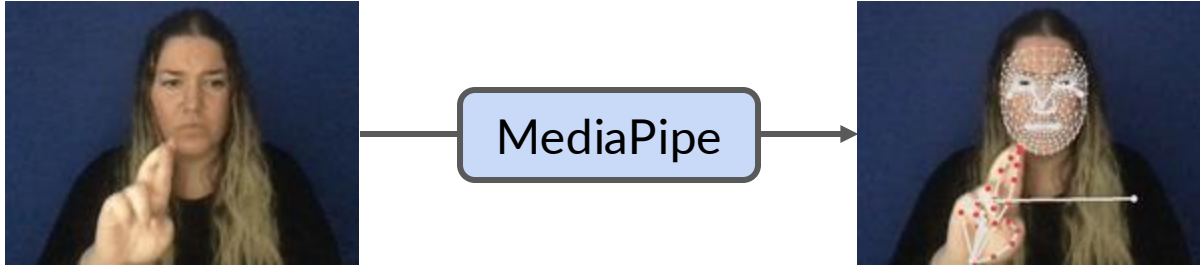


# Fingerspelling detection + alignment: multitask model



*Relativistic electromagnetism is a physical phenomenon explained in...*

# Fingerspelling detection + alignment: multitask model



*Relativistic electromagnetism is a physical phenomenon explained in...*

# Fingerspelling detection + alignment: multitask model



MediaPipe



GCN  
+  
Transformer

*Relativistic electromagnetism is a physical phenomenon explained in...*

# Fingerspelling detection + alignment: multitask model

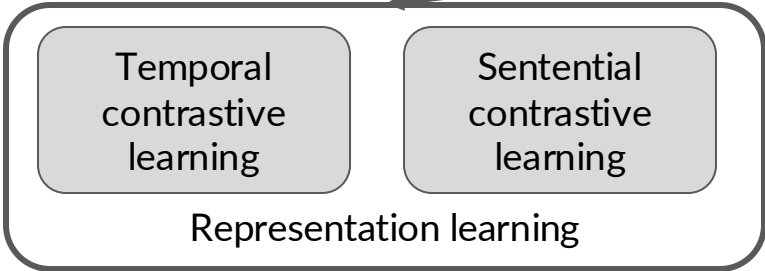


MediaPipe



GCN  
+  
Transformer

*Relativistic electromagnetism is a physical phenomenon explained in...*



# Fingerspelling detection + alignment: multitask model



MediaPipe



GCN  
+  
Transformer

*Relativistic electromagnetism is a physical phenomenon explained in...*

Temporal contrastive learning      Sentential contrastive learning

Representation learning

Fingerspelling detection      Fingerspelling alignment

Fine-tuning



# Sign retrieval

*"Relativistic  
electromagnetism"*



Dictionary lookup

*"The use of retarded potentials to describe electromagnetic fields from source-charges is an expression of relativistic electromagnetism."*



Video search

# Sign retrieval

“Relativistic  
electromagnetism”



Dictionary lookup

“The use of retarded potentials to describe electromagnetic fields from source-charges is an expression of **relativistic electromagnetism.**”



Video search

# Pressures for Communicative Efficiency in American Sign Language



Kayo  
Yin



Terry  
Regier



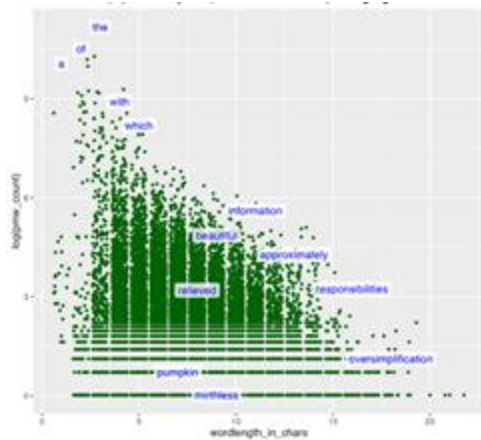
Dan  
Klein

# Efficiency shapes human language

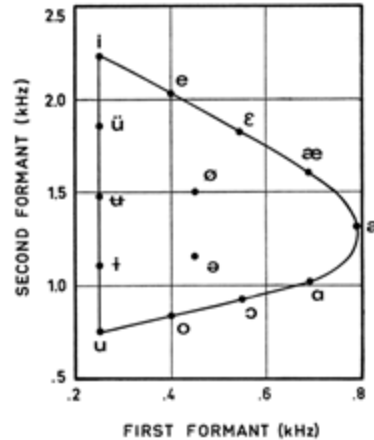
Efficiency: successful communication with **minimal effort** by sender + receiver

# Efficiency shapes human language

Efficiency: successful communication with **minimal effort** by sender + receiver



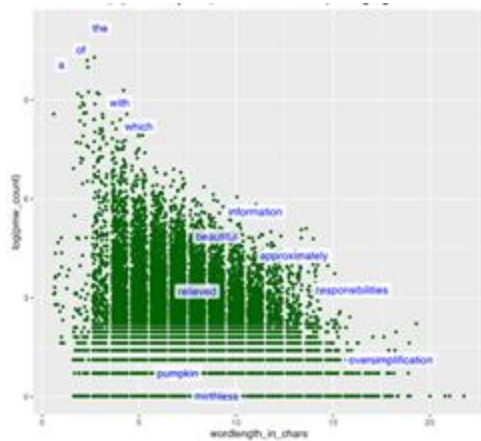
Frequent/informative words are shorter  
(Zipf, 1935; Piantadosi et al., 2011)



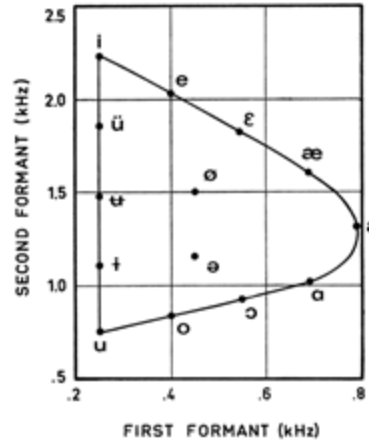
Vowel space maximizes  
perceptual contrast  
(Liljencrants & Lindblom, 1972)

# Efficiency shapes human language

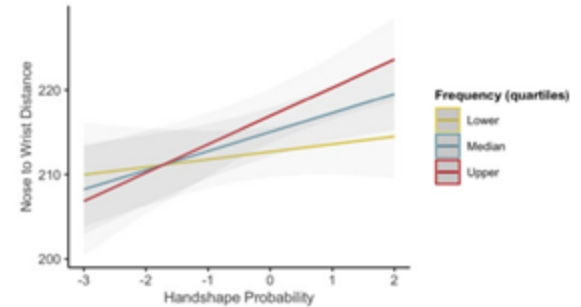
Efficiency: successful communication with **minimal effort** by sender + receiver



Frequent/informative words are shorter  
(Zipf, 1935; Piantadosi et al., 2011)



Vowel space maximizes perceptual contrast  
(Liljencrants & Lindblom, 1972)



Infrequent ASL signs are produced closer to face  
(Caselli et al., 2022)

