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DOI:
10.16995/glossa.10229

Lutzenberger, Hannah & Mudd, Katie & Stamp, Rose & Schembri, Adam. 2023. The social structure of signing communities and lexical variation: A cross-linguistic comparison of three unrelated sign languages. *Glossa: a journal of general linguistics* 8(1). pp. 1–40. DOI: https://doi.org/10.16995/glossa.10229

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The social structure of signing communities and lexical variation: A cross-linguistic comparison of three unrelated sign languages

Hannah Lutzenberger, University of Birmingham, UK, h.lutzenberger@bham.ac.uk

Katie Mudd, University of Amsterdam, NL, katie.mudd@ai.vub.ac.be

Rose Stamp, Bar Illan University, IL, rose.stamp@biu.ac.il

Adam Schembri, University of Birmingham, UK, a.schembri@bham.ac.uk

Claims have been made about the relationship between the degree of lexical variation and the social structure of a sign language community (e.g., population size), but to date there exist no large-scale cross-linguistic comparisons to address these claims. In this study, we present a cross-linguistic analysis of lexical variation in three signing communities: Kata Kolok, Israeli Sign Language (ISL) and British Sign Language (BSL). Contrary to the prediction that BSL would have the lowest degree of lexical variation because it has the largest population size, we found that BSL has the highest degree of lexical variation across the entire community (i.e., at the global level). We find, however, that BSL has the lowest degree of lexical variation at the local level, i.e., within clusters of participants who group most similarly lexically. Kata Kolok and ISL, on the other hand, exhibit less of a distinction between variation at the global and local levels, suggesting that lexical variation does not pattern as strongly within subsets of these two communities as does BSL. The results of this study require us to reassess claims made about lexical variation and community structure; we need to move towards an approach of studying (lexical) variation which treats communities equally on a theoretical level and which respects the unique social-demographic profile of each community when designing the analysis by using a community-centered approach.

1 Introduction

Lexical variation is one of the most frequent markers of dialectal differences; speakers of British English show regional preferences: for example, *sofa* for speakers from the south, *couch* for speakers from the north, and *settee* for speakers from the Midlands (Grieve et al. 2019). Similarly, signers of British Sign Language (BSL) show regional variation in color and number signs (Stamp et al. 2014), among them 17 variants for *purple*. The amount of lexical variation has often been associated with specific "types" of signing communities: smaller and more homogeneous communities are claimed to show considerably more lexical variation than larger and more heterogeneous ones (e.g., Meir et al. 2012). A similar relation between social structure and linguistic structure has been suggested for spoken languages (Wray & Grace 2007) under the *linguistic niche hypothesis*, although the main focus is on morphological complexity (Lupyan & Dale 2010). Moreover, it has been hypothesized that the high degree of variation at the lexical level in smaller signing communities is due to i) high degrees of shared context facilitated by frequent face-to-face interaction, ii) small community size that allows for remembering individual variation, and iii) the absence of deaf education[1] (de Vos 2011; Meir et al. 2012; Tkachman & Hudson Kam 2020). This claim is based on anecdotal evidence; robust cross-linguistic comparisons do not exist: "While we have not systematically compared the amount of lexical variation across sign languages, our experience with more established sign languages indicates noticeably less lexical variation, especially for everyday concepts, than we have found in [Al-Sayyid Bedouin Sign Language (ABSL), a young sign language used by a small Bedouin community in Israel]" (Meir et al. 2012: 276). Though ABSL and Israeli Sign Language (ISL) are around the same age, Meir et al. (2012) suggest that ABSL has more variation than ISL because of the larger size and the higher degree of heterogeneity of the ISL community, and also because ISL is used in a school setting. Meir et al. (2019) echo these claims by providing evidence from a pilot study of lexical variation in ISL. In this paper, we present a cross-linguistic comparison of lexical data from three different communities and three unrelated sign languages.

The literature on lexical variation reveals a systematic bias in the way variation has been studied and framed in signing communities: in relatively larger, older signing communities, variation is seen as reflecting sociolinguistic diversity while variation in smaller, younger signing communities is often understood as a phenomenon of language emergence (see Braithwaite 2020; Safar 2021; Horton 2022). Similarly, the use of a sign language in a school setting has been argued to both promote standardization in small signing communities (Meir et al. 2012) and to explain school-based variation in larger signing communities (Quinn 2010). In larger signing communities, the focus has been on sociolinguistic factors that drive lexical variation such as

[1] Deaf education refers to the education of children and young adults who are deaf or hard of hearing. Historically, deaf students have often been taught in separate schools, but recently deaf students attending mainstream schools alongside hearing students has become more common.

age, gender, or region (e.g., Lucas 2001), mirroring research on spoken language dialectology (e.g., Orton 1962). These studies suggest that similar social factors also govern variation in different sign languages; lexical variation is influenced by gender (LeMaster 2006), ethnicity (McCaskill et al. 2009; 2011; R. McKee & McKee 2011), schooling (Stamp et al. 2014), age (Lucas 2001; Stamp et al. 2014; Sagara 2016; Sagara & Palfreyman 2020) and region (Stamp et al. 2014; Sagara 2016; Chen & Gong 2020; Osugi 2020; Sagara & Palfreyman 2020).

In smaller signing communities, the focus is often on the degree of variation (e.g., Israel & Sandler 2009; Sandler et al. 2011; Hartzell et al. 2019). The presence of any kind of variation, such as the existence of several sign variants for a concept, is often understood as a lack of conventionalization (e.g., Meir & Sandler 2019). Some studies, however, suggest that variation is also influenced by social variables in smaller signing communities (see also Power 2020 for a historical account). For instance, kinship relations among signers seem to reduce lexical variation in smaller communities such as in signers of ABSL (Sandler et al. 2011), signers of San Juan Quiahije Chatino Sign Language (Hou 2016), signers of Yucatec Maya Sign Language (Safar 2020; 2021) and homesigners[2] in Guatemala (Horton 2018). Similarly, social networks seem to shape lexical variation among signers; social interaction patterns influence lexical overlap (Osugi & Supalla & Webb 1999; Reed 2021; Horton 2022). In addition, Mudd et al. (2020; 2021) show different lexical preferences between male and female as well as hearing and deaf signers of Kata Kolok. These studies typically focused on one sociolinguistic factor at a time, thus more work is needed to explore the effect of multiple sociolinguistic factors on lexical variation in smaller communities.

In sum, lexical variation has been studied in different ways in different communities. This reflects both ideological and methodological issues. First, a high degree of variation in larger signing communities is analyzed as indexing sociolinguistic diversity and therefore treated as a marker of linguistic richness; a high degree of variation in smaller communities is analyzed as a lack of conventionalization and treated as a marker of linguistic 'immaturity' (discussed in Lutzenberger et al. 2021; Lutzenberger 2022). This can be linked to framing research within developmental clines that assume older sign languages like American Sign Language (ASL) as an endpoint in terms of the development of linguistic features (Hou 2016; Kusters & Hou 2020; Hou & de Vos 2021). A second, less widely discussed issue is the lack of consensus as to i) what counts as a lexical (vs. phonological) variant and ii) how lexical variation is studied in terms of methodologies of data collection, annotation, and analysis. The methodological inconsistencies between studies of (lexical) variation across sign languages make it difficult to compare results,

[2] *Homesign* traditionally describes the communication of an isolated deaf child with their hearing family. Recently, this term has been critiqued in light of the diversity and richness of various signing systems (Goico & Horton 2023).

a fact which needs to be considered when examining claims about the relationship between community size and variation.

2 The current study

This exploratory study aims to examine if there is support for the claim that certain sign languages may have more lexical variation than others by investigating lexical variation systematically across three different signing communities. As mentioned, community size, homogeneity, language age, and deaf education are some of the factors which have been suggested to affect the degree of lexical variation in sign languages (de Vos 2011; Meir et al. 2012; Meir & Sandler 2019; Tkachman & Hudson Kam 2020).

It has been proposed that ABSL has a higher degree of lexical variation than ISL, because of the larger size and lower degree of homogeneity in the ISL community (Meir et al. 2012; Meir & Sandler 2019). As such, small, homogenous communities would be expected to have the highest degree of lexical variation. These claims are based on anecdotal evidence (Meir et al. 2012) and a pilot study of lexical variation in ISL (Meir & Sandler 2019), and currently no large-scale systematic comparison addresses these claims. In the present study, we explore this hypothesis by conducting a cross-linguistic comparison of lexical variation across three sign languages: Kata Kolok, ISL, and BSL. The communities which use these sign languages are of different sizes, ages, and vary on various other sociolinguistic factors. Given that we do not have a way of assessing the degree of homogeneity in these communities, we focus on how community size may affect lexical variation. Following from the hypothesis generated by Meir et al. (2012), based on community size alone, Kata Kolok would be predicted to have the highest degree of lexical variation as it has the smallest community size, BSL would be predicted to have the lowest degree of lexical variation as it has the largest community size, and the lexical variation in ISL would be predicted to fall somewhere between these two languages given the community size also falls somewhere in between.

It should be emphasized that the data used in this study were collected for other purposes and as such this cross-linguistic study presents an exploratory analysis which may lead to further hypothesis testing. Additionally, we wish to note that placing sign languages with different socio-demographic profiles into categories such as “established” vs. “emerging” sign languages has been heavily critiqued (e.g., Hou 2016; Kusters & Hou 2020; Hou & de Vos 2021), partly because it downplays the sociolinguistic diversity of signing communities. While the claim investigated in the present study is based on a binary distinction of types of sign languages/signing communities, we do not believe that it is necessary to subscribe to this view to explore the basis of this claim. On the contrary, by investigating the patterns of lexical variation found across these three communities, we aim to investigate the validity of this claim and contribute to the debate by showing whether these categorizations are supported by empirical data. In contrast to previous studies, our cross-linguistic comparison is based on quantitative methods. Crucially, we follow a community-centered approach; while the end goal is a cross-linguistic comparison, we analyze each community individually, emphasizing their unique socio-demographic profiles, and only in a second step extend the existing analyses to gain cross-linguistic insights.

The paper is structured as follows: we first introduce all three signing communities with socio-demographic sketches. We then explain the methodology used in this study, detailing the different datasets (data collection and annotation), and the data analysis used (hierarchical clustering on lexical distances between participants in each community). After presenting the results, first for each community and then cross-linguistically, we conclude the paper with an extensive discussion, focused on the different levels at which lexical variation can be analyzed, the advantages and implications of using a community-centered approach to study lexical variation, and how this paper can encourage future work and delineate best practices for similar types of investigations.

