A CROSS-LINGUISTIC COLLECTION OF HANDSHAPES FROM 12 PUBLIC SIGN LANGUAGE RESOURCES

Longqian MING

Universität Zürich
longqian.ming@uzh.ch

1. INTRODUCTION

Sign Languages are visual-spatial languages that utilize handshapes, movements, and locations in a three-dimensional space, along with facial expressions and body movements, to articulate. Same as spoken languages, Sign Languages are unique to different regions and cultures, such as American Sign Language(ASL), British Sign Language(BSL), Chinese Sign Language(CSL), and so on. Sign Languages are natural languages that rely on the visual modality rather than auditory, making them accessible primarily to the Deaf and Hard-of-hearing communities.

1.1. Motivation

PHOIBLE [1] is a repository of cross-linguistic phonological inventory data, which have been extracted from source documents and tertiary databases and compiled into a single searchable web portal. The release 2.0 from 2019 includes 3020 inventories that contain 3183 segment types found in 2186 distinct languages. PHOIBLE is a valuable resource for phonetics and phonology, typological linguistic research [2], and computational tasks such as speech recognition [3](especially for under-resourced languages). Inventory is the name used in PHOIBLE [1], an inventory differs from a language - a language could have multiple inventories.

However, PHOIBLE does not contain any sign languages, which is reasonable because sign language phonology differs greatly from spoken language phonology. There is no unified "IPA" [4] system for sign languages. The phonology of sign languages has not been universally defined, and the present categories are mainly focused on manual movements only [5, 6, 7]. Some signs can be articulated using non-manual features alone, but signs like these and non-manual minimal pairs are infrequent compared to manual features [8]. In addition, some non-manuals like eyebrows are linked to intonation in spoken languages. It is unclear how non-manuals play a role in phonological models [8]. As a result, only manual features are included in the common phonological models of sign languages.

This report illustrated the first attempt at establishing a sign language "PHOIBLE", by collecting handshapes of sign languages from public valid resources. There are 12 inventories of handshapes collected, from 12 sign languages. Some of the resources are found in The Sign Language Dataset Compendium [9]. It should be noted that the handshapes represent sign language lexicons, which are more than the fingerspelling of alphabet and digitals. Furthermore, one resource of each sign language might not be enough to cover a sign language fully, for example, there might be dialects, and the more valid resources, the more comprehensive.

2. HANDSHAPES OF THE WORLD'S SIGN LANGUAGES

A total of 12 inventories of handshapes are collected here, given a brief introduction of each dataset and a screenshot of the handshapes in each inventory.

2.1. American Sign Language (ASL)

The handshapes of ASL were taken from ASL-LEX 2.0 Project: A database of lexical and phonological properties for 2,723 signs in the American Sign Language [10]. The handshapes are displayed in Figure 1.

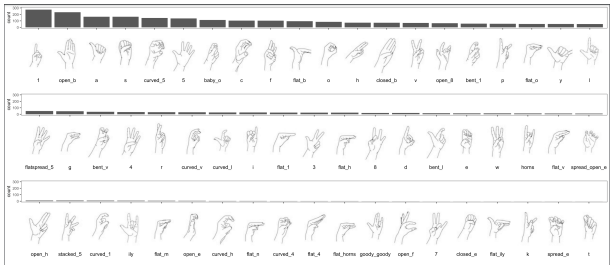


Figure 1: ASL handshapes, taken from ASL-LEX 2.0 [10], ordered by frequency in the database. The names attached are the handshape names.

Figure 2: CSL handshapes, taken from a CSL linguistics book [11], each handshape is accompanied by one name written in simplified Chinese spoken language characters

2.2. Chinese Sign Language(CSL)

The handshapes of CSL come from a CSL linguistics book [11], not from a lexicon database. According to the knowledge of CSL and comments from Deaf people, this handshape collection needs modification, because some lexicons are lost, but it is the most valid collection so far. Figure 2 shows the CSL handshapes from the book.

2.3. German Sign Language(DGS)

The handshape phonemes of DGS are from a book explaining the Grammar of German Sign Language from the Perspective of Deaf Professionals [12]. 30 handshapes are included. See Figure 3.

Figure 3: DGS handshapes, taken from a book explaining the Grammar of German Sign Language from the Perspective of Deaf Professionals [12]. Each handshape is defined using the minimal pair method.

2.4. Hong Kong Sign Language(HKSL)

Handshapes of HKSL were extracted from the handshape font created by the Centre for Sign Linguistics and Deaf Studies(CSLDS), Chinese University of Hong Kong(CUHK) [13]. A screenshot is shown in Figure 4

2.5. Swedish Sign Language(SSL)

In the Sweden Sign Language dictionary created by Stockholm University [14], words can be searched by phonemes (handshapes, place of articulation, orientation). See Figure 5 for the handshapes used in this collection.

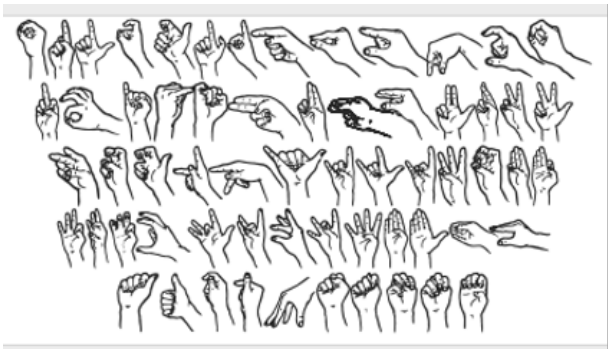


Figure 4: HKSL handshapes, taken from a HKSL handshape font [13], developed by Centre for Sign Linguistics and Deaf Studies(CSLDS), Chinese University of Hong Kong(CUHK). Some handshapes in this figure are the same but with different orientations, thus they were collected as 1 handshape.

