Natural Language Processing for Signed Languages

Kayo Yin

Berkeley NLP

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

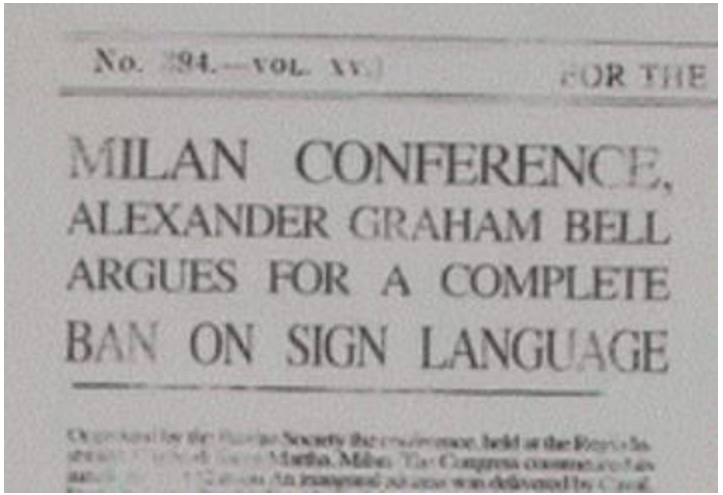
- Predominant in the US and anglophone Canada
- Often used as a lingua franca

American Sign Language

Gallaudet memorial

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

American Sign Language



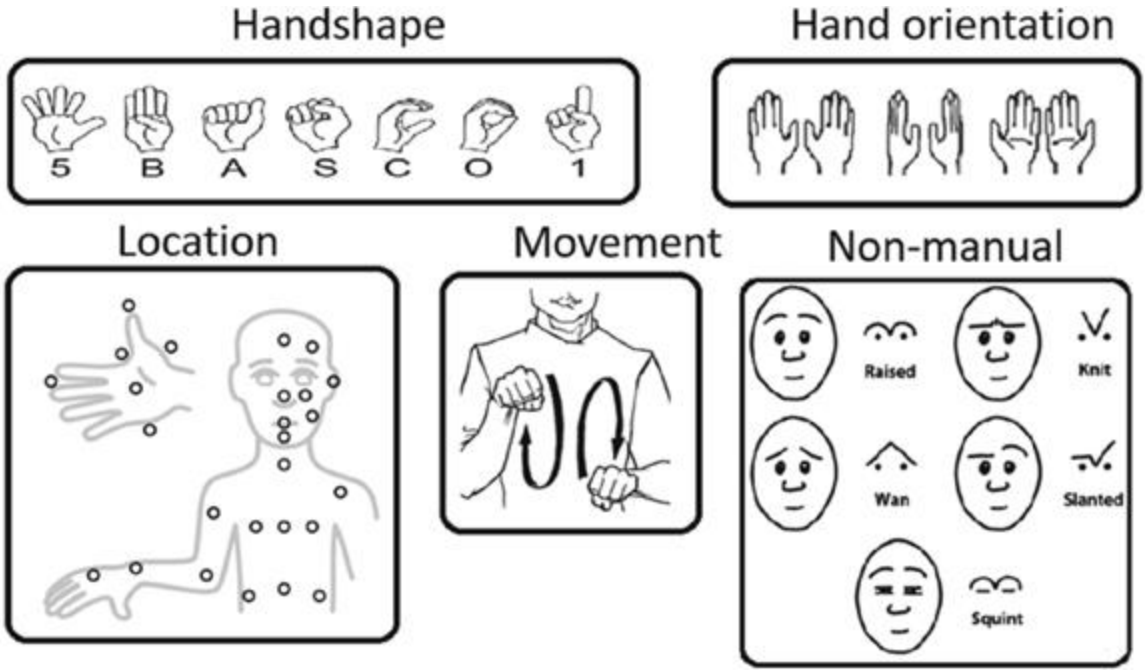
No. 294.—VOL. XV.] FOR THE

MILAN CONFERENCE,
ALEXANDER GRAHAM BELL
ARGUES FOR A COMPLETE
BAN ON SIGN LANGUAGE

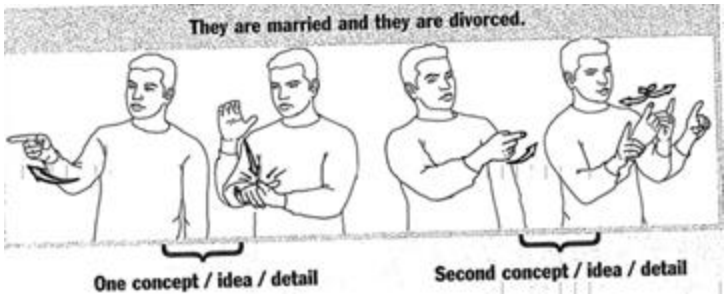
1880 Milan Conference

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

Phonology


Handshape
5
B
A
S
C
O
1
Hand orientation
Location
Movement
Non-manual
Raised
Knit
Wan
Slanted
Squint

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

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

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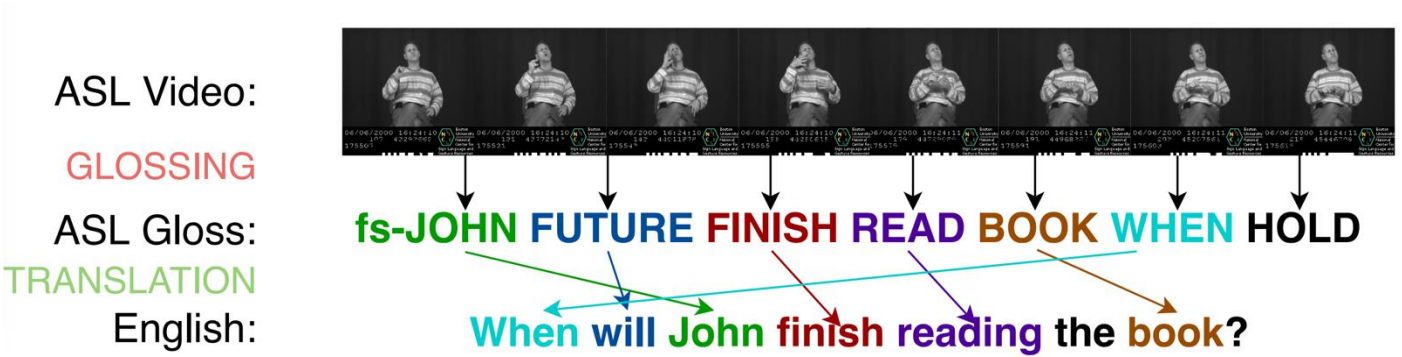