3 Socio-demographic sketches

3.1 Kata Kolok

Kata Kolok is the sign language of an enclave of ~3,000 inhabitants in rural Bali, Indonesia (Marsaja 2008; de Vos 2012). The language emerged spontaneously due to a high incidence of sustained hereditary deafness (Winata et al. 1995). Today, approximately 35 of the village's permanent residents are deaf (Lutzenberger 2019).

The community's social network is tightly knit. By birth, villagers belong to one of ten village clans and live in family compounds with relatives. Marriage patterns follow patrilineal traditions and, in the past, it has been common to marry someone from the same village (Friedman et al. 1995). Following a long period of geographical isolation, the mobility of villagers has increased over the recent years. This affects marriage patterns in a way that it is now common to have spouses from different villages. Similarly, work opportunities have long centered around subsistence farming, small sets of livestock, and small local businesses but are gradually shifting to a wider range of occupations (Lutzenberger 2019). As a result, contact between hearing and deaf people across the island is steadily increasing (Moriarty 2020).

A large proportion of the community uses Kata Kolok. At least six generations of deaf signers (with signers of generation three through six currently living in the village) have acquired Kata Kolok (Marsaja 2008; de Vos 2012). Families with deaf members often pass the language on to their children as (one of) their first language(s) and many hearing villagers with or without deaf family members acquire signing skills at various points in their lives. While some learn Kata Kolok from their deaf relatives early in life, others acquire it only later, e.g., when working alongside deaf people. In short, many hearing villagers can sign with varying degrees of fluency (Marsaja 2008), and Kata Kolok serves as the primary language for deaf villagers.

From a linguistic perspective, Kata Kolok is a relatively well-studied small sign language. It has been described as a language isolate with minimal contact to other signed and spoken languages (Marsaja 2008; Perniss & Zeshan 2008; de Vos 2012). A low degree of convergence has been found in core domains of the lexicon; specifically, Kata Kolok uses a small set of lexicalized signs for color and kinship terms (four color and three kinship signs, according to de Vos 2011, 2012), mirroring other small signing communities (e.g., Washabaugh 1986; Nyst 2007; Schuit 2014). Moreover, lexical preferences in Kata Kolok are influenced by whether signers are hearing or deaf (Mudd et al. 2020), and by gender, with male participants showing greater lexical uniformity than female participants in response to a picture description task (Mudd et al. 2021). Variation is also attested in the phonological form of signs (Lutzenberger et al. 2021).

3.2 ISL

Israel has an abundance of sign languages, most of which have emerged spontaneously within the last century (Meir & Sandler 2008). The dominant sign language in Israel is ISL, with an estimated 10,000 users. It is the language of the national deaf association, the education system, and sign language interpreting programs.

ISL is a relatively young sign language, roughly 90 years old, which arose with the formation of the deaf community in Israel in the 1930s, beginning with the establishment of the first school for the deaf in 1932 in Jerusalem. As in many deaf communities, 90–95% of deaf children grow up in hearing families (Mitchell & Karchmer 2004), so the school environment is key for the transmission of the language. As a result, regional variants result from the variation that emerges in different school communities (Quinn 2010; Stamp et al. 2014).

Israel is rich in diversity, both linguistically and culturally. Many of the first generation ISL signers, who are now the older population in Israel, immigrated from Europe, North Africa, and Asia. Today, younger deaf people (third or fourth generation ISL signers) are multilingual and are exposed to a variety of signed, spoken, and written languages. Jews in Israel are classified as belonging to two major groups: Ashkenazi or Mizrahi[3]. While Ashkenazi Jews are typically of European origin (mostly countries like Germany, Russia, and France), Mizrahi Jews descend from countries including Yemen, Iraq, and North Africa. There are anecdotal claims that suggest that differences exists between the signing of Ashkenazi and Mizrahi deaf individuals within specific semantic categories such as Jewish holidays. In addition to these Jewish groups, ethnicity is also defined within different groups across Israel and Palestine. The Arab community constitutes a fifth of Israel's population, and adds to the linguistic, cultural, and religious diversity. It is claimed that specific examples of ISL variation exist between the signing of Arab and Jewish signers.

[3] We use the term Mizrahi here following Yaeger-Dror (1988: 287).

The deaf Israeli community has undergone rapid changes due to increased mobility, increased exposure to different languages within the education system, and changes in social communication and technologies. These changes have led to increased contact between languages and language varieties. The Corpus of ISL project which started in 2020 provided an ideal opportunity to capture the linguistic variation in ISL and to explore linguistic change. Research to date on ISL includes studies on the emergence of the language (Cohen & Namir & Schlesinger 1977) and its structural properties (e.g., Aronoff et al. 2008; Sandler 2012; Dachkovsky & Stamp & Sandler 2018; Stamp & Sandler 2021). For example, a small-scale pilot study suggested a reduction in lexical variation across age groups in ISL (Meir & Sandler 2019).

3.3 BSL

BSL is the majority sign language in the UK, with figures from the 2021 Census for England and Wales suggesting over 22,000 people use it as their main language, although reliable estimates for the total number of deaf and hearing signers are lacking. BSL is a comparatively institutionalized sign language – there is a rich range of language documentation materials, including learning materials (e.g., CityLit & Napier & Fitzgerald 2008) and learner grammars (Sutton-Spence & Woll 1999), national standards for the accreditation of BSL learning and the certification of BSL/English interpreters. It is the language of instruction in a small number of schools for deaf children. BSL is taught in community colleges, and there are BSL degree programs in universities. Some BSL interpreting is provided on British television, and *See Hear*, with deaf presenters using BSL, is a regularly broadcast program. Official recognition by the UK government came in 2022 with a BSL Act for England and Wales, following an earlier 2015 BSL Act in Scotland.

The origins of BSL are not known, as relatively few historic descriptions of sign language use exist. Researchers are confident that BSL is, however, relatively 'old' when compared to many other sign languages. The earliest records of sign language use in the UK date back to the 15th century, and there is evidence to link modern BSL with signing varieties described in the 17th century linked to the establishment of the first private school for deaf children (Schembri et al. 2010). By the early 20th century, many more schools for the deaf had been established in the UK, most of them residential and therefore central to the transmission of signed varieties. The Royal Association for the Deaf, the oldest charitable organization for the welfare of deaf adults, opened in 1841, and the British Deaf Association was established in 1890.

Research on the linguistics of BSL began in the 1970s (Deuchar 1984; Kyle & Woll 1985). After its initial use, the term *British Sign Language* (BSL) (Brennan 1975), became widespread and widely accepted in the British deaf community, although some have proposed alternate names for the varieties used in Scotland (Scottish Sign Language) and Northern Ireland (Northern Ireland Sign Language). There is a published BSL dictionary (Brien 1992), a digital corpus (Schembri et al. 2013) and an online dictionary based on this corpus data (BSL Signbank; Fenlon & Cormier & et al. 2014). The BSL Corpus has provided data for academic research on aspects of the structure and use of the grammar of BSL and represents a permanent record of the language as used in the early 21st century. For instance, Stamp et al. (2014) showed that lexical variation in BSL reflects a signer's region of origin (along with the location of the school a signer attended), age, and language background (if the signer has deaf or hearing parents). In addition, dialect leveling means younger signers are using fewer distinct regional variants compared to older signers.

4 Methodology

We describe the dataset for each sign language separately and then explain details about data coding and analysis. For all signing communities, we rely on re-analyzing existing datasets. All data has been transcribed using ELAN (Crasborn & Sloetjes 2008; 'ELAN [Computer software]' 2020). Given the community-centered approach in this study, analyses vary across the different datasets using the most suitable design for each of them. Similar to Horton (2022), we investigate variation on two levels: the global level (i.e., entire community) and the local level (i.e., sociolinguistic subgroups).

One major methodological decision made here has to do with how lexical variants are classified. We categorize sign variants using *motivation and mapping*. This method is similar if not identical to the methods used in other investigations of lexical variation in various sign languages (Richie et al. 2014; Hartzell et al. 2019; Reed, 2019; Mudd et al. 2020) and as used by Hou (2016) to annotate lexical items representing a type of iconic patterning.

In this study, sign variants are analyzed based on their motivation and mapping; form variation in terms of traditional phonological parameters (location, movement, and handshape) is disregarded given that we still need to further investigate what drives form variation in all of the sign languages in this study (although Fenlon et al. 2013 partly investigate this for some BSL signs).[4] Let us take the example of selected sign variants in response to the picture stimulus *butterfly* (**Figure 1**; reproduced from Mudd et al. 2020). Sign variants sharing the same motivation and mapping are grouped together. The motivation for all three of the signs in **Figure 1** is the wings of the butterfly. The difference in where the wings are mapped leads us to categorize them in the following manner: the variants BUTTERFLY-3A and BUTTERFLY-3B both map the entire insect onto the signer's hands and differ only in the orientation of the palm, and thus are categorized together as BUTTERFLY-3. BUTTERFLY-1 maps the wings of the insect onto the signer's arms.

[4] As noted by an anonymous reviewer, the motivation and mapping criteria does not disregard form in its entirety. Elements of sign formation are involved in the decision making about collapsing or separating variants. However, these are related to the mapping (Taub 2001) rather than the traditional phonological parameters (Stokoe 1960); e.g., in Figure 1, this is evident in distinguishing sign variants based on the mapping (wings to arms vs. wings to hands), i.e. what aspect of the concept maps onto what body part of the signer.

Given the difference in mapping, BUTTERFLY-1 is coded as a separate variant. While we find this method well suited to study lexical variation, especially without form documentation, this method is not without its limitations, some of which are discussed in Section 6.3.

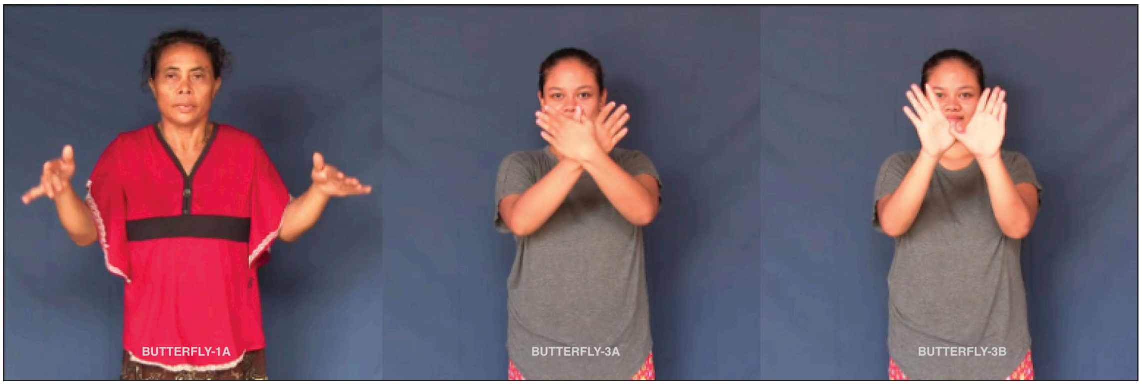

Figure 1: Three variants produced in response to the stimulus *butterfly*.