# Language contact in ASL



Fingerspelling

# Language contact in ASL



Fingerspelling



Loan signs



# Language contact in ASL



Fingerspelling

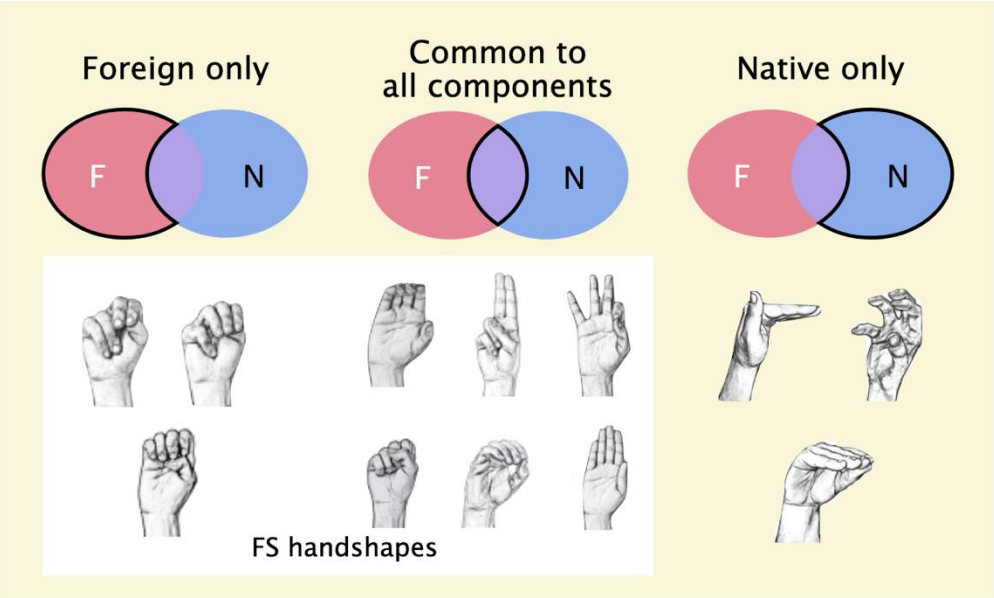


Loan signs

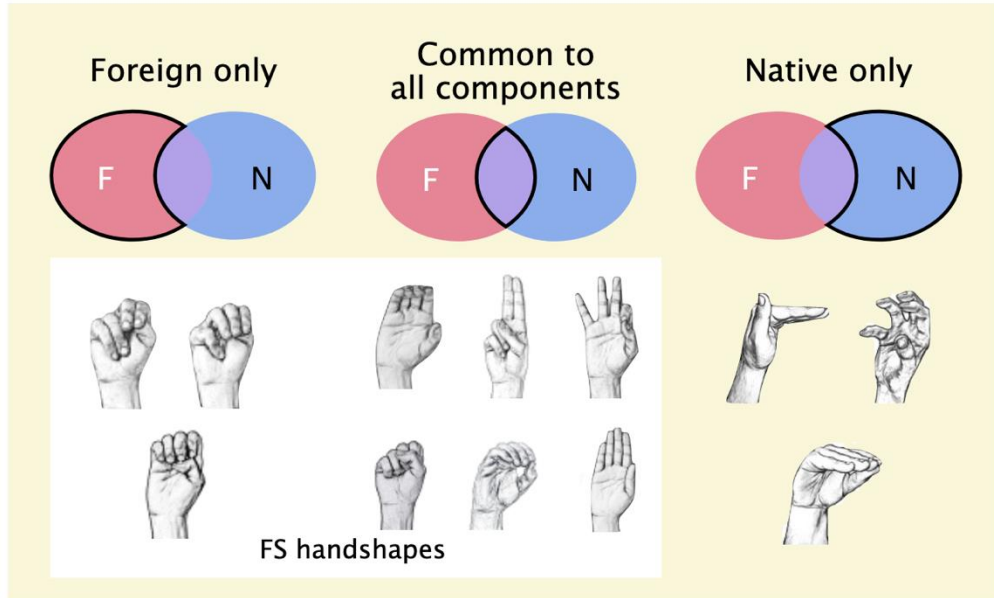


Initialized signs

# Efficiency shapes ASL handshapes?

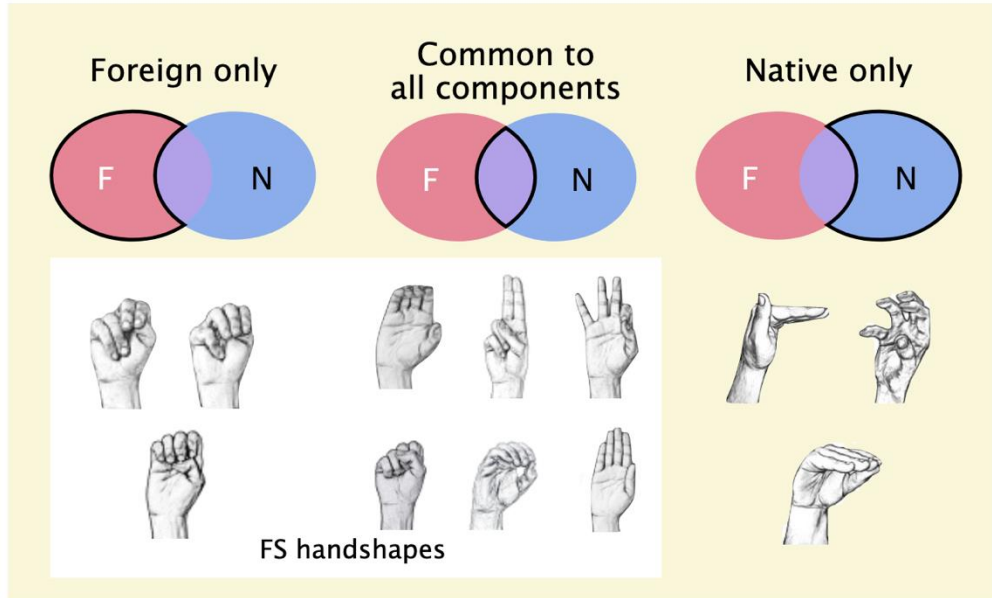


# Efficiency shapes ASL handshapes?



19 out of 22 handshapes in ASL  
fingerspelling appear in native ASL signs

# Efficiency shapes ASL handshapes?



19 out of 22 handshapes in ASL fingerspelling appear in native ASL signs

-> Compare pressures from **English** and **ASL** on handshape efficiency

# Research questions

RQ1. Do FS handshapes reflect pressures for **communicative efficiency**?

# Research questions

RQ1. Do FS handshapes reflect pressures for **communicative efficiency**?

RQ2. If so, do they **jointly optimize** pressures from English and ASL?

# Research questions

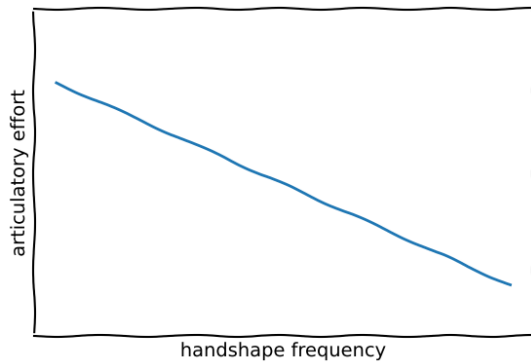
RQ1. Do FS handshapes reflect pressures for **communicative efficiency**?

RQ2. If so, do they **jointly optimize** pressures from English and ASL?

RQ3. Alternatively, pressure for efficiency mostly or all from **ASL usage**?