Figure 5: Swedish Sign Language handshapes from a SSL online dictionary [14], which includes about 25,200 SSL lexicons. The handshape names are given to each handshape.

2.6. British Sign Language(BSL)

A British Sign language corpus, BSL SignBank, includes over 2500 signs from roughly 12 hours (50,000 sign tokens) from BSL [15]. The handshapes are displayed in the "search by sign features" tool. Figure 6 shows the handshapes contained.

Figure 6: BSL handshapes, taken from an online BSL corpus [15], including over 2500 signs. The handshapes from the same category are grouped.

2.7. Australian Sign Language(Auslan)

Johnston in 1998 found 62 handshapes listed in the Auslan dictionary, however, only 37 are the core handshapes used, with the remaining 25 seen as non-significant variations of these [16]. 5 years later, Johnston and Schembri published a more recent version with 39 handshapes included [17]. The 39 Auslan handshapes are shown in Figure 7.

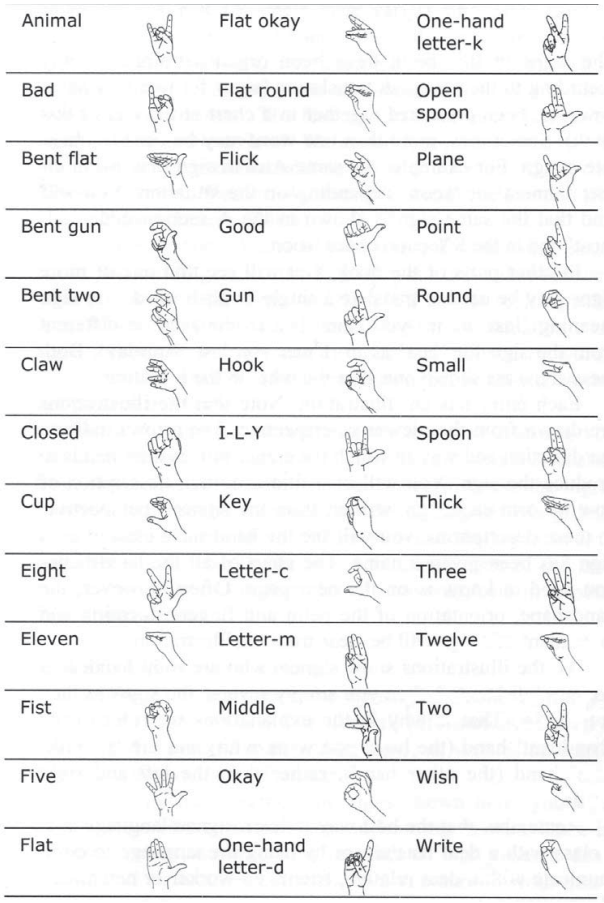


Figure 7: Auslan handshapes, taken from a dictionary of Auslan [17]. The name of each handshape is also displayed.

2.8. New Zealand Sign Language(NZSL)

The Online Dictionary of NZSL is a multimedia digital resource designed for use by learners and teachers of NZSL, Deaf people, families and associates of Deaf people, interpreters, researchers, and public agencies, among others. The dictionary is a reference tool that allows users to search for the NZSL vocabulary through either English / Te Reo Māori words or by the visual features of signs themselves [18]. The handshapes are in Figure 8.

Figure 8: New Zealand Sign Language handshapes, taken from an online dictionary of NZSL [18]. The handshapes from the same category are grouped.

2.9. Taiwan Sign Language(TSL)

The daily sign language dictionary is developed by the Ministry of Education in Taiwan for learning Sign Language [19]. 60 basic handshapes are collected, see Figure 9.

2.10. Korean Sign Language(KSL)

The Korean Sign Language Dictionary is an online dictionary for KSL [20]. Signs are searchable with keywords and organized into categories. The handshapes (Figure 10) searching is available.

2.11. Danish Sign Language(DTS)

The Danish Sign Language Dictionary contains approx. 2,250 of the most common signs in Danish Sign Language. The dictionary was originally developed by the Communication Center for Sign Language and Sign Support (KC) in cooperation with the Danish Association for the Deaf from 2003

Figure 9: Taiwan Sign Language handshapes, taken from an online TSL learning portal[19]. Each handshape has 1 name written in traditional Chinese Spoken Language.

to 2008. After the first edition was completed, the Danish Sign Language Dictionary was maintained and further developed by Copenhagen University of Applied Sciences [21]. By clicking searching by hand, the handshapes will be displayed(like in Figure 11).

2.12. Netherland Sign Language(NGT)

The handshapes of NGT are from the Global Signbank. Global Signbank is a lexical database for sign languages. It is the successor to NGT Signbank, the lexical database of the annotated NGT corpora at Radboud University, which includes the ECHO corpus (2004), Corpus NGT (2006–2023), Handy Signs (signs for experiments, 2012-2016) [22]. This corpus needs an account to access most of the data. Figure 12 is the screenshot of NGT handshapes publically accessible.