4.1 The Kata Kolok dataset

Data for Kata Kolok has been collected and annotated previously to explore lexical variation (for details on the dataset see Mudd et al. 2020). Responses to 36 picture stimuli were elicited from 20 deaf and 26 hearing Kata Kolok signers who were sampled based on whether they were deaf or hearing, their age, their gender, which village clan they belonged to and whether they had deaf family members. Stimuli included five semantic domains: foods (*rambutan, salt, coffee, garlic, rice, mango, dragonfruit, chili, palm sugar*), colors (*black, white, yellow, red*), animals (*cat, dog, chicken, pig, cow, horse, butterfly, gecko, turtle*), religion (*sarong, pray, tridatu* – yarn bracelet with religious significance, *blayag* – steamed rice wrapped in a leaf, *flower, offering*), and miscellaneous (*mobile phone, sandals, cock fight, rice cooker, mandi* – traditional Indonesian shower, *shovel, camera*). We ensured that these stimuli are familiar to all participants and culturally relevant by using locally taken photographs or pictures sourced online that matched life in Bali. Stimuli were selected based on different degrees of variation that were expected due to fieldwork observations. The lexical elicitation task was embedded in a session containing an interview and several other (lexical) elicitation tasks. Elicitation sessions were led by a deaf local research assistant and videotaped. Instructions were kept to a minimum without any specific requests to provide one or multiple signs.

Target signs, defined as relevant descriptions of the stimulus picture, excluding anecdotes, examples, etc., were annotated. Crucially, we only included sign variants that occurred at least three times in the data to minimize idiosyncratic variation. Color stimuli were eliminated because they led to confusion and often failed to elicit target signs.

4.2 The ISL dataset

The ISL data was collected as part of the Corpus of ISL for which 120 deaf ISL signers from four broad regions around Tel Aviv, Haifa, Be'er Sheva, and Jerusalem were sampled (Stamp & Ohanin & Lanesman 2022). For this study, a sample of 62 signers was analyzed. Of this sample, 13 participants are from the Be'er Sheva region, 17 participants are from the Haifa region, 4 participants are from the Jerusalem region and 28 participants are from the Tel Aviv region. The remaining data had yet to be annotated at the time of this study and are therefore was not included in this study. The data for this study were elicited as part of the lexical elicitation task, conducted online using Google Meet, in which participants met with a deaf fieldworker assigned to each collection site. Information regarding signers' social backgrounds including their language background, education, language preferences, etc., was collected using a questionnaire.

The task aimed to elicit participant's preferred variants for 41 concepts within the following semantic domains: foods (*banana, beer, carrot, pizza, cheese, chocolate, falafel, honey, bread*), animals (*animal, dove, monkey*), colors (*brown, green, pink, purple, yellow*), countries (*Syria, country*), places (*market, hospital, kindergarten, place*), place names (*city, country, Hermon, Netivot*), home items (*shoe, kitchen*), cultural groups (*Ashkenazi, Mizrahi*), kinship terms (*family, grandmother, grandfather*), and other (*council-tax, ten-shekel, zoom, covid, come, do, bus*). Stimuli were selected based on the fact that they are known to show considerable variation in ISL and possibly associated with social factors, such as age, gender, ethnicity, religion, regional background. Participants were encouraged to give their preferred variant(s) and to mention other variants they know or have seen. Each stimulus was presented on a slide, showing a picture together with the sign's closest Hebrew and Arabic equivalent translations (e.g., a colored orange square with the Hebrew word כתום and Arabic برتقالي to elicit the sign for 'orange'; **Figure 2**). Following Mudd et al. (2020), responses were treated as a single lexical variant if the variants shared the same motivation and mapping. In addition to annotating each variant with its relevant gloss (e.g., BANANA1, BANANA2), we also coded whether the sign was the signer's preferred variant or not.

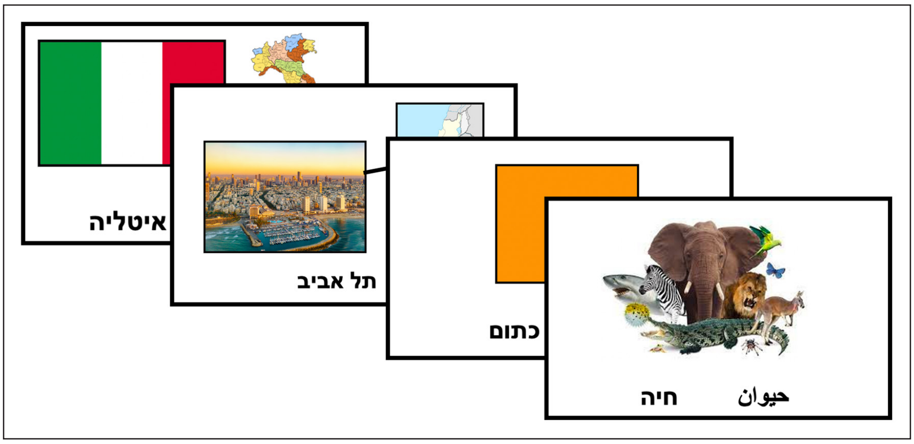

Figure 2: Examples of the slides used in the lexical elicitation task in ISL.

4.3 The BSL dataset

The BSL data was collected as part of the BSL Corpus project (Schembri et al. 2013). To obtain samples of regional variation, data was collected from eight locations across the UK: London, Glasgow, Cardiff, Belfast, Bristol, Birmingham, Manchester, and Newcastle. In total, 249 deaf individuals were filmed, roughly 30 at all sites. Schembri et al. (2013) attempted to recruit 'lifelong' users of BSL who were representative of typical signers from their region (almost all were British born, exposed to BSL before the age of seven, and had lived in the region where they were filmed for the previous 10 years). Deaf fieldworkers recruited local deaf people and mixed the sample for age, gender, social class, and family background (belonging to either a deaf or hearing family).

The original task analyzed signs for 41 selected concepts across various semantic domains, presented on PowerPoint slides by the deaf research assistants using the equivalent words in English and related illustrations (for methodological details see Stamp et al. 2014). Stimuli were selected based on the fact that they were known to show considerable variation, and that this variation was reportedly associated with social factors. Participants were asked to respond with their preferred sign for each concept. Data annotation in the original study proceeded by distinguishing variants based on whether variants shared two out of three formational parameters of handshape, location, and movement.

In the current analysis, there are a two key differences from the original analysis (Stamp et al. 2014): (i) the subset of concepts used, and (ii) the grouping of variants according to motivation and mapping. First, a subset of concepts was selected for this analysis, consisting of 21 concepts: colors (*brown, green, grey, purple, yellow*), countries (*America, Britain, China, France, Germany, India, Ireland, Italy*), and place names (*Belfast, Birmingham, Bristol, Cardiff, Glasgow, London, Manchester, Newcastle*). Notably, numbers were not included in this study because number signs are not suitable for our motivation and mapping criteria; specifically, all signs produced for a given number would typically be grouped in the same category (for a discussion see Section 6.3) which defeats the purpose of assessing lexical distances. Second, all coded data was re-grouped based on our motivation and mapping criteria to match the data coding from Kata Kolok and ISL. In the initial study, phonological and lexical aspects were used to decide whether sign variants should be merged or analyzed as separate variants. For this study, we reviewed all sign variants coded in the original study and judged whether certain variants should be merged or kept separate based on the reasoning explained in Section 4. Importantly, if signs were fully fingerspelled, they were excluded. Initialized signs are treated as regular signs as described above (Section 4).

4.4 Analyses

Datasets and Datasets and analysis files are publicly available at https://doi.org/10.6084/m9.figshare.22220401.v1.

4.4.1 Lexical distances

We study variation at the global level (i.e., on community level) as well as at the local level (i.e., within subgroups) using a variety of quantitative methods. For each community, we use a clustering algorithm on the lexical distances between participants, which we visualize using a dendrogram. At the global level, we calculate the mean and standard deviation of all the lexical distances per community. To study variation at the local level, we assess clustering within subgroups of the population by calculating the silhouette coefficients of different clusters. First, we study local and global variation per community and then compare the three communities.

The basis of our analysis relies on lexical distances between all pairs of participants per community, such that each participant in every community is paired with every other participant in their community. For each pair of participants in a community, we compare their responses to each stimulus to the responses of every other participant to the same stimulus. For Kata Kolok, as shown in **Figure 3**, we use a distance measure called Jaccard distance[5] to compare the full response produced by participants as in the Kata Kolok community participants often produced more than one sign in response to stimuli (as used in Mudd et al. 2021). We think this distance measure most accurately captures the variation at the lexical level between participants. Following this, we analyzed the ISL data in the same way, using Jaccard distance between participants in the ISL community. For BSL, only the first sign produced by participants is compared. This is because participants were asked to produce their (one) preferred sign in response to the stimulus (e.g., Stamp et al. 2014). **Table 1** provides an overview of the methodology per community.

Because much of our analysis makes use of hierarchical clustering of the lexical distances between participants, we start with an in-depth example of how this works with a subset of five participants from the Kata Kolok community: HGU, JU, P1 HSJ and SB.

We begin with some information about the participants: HGU is hearing and has a deaf spouse from a different village. They live in a central family compound with exclusively hearing individuals within the Santun clan. HGU has regular contact with deaf villagers through work and friends, and as such he converses easily with deaf villagers of different ages. JU is a deaf signer (generation 5) of the Ceblong clan. He lives with his deaf parents, stepsister and deaf stepmother, his deaf spouse from a different village and three hearing children in a mixed deaf-hearing family compound alongside his deaf cousin SB. He regularly works away from home. P1 is a deaf signer (generation 5) of the Tihing clan. As a member of one of the big deaf families,

[5] Jaccard distance is equal to 100 minus the Jaccard index or Jaccard similarity, and has been used in similar analyses (e.g., Horton 2022).