# Predictions

P1. FS handshapes that appear **frequently** in ASL signs are **easier to produce**

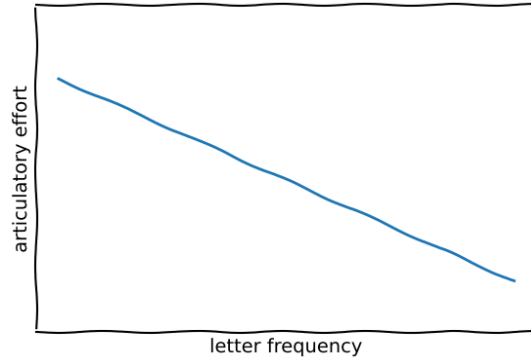
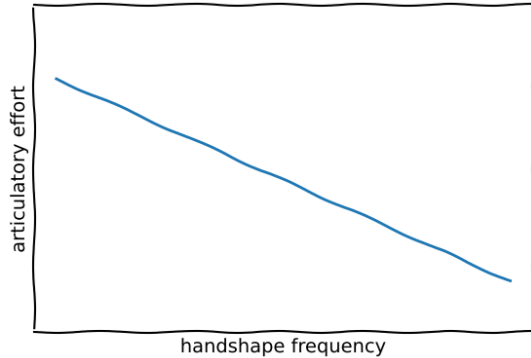




# Predictions

P1. FS handshapes that appear **frequently** in ASL signs are **easier to produce**

P2. **Frequent** letters in English are **easier to sign** in ASL fingerspelling



# Predictions

P1: Handshape freq.  $\uparrow$ , art. effort  $\downarrow$

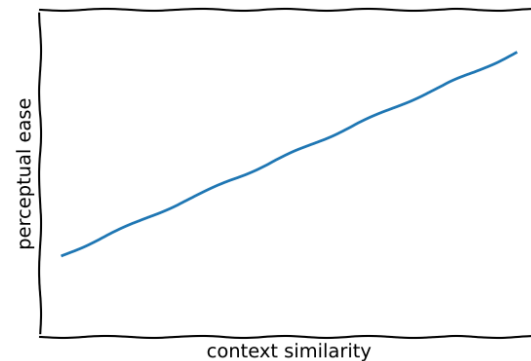
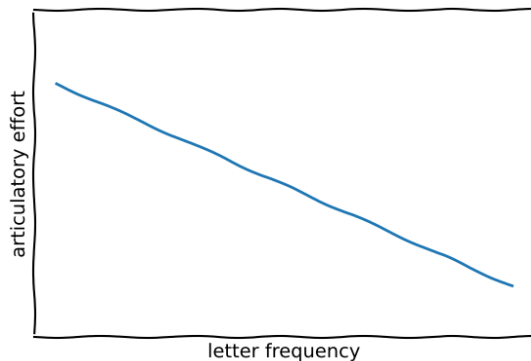
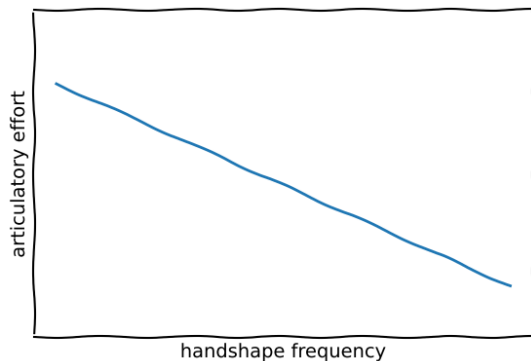
P2: Letter freq.  $\uparrow$ , art. effort  $\downarrow$

P3: Confusable  $\uparrow$ , perceptual ease.  $\uparrow$

P1. FS handshapes that appear **frequently** in ASL signs are **easier to produce**

P2. **Frequent** letters in English are **easier to sign** in ASL fingerspelling

P3. Pairs of letters that appear in **similar contexts** look **more different**



# Usage metrics

- Handshape frequency in ASL
- Letter frequency in English
- Letter confusability in English

P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑

# Usage metrics: handshape frequency

- Handshape frequency
  - ASL-LEX (Caselli et al., 2017)

P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑



Alternate English Translations:

cheese, dairy, food

About the sign:

Entry ID	cheese
English Word Frequency	3.299
Frequency	5.63
Deaf Signer Iconicity	1.55
Initialized Sign	0
Fingerspelled Loan Sign	0
Compound	0
Number Of Morphemes	1

Handshape Image



# Usage metrics: handshape frequency

- Handshape frequency
  - ASL-LEX (Caselli et al., 2017)
  - 1204 signs with FS handshapes

P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑



Alternate English Translations:

cheese, dairy, food

About the sign:

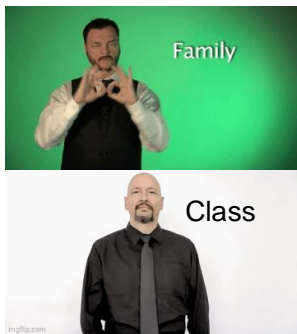
Entry ID	cheese
English Word Frequency	3.299
Frequency	5.63
Deaf Signer Iconicity	1.55
Initialized Sign	0
Fingerspelled Loan Sign	0
Compound	0
Number Of Morphemes	1

Handshape Image



# Usage metrics: handshape frequency

- Handshape frequency
  - ASL-LEX (Caselli et al., 2017)
  - 1204 signs with FS handshapes
    - 903 native, 271 initialized, 30 loan



Initialized signs



Loan signs

P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑



Alternate English Translations:

cheese, dairy, food

About the sign:

Entry ID	cheese
English Word Frequency	3.299
Frequency	5.63
Deaf Signer Iconicity	1.55
Initialized Sign	0
Fingerspelled Loan Sign	0
Compound	0
Number Of Morphemes	1

Handshape Image



# Usage metrics

- Letter frequency
  - 10,000 Wikipedia articles in English

P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑



# Usage metrics

- Letter frequency
  - 10,000 Wikipedia articles in English

P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual cont. ↓



the, be, ..., complicit, macaroni, ..., phytic, piedmontese



# Usage metrics

- Letter frequency
  - 10,000 Wikipedia articles in English
  - Discard 20,000 most frequent words

P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual cont. ↓



~~the, be, ..., complicit, macaroni, ..., phytic, piedmontese~~

# Usage metrics

- Letter frequency
  - 10,000 Wikipedia articles in English
  - Discard 20,000 most frequent words
  - Letter distribution in remaining 71,785 words

P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual cont. ↓



macaroni, ..., phytic, piedmontese

# Usage metrics

- Letter confusability
  - Conditional entropy (CE)

$$H(X|C)$$

P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑

# Usage metrics

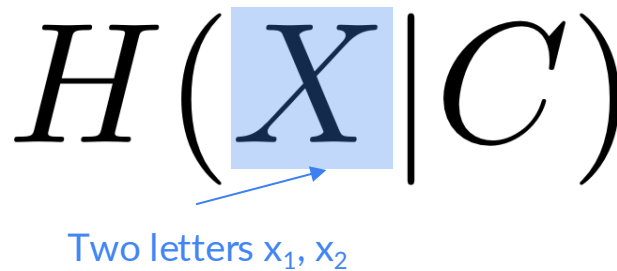
- Letter confusability
  - Conditional entropy (CE)

P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑

$H(X|C)$



Two letters  $x_1, x_2$

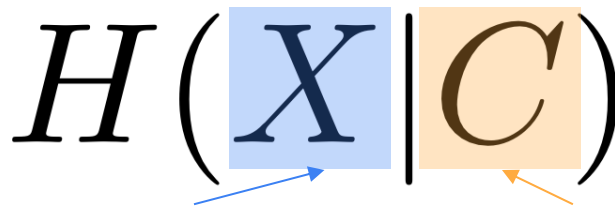
# Usage metrics

- Letter confusability
  - Conditional entropy (CE)