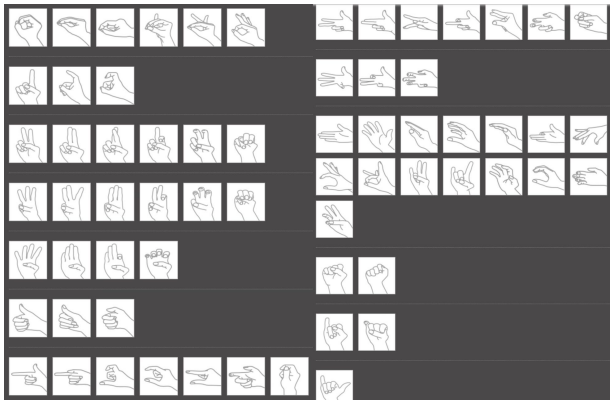


Figure 10: Korean Sign Language handshapes, taken from an online KSL dictionary [20]. The handshapes from the same category are grouped.

Figure 11: Danish Sign Language handshapes, taken from an online DTS dictionary [21]. The derivatives of handshapes are not displayed because only 1 class of derivatives can be opened at one time.

Figure 12: Netherland Sign Language handshapes, taken from an online lexical database [22]. The handshapes from the same category are grouped.

3. SIGNWRITING INTRODUCTION

Although different resources usually provide pictures to illustrate the handshapes, there is no universal standard to write them down digitally, which creates inconsistencies and difficulties in documentation and research. To address this issue, we use Sutton SignWriting to notate handshapes cross-linguistically, providing a standardized and visually intuitive method to represent sign languages in a digital format, ensuring consistency and accessibility for linguistic analysis and communication.

Sutton SignWriting is a universal and complete script for written sign language, recognized by ISO 15924 as "Sgnw". It is widely used internationally and serves as a standard for writing sign languages both by hand and by computer. Formal SignWriting is a computerized version of Sutton SignWriting, designed to represent signs as two-part words. Each word is a character string that can be processed by regular expressions, optimized for display, searching, sorting, and text flow. The online Memo is available [23]. Here is a brief introduction to Formal SignWriting and the strings defining handshapes.

3.1. Formal SignWriting

Signs are written as SignWriting words with mathematical names of ASCII characters from the inventory: *ABLMRS0123456789xabcdef*. The string is called "Formal SignWriting in ASCII (FSW)". SignWriting also has a Unicode character design (SWU). For example, in Figure 13, the fist on the right corresponds to the Unicode character on the left. The FSW defining this symbol is "S20310". The SWU font must be downloaded (Download SignWriting font: SignWriting 2010), or paste the string "S20310" into this website Sutton SignWriting. The last 2 characters mean the orientation of the symbol, spinning in vertical (to the floor) and horizontal (to the floor) directions. So, only the 3 tokens after "S" defined the shape of the hand, for example, S203. For one handshape, there can be several SWU symbols, because a single handshape can have different orientations and directions.

Figure 13: the handshape and Unicode character for the FSW code "S20310"

4. DATA CONSTRUCTION

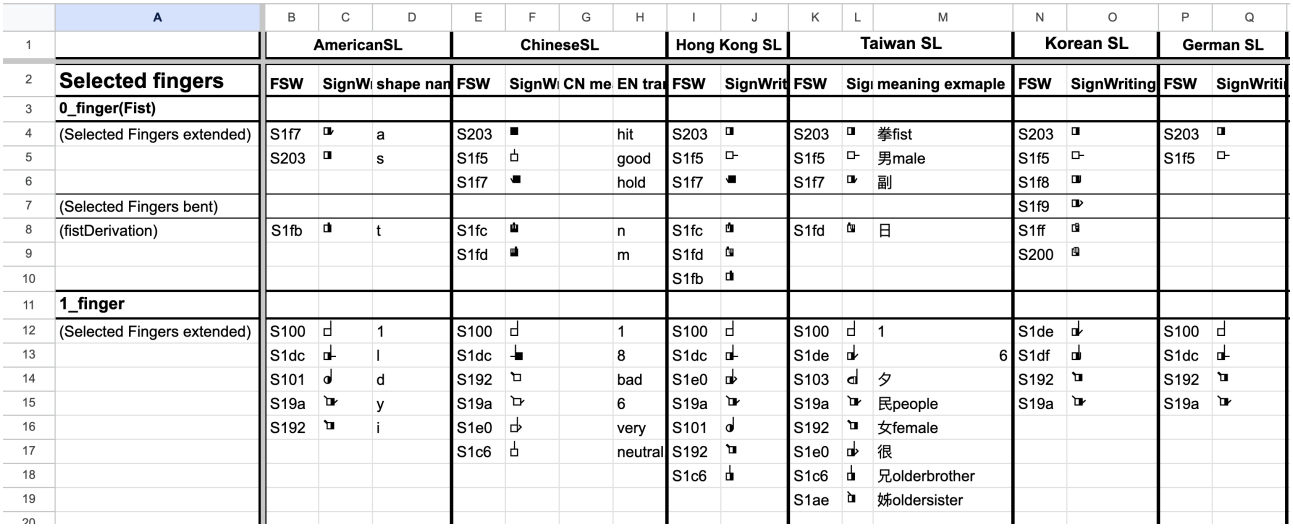
We collected all handshapes displayed in Chapter 2 into a Google Spreadsheet. The original sheet contains original data. Both FSW and SWU were used for each handshape. The one hot sheet will be further filled, and will be used as original sheet version 2. The handshape in total includes 141 different handshapes and their features.