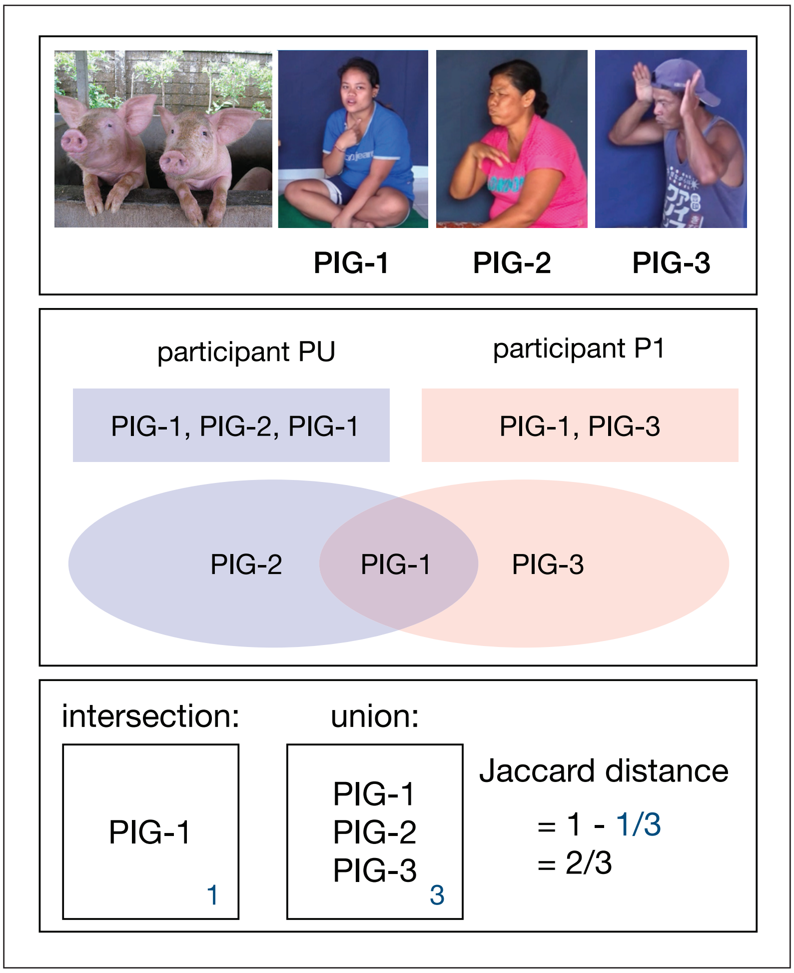

Figure 3: Calculating the Jaccard distance between participant PU and P1's response to the stimulus pig. Both their productions consisted of the target PIG-1 (intersection = 1) and all the targets produced by the pair are PIG-1, PIG-2, and PIG-3 (union = 3). The Jaccard distance between these productions is 2/3, yielded by 1 – Jaccard similarity, which is the intersection divided by the union (= 1 / 3).

she lives in a family compound with several deaf sisters, parents, two deaf daughters, and several other deaf family members and as the oldest daughter, carries out many religious duties. HSJ is hard of hearing and married to a deaf villager with hearing parents. Although belonging to the Santun clan, their house is located at the village outskirts and HSJ generally works locally. SB is a deaf signer (generation 5) of the Ceblong clan. He is the cousin of P1 and JU and has two deaf parents. He is married to a deaf woman from a different village and has two hearing children. He resides in the center of the village in a mixed deaf-hearing family compound with JU with whom he often works, both locally and away.

Community	**Dataset**	**Number of participants**	**Geographic diversity**	**Number of stimuli**	**Number of semantic classes of stimuli**	**Number of tokens analyzed**	**Variants analyzed**
Kata Kolok	Mudd et al. 2020	46	Kata Kolok community	36	5	1656	all targets produced
ISL	Stamp, Ohanin & Lanesman 2022	62	4 regions across Israel	41	10	2542	all targets produced
BSL	Schembri et al. 2013; Stamp et al. 2014	249	8 locations across the UK	21	3	5229	first target produced

Table 1: Summary of methodology per community.

Table 2 shows a subset of the lexical distances between these five Kata Kolok participants, forming the basis for our analysis.

	HGU	JU	P1	HSJ	SB
HGU	0	0.39	0.39	0.21	0.38
JU	0.39	0	0.35	0.44	0.28
P1	0.39	0.35	0	0.44	0.26
HSJ	0.21	0.44	0.44	0	0.40
SB	0.38	0.28	0.26	0.40	0

Table 2: Subset of the Jaccard distance matrix showing five participants: HGU, JU, P1, HSJ and SB. Each value in the table consists of the Jaccard distance between two individuals for all stimuli to which they both responded. Values that are not greyed out are used in the rest of the example. The other values are redundant or the distance from a participant to themselves (distance = 0).

4.4.2 Variation at different levels

4.4.2.1 Variation at the global level

To study variation at the global level, we calculate the mean and standard deviation of all the lexical distances per community. That is, we calculate the distances for each pair of participants, i.e., from each participant to every other participant. We then compare these values across the three communities. Following our example with the subset of participants from the Kata Kolok community using the lexical distance matrix in **Table 2**, the mean of the lexical distances is 0.35 and the standard deviation is 0.07.

4.4.2.2 Variation at the local level

We explored several methods to understand how variation is conditioned at the local level, and what characterizes this variation, as well-suited methods to study variation at the lexical level across sign languages have yet to be identified (for a discussion see Section 1.1 from Mudd et al. 2020; Kimmelman et al. 2022).

Here, we focus on hierarchical clustering to study lexical preferences within communities in an exploratory fashion. This method builds clusters in a bottom-up fashion from the initial matrix (**Table 2**): in this method, each participant is initially considered to belong to their own cluster, and depending on the proximity to others in the lexical distance matrix, they are successively merged. To determine which clusters are merged we use the average distance between clusters as the linkage criteria[6]. The result of this process produces a linkage matrix (**Table 3**) that we visualize using a dendrogram, a tree-like visual used to represent the result of the clustering.

[6] It should be noted that several alternatives to taking the average exist and that we have not explored these alternatives or the effect of using them.

id1	id2	lexical distance	cluster size
HGU	HSJ	0.21	2
P1	SB	0.26	2
JU	P1-SB (2)	0.31	3
HGU-HSJ (1)	JU-P1-SB (3)	0.41	5

Table 3: Linkage matrix showing the distances between participants and clusters, starting with the shortest distance between participants (HGU and HSJ), and ending with the largest distance between clusters (HGU-HSJ and JU-P1-SB). The numbers to the right of the clusters of participants refer to the clusters shown on Figure 4.

The shortest distance from the lexical distance matrix (**Table 2**) is selected: 0.21, the lexical distance between HGU and HSJ. This is the first cluster, shown in the first row of **Table 3**. Now, these individual participants are no longer considered as separate, but as a cluster. As a cluster, distances between HGU-HSJ and all other participants are recomputed, taking the average of the distances between HGU to another participant and HSJ to another participant. Next, the shortest distance is again selected to form the next cluster: the shortest distance is between participants P1 and SB, shown on the second row of **Table 3**. The process of recomputing the distances between clusters is repeated, and a new cluster is then formed: JU, P1 and SB. Finally, the two remaining clusters are merged, forming a final cluster consisting of all five participants.

It is possible to visualize these distances and clusters using dendrograms (a basic tree visualization; **Figure 4**). The branch lengths correspond to the distances from **Table 3** and the branch connections correspond to the clusters created. In our analysis we use a dendrogram to visualize each distance matrix, though it is possible to use other visualization techniques. The advantages and disadvantages of the different visualization techniques are beyond the scope of the present study and could be the subject of future work. Other candidates to visualize the lexical distance matrices include multidimensional scaling (as used in Mudd et al. 2020) and neighbor net graphs estimated using SplitsTree (Huson & Bryant 2006).

Once the dendrogram is drawn it is possible to investigate clusters in different ways, for example by assigning a cutoff point on the y-axis and seeing how many clusters there are or by setting the number of desired clusters. It is of course also possible to visually inspect the dendrogram to better understand the structure of the clustering; for example, here, it is obvious that there are several clusters, one consisting of HGU and HSJ and another consisting of P1, SB and JU, where P1 and SB form a sub-cluster. The length of the horizontal lines indicates the distance between individuals or clusters; it can be seen here for example that HGU and HSJ have a shorter lexical distance to each other (a lexical distance of 0.21) than P1 and SB (a lexical distance of 0.26). In addition, the proximity of clusters on the x-axis is informative about the lexical distances between clusters as well.

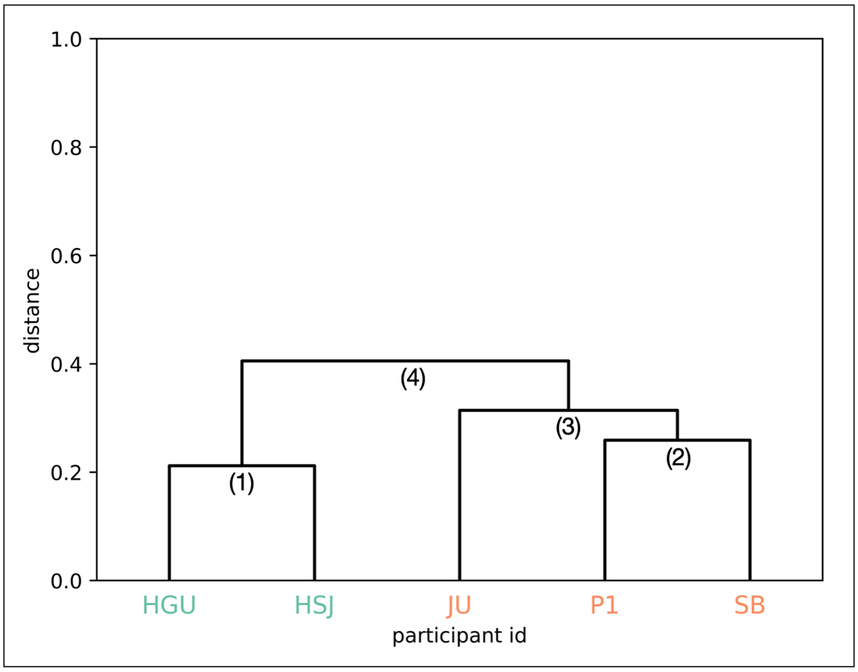

Figure 4: Dendrogram of the normalized lexical distance matrix with a subset of participants from the Kata Kolok community: HGU, JU, P1, HSJ and SB. The distances on the y-axis indicate the distances between participants and clusters. The coloring of the participant ids corresponds to the clusters in which participants are placed given the optimal number of clusters (here, 2) according to silhouette score calculations. There are two clusters: HGU and HSJ in turquoise on the left, and JU, P1 and SB in orange on the right.