P1: Handshape freq.  $\uparrow$ , art. effort  $\downarrow$

P2: Letter freq.  $\uparrow$ , art. effort  $\downarrow$

P3: Confusable  $\uparrow$ , perceptual ease.  $\uparrow$



Two letters  $x_1, x_2$

Four preceding characters  
in a word

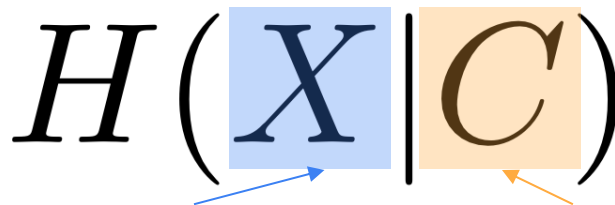
# Usage metrics

- Letter confusability
  - Conditional entropy (CE)
  - Letter pairs with high CE = more confusable

P1: Handshape freq.  $\uparrow$ , art. effort  $\downarrow$

P2: Letter freq.  $\uparrow$ , art. effort  $\downarrow$

P3: Confusable  $\uparrow$ , perceptual ease.  $\uparrow$



Two letters  $x_1, x_2$

Four preceding characters  
in a word

# Handshape effort

- Articulatory effort
- Perceptual effort

P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑

# Handshape effort

- Articulatory effort
- Perceptual effort

Data for FS handshapes?

P1: Handshape freq. ↑, art. effort ↓

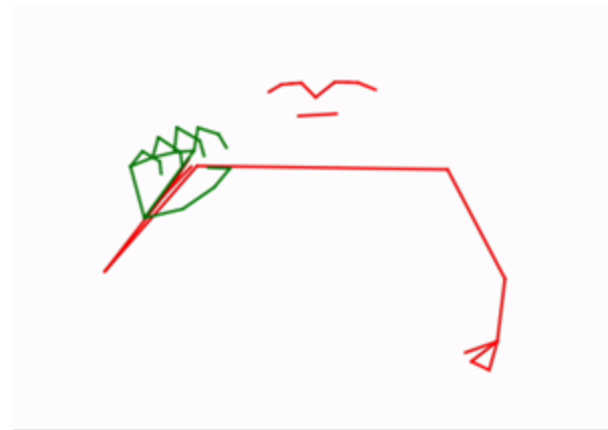
P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑



# Google ASL Fingerspelling Dataset

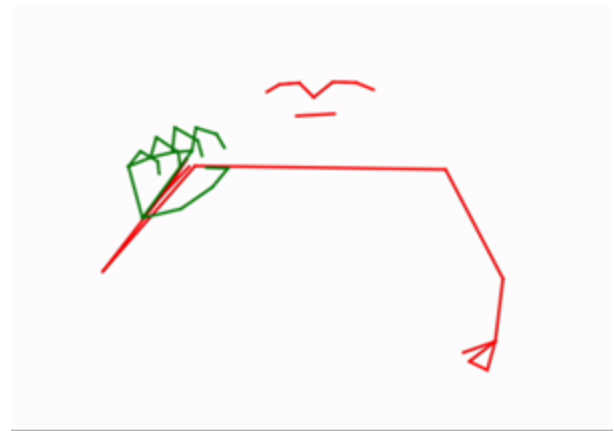
- 100k+ fingerspelled phrases



did you have a good time

# Google ASL Fingerspelling Dataset

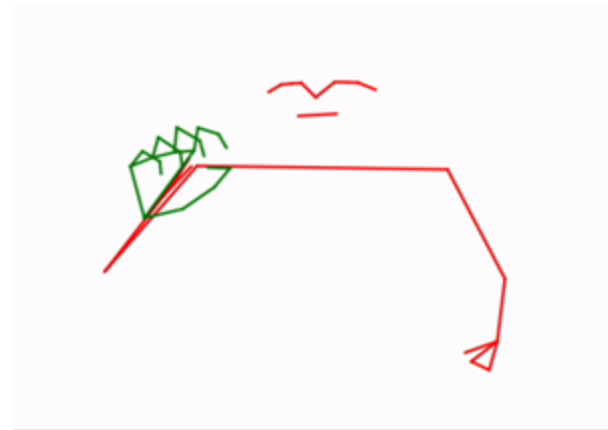
- 100k+ fingerspelled phrases
- No character-level labels



did you have a good time

# Google ASL Fingerspelling Dataset

- 100k+ fingerspelled phrases
- No character-level labels
- Heuristic algorithm + manual post-correction
  - 1062 letters extracted



did you have a good time

# Handshape effort: metrics

P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑

## Articulatory effort

- Finger independence

$$FI(\text{hand}) = \sum_{\mathcal{J}} \sum_{\alpha, \alpha' \in \mathcal{J} | \alpha \neq \alpha'} D(\alpha, \alpha') / N$$

# Handshape effort: metrics

P1: Handshape freq.  $\uparrow$ , art. effort  $\downarrow$

P2: Letter freq.  $\uparrow$ , art. effort  $\downarrow$

P3: Confusable  $\uparrow$ , perceptual ease.  $\uparrow$

Articulatory effort

- Finger independence

$$D(\alpha, \beta) = |\alpha - \beta| \bmod 2\pi$$

Distance between two joint angles

$$FI(\text{hand}) = \sum_{\mathcal{J}} \sum_{\alpha, \alpha' \in \mathcal{J} | \alpha \neq \alpha'} D(\alpha, \alpha') / N$$

# Handshape effort: metrics

## Articulatory effort

- Finger independence

P1: Handshape freq.  $\uparrow$ , art. effort  $\downarrow$

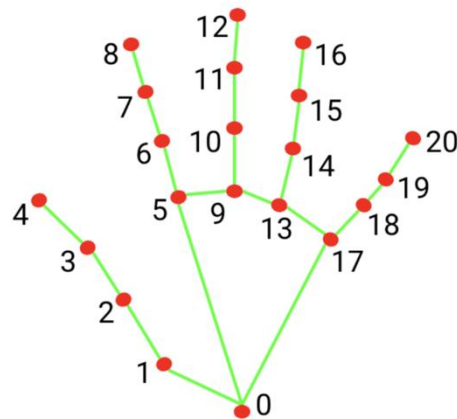
P2: Letter freq.  $\uparrow$ , art. effort  $\downarrow$

P3: Confusable  $\uparrow$ , perceptual ease.  $\uparrow$

$$D(\alpha, \beta) = |\alpha - \beta| \bmod 2\pi$$

Distance between two joint angles

$$FI(\text{hand}) = \sum_{\mathcal{J}} \sum_{\alpha, \alpha' \in \mathcal{J} | \alpha \neq \alpha'} D(\alpha, \alpha') / N$$



# Handshape effort: metrics

## Articulatory effort

- Finger independence

P1: Handshape freq.  $\uparrow$ , art. effort  $\downarrow$

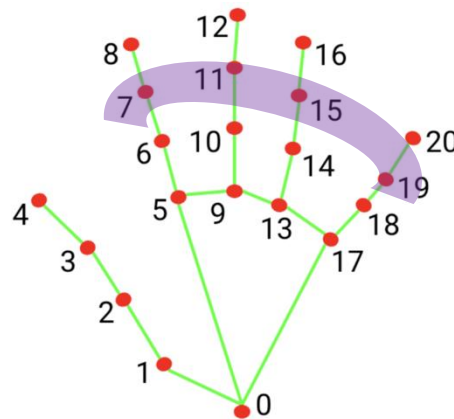
P2: Letter freq.  $\uparrow$ , art. effort  $\downarrow$