4.1. How the original sheet version 1 was filled step by step

Filling in the spreadsheet is repetitive work, but the matchings have to be done manually. Following is the process for filling out the spreadsheet.

1. Create SignWriting symbols. For example, open the ASL handshape resource, create a blank dictionary in "SignMaker 2017", find the most match SignWriting Unicode symbol for every handshape in the "symbol panel" on the right part of the website. When the matching is done, the dictionary containing handshapes in FSW form can be exported from the central panel 'More'>'System'>'Export Dictionary'. Open this exported dictionary 'xxx.js', where the FSW codes are listed, which will be later filled in the spreadsheet.
2. Fill FSW codes and SignWriting Unicode symbols in the spreadsheet: open "Sutton SignWriting", copy and paste one FSW code into the box. The SignWriting Unicode symbol will be displayed at the same time on the right panel. Then paste the SignWriting Unicode symbol and the "SXXX" number copied from the middle of FSW which only defines its handshape into the spreadsheet. Make sure to choose the right category, for example "1_finger>(Selected Fingers extended)".

Part of the spreadsheet is displayed in Figure 14.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1		AmericanSL			ChineseSL				Hong Kong SL		Taiwan SL			Korean SL		German SL	
2	**Selected fingers**	FSW	SignW	shape nan	FSW	SignW	CN me	EN tra	FSW	SignWrit	FSW	Sig	meaning exmaple	FSW	SignWriting	FSW	SignWriti
3	**0_finger(Fist)**																
4	(Selected Fingers extended)	S1f7		a	S203			hit	S203		S203		拳fist	S203		S203	
5		S203		s	S1f5			good	S1f5		S1f5		男male	S1f5		S1f5	
6					S1f7			hold	S1f7		S1f7		副	S1f8			
7	(Selected Fingers bent)													S1f9			
8	(fistDerivation)	S1fb		t	S1fc			n	S1fc		S1fd		日	S1ff			
9					S1fd			m	S1fd					S200			
10									S1fb								
11	**1_finger**																
12	(Selected Fingers extended)	S100		1	S100			1	S100		S100		1	S1de		S100	
13		S1dc		l	S1dc			8	S1dc		S1de		6	S1df		S1dc	
14		S101		d	S192			bad	S1e0		S103		夕	S192		S192	
15		S19a		y	S19a			6	S19a		S19a		民people	S19a		S19a	
16		S192		i	S1e0			very	S101		S192		女female				
17					S1c6			neutral	S192		S1e0		很				
18									S1c6		S1c6		兄olderbrother				
19											S1ae		姊oldersister				
20																	

Figure 14: Part of the spreadsheet. The leftmost column shows the 3 tiers of classifications following the HamNoSys Handshapes chart (Figure 15). The first tier is "Selected Fingers" and "Thumb Opposition", and the second tier is the number of fingers selected and the spreadness of fingers, for example, "1_finger", "2_nonspread". The third tier is the shape of selected fingers, for example, "extended".

4.2. The design of the spreadsheet

1. Horizontal column: language names, ASL, CSL...
2. Vertical column: The reference is HamNoSys handshape chart classification(HamNoSys – Hamburg Notation System for Sign Languages). Figure 15 explains what the handshapes look like with different features. This spreadsheet adds 3_nonspread and 3_spread, deletes "hitchhiker's fingers", "Fingertip- Thumb's Interphalangeal Joint Opposition", and "Fingertip- Thumb's Metacarpophalangeal Joint Opposition" because they're trivial differences of thumb, and no handshapes are collected in these 3 categories.
3. After filling the spreadsheet, "derivation" was specified into "Xfinger_differshape" and "inFistfinger_up", because these are the only derivation types collected. Derivation does not appear in every category, because it is impossible to happen, for example, to make a "inFistfinger_up" in "4_nonspread".
4. As a result, the collection contains 3 levels of categories. The top category differentiates whether the thumb is opposite to the palm or not. The secondary category differentiates the number of selected fingers(excluding the thumb) and spreadness. The tertiary category differentiates the shape of the selected fingers. Table 1 gives an example of the 3 levels of classifications.

Top category	Selected fingers
Secondary category	0_finger (Fist)
Tertiary category	Selected Fingers extended Selected Fingers bent fistDerivation

Table 1: An example of the 3 levels classifications used for classification when filling handshapes into the spreadsheet. Searching starts from the top category to the tertiary category. Each handshape is located under the tertiary category.

This spreadsheet serves as the original sheet version 1. However, this spreadsheet is difficult to be imported into data processing. For further processing, a one-hot sheet is super important, which should be the original sheet version 2. This collection provides insights into the universal properties of signed languages and unique linguistic features. This can help identify commonalities and distinctions that might reflect historical connections or independent evolution. A comprehensive database of handshapes allows for a detailed study of their role in the phonological systems of different sign languages, enhancing our understanding of sign language structure. This collection can also provide insights into the cognitive processes in sign language production and perception, identifying patterns and regularities in handshape usage across languages.