We determine the optimal number of clusters by calculating silhouette coefficients for different numbers of clusters[7] (see **Table 4**). The silhouette coefficient is a measure of how similar a data point is to the cluster it has been assigned to compared to the points in the nearest cluster. The higher the coefficient (possible values range from -1 to 1), the more similar the data points within clusters are to each other. For each community we select the number of clusters with the highest silhouette coefficient. We discuss both the silhouette coefficient and the number of clusters associated with the coefficient in relation to the community profile. For the five participants in this study, the silhouette score is highest (0.35) when participants are assigned to two clusters, as can be seen in **Table 4**. When participants are assigned to two clusters, the first cluster consists of HGU and HSJ and the second cluster consists of JU, P1 and SB (see **Figure 4**).

[7] Silhouette coefficients were first introduced by Rousseeuw (1987). Useful documentation on how to calculate the silhouette coefficient of samples can be found here: https://scikit-learn.org/stable/modules/generated/sklearn.metrics.silhouette_score.html

Number of clusters	Silhouette score
2.0	0.35
3.0	0.25
4.0	0.25
5.0	0.25

Table 4: Silhouette scores for different numbers of clusters in the subset of five Kata Kolok participants. Because the silhouette score is highest for when there are two clusters, we consider this to be the optimal number of clusters for this sample.

We now calculate the mean and standard deviation of the optimal clustering to better understand variation at the local level. Following our example, the mean of the first cluster (participants HGU and HSJ) is 0.21 (SD = 0.0). The mean of the second cluster (participants JU, P1 and SB) is 0.30 (SD = 0.4). Together, the mean of these clusters is 0.25 (SD = 0.02). Compared to the global level mean lexical distance (M = 0.35; SD = 0.07), the local level lexical distance is lower (M = 0.25; SD = 0.02) which indicates that lexical patterning exists amongst subgroups (or clusters) of the sample.

Next, we visualize the optimal clusters of the hierarchical clustering by coloring the participant labels on the dendrogram, indicating which cluster they have been assigned to, as shown for our example in **Figure 4**. In the results section, we provide some additional qualitative commentary on the dendrogram using several sources: 1) by visually interpreting the dendrogram, 2) from the researcher's knowledge of the communities, and 3) from what has been found to influence variation in different communities from previous studies (e.g., Stamp et al. 2014; Mudd et al. 2020). As discussed, the dendrogram shows lexical proximity between participants. In our example, why might certain participants be closer lexically than others? In a previous study, Mudd et al. (2020) found that deaf and hearing participants had different lexical preferences. This is also reflected in the clusters found here, with the two hearing participants forming one cluster (HGU and HSJ) and the three deaf participants forming a second cluster (JU, P1 and SB). Additionally, the three participants in the second cluster are part of the same extended family and frequently spend time together. SB and P1 are closer in age than JU who is slightly older.

5 Results

In this section, we first report global and local variation in each community separately and then compare the amount of variation and how variation appears to be conditioned across the three communities. As a reminder, we used the Jaccard distance for KK and ISL data and analyzed the first response for BSL data.

5.1 Variation in the Kata Kolok community

5.1.1 Variation at the global level

The average lexical distance in the Kata Kolok community is 0.5 (SD = 0.09).

5.1.2 Variation at the local level

Though there are various ways to determine an optimal number of clusters in a dataset, we use silhouette coefficients to assess different numbers of clusters for each linguistic community. As a reminder, the silhouette coefficient is a measure of how similar a data point is to the cluster it has been assigned to compared to the points in other clusters. In this analysis, we present the number of clusters with the highest silhouette score: we color the clusters in the dendrogram, and we discuss the mean and standard deviation of each cluster and across all clusters.

For the Kata Kolok community, the optimal number of clusters is two (see **Figure 5**). The average lexical distance across the clusters is 0.50 (SD = 0.06).

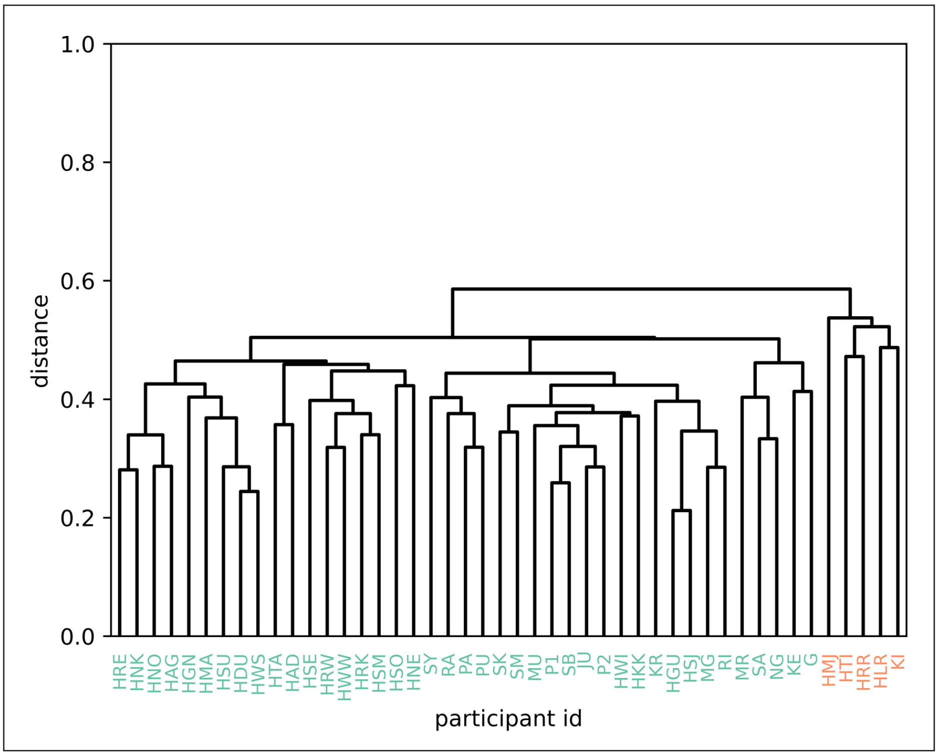

Figure 5: Dendrogram representing the hierarchical clustering of the lexical distances of participants in the Kata Kolok community. Participant ids are colored by the cluster that participants belong to based on the optimal number of clusters according to silhouette score calculations. The optimal number of clusters is two: cluster one (turquoise, left) has a mean of 0.47 (SD = 0.08) and cluster two (orange, right) has a mean of 0.52 (SD = 0.04). The average lexical distance across clusters is 0.50 (SD = 0.06).

For the Kata Kolok community, there is a large cluster of hearing participants (ids on the x-axis starting with ‘H’) on the left side of the dendrogram and a cluster of deaf participants (ids on the x-axis not starting with ‘H’) on the right of this cluster. Both the hearing and deaf clusters have comparable amounts of lexical variation; the vertical lines where both clusters meet are of similar heights. Finally, there is a small cluster on the right side of the dendrogram containing five participants. The vertical lines are very large, indicating that these participants have little lexical overlap with other participants. Interestingly, this cluster includes one deaf participant (KI) who is an unmarried, elderly woman living alone in a primarily hearing family compound (one teenager who is currently attending a deaf school in Denpasar is the only other deaf individual in her clan). HMJ, HTI and HLR are all elderly hearing participants from different clans, and none of them are from KI’s clan. HRR is an older participant from the middle-aged group. HMJ, HTI and HRR have at least one deaf family member.

5.2 Variation in the ISL community

5.2.1 Variation at the global level

The average lexical distance in the ISL community is 0.48 (SD = 0.10).

5.2.2 Variation at the local level

For the ISL community, the optimal number of clusters is two (see **Figure 6**). The average lexical distance across the clusters is 0.51 (SD = 0.04).

For the ISL community, a few clusters on the right side of the dendrogram appear with comparable amounts of variation (vertical lines similar in length). However, within these clusters, there is still a high degree of lexical variation, as the vertical lines are high. On the left of this, participants are added to the clusters in pairs or individually, indicating that their lexical distance from other participants is large. The two clusters in **Figure 6** capture a large group (turquoise, right) and a small group of two participants (orange, left). The large cluster includes participants with various socio-demographic backgrounds whereas the smaller cluster consists of two of the oldest participants in the sample who, despite being in the same cluster, show quite a large lexical distance from each other. Both participants are men in their 80s or 90s and are much older than others in their age group. Although H22 has lived in Haifa for most of his life, he attended Israel’s first deaf school in Jerusalem after migrating from Germany. T12 lives in Tel Aviv and migrated from Hungary. The larger cluster consists of some participants with relatively low lexical distances from each other, e.g., H11 and H12. These two individuals, one male and one female, are both young and attended the same school in the Haifa area. Similarly, there is a cluster of eight individuals (H12, H11, H08, H17, H04, H14, H10 and H06) who vary in gender and age (younger and middle age groups), and all reside in the Haifa area. Finally, participants B05 and T27 also have a short lexical distance from each other. Even though both participants reside in different cities and attended different schools, they are both young (the youngest in our sample) females, with similar ethnic backgrounds, which may in part explain their lexical proximity.