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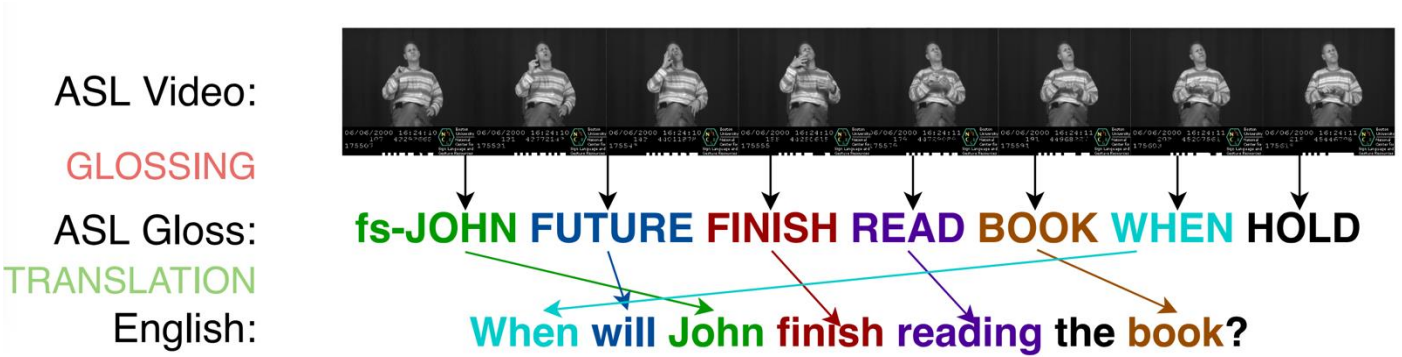
- Misinformed representations
  - “Tyranny of glossing” (Hochgesang, 2022)



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- ~ 40 public datasets

Current progress in AI for signed languages

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

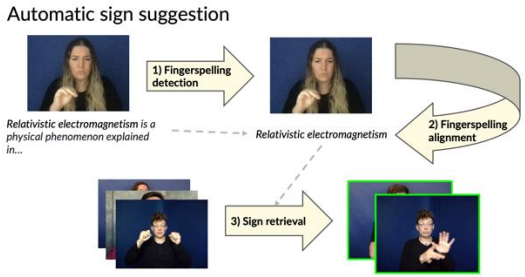
My research

2 projects:

My research

2 projects:

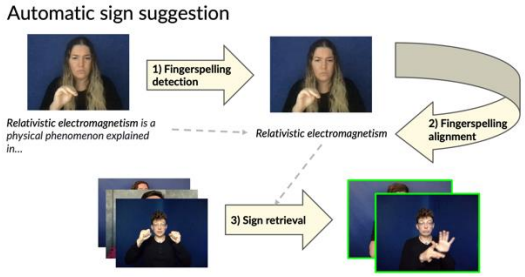
- AI tools to support deaf education

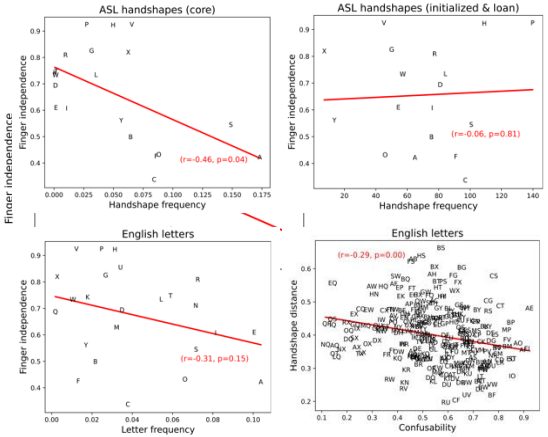


My research

2 projects:

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





BERKELEY ARTIFICIAL INTELLIGENCE RESEARCH

Microsoft Research

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

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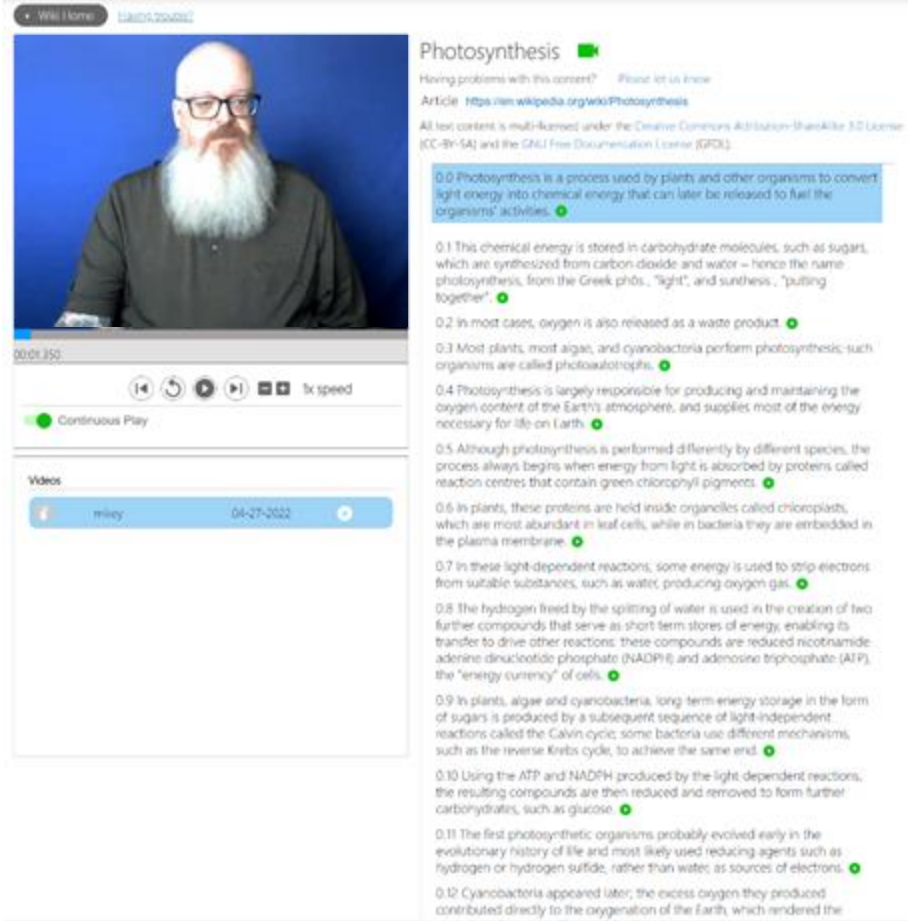
- STEM resources in ASL are **scarce**

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



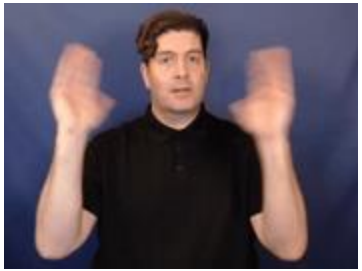
Interpreting STEM articles is hard

- Fingerspelling in place of ASL sign

“relativistic electromagnetism”

Interpreting STEM articles is hard

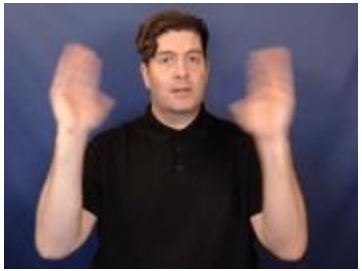
- Fingerspelling in place of ASL sign
- Inconsistent technical signs



“relativistic electromagnetism”

Interpreting STEM articles is hard

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

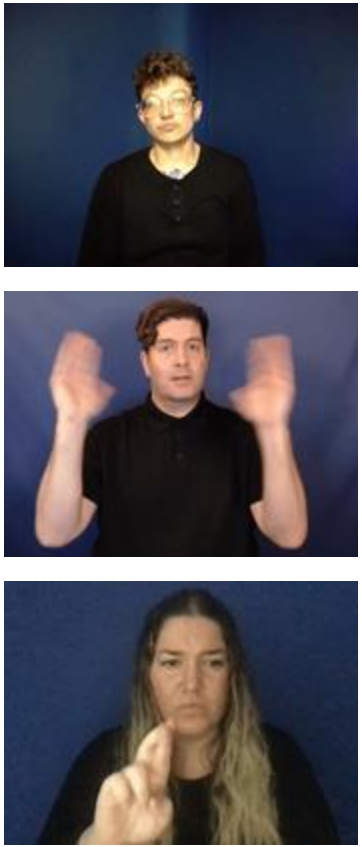


“relativistic electromagnetism”