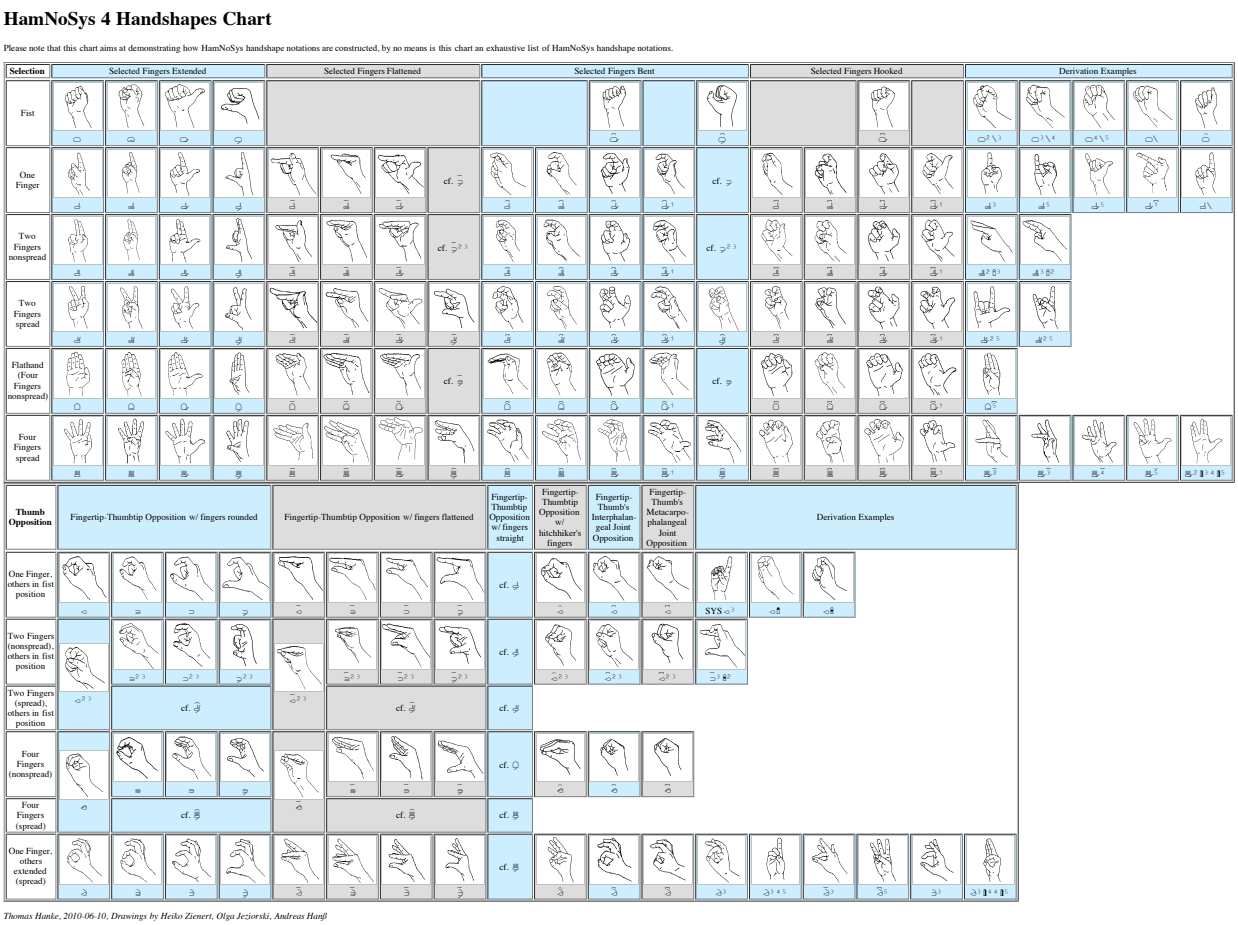


Figure 15: HamNoSys Handshapes chart, which is the reference for filling the handshape collection spreadsheet

5. ANALYSIS OF THE SPREADSHEET

5.1. How many different handshapes in total?

In total, 141 different handshapes are retrieved from the 637 entries. The frequencies of each handshape are calculated as well. It means how many language inventories a handshape belongs to. See Figure 16: 45 handshapes are unique to only one language inventory, which is significantly higher than the others. The bars representing handshapes shared by 2 to 6 language inventories show a gradual decrease, with counts ranging from 17 to 5. Handshapes shared by 7 language inventories show a significant drop, at 2. From 8 to 12 language inventories, the number of shared handshapes remains relatively low and steady, with counts generally below 5 to 10. A previous study collecting handshapes from 33 sign

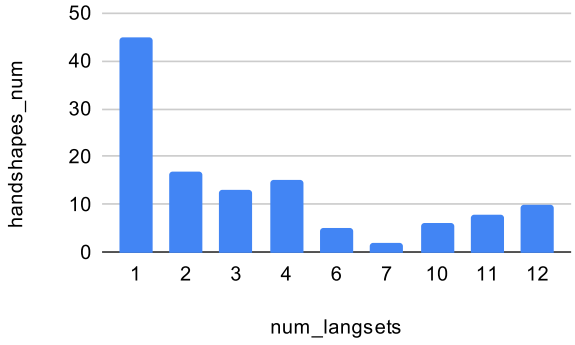


Figure 16: How many handshapes are retrieved from how many language inventories

languages summarized 160 different handshapes [24]. This suggests that the 141 handshapes collected in this report are representative. If increasing the number of language inventories, the number of different handshapes might increase but is less likely to spike.