P3: Confusable  $\uparrow$ , perceptual ease.  $\uparrow$

$$D(\alpha, \beta) = |\alpha - \beta| \bmod 2\pi$$

Distance between two joint angles

$$FI(\text{hand}) = \sum_{\mathcal{J}} \sum_{\alpha, \alpha' \in \mathcal{J} | \alpha \neq \alpha'} D(\alpha, \alpha') / N$$



# Handshape effort: metrics

## Articulatory effort

- Finger independence

P1: Handshape freq.  $\uparrow$ , art. effort  $\downarrow$

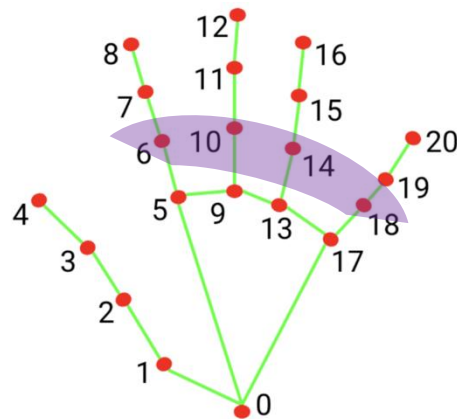
P2: Letter freq.  $\uparrow$ , art. effort  $\downarrow$

P3: Confusable  $\uparrow$ , perceptual ease.  $\uparrow$

$$D(\alpha, \beta) = |\alpha - \beta| \bmod 2\pi$$

Distance between two joint angles

$$FI(\text{hand}) = \sum_{\mathcal{J}} \sum_{\alpha, \alpha' \in \mathcal{J} | \alpha \neq \alpha'} D(\alpha, \alpha') / N$$





# Handshape effort: metrics

## Articulatory effort

- Finger independence

P1: Handshape freq.  $\uparrow$ , art. effort  $\downarrow$

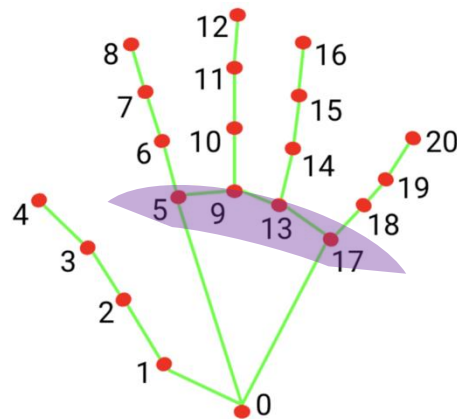
P2: Letter freq.  $\uparrow$ , art. effort  $\downarrow$

P3: Confusable  $\uparrow$ , perceptual ease.  $\uparrow$

$$D(\alpha, \beta) = |\alpha - \beta| \bmod 2\pi$$

Distance between two joint angles

$$FI(\text{hand}) = \sum_{\mathcal{J}} \sum_{\alpha, \alpha' \in \mathcal{J} | \alpha \neq \alpha'} D(\alpha, \alpha') / N$$



# Handshape effort: metrics

P1: Handshape freq.  $\uparrow$ , art. effort  $\downarrow$

P2: Letter freq.  $\uparrow$ , art. effort  $\downarrow$

P3: Confusable  $\uparrow$ , perceptual ease.  $\uparrow$

Articulatory effort

- Finger independence



“B”: low FI

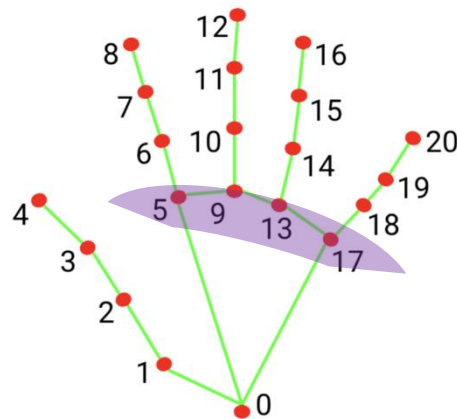


“R”: high FI

$$D(\alpha, \beta) = |\alpha - \beta| \bmod 2\pi$$

Distance between two joint angles

$$FI(\text{hand}) = \sum_{\mathcal{J}} \sum_{\alpha, \alpha' \in \mathcal{J} | \alpha \neq \alpha'} D(\alpha, \alpha') / N$$



# Handshape effort: metrics

## Articulatory effort

- Finger independence

## Perceptual effort

P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑

# Handshape effort: metrics

## Articulatory effort

- Finger independence

## Perceptual effort

- Handshape distance

P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑

$$D(\alpha, \beta) = |\alpha - \beta| \bmod 2\pi$$

Distance between two joint angles

$$HD(\text{hand}_1, \text{hand}_2) = \sum_{\alpha \in \text{hand}_1, \beta \in \text{hand}_2} D(\alpha, \beta) / N$$

# Handshape effort: metrics

## Articulatory effort

- Finger independence

## Perceptual effort

- Handshape distance

P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑

$$D(\alpha, \beta) = |\alpha - \beta| \bmod 2\pi$$

Distance between two joint angles

$$HD(\text{hand}_1, \text{hand}_2) = \sum_{\alpha \in \text{hand}_1, \beta \in \text{hand}_2} D(\alpha, \beta) / N$$

# Handshape effort: metrics

P1: Handshape freq.  $\uparrow$ , art. effort  $\downarrow$

P2: Letter freq.  $\uparrow$ , art. effort  $\downarrow$

P3: Confusable  $\uparrow$ , perceptual ease.  $\uparrow$

## Articulatory effort

- Finger independence

## Perceptual effort

- Handshape distance

$$D(\alpha, \beta) = |\alpha - \beta| \bmod 2\pi$$

Distance between two joint angles

$$HD(\text{hand}_1, \text{hand}_2) = \sum_{\alpha \in \text{hand}_1, \beta \in \text{hand}_2} D(\alpha, \beta) / N$$