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”

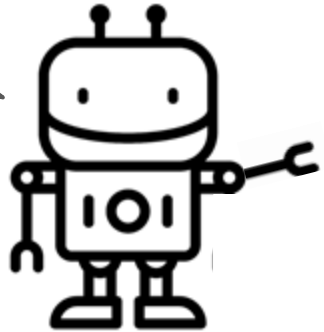
Automatic sign suggestion

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

2) Fingerspelling alignment

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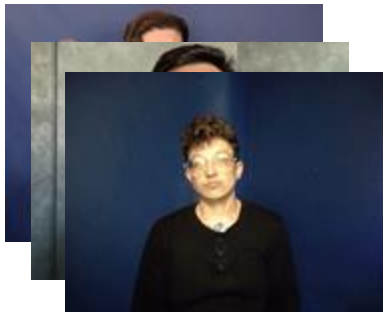
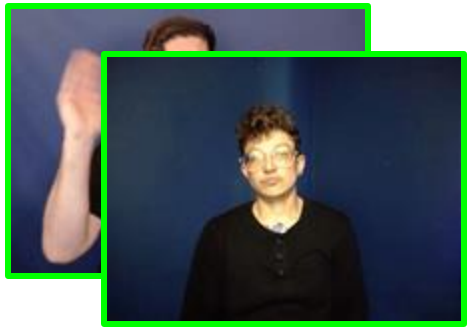
Relativistic electromagnetism



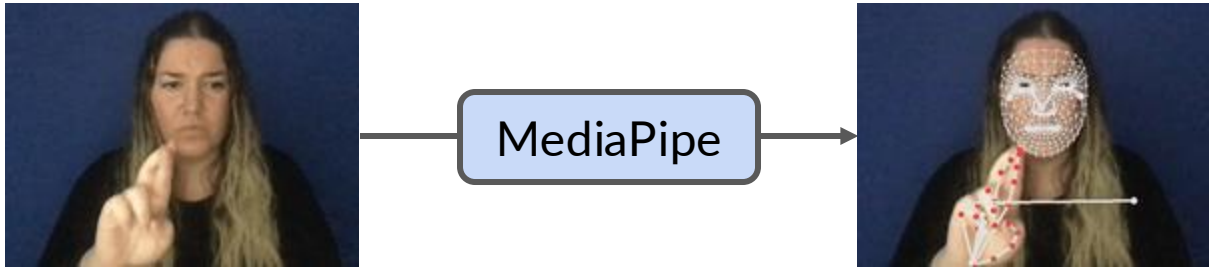
3) Sign retrieval



Fingerspelling detection + alignment: multitask model

Relativistic electromagnetism is a physical phenomenon explained in…

Fingerspelling detection + alignment: multitask model



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Fingerspelling detection + alignment: multitask model

MediaPipe

GCN
+
Transformer

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Temporal contrastive learning

Sentential contrastive learning

Representation learning

Fingerspelling detection + alignment: multitask model

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Temporal contrastive learning

Sentential contrastive learning

Representation learning

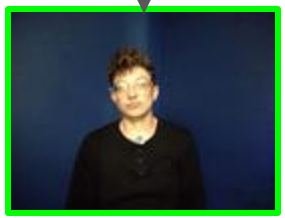
Fingerspelling detection

Fingerspelling alignment

Fine-tuning

Sign retrieval

“Relativistic electromagnetism”



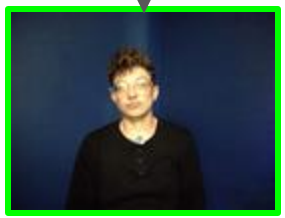
Dictionary lookup

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

Video search

Sign retrieval

“Relativistic electromagnetism”



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Video search

BAIR
BERKELEY ARTIFICIAL INTELLIGENCE RESEARCH

Berkeley Linguistics

Pressures for Communicative Efficiency in American Sign Language

Kayo Yin

Terry Regier

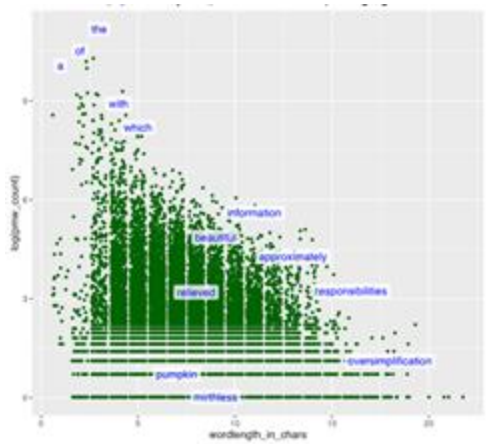
Dan Klein

Efficiency shapes human language

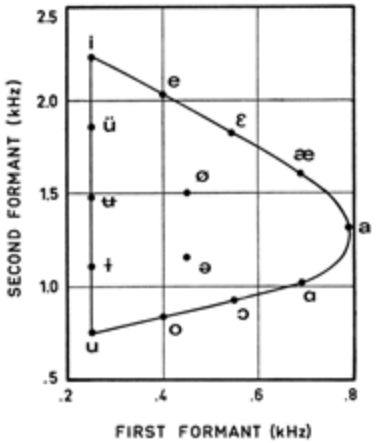
Efficiency: successful communication with **minimal effort** by sender + receiver

Efficiency shapes human language

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



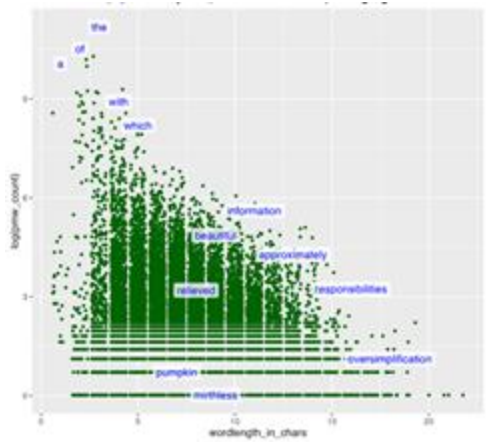
Frequent/informative words are shorter
(Zipf, 1935; Piantadosi et al., 2011)



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

Efficiency shapes human language

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



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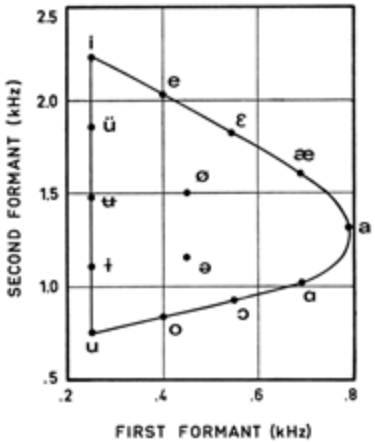

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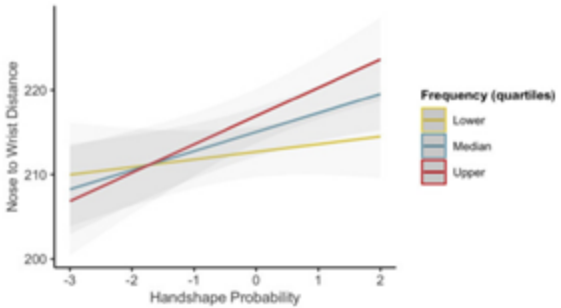