5.2. Unique handshapes

45 handshapes are unique to only one language inventory. Figure 17 shows the number of unique handshapes each language inventory contains. Even though the Netherlands Sign Language inventory and Korean Sign Language inventory elicited a high number of unique handshapes, this number might not suggest linguistic richness or less borrowing or influence from other sign languages but needs further verification. From Figure 18, it is clear that the handshape numbers of Netherlands Sign Language and Korean Sign Language inventories are among the top three. Apart from the 45

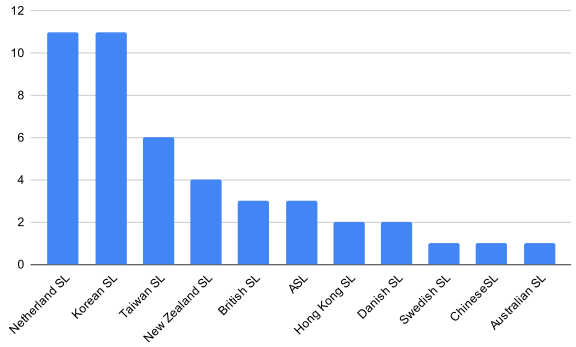


Figure 17: number of unique handshapes each language inventory contains

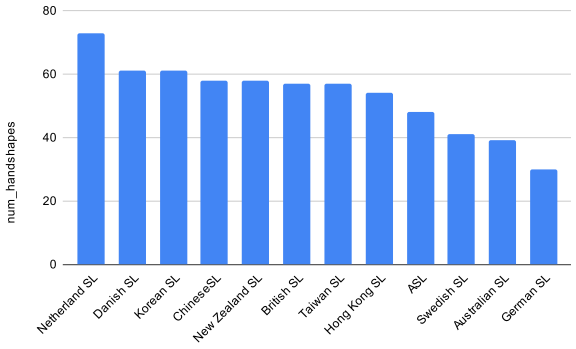


Figure 18: number of handshapes of each language inventory

unique handshapes, 96 handshapes are shared by more than one language inventory. The identical handshapes could highly possibly deliver very different meanings in different cultures[25]. A cross-cultural comparison of identical sign language handshapes is valuable.

5.3. Handshape types that are not found in the Sign Language inventories

Figure 19 displays the 14 kinds of handshapes that were not found in the 12 language inventories. Many of these handshapes involve complex and difficult finger positions that are uncomfortable to maintain. For example, open the palm of your hand and fold, in order, baby, ring, middle, index finger. It is comfortable when folding the ring finger only. In the evolution of natural languages, biological constraints push toward cross-linguistic homogeneity while linguistic, cultural, and historical processes promote language diversification [24, 26]. It means that if the handshape is easy and comfortable to form, it is more possible to be shared by different sign languages.

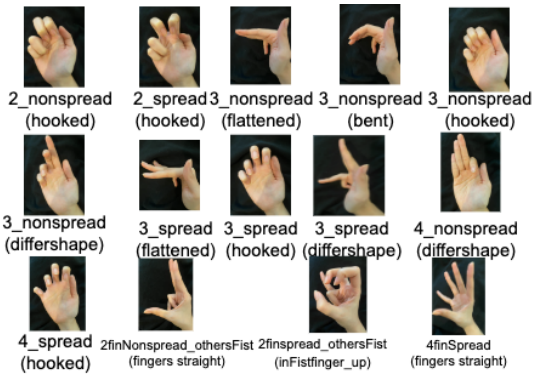


Figure 19: Handshape types that are not found in the Sign Language inventories. The names correspond with categories in the spreadsheet.

5.4. Distribution of handshapes in different category levels

5.4.1. In superior category level "Selected Fingers" and "Thumb Opposition"

"Selected Fingers" and "Thumb Opposition" are the 2 superior categories. The difference is whether the thumb is at the opposite position of the palm or not. Selected Fingers 0/1/2/3/4 and Oppo1/2/4 refer to that, apart from the thumb, how many fingers are used(not in the fist position). "1fin_othersNonfist" is similar to "oppo1", while the 3 other fingers are not in the fist position.

Table 2 and Table 3 listed the number of handshapes with different numbers of fingers used.

Selected Fingers	num_handshapes
2	25
4	24
1	21
0(Fist)	11
3	5
total	86

Table 2: Number of Handshapes in the superior category "Selected Fingers", in this category no thumb is opposite to the palm

Thumb opposition	num_handshapes
oppo1	11
oppo2	11
oppo4	11
1fin_othersNonfist	22
total	55

Table 3: Number of Handshapes in the superior category "Thumb Opposition ", in this category all thumbs are opposite to the palm. In 'oppo1/2/4', other fingers are in the fist position. In 'fin_othersNonfist', 3 other fingers are extended, flattened, or bent.

The total number of handshapes in "Selected Fingers" is 86, bigger than that in "Thumb Opposition" which is 55. If the thumb is not opposite, the most common number of selected fingers is 1, 2, or 4. If the thumb is opposite, 1 finger with 3 other fingers at the non-fist position appears to be more than the other types.