“N” and “T”: low HD



“N” and “B”: high HD

# Results: pressure from ASL

P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

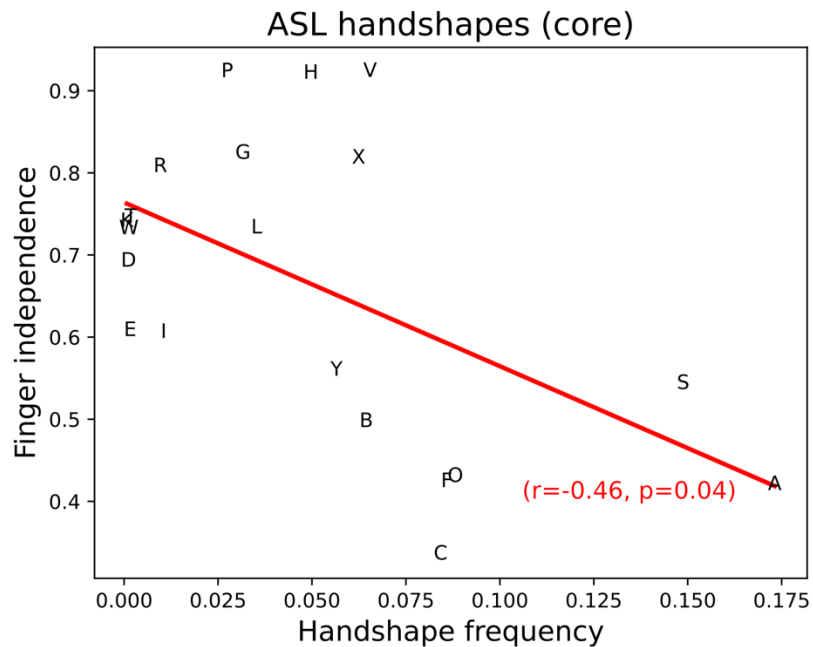
P3: Confusable ↑, perceptual ease. ↑

# Results: pressure from ASL

P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑

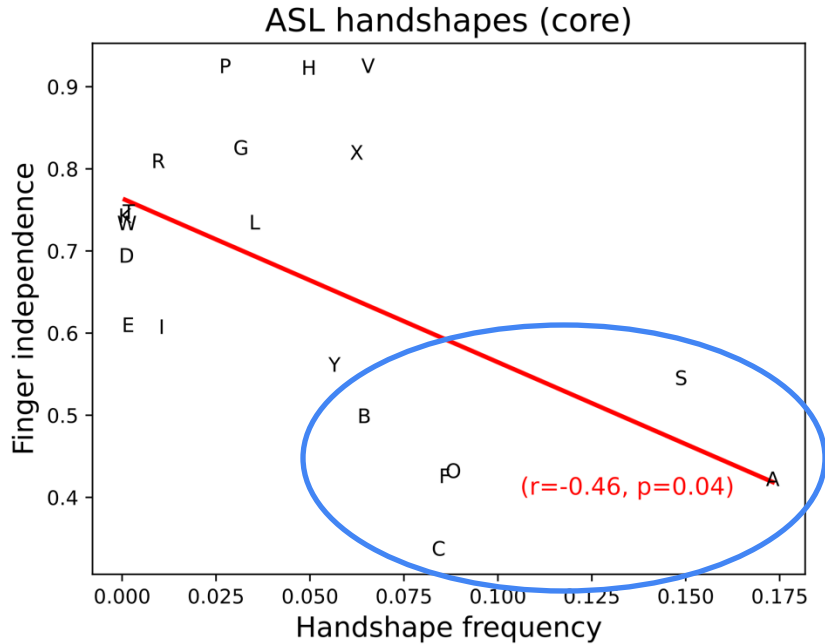




# Results: pressure from ASL



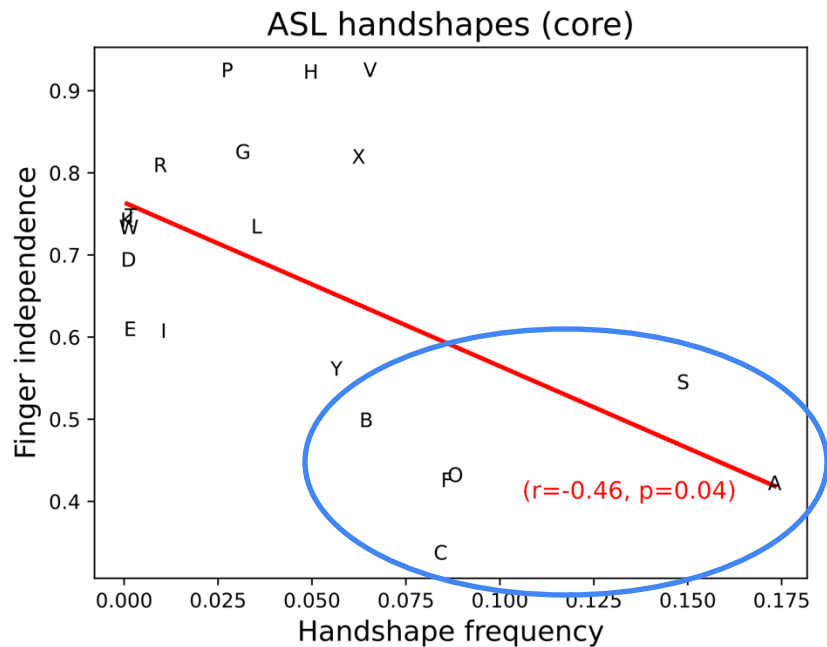
- P1: Handshape freq.  $\uparrow$ , art. effort  $\downarrow$
- P2: Letter freq.  $\uparrow$ , art. effort  $\downarrow$
- P3: Confusable  $\uparrow$ , perceptual ease.  $\uparrow$



# Results: pressure from ASL



- P1: Handshape freq.  $\uparrow$ , art. effort  $\downarrow$
- P2: Letter freq.  $\uparrow$ , art. effort  $\downarrow$
- P3: Confusable  $\uparrow$ , perceptual ease.  $\uparrow$



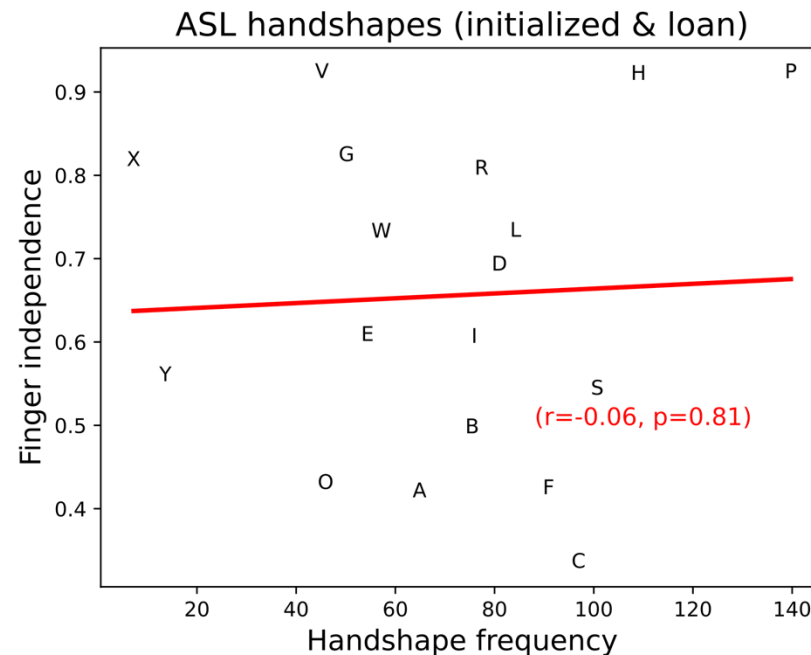
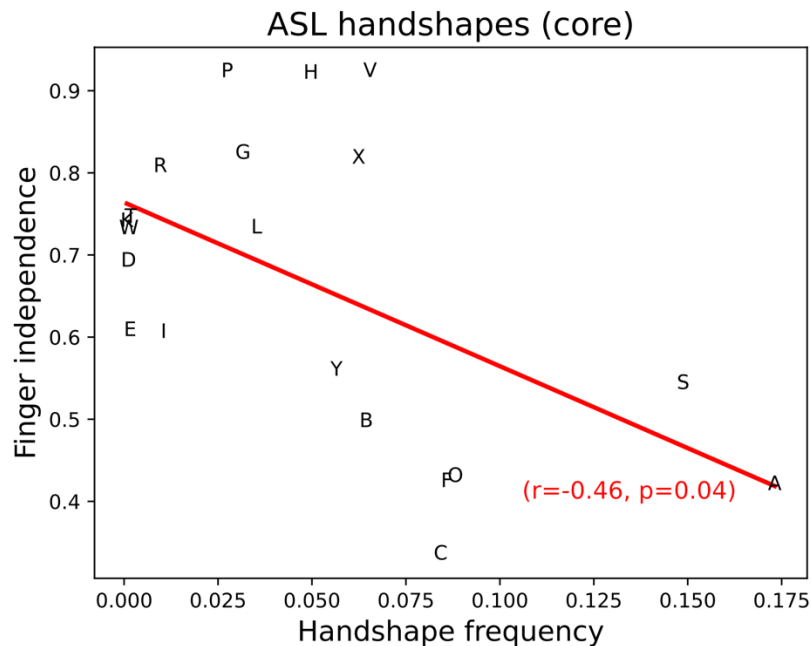
Unmarked handshapes (Battison, 1978):