Infrequent ASL signs are produced closer to face
(Caselli et al., 2022)

Language contact in ASL

Fingerspelling

Language contact in ASL

Fingerspelling

Loan signs

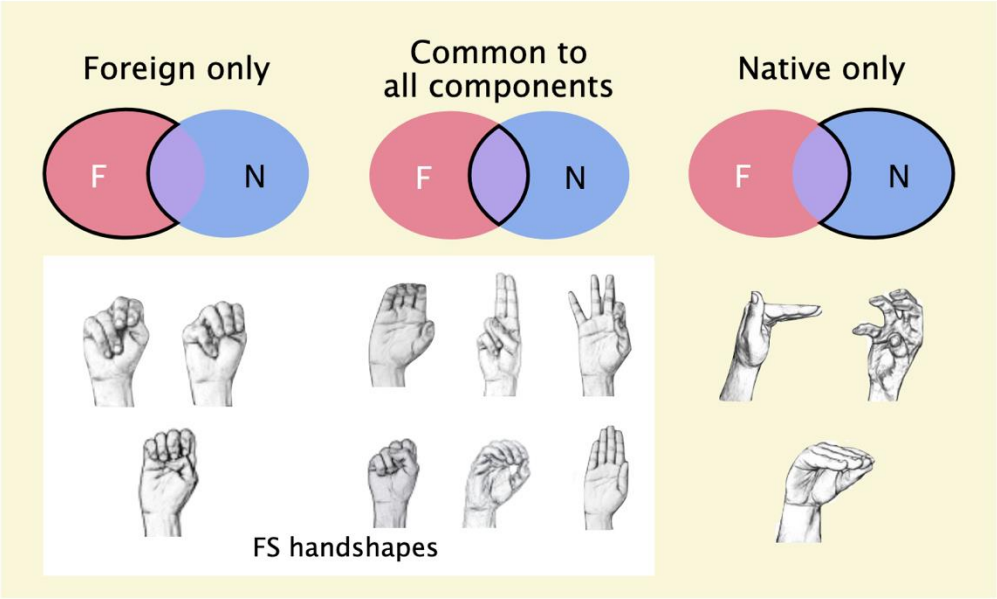
Language contact in ASL

Fingerspelling

Loan signs

Initialized signs

Efficiency shapes ASL handshapes?



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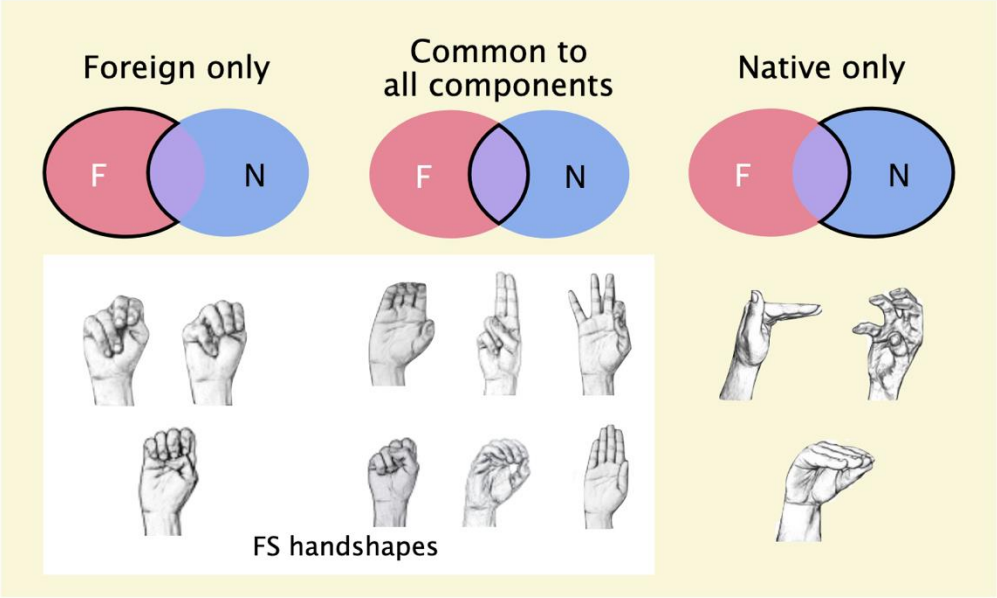
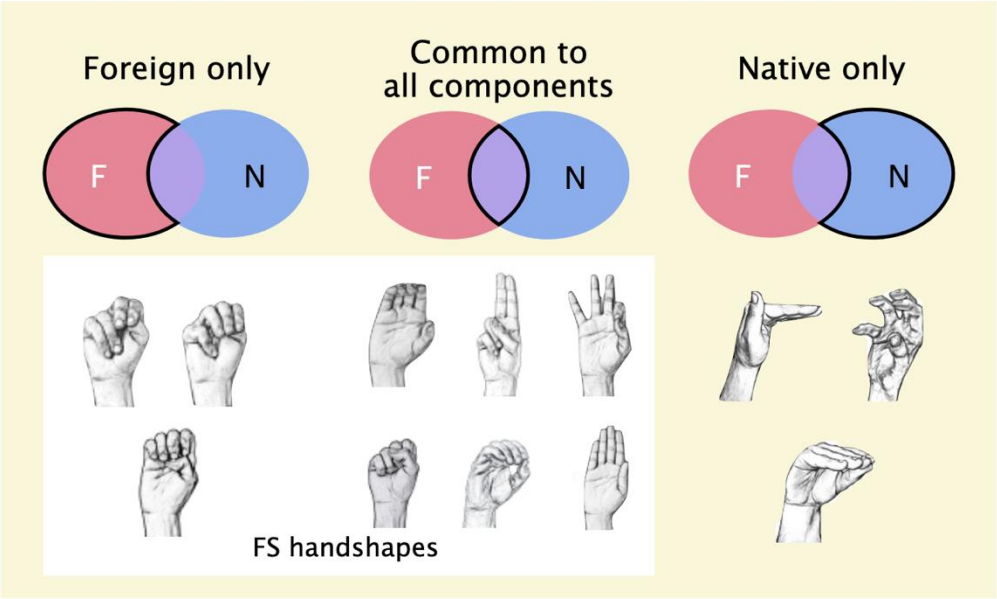


19 out of 22 handshapes in ASL fingerspelling appear in native ASL signs

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**?

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

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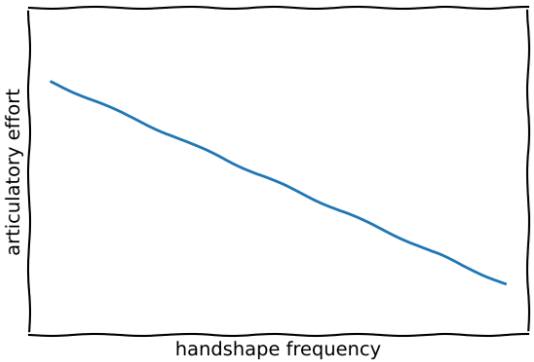
RQ2. If so, do they **jointly optimize** pressures from English and ASL?