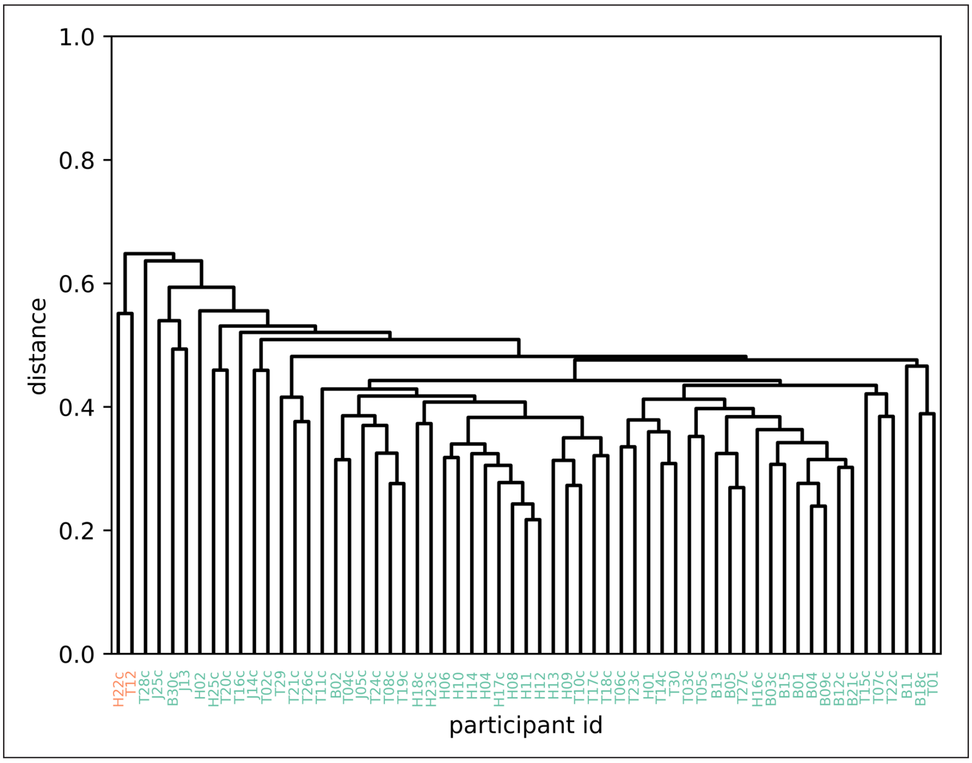

Figure 6: Dendrogram representing the hierarchical clustering of the lexical distances of participants in the ISL community. Participant ids are colored by the cluster that participants belong to based on the optimal number of clusters according to silhouette score calculations. The optimal number of clusters is two: cluster one (orange, left), consisting of two participants, has a mean of 0.55 (SD = 0.0). Cluster two (turquoise, right) has a mean of 0.47 (SD = 0.09). The average lexical distance across clusters is 0.51 (SD = 0.04).

5.3 Variation in the BSL community

5.3.1 Variation at the global level

The average lexical distance in the BSL community is 0.56 (SD = 0.15).

5.3.2 Variation at the local level

In contrast to the Kata Kolok and ISL communities, the optimal number of clusters in the BSL community is 20. Several clusters consist only of one participant. There is substantial variation in the average lexical distance within clusters: cluster eight has a very low average lexical distance

(M = 0.19, SD = 0.09) while cluster 11 has a larger lexical distance (M = 0.41, SD = 0.09). The average lexical distance across all clusters is 0.34 (SD = 0.09).

Overall participants appear to cluster with others from their region (shown in **Figure 7** by the start of the participant ids, e.g., BL for Belfast and GW for Glasgow), but that does not entirely explain the clustering. There are only eight regions but 20 'optimal' clusters.

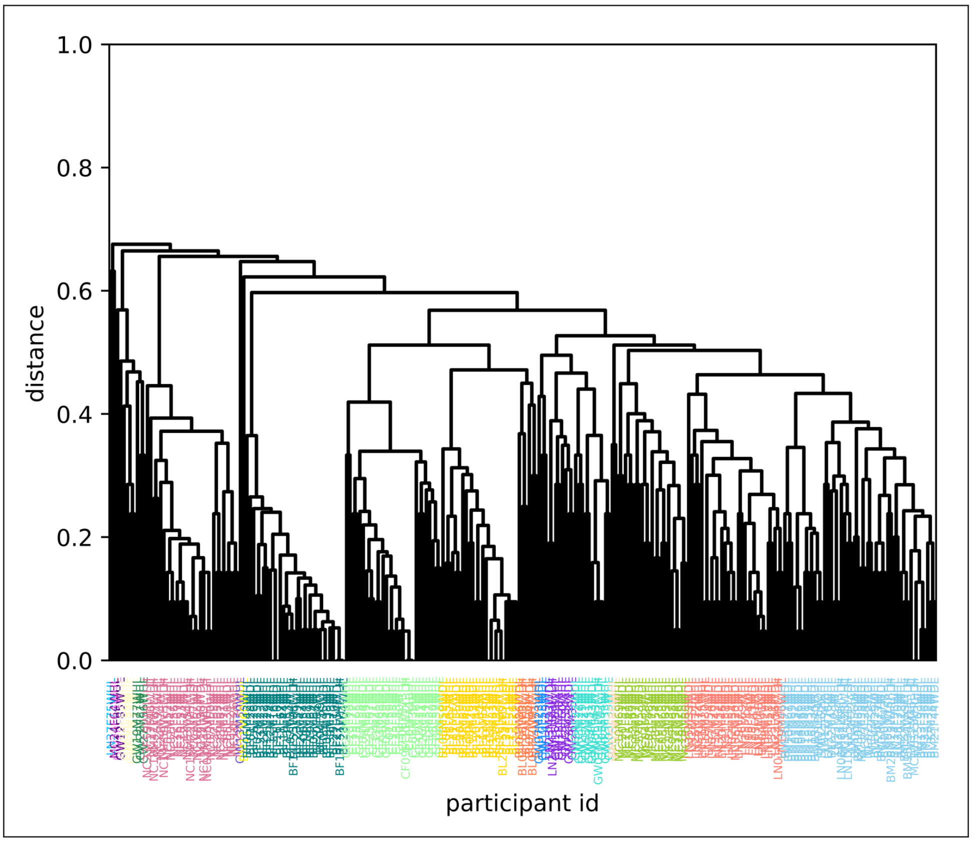

Figure 7: Dendrogram representing the hierarchical clustering of the lexical distances of participants in the BSL community. Participant ids are colored by the cluster that participants belong to based on the optimal number of clusters according to silhouette score calculations. The optimal number of clusters is 20. The average lexical distance across clusters is 0.34 (SD = 0.09). Across all participants the average lexical distance is 0.56 (SD = 0.15).

If we examine the six individuals who form their own clusters more closely, their ages range from 50 to 85 years old, so it is possible that some of the more elderly individuals might use BSL variants that most BSL signers no longer use (indeed GW12 is amongst the oldest participants in the sample). There are other possible explanations, however. For example, LN37 has spent many years living in Australia, the USA, Israel, and South Africa. It is possible that she has retained some lexical items from the different sign languages used in these countries. MC24 attended a deaf school founded and run by Belgian priests/nuns and may have retained some distinct lexical variants that go back to a signing variety influenced by the initial language of instruction, Flemish Sign Language. In contrast, two other Manchester signers who also attended the school are in the same cluster (MC16 and MC17) as the bulk of Manchester signers, but MC16 and MC17 are siblings with deaf parents (unlike MC24) and Stamp et al. (2014) show that individuals from deaf families are more likely to use lexical signs more typical of the region. Next, GW28 is a woman who attended a Catholic school in Glasgow where a variety of Irish Sign Language was used but does not cluster with other Glasgow signers who attended the same school: instead GW01, GW03, GW06, GW24, and GW29 fall into a larger cluster of Glasgow signers which is yet a different cluster from Glasgow signers who attended Protestant schools for deaf children and use different lexical variants than the Catholic signers. Signers from Bristol are also divided into different clusters, with one cluster representing those who attended the local school for deaf children while another represents those who were not educated locally. Two London and Manchester signers (LN12 and MC11) who attended schools in Coventry (a small city close to Birmingham) pattern together with other signers from the Birmingham cluster.

5.4 Cross-linguistic comparison of variation

5.4.1 Variation at the global level

As shown in **Figure 8**, the average lexical distance in the BSL community ($M = 0.56$, $SD = 0.15$) is higher than the average lexical distance in the Kata Kolok community ($M = 0.5$, $SD = 0.09$) and the ISL community ($M = 0.49$, $SD = 0.11$). To assess whether these differences are significant, we ran a t-test between the communities and found significant differences between the three pairs of communities: between KK and ISL ($t = 3.47$, $p < 0.001$); between KK and BSL ($t = 21.58$, $p < 0.001$); and between BSL and ISL ($t = 31.17$, $p < 0.001$).

Aiming to control for the fact that the BSL sample is much larger than the KK and ISL samples, we did an additional analysis to rule out that the sample size is a driving factor in determining the level of lexical variation in the BSL community. Given that the smallest sample size in our study is 46 participants (Kata Kolok community), we resampled 46 participants from the BSL sample (249 participants). With this subsample we calculated the mean and the standard deviation of the lexical distances. We repeated this process 10,000 times and found that the average mean and the average standard deviation of the 10,000 recalculated subsamples is the same as the original full sample of 249 participants ($M = 0.56$; $SD = 0.15$). While the subsamples do exhibit some variation, as the average mean of the subsample and the mean of the real sample are equivalent, we can confirm that the result is not due to a difference in sample sizes.

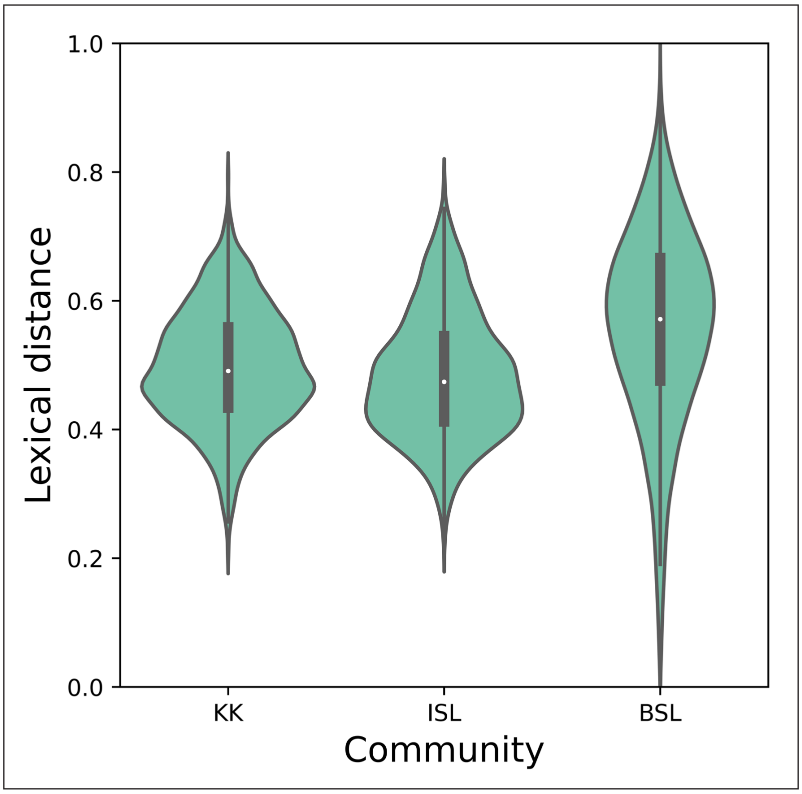

Figure 8: Violin plot showing the median (white dot), interquartile range (thick black bar), and the distribution of lexical distances across the three communities: Kata Kolok (median = 0.49, IQR = 0.12), ISL (median = 0.47, IQR = 0.13) and BSL (median = 0.57, IQR = 0.19). The BSL community (M = 0.56, SD = 0.15, 30876 lexical distances) has a higher average lexical distance than the Kata Kolok community (M = 0.5, SD = 0.09, 1035 lexical distances) and the ISL community (M = 0.49, SD = 0.11, 1830 lexical distances).