B, A, S, C, O, 1, 5

# Results: pressure from ASL



- P1: Handshape freq.  $\uparrow$ , art. effort  $\downarrow$
- P2: Letter freq.  $\uparrow$ , art. effort  $\downarrow$
- P3: Confusable  $\uparrow$ , perceptual ease.  $\uparrow$



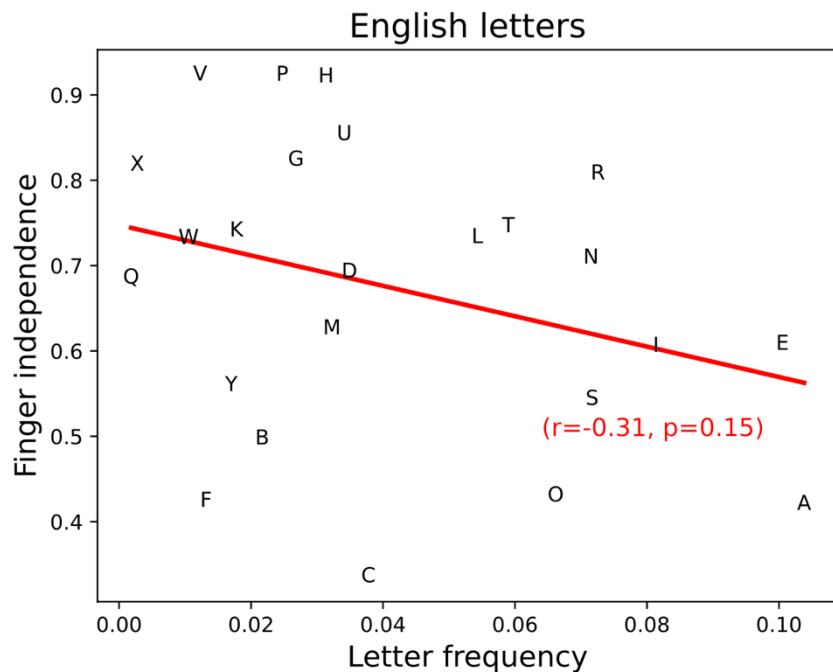
# Results: pressure from English



P1: Handshape freq.  $\uparrow$ , art. effort  $\downarrow$

P2: Letter freq.  $\uparrow$ , art. effort  $\downarrow$

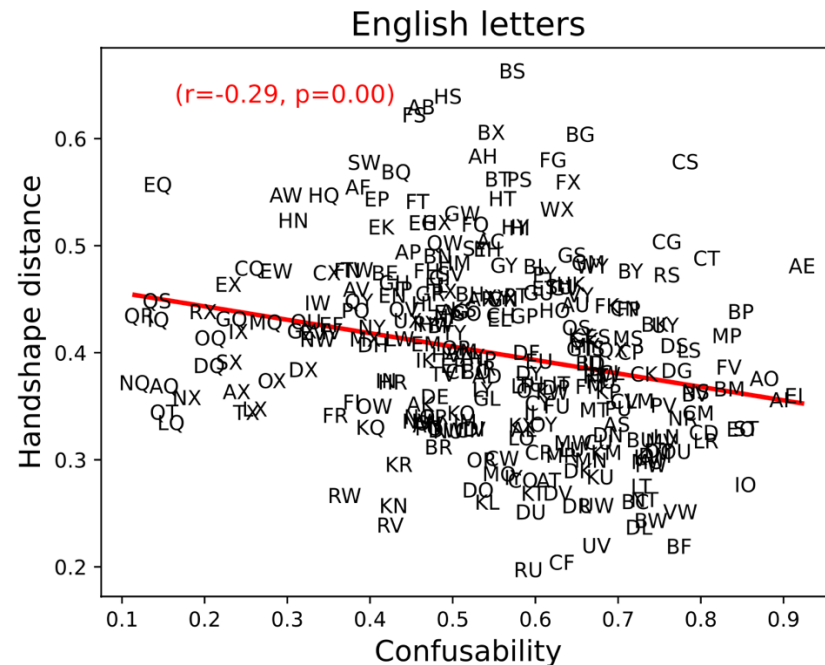
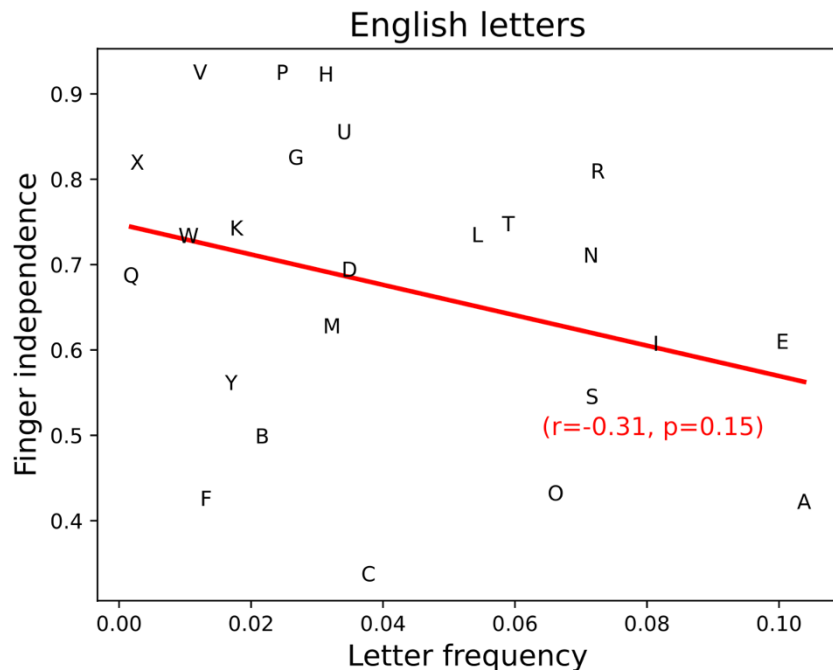
P3: Confusable  $\uparrow$ , perceptual ease.  $\uparrow$



# Results: pressure from English



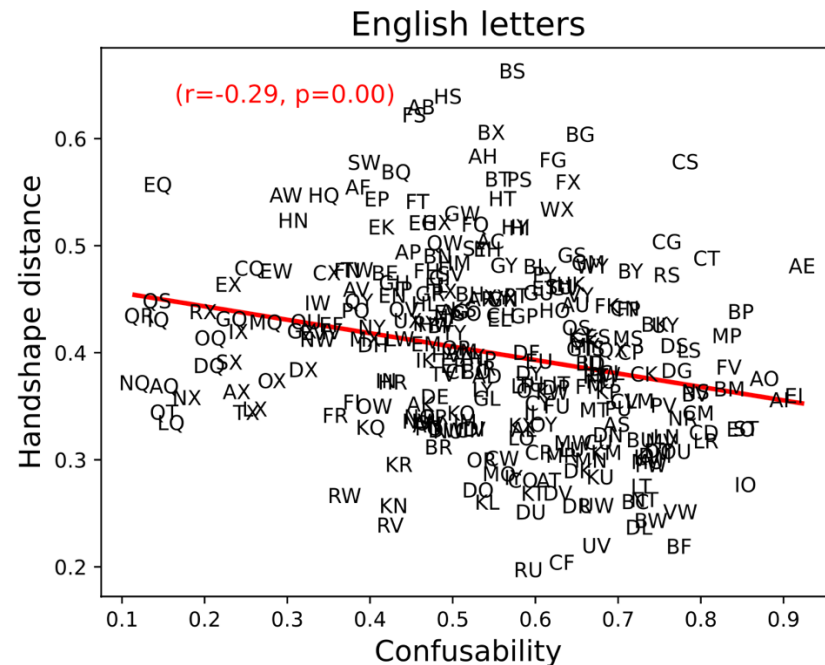
- P1: Handshape freq.  $\uparrow$ , art. effort  $\downarrow$
- P2: Letter freq.  $\uparrow$ , art. effort  $\downarrow$
- P3: Confusable  $\uparrow$ , perceptual ease.  $\uparrow$