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

Predictions

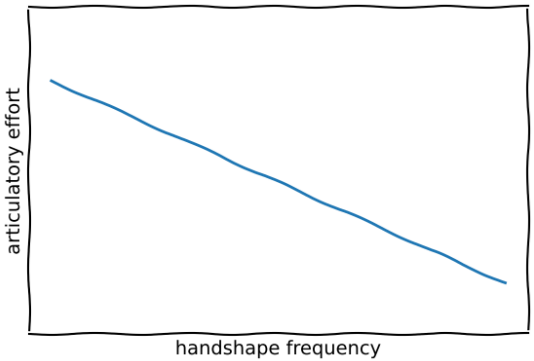
P1. FS handshapes that appear **frequently** in ASL signs are **easier to produce**

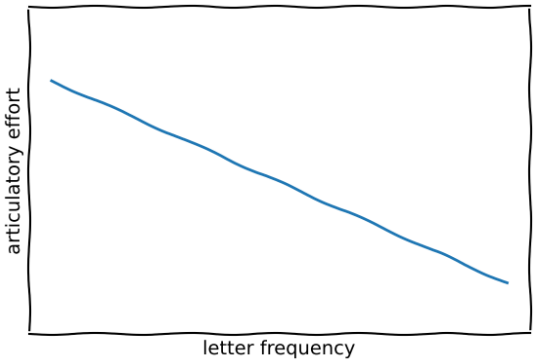


Predictions

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





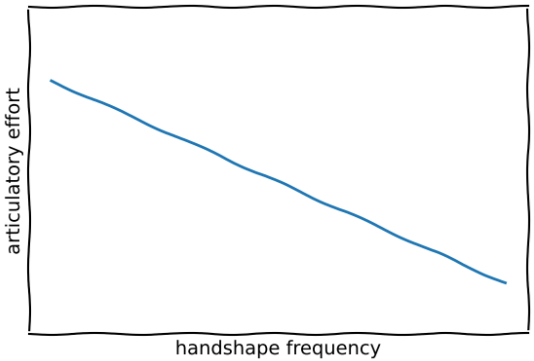
P1: Handshape freq. ↑, art. effort ↓
P2: Letter freq. ↑, art. effort ↓
P3: Confusable ↑, perceptual ease. ↑

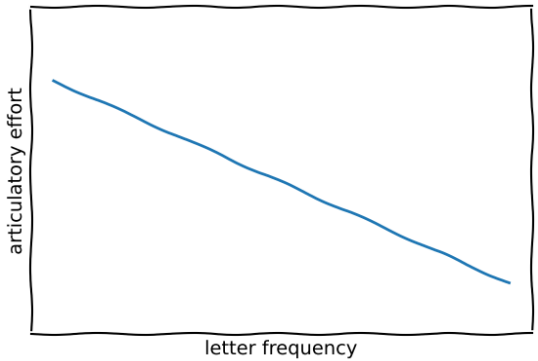
Predictions

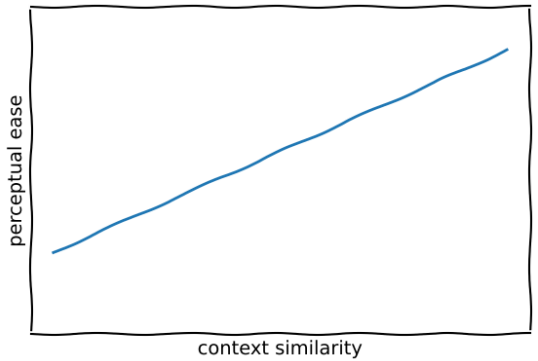
P1. FS handshapes that appear **frequently** in ASL signs are **easier to produce**

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

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







Usage metrics

P1: Handshape freq. ↑, art. effort ↓
P2: Letter freq. ↑, art. effort ↓
P3: Confusable ↑, perceptual ease. ↑

- 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 ↓
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Usage metrics: handshape frequency

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  - 1204 signs with FS handshapes

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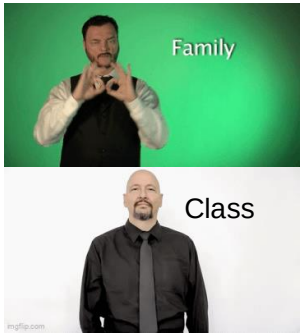
P3: Confusable ↑, perceptual ease. ↑

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. ↑

Usage metrics

- Letter frequency
  - 10,000 Wikipedia articles in English

P1: Handshape freq. ↑, art. effort ↓
P2: Letter freq. ↑, art. effort ↓
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Usage metrics

- Letter frequency
  - 10,000 Wikipedia articles in English

the, be, …, complicit, macaroni, …, phytic, piedmontese

P1: Handshape freq. ↑, art. effort ↓
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Usage metrics

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

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

P1: Handshape freq. ↑, art. effort ↓
P2: Letter freq. ↑, art. effort ↓
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Usage metrics

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

macaroni, …, phytic, piedmontese

P1: Handshape freq. ↑, art. effort ↓
P2: Letter freq. ↑, art. effort ↓
P3: Confusable ↑, perceptual ease. ↑

Usage metrics

- Letter confusability
  - Conditional entropy (CE)

$$H(X|C)$$

P1: Handshape freq. ↑, art. effort ↓
P2: Letter freq. ↑, art. effort ↓
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Usage metrics

- Letter confusability
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$$H(X|C)$$

Two letters x_1, x_2

P1: Handshape freq. ↑, art. effort ↓
P2: Letter freq. ↑, art. effort ↓
P3: Confusable ↑, perceptual ease. ↑

Usage metrics

- Letter confusability
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$$H(X|C)$$

Two letters x_1, x_2

Four preceding characters in a word

P1: Handshape freq. ↑, art. effort ↓
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Usage metrics

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

$$H(X|C)$$

Two letters x_1, x_2

Four preceding characters in a word

Handshape effort

- Articulatory effort
- Perceptual effort

P1: Handshape freq. ↑, art. effort ↓
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Data for FS handshapes?

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

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Handshape effort: metrics

Articulatory effort

- Finger independence

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

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

Distance between two joint angles

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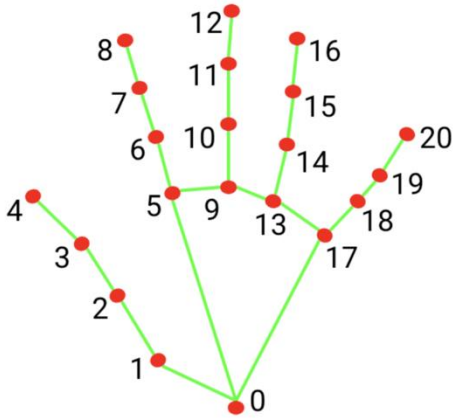

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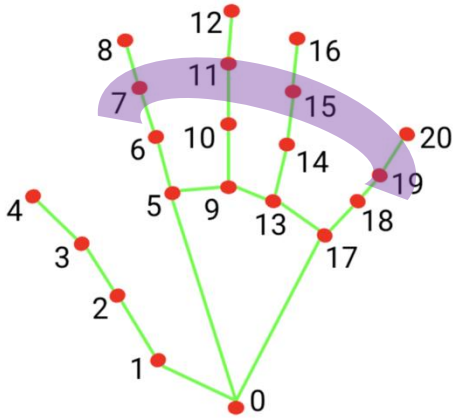