4.2 Variation at the local level

Now we further investigate lexical variation by looking at the local level within each community to see if there are differences in the amount of variation within subgroups. When comparing the results of the optimal clustering of the three communities, two things immediately stand out: the higher number of clusters in the BSL community and the lower average lexical distance across clusters in the BSL community.

The optimal number of clusters for the Kata Kolok and ISL communities is two and for the BSL community it is 20. The average lexical distance in the BSL community across clusters is 0.34 (SD = 0.09) and for the Kata Kolok and ISL communities the average lexical distance across clusters is close to 0.5 (Kata Kolok community: M = 0.50, SD = 0.06; ISL community: M = 0.51, SD = 0.04). For a summary, see **Table 5**.

	optimal number of clusters	silhouette score of the optimal cluster	average number of participants per optimal cluster	lexical distance across optimal clusters
Kata Kolok	2	0.18	M = 23 (41 in cluster 1; 5 in cluster 2)	M = 0.50; SD = 0.06
ISL	2	0.26	M = 30.5 (59 in cluster 1; 2 in cluster 2)	M = 0.51; SD = 0.04
BSL	20	0.29	M = 12.45 (max = 46; min = 1 in 6 clusters)	M = 0.34; SD = 0.09

Table 5: Summary statistics describing the optimal clusters for the lexical distance per community.

In **Figure 9** the variation in the dendrograms representing the hierarchical clustering of the communities can be seen. The BSL dendrogram is denser and darker as there are more participants in the sample. Crucially, the clusters are most apparent in this visualization: the clusters are further away from each other, which is evident by the height of the vertical line before clusters meet. This indicates that there are subgroups of this community with distinct lexical preferences. For the Kata Kolok and ISL communities, variation appears to be more similar: there are fewer distinct subgroups compared to the BSL community. In comparison, variation appears relatively high across these two communities. This is not to say that subgroups with lexical preferences do not exist in these communities, but rather that they are not as pronounced as in the BSL community, which is reflected in the lower mean lexical distance within the clusters of participants as per the optimal clustering. For instance, beyond the clusters marked in colors on the dendrogram, in the Kata Kolok community it is apparent that hearing and deaf individuals have different lexical preferences (participant ids starting with 'H' are hearing and those without are deaf); specifically, a larger cluster of hearing signers falls on the left of the dendrogram and only four hearing signers intersperse the 'deaf cluster' within the turquoise cluster – notably all of them are men, one of them married to a deaf person and two of them heavily involved with the deaf villagers and teachers at the deaf unit. While these groups exhibit different lexical preferences, they are not as distinct as the lexical preferences in the BSL community by region, supported by the fact that according to the optimal clustering these Kata Kolok participants are clustered together while BSL participants are grouped into smaller optimal clusters with participants sharing lexical patterns.

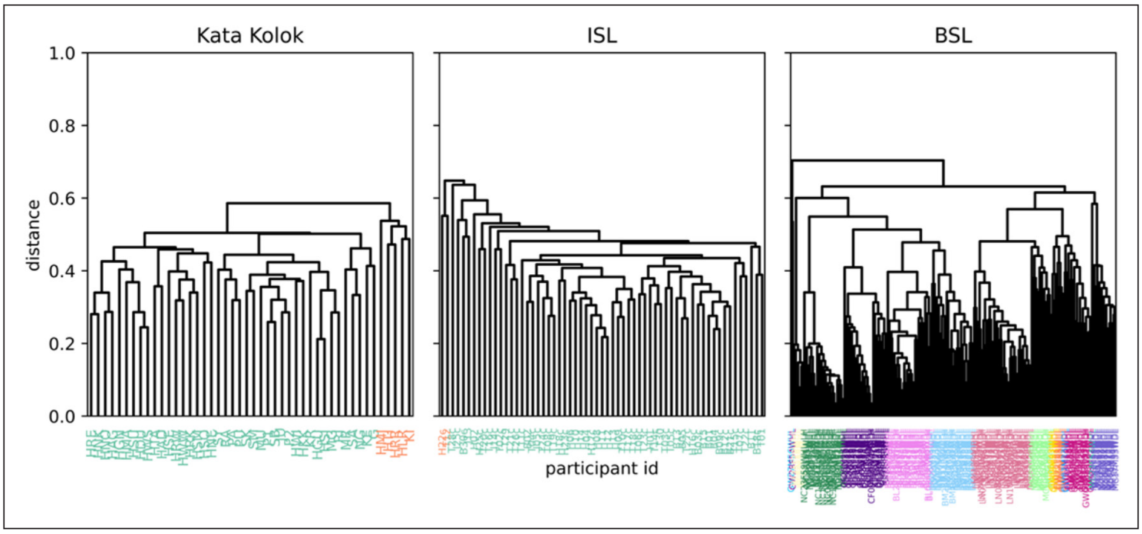

Figure 9: Dendrograms showing hierarchical clustering of the lexical distances between participants in the Kata Kolok community (left), ISL community (middle) and BSL community (right).

6 Discussion & conclusion

6.1 Variation at different levels

In this paper we have investigated the relationship between the social structure of a signing community and lexical variation. As a reminder, following the claim from Meir et al. (2012) that a larger population size leads to less lexical variation, it would be predicted that BSL would have the least variation, Kata Kolok the most variation and ISL somewhere in between based on the community sizes alone. We conducted a cross-linguistic comparison of lexical variation using existing lexical elicitation task data. Having collected data from different communities, there were differences in our datasets and the ways in which we analyzed them (e.g., Jaccard distance for Kata Kolok and ISL vs. first sign produced for BSL; see **Table 1**). Using quantitative techniques, we explored and compared lexical variation within these communities. We distinguish between variation at the global (i.e. community level) and the local level (i.e. within subgroups).

Variation in our data at the global level does not support the claim made by Meir et al. (2012). We found that BSL (relatively older and larger signing community) exhibits the most lexical variation at the global level, while Kata Kolok (relatively older and smaller signing community) and ISL (relatively younger and medium-sized signing community) exhibit a lower degree of lexical variation. At the local level, a different picture emerges: BSL exhibits more distinct subgroups than Kata Kolok or ISL, evident in the low degree of variation within clusters. In contrast, there is much more variation within each cluster of participants in Kata Kolok and ISL.

These findings lead us to suggest that previous research lacks explicit consideration of the level (global vs. local) at which lexical variation is analyzed (see also Horton 2022). Studies on lexical variation in relatively small and young sign languages, such as Kata Kolok and ABSL, have commonly analyzed community-wide variation at the global level. In contrast, studies on relatively larger and older sign languages, such as BSL or ASL (Lucas & Bayley & Valli 2001), typically analyze how lexical variation is influenced by sociolinguistic factors at the local level. Despite this fundamental difference in how lexical variation has been analyzed in different communities (Braithwaite 2020; Safar 2020), comparisons have been made cross-linguistically with little acknowledgement of the differences in methods. These results and their framing have contributed to an assumption of a developmental cline across sign languages, in which 'mature' sign languages (like ASL) are regarded as the end goal in terms of linguistic feature development (Kusters & Hou 2020). In this way, we caution against a low or high level of lexical variation (be it at the local or global level) as being seen as the end goal for a language. Rather, we suggest that the degree of lexical variation within a community can be explained in large part by the sociolinguistic makeup of the community. In this study, we focused on community size as it was a quantifiable social factor that had clear predictions from previous research, but more research is needed into different factors such as language age, schooling and education, setting of language emerging (e.g., school vs. village) to determine how each factor contributes towards lexical variation.

A main contribution of this study is that it highlights different levels at which languages can be analyzed, and we emphasize that variation needs to be compared at the same level across languages. In this study we have outlined quantitative methods to compare variation at the global and local levels, suggesting tools to compare (lexical) variation across sign languages.

6.2 A community-centered approach to studying variation

We have focused on developing a community-centered approach to analyzing variation within a community as well as between communities. By a *community-centered approach,* we mean that the priority is developing the appropriate analytical method per community, as opposed to prioritizing a homogenous method across all communities. This approach comes with advantages and disadvantages which we will discuss below. Ultimately, we argue that a community-centered approach is the only viable way to study variation across communities with different profiles.

To understand variation in a community, it is crucial to design the study with the community in mind; first, data collection should reflect the linguistic and cultural norms of the community, ranging from how the data is collected (e.g., where and how? Is there an interlocutor during the data collection and if so, who?) to what stimuli are used (e.g., elicitation vs. spontaneous tasks).

If measuring lexical variation, depending on the goal of the study, it likely makes sense to include stimuli that are culturally relevant to participants. For instance, in the Kata Kolok community, the stimuli included tropical fruit, such as mango, dragonfruit, and rambutan. Given the cultural differences between the communities, it would make little sense to include the same stimuli for each community in this study.

On a similar note, the analysis of the collected data should also be designed with the community in mind. As this depends largely on the research question and type of study, we will provide an example to showcase how this applied here. While previous studies have typically included only one sign variant produced by participants (e.g., Stamp et al. 2014 for BSL), it is becoming more common to analyze lexical variation using distance measures which account for multiple variants (e.g., Horton 2018; 2022). Considering multiple variants to analyze lexical variation is useful in many cases, for example when it may be unnatural for participants to give a single variant in response to a task or when collocations, compounds, or descriptions are used. Here, we chose to analyze all variants produced by Kata Kolok participants because participants typically responded to a stimulus with a string of variants. For the analysis of ISL, we also analyzed all variants produced by participants. For BSL, we chose to analyze the first variant only based on the instructions given to participants (Stamp et al. 2014).

One may argue that comparing data collected and analyzed in different ways is not a valid way to compare cross-linguistically. Typically, in experimental design, the goal is to minimize differences in these factors. However, we would argue that collecting and analyzing the data from communities with profiles as different as the ones in our study would not lead to accurate results. This is not to say that there are not instances where it would make sense to have a more homogenous approach to experimental design; rather, the focal point of the study should be on how to most accurately study variation within each community before focusing on comparing cross-linguistically.