5.4.2. The spreadness of handshapes, the Secondary category

Table 4 and Table 5 show the spreadness of handshapes. For handshapes with less than 2 fingers used in addition to the thumb, it is impossible to spread. For handshapes in the "Selected Fingers" category, the spreadness comes from the selected fingers. For handshapes in the "Thumb Opposition" category, the spreadness means the fingers forming circles with the thumb are spread or not. In both categories, spread handshapes are more than nonspread handshapes.

5.4.3. The shape of fingers, the Tertiary category

6 shapes of fingers selected in "Selected Fingers" category are identified. for the "Thumb Opposition" category, fingers in the circle are classified into 4 shapes. Figure 20 and Figure 21 illustrate the number of handshapes with different shapes of fingers.

selectedfin_spreadness	num_handshapes
nonspread	21
spread	31
cannot_spread	34
total	86

Table 4: Table showing the spreadness and number of handshapes.

circlefin_spreadness	num_handshapes
nonspread	17
spread	25
cannot_spread	13
total	55

Table 5: Spreadness Circlefin Handshapes

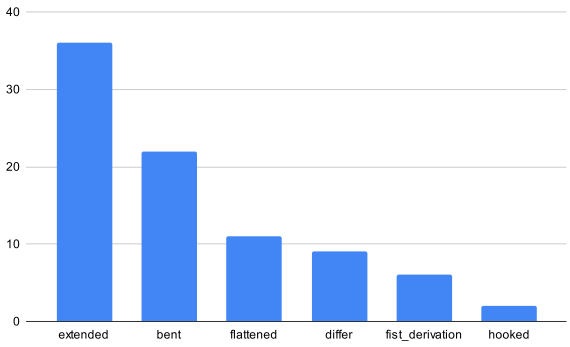


Figure 20: The number of handshapes with different shapes of fingers in "Selected Fingers"

In summary, both figures show a variety of handshapes, with 'extended' and 'bent' being quite prominent in the "Selected Fingers" category, while 'rounded' and 'flattened' are the most common in the "Thumb Opposition" category. The least common shapes are 'hooked' and 'straight', respectively.

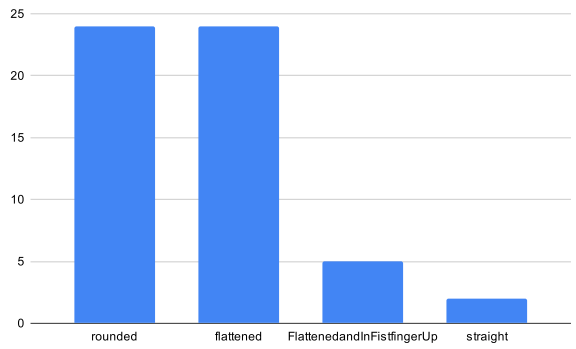


Figure 21: The number of handshapes with different shapes of fingers in "Thumb Opposition"

6. CONCLUSION

This report explains the first attempt at establishing a cross-linguistic database for sign language research, with a focus on phonology and collecting handshape phonemes. From the 12 language inventories of 12 sign languages, 637 entries were collected. From the current dataset, 141 different handshapes were retrieved. The Netherlands and Korean datasets show a high number of handshapes unique to only one language inventory. But this cannot suggest linguistic richness or less borrowing or influence from other sign languages. The handshape types not found in this collection infer the biological constraints of forming handshapes, which is important for communication efficiency [27]. For identical handshapes shared by more than one country, cultural diversity should be considered.

Delving into the number of handshapes in different categories, "Selected Fingers" at the numbers 1, 2, and 4 are commonly found in the datasets. For the "Thumb Opposition" category, the number of 1 finger selected with the other 3 at the non-fist position outweighs the number of 1, 2, and 4 fingers selected with the others at the fist position. Spread finger handshapes appear to be more than nonspread handshapes. 'extended', 'bent', 'rounded', and 'flattened(Thumb Opposition)' are the most common shapes of fingers selected.

For further work, a one-hot sheet is super needed. A cross-cultural comparison of identical handshapes is also interesting.

7. LIMITATIONS

1. SignMaker cannot create new SignWriting Unicodes on our own, what we can do is to select existing symbols, and for a few handshapes we cannot find a symbol completely the same, so we use the most similar SignWriting Unicode symbol.
2. The natural sign language, which can be understood as the 'informal' form used by signers in daily life, might have a lot more other handshapes, which are ignored in the collection of handshapes. (only from what I know about Chinese Sign Language).
3. Some handshapes from the examples have the same selected finger and how they are positioned. If it's just the open quotient looks slightly different, then it is considered the same handshape, because of the first limitation.
4. We didn't count the frequency of handshapes used in every sign language lexicon, like the ASL inventory in Figure 1.
5. Sign languages, as under-resourced languages, lack valid resources that can be used to collect cross-linguistic databases. The best way is to collaborate with researchers, especially those involving Deaf communities.

8. REFERENCES

[1] S. Moran and D. McCloy, Eds., *PHOIBLE 2.0*. Jena: Max Planck Institute for the Science of Human History, 2019. [Online]. Available: https://phoible.org/

[2] E. M. Ponti, H. O'Horan, Y. Berzak, I. Vulić, R. Reichart, T. Poibeau, E. Shutova, and A. Korhonen, "Modeling language variation and universals: A survey on typological linguistics for natural language processing," *Computational Linguistics*, vol. 45, no. 3, pp. 559–601, Sep. 2019. [Online]. Available: https://aclanthology.org/J19-3005

[3] X. Li, "Low-Resource Speech Recognition for Thousands of Languages," 8 2023. [Online]. Available: https://kilthub.cmu.edu/articles/thesis/Low-Resource_Speech_Recognition_for_Thousands_of_Languages/24011307

[4] "International Phonetic Alphabet (IPA) chart Unicode "keyboard"," https://westonruter.github.io/ipa-chart/keyboard/.