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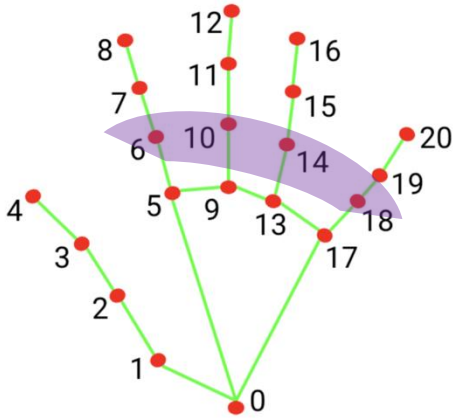

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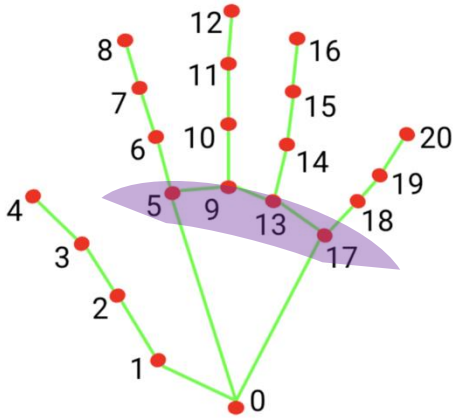

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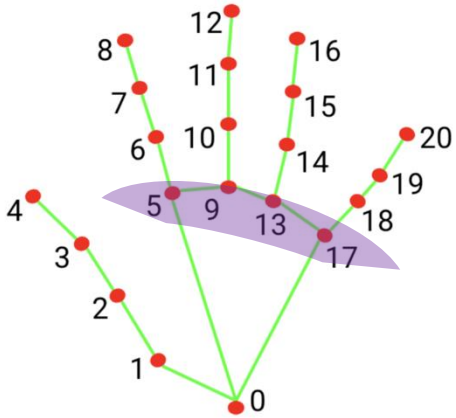
“B”: low FI “R”: high FI



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Perceptual effort

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Handshape effort: metrics

Articulatory effort

- Finger independence

Perceptual effort

- Handshape distance

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

Distance between two joint angles

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

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Handshape effort: metrics

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Perceptual effort

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“N” and “T”: low HD

“N” and “B”: high HD

Results: pressure from ASL

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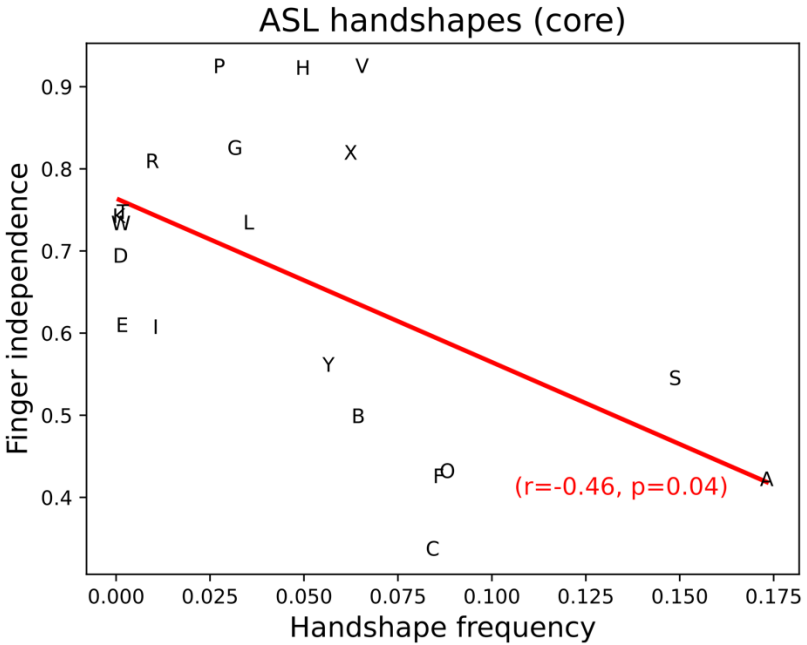

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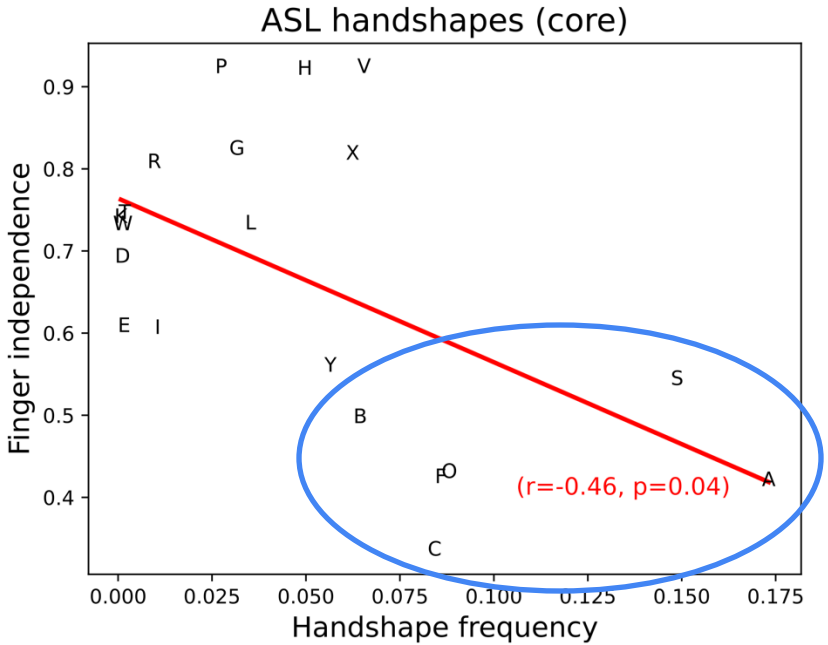

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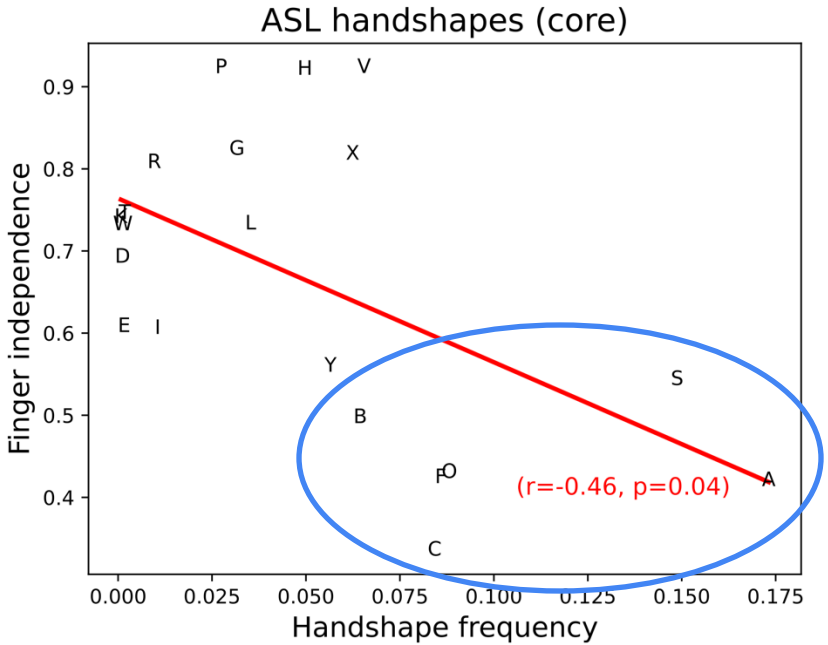