This is the first attempt at this type of analysis. Much more work remains to be done, especially in understanding how different social factors simultaneously explain variation. Previous studies using different analytical tools (e.g., logistic regression in Stamp et al. 2014) have considered multiple social factors simultaneously, but because of limitations of this method (see Mudd et al. 2020 for further discussion), we use different analytical tools, such as clustering algorithms. Using the latter, it is unclear to us how to analyze more than one social factor at a time, and more work must be done to determine an approach which allows us to simultaneously consider how multiple social factors influence variation. The combination of using statistical tools with small sample sizes to study various social factors is challenging; typically, this would require a much larger sample, which is simply not possible in certain communities (e.g., we sampled half of the deaf Kata Kolok community, see also Lutzenberger 2023). More work is required to find the optimal statistical tools to tease this apart and to balance this with more qualitative approaches to understanding variation.

6.3 Limitations

Naturally, there are several challenges and limitations to this study. In the following, we highlight three challenges: i) defining a lexical variant, ii) operationalizing motivation and mapping as a grouping variable, and iii) considering lexical frequency as a confounding variable.

One challenge that we faced in analyzing the data from different communities is how to define a lexical variant. In some studies, lexical variants are distinguished from phonological variants based on the number of shared phonological parameters (e.g., Stamp et al. 2014): if a variant differed by more than two parameters, it was defined as a lexical variant; if a variant only differed in one parameter, it was considered as a phonological variant. For languages like Kata Kolok (for which the documentation of phonology is only starting), this approach might be difficult as there is less literature to determine whether certain features are contrastive or not (Lutzenberger 2022). Other studies follow theories of the hierarchical representations of signs more closely and base their analysis on more fine-grained featural distinctions between signs (e.g., Crasborn et al. 2020; Lutzenberger 2022). In other studies, lexical variants are established based on motivation and mapping (e.g., Hartzell et al. 2019; Mudd et al. 2020; Reed 2021). Kimmelman et al. (2022) provide a thorough discussion of this issue and clearly show the limitations of different approaches and suggest using networks to represent relations between sign variants visually. It remains an open question as to what is the best approach, and to what degree the community profile should affect the approach chosen for this specific issue.

Here, we used motivation and mapping to group sign variants, primarily as a methodological decision. We have not conducted independent studies investigating the iconic properties of different signs due to time and resource limitations. It should be noted that grouping variants according to their motivation and mapping is not always straightforward. Number signs from the BSL dataset were particularly challenging, as laid out in Section 4; for signs like BSL 'three', all three variants could be grouped together because all use three fingers to represent the entity three or grouped separately based on that THREE-2 might have originated from co-speech gesture used in mainland Europe (**Figure 10**). Primarily for this reason, we decided to exclude the number signs from the BSL dataset. Note that this does not hold for initialized signs for which a motivation in fingerspelling can be argued.[8]

[8] For an example, see the BSL variants of 'yellow' available on BSL Signbank: https://bslsignbank.ucl.ac.uk/dictionary/words/yellow-1.html. YELLOW-1 is the only example of a sign that is motivated by fingerspelling and all other variants show different motivations. Therefore, all listed variants are considered separate variants.

Figure 10: Three variants for the number three in BSL (BSL Signbank).

While we have provided the reasoning for our decision in Section 4, various studies targeting iconic properties of the signs included in this analysis could complement the present study and corroborate whether our coding reflects more objective measures of sign motivation. We can envisage at least three different types of studies: first, a study dedicated to exploring different types of iconicity in sign variants, following for example studies on patterned iconicity (Padden et al. 2013; Hwang et al. 2017; Hou 2018) would allow comparisons to existing studies which have relied on categorizing studies based on their iconic properties (e.g., Richie & Yang & Coppola 2014; Hou 2016; Horton 2018; Neveu 2019; Reed 2019; Horton & Riggle 2019; Mudd et al. 2020). Second, a study exploring how participants interpret the origin of sign variants based on interviews could provide deeper insights into participants' intuitions about how to group variants based on their motivation. No study investigating the community's judgement on the grouping of variants exists for the languages included in this study, yet we believe that this type of study promises interesting findings. For instance, preliminary judgement data of phonological variants from Kata Kolok suggest that participants recognize different variants (Lutzenberger 2022). Lastly, several experimental studies with participants from the respective communities could shed light on how community members perceive sign variants. While studies targeting sign motivation would certainly enrich the current study, we believe that classifying signs according to their motivation in the way we have done here is sufficient for the purposes of this study. Note that the elicited data presented here do not provide insights into how signers accommodate to interlocutors and to what extent sign variants are recognized among signers in spontaneous conversation (see discussion of passive synonyms in Mudd et al. 2020). Nevertheless, there is evidence that the variants used in lexical elicitation tasks are largely congruent with the variants used in more spontaneous tasks, such as conversation (Stamp et al. 2014).

Finally, it is unclear how our findings are influenced by lexical frequency. Previously, Mudd et al. (2020) hypothesized a relation between concept frequency and lexical variation: the more frequent a concept is, the fewer variants would be expected. However, research on language change in spoken languages shows that more frequent words change more quickly (Frisch 1996; Bybee & Hopper 2001; Bybee 2010), and research on signed languages suggests that more frequent items exhibit greater form variation (Schembri et al. 2009; Fenlon et al. 2013). We lack crucial information to investigate these hypotheses thoroughly; there is no study quantifying how often a concept is discussed and most sign language corpora lack the size and number of annotations needed to be used for reliable measures of lexical frequency (D. McKee & Kennedy 2006; Johnston 2011; Fenlon & Schembri & et al. 2014; Smith & Hofmann 2020; but see Börstell & Hörberg & Östling 2016; and Börstell & Crasborn & Schembri 2019 for how lexical frequency and sign duration are related). Future studies of lexical frequency could complement and expand upon the current one, to understand the role of frequency on lexical variation.

6.4 Future work and best practices

Having laid out the advantages and disadvantages of a community-centered approach to cross-linguistic comparisons, we now give recommendations on how this work could be continued. We suggest a set of best practices for future cross-linguistic comparisons and to extend beyond the work presented here through collaborations with other researchers.

First, the cross-linguistic comparison in this study is bigger in terms of its sample size per community and number of stimuli included for each community than most existing comparative research (such as the cross-linguistic comparison of phonology in three sign languages: ABSL, ISL, ASL by Sandler et al. 2011). Nevertheless, our study includes only three of 215 documented sign languages across the world (Hammarström et al. 2022), making it difficult to truly tease apart the hypotheses about how social structure governs lexical variation. The findings therefore only provide a limited picture of lexical variation and its relationship with social factors in different sign languages.

More sign languages need to be investigated (and included in the comparison) to test the robustness of the findings and generalizations made based on our sample. Doing robust cross-linguistic and community-centered comparisons, however, requires extensive knowledge about the signing community and the sign language that is impossible for a single researcher to gain and to provide; collaborations are needed. Only through researchers and community members sharing their expertise can community-centered comparisons be enlarged. Crucially, successful inclusion of data from other studies into community-centered analyses requires excellent meta documentation; each data collection and each signing community needs to be described in great detail (see above for elaborate explanations why this is necessary). For example, a detailed and up-to-date sociodemographic sketch is needed to understand the community and select the appropriate analyses; exact details on the lexical elicitation tasks and the data collection are needed to assess how data should be processed and analyzed, e.g. whether all or only the first variant should be included in the analysis or whether specific variants need to be excluded for certain reasons; details on the coding decisions are necessary to understand the way different variants have been grouped a priori. All this information is necessary to attempt valid cross-linguistic comparisons.

Based on the insights from the present study, we list the minimal requirements for other datasets to be included in this type of cross-linguistic comparison in the future (and by extension, what is the necessary information for any large-scale comparison across different languages). Minimally, a thorough sociolinguistic description of the profile of the signing community, including details about relevant social factors, and annotated data is needed. It is useful to focus on the social factors that are important to the specific community but also, if possible, provide some information on common social factors or social factors reported for other languages in the study. A lexical elicitation task should be designed with culturally appropriate stimuli used to elicit signs for common concepts from signers from a sign language. A deaf researcher or collaborator should guide participants through the task. The data should be annotated and transcribed. Under these conditions, various kinds of datasets from different signing communities can be included in the comparisons. For example, in an ongoing project, de Vos et al. (in prep.) explore lexical variation among data from Balinese homesigners and compare it to data from Kata Kolok signers.

To sum up, community-centered cross-linguistic comparisons (of lexical variation) require collaborations. Following this, we strongly encourage transparency of data. It is important to openly share data, metadata, and code online, to facilitate collaborative efforts. This will ultimately allow us to gain valuable insights into the diversity of sign languages, paving the way not only for community-centered, large-scale comparisons but also for broadening the scope of existing approaches: a community-centered approach does not limit oneself to specific “types” of data from certain signing communities; on the contrary, it allows for the analysis of various different community constellations on equal footing, enabling us to better understand lexical variation.

Data availability

All datasets and analysis files can be found in the following repository: https://doi.org/10.6084/m9.figshare.22220401.v1. Please see the README.md/pdf file in the repository for an explanation of how to run the scripts.

Ethics and consent

Informed consent has been collected for each dataset within the project the data has been originally collected for (references provided in the methods section).

Funding information

This work was supported by a European Research Council Advanced Grant (ERC-ADG 885220 SignMorph) awarded to Adam Schembri, by an Amsterdam Brain and Cognition (ABC) Talent Grant awarded to Katie Mudd, and by the Israeli Science Foundation (grant no. 2757/20) and the Data Sciences Institute small grant awarded to Rose Stamp.

Acknowledgements

For the Kata Kolok data, we would like to thank all Kata Kolok signers, especially those who participated in this study and our research assistants assisting with data collection, especially Ni Made Sumarni. For the ISL data, we gratefully thank all those who contributed towards the Corpus of ISL project. Thanks to Eliran Ben HaRosh, Shlomi Biton, Karin Biton, Dana Kadosh, Sara Lanesman, Debi Menashe, Ora Ohanin, and Avihai Shbo, and a special thanks to all of the deaf individuals who agreed to participate. For the BSL data, we would like to thank Jordan Fenlon, Ramas McRae (formerly Rentelis), Sally Reynolds, Kearsy Cormier, and other members of the BSL Corpus team, as well as the 249 members of the British deaf community who gave up their time to participate in the project. We also thank Yannick Jadoul, Marnix van Soom, and Bart de Boer for their helpful feedback and ideas for the analysis and three anonymous reviewers for very helpful comments which were invaluable for improving this manuscript.

Competing interests

The authors have no competing interests to declare.

Author contributions

HL and KM: Conceptualization, data collection, annotation and curation, formal analysis, methodology, visualization, writing original draft & review and editing. RS and AS: Data collection and annotation, supervision, writing – original draft (ISL and BSL sections), writing – review & editing (feedback). KM, RS and AS: Funding acquisition.

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