[5] W. Sandler, "The phonological organization of sign languages," *Language and linguistics compass*, vol. 6, pp. 162–182, 03 2012.

[6] Kooij and E. van der kooij, "Phonological categories in sign language of the netherlands : the role of phonetic implementation and iconicity /," 01 2002.

[7] K. Cormier, D. Brentari, and J. Fenlon, *Sign language phonology*, 07 2018.

[8] j. Fenlon, D. Brentari, and K. Cormier, *The phonology of sign languages*, 04 2017.

[9] M. Kopf, M. Schulder, and T. Hanke, "The Sign Language Dataset Compendium: Creating an overview of digital linguistic resources," in *Proceedings of the LREC2022 10th Workshop*

on the Representation and Processing of Sign Languages: Multilingual Sign Language Resources, E. Efthimiou, S.-E. Fotinea, T. Hanke, J. A. Hochgesang, J. Kristoffersen, J. Mesch, and M. Schulder, Eds. Marseille, France: European Language Resources Association (ELRA), 2022, pp. 102–109. [Online]. Available: https://www.sign-lang.uni-hamburg.de/lrec/pub/22025.pdf

[10] Z. Sehyr, N. Caselli, A. Cohen-Goldberg, and K. Emmorey, "The asl-lex 2.0 project: A database of lexical and phonological properties for 2,723 signs in american sign language," *Journal of deaf studies and deaf education*, vol. 26, 02 2021.

[11] 吕会华, 中国手语语言学. 北京: 知识产权出版社, 2019.

[12] C. Papaspyrou, *Grammatik der deutschen Gebärdensprache aus der Sicht gehörloser Fachleute*. Signum, 2008.

[13] CSLDS, CUHK, "Handshape fonts," http://www.cslds.org/v4/resources.php?id=1, n.d., accessed: 2024-07-14.

[14] Svenskt teckenspråkslexikon. (2023) Svenskt teckenspråkslexikon. Hämtad februari 2023. [Online]. Available: https://teckenspraklexikon.su.se

[15] J. Fenlon, K. Cormier, R. Rentelis, A. Schembri, K. Rowley, R. Adam, and B. Woll, *BSL SignBank: A lexical database of British Sign Language*, first edition ed. Deafness, Cognition and Language Research Centre, University College London, 2014.

[16] T. A. Johnston, *Signs of Australia: A new dictionary of Auslan (Australian Sign Language)*. North Rocks Press, 1998.

[17] T. Johnston and A. Schembri, Eds., *The Survival Guide to Auslan: a beginner's pocket dictionary of Australian Sign Language*. North Rocks Press, 2003.

[18] D. McKee, R. McKee, S. Pivac Alexander, L. Pivac, and M. Vale, *Online dictionary of New Zealand Sign Language*. Deaf Studies Research Unit, Victoria University of Wellington, 2011.

[19] T. Ministry of Education. (2019) Basis of sign language. Accessed: 2024-07-14. [Online]. Available: https://special.moe.gov.tw/signlanguage/basis/detail/7c338ab6-87a9-46cc-a50f-34b82b4dac8a#B

[20] National Institute of Korean Language. (n.d.) Korean sign language dictionary. Accessed: 2024-07-14. [Online]. Available: https://sldict.korean.go.kr/signhand/hand/main.do

[21] Tegnspog.dk. (2023) Tegnsprog.dk. Accessed: 2024-07-14. [Online]. Available: https://www.tegnsprog.dk/

[22] O. Crasborn, R. Bank, I. Zwitserlood, E. van der Kooij, E. Ormel, J. Ros, A. Schüller, A. de Meijer, M. van Zuilen, Y. E. Nauta, F. van Winsum, and M. Vonk, "Ngt dataset in global signbank," 2020.

[23] S. E. S. Jr, "Formal SignWriting," Internet Engineering Task Force, Internet-Draft draft-slevinski-formal-signwriting-09, Jan. 2022, work in Progress. [Online]. Available: https://datatracker.ietf.org/doc/draft-slevinski-formal-signwriting/09/

[24] M. Miozzo and F. Peressotti, "How the hand has shaped sign languages," *Scientific Reports*, vol. 12, no. 1, p. 11980, 2022.

[25] D. Archer, "Unspoken diversity: Cultural differences in gestures," *Qualitative sociology*, vol. 20, pp. 79–105, 1997.

[26] M. C. Gavin, C. A. Botero, C. Bowern, R. K. Colwell, M. Dunn, R. R. Dunn, R. D. Gray, K. R. Kirby, J. McCarter, A. Powell *et al.*, "Toward a mechanistic understanding of linguistic diversity," *BioScience*, vol. 63, no. 7, pp. 524–535, 2013.

[27] K. Yin, T. Regier, and D. Klein, "American sign language handshapes reflect pressures for communicative efficiency," *arXiv preprint arXiv:2406.04024*, 2024.