Unmarked handshapes (Battison, 1978):

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

Results: pressure from ASL

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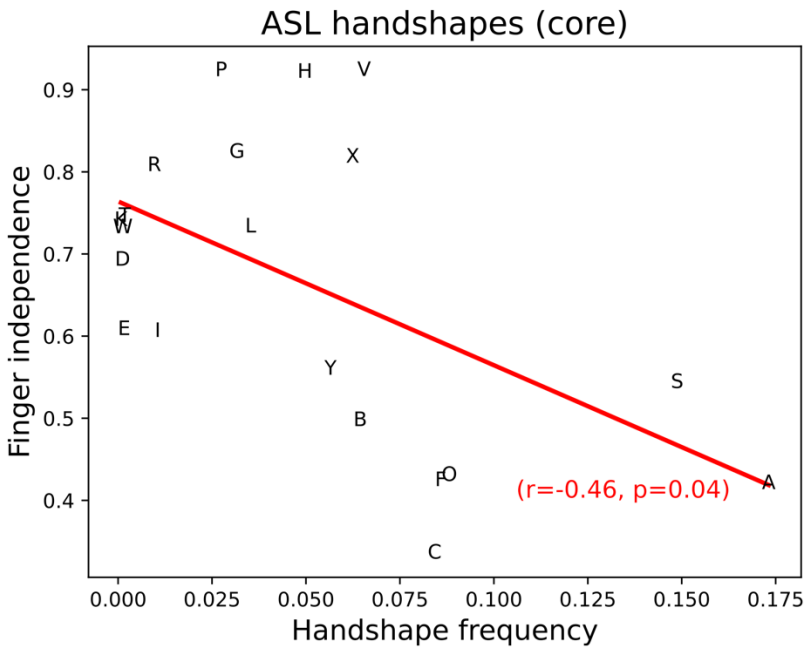
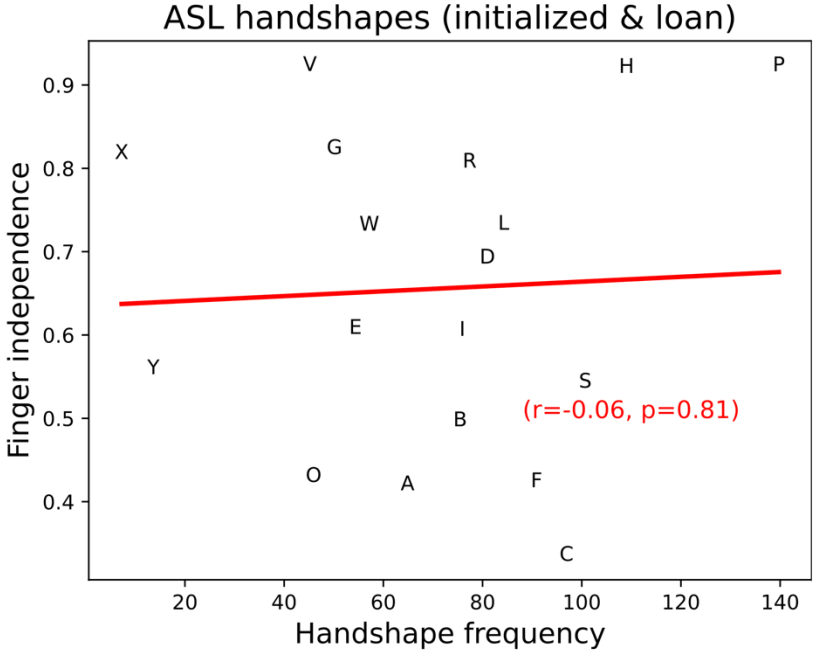
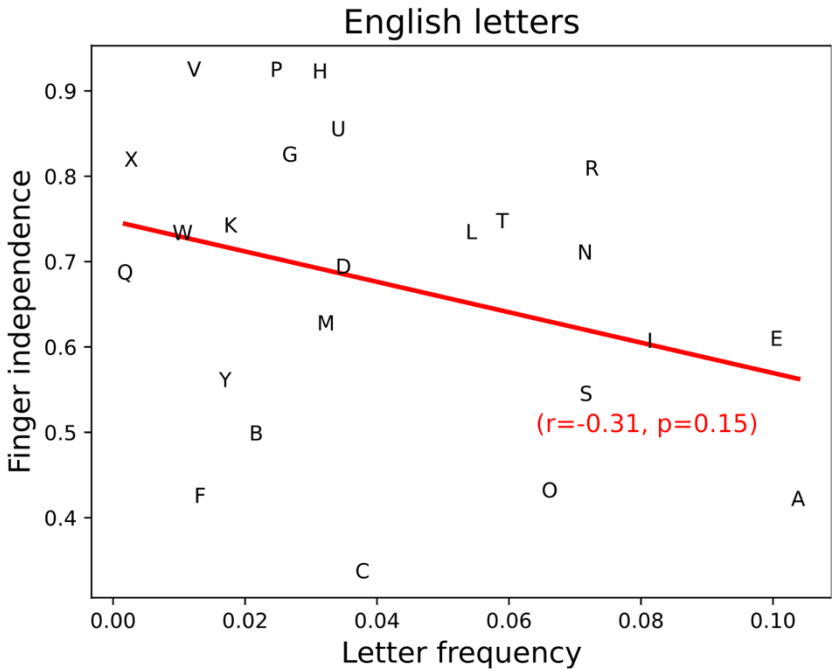




Results: pressure from English



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Results: pressure from English

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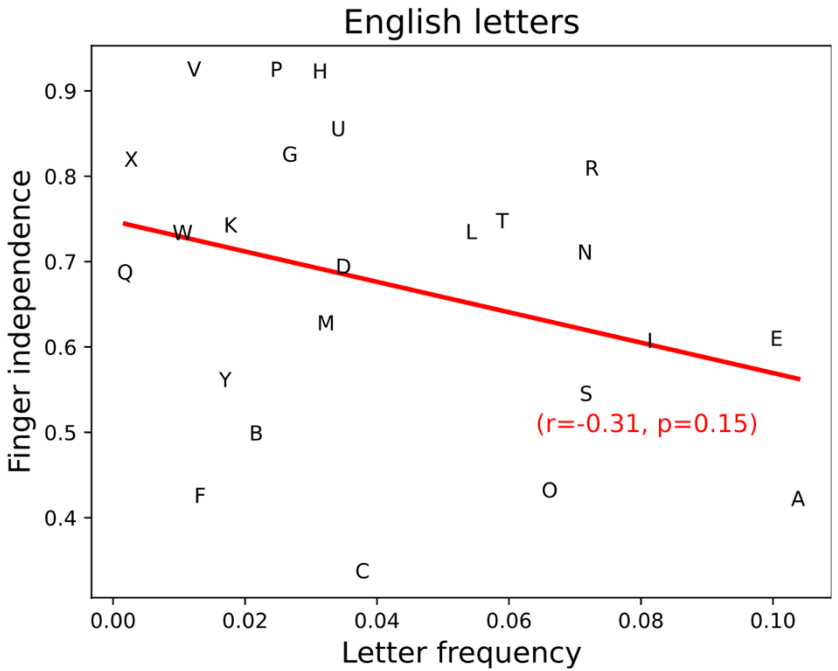