# Results: pressure from English



- P1: Handshape freq.  $\uparrow$ , art. effort  $\downarrow$
- P2: Letter freq.  $\uparrow$ , art. effort  $\downarrow$
- P3: Confusable  $\uparrow$ , perceptual ease.  $\uparrow$

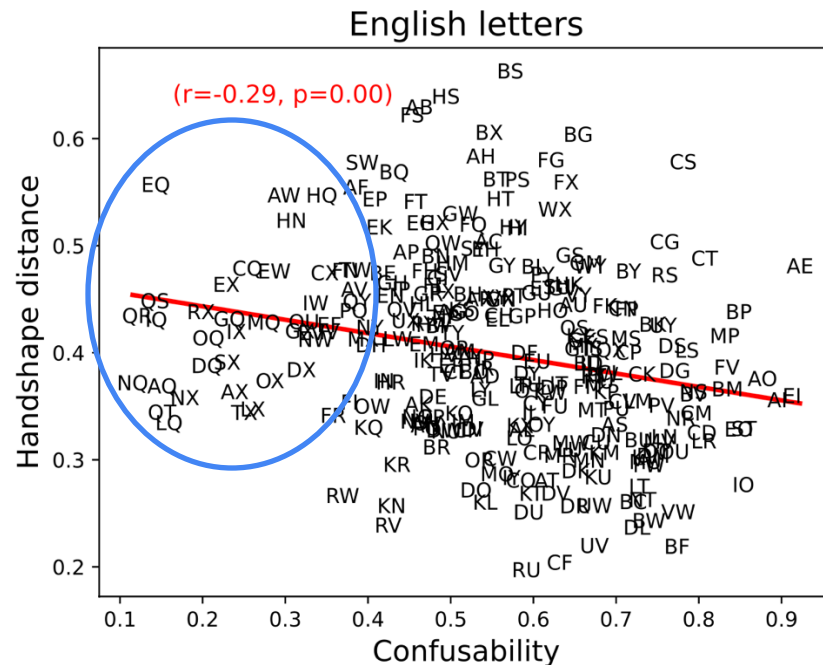


# Results: pressure from English



- P1: Handshape freq.  $\uparrow$ , art. effort  $\downarrow$
- P2: Letter freq.  $\uparrow$ , art. effort  $\downarrow$
- P3: Confusable  $\uparrow$ , perceptual ease.  $\uparrow$

Confusability and letter frequency  
are highly correlated



# Results: pressure from English

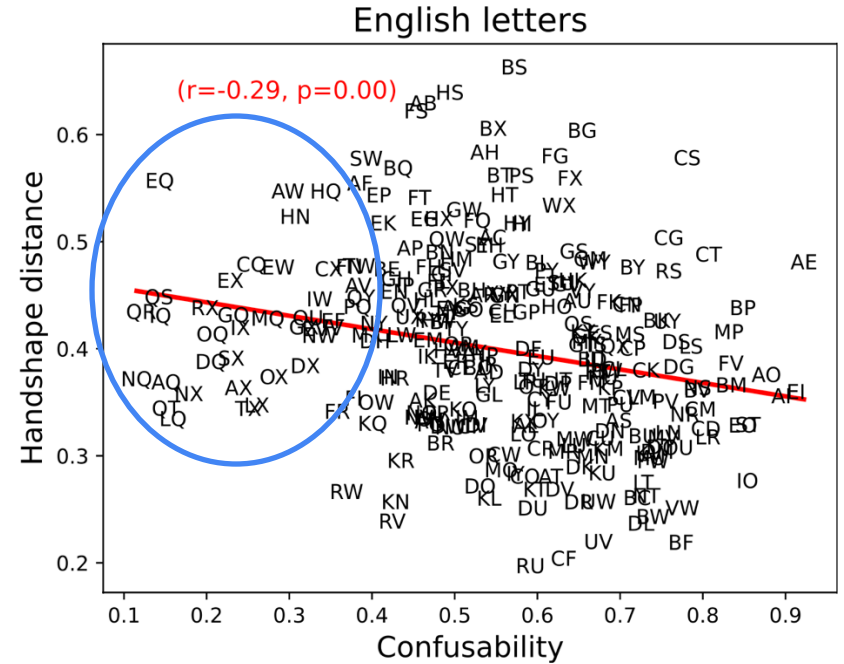


P1: Handshape freq.  $\uparrow$ , art. effort  $\downarrow$

P2: Letter freq.  $\uparrow$ , art. effort  $\downarrow$

P3: Confusable  $\uparrow$ , perceptual ease.  $\uparrow$

Confusability and letter frequency  
are highly correlated





# Takeaways



P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑

RQ1. Do FS handshapes reflect pressures for **communicative efficiency**? 

RQ2. If so, do they **jointly optimize** pressures from English and ASL?

RQ3. Alternatively, pressure for efficiency mostly or all from **ASL usage**?

# Takeaways



P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑

RQ1. Do FS handshapes reflect pressures for **communicative efficiency**?



RQ2. If so, do they **jointly optimize** pressures from English and ASL?



RQ3. Alternatively, pressure for efficiency mostly or all from **ASL usage**?

# Takeaways



P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑

RQ1. Do FS handshapes reflect pressures for **communicative efficiency**?



RQ2. If so, do they **jointly optimize** pressures from English and ASL?



RQ3. Alternatively, pressure for efficiency mostly or all from **ASL usage**?



# Takeaways



P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑

RQ3. Alternatively, pressure for efficiency mostly or all from **ASL usage**?



Why?

# Takeaways



P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑

RQ3. Alternatively, pressure for efficiency mostly or all from **ASL usage**?



Why?

- ASL fingerspelling is invented by hearing educators ([Padden and Gunsauls, 2003](#))

# Takeaways



P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑

RQ3. Alternatively, pressure for efficiency mostly or all from **ASL usage**?



Why?

- ASL fingerspelling is invented by hearing educators ([Padden and Gunsauls, 2003](#))
- Frequent words undergo faster language change ([Bybee, 2015](#); [Caselli et al., 2022](#))

# Takeaways



P1: Handshape freq. ↑, art. effort ↓

P2: Letter freq. ↑, art. effort ↓

P3: Confusable ↑, perceptual ease. ↑

RQ3. Alternatively, pressure for efficiency mostly or all from **ASL usage**?



Why?

- ASL fingerspelling is invented by hearing educators ([Padden and Gunsauls, 2003](#))
- Frequent words undergo faster language change ([Bybee, 2015](#); [Caselli et al., 2022](#))
- Foreign components obey fewer phonological rules ([Brentari and Padden, 2001](#))

Conclusion



Lots of cool ways to extend NLP to  
signed languages yet to be explored

Lots of cool ways to extend NLP to signed languages yet to be explored



Motion Light Lab @ Gallaudet University

Lots of cool ways to extend NLP to signed languages yet to be explored

Really important to work with Deaf people for AI products



Motion Light Lab @ Gallaudet University

Thoughts? Reactions? Questions?