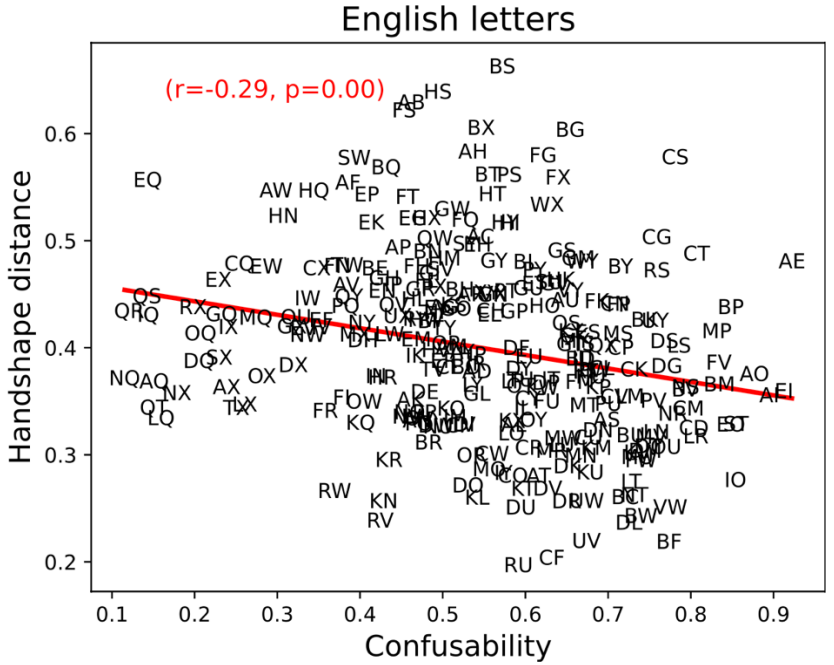

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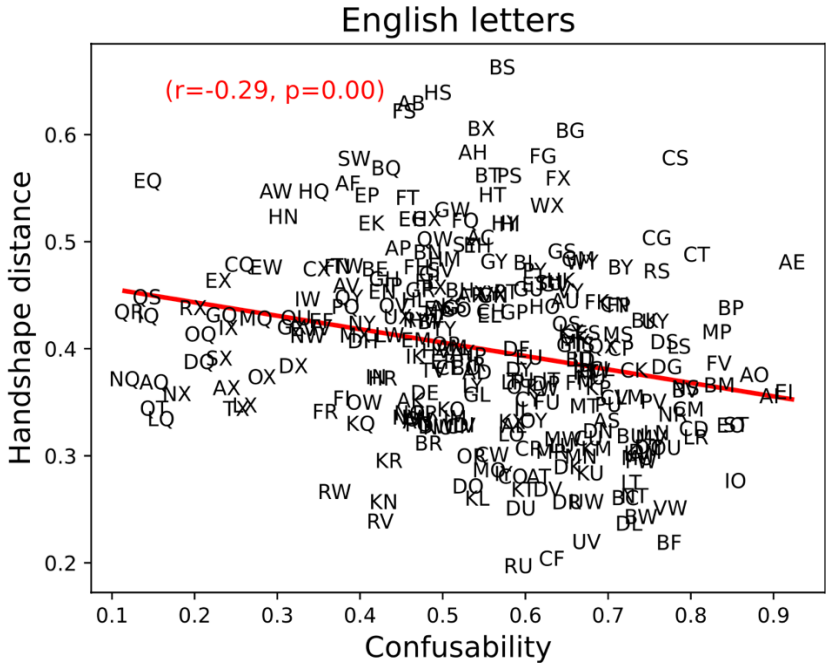

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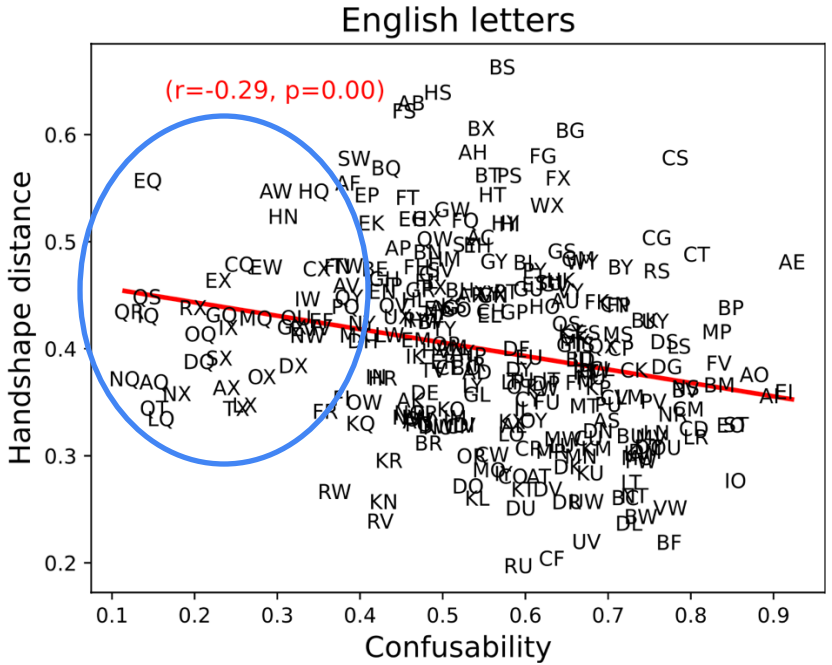
Confusability and letter frequency are highly correlated



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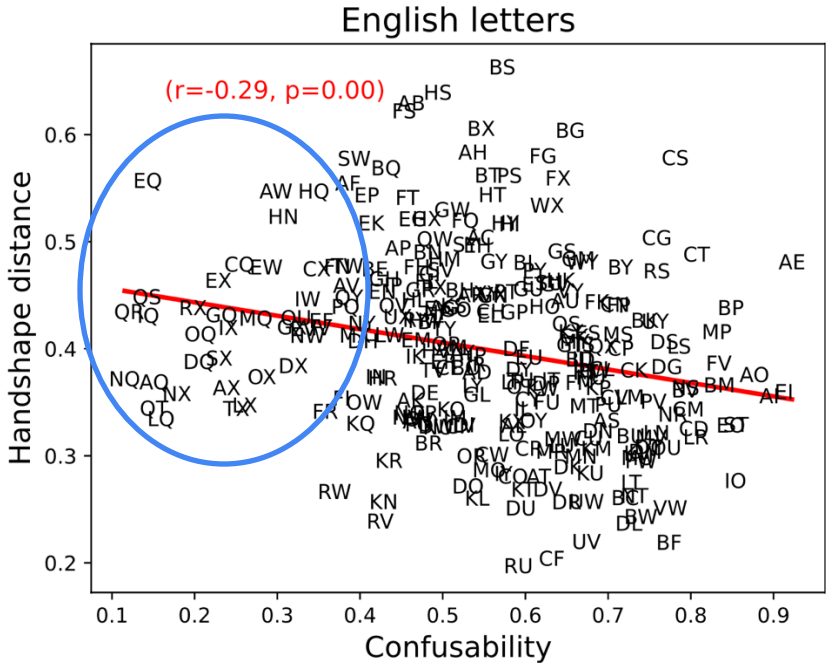

Takeaways

P1: Handshape freq. ↑, art. effort ↓
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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**?

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Why?

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

Why?

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

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

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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

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Motion Light Lab @ Gallaudet University

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Really important to work with Deaf people for AI products

Motion Light Lab @ Gallaudet University

Thoughts? Reactions? Questions?