NATIONAL RESEARCH UNIVERSITY
HIGHER SCHOOL OF ECONOMICS

Anna G. Klezovich

AUTOMATIC EXTRACTION OF HANDSHAPES INVENTORY IN RUSSIAN SIGN LANGUAGE

BASIC RESEARCH PROGRAM

WORKING PAPERS

SERIES: LINGUISTICS

WP BRP 86/LNG/2019

Anna G. Klezovich[2]

AUTOMATIC EXTRACTION OF HANDSHAPES INVENTORY IN RUSSIAN SIGN LANGUAGE[3]

The Prosodic model of phonology (Brentari 1998) implies that all signs in any sign language have prosodic and inherent features. This dichotomy (movement feature vs. all other features) occurs to some extent in all phonological theories. The idea derives from Liddell & Johnson's (1994) Movement-Hold model, where they proposed that movements can be in most cases derived from the knowledge of holds and their relative order, and that it is sufficient to describe in-detail only holds. Therefore, when it comes to describing *phonemic* inventories of a particular sign language, researchers focus on the building of separate phonemic inventories for each of the inherent features (or for features of holds) (Channon & Hulst 2011), namely handshape, location, and orientation (e.g. van der Kooij (2002) for Sign Language of the Netherlands (NGT) – only handshapes inventory, Nyst (2007) for Adamorobe Sign Language (AdaSL) – handshapes and locations inventories, etc.).

This research focuses on handshapes inventory for Russian Sign Language (RSL). First, I automatically extract positions without movement (i.e. holds) using an algorithm developed on the basis of Börstell's (2018) script. Then I manually annotate holds for the handshapes with respect to Hamburg Notation System (HamNoSys; Hanke 2004) and describe resulting phonetic handshapes inventory for RSL, comparing this data with other sign languages. The last but not the least, the enventory of phonemic hanshapes for RSL is derived from the phonetic one under van der Kooij's (2002) model of phonology.

JEL Classification: Z.

Keywords: phonetic inventory of handshapes, phonemic inventory of handshapes, Russian Sign Language, sign language phonology, holds extraction.

[2] National Research University Higher School of Economics. School of Linguistics. E-mail: anna.klezovich@yandex.ru

[3] The publication was prepared within the framework of the Academic Fund Program at the National Research University Higher School of Economics (HSE) in 2019 — 2020 (grant №18-05-0053) and by the Russian Academic Excellence Project «5-100». The author is grateful to Vadim Kimmelman (University of Bergen) and George Moroz (Higher School of Economics) for supervising the thesis, this publication is based on.

1. Introduction

What is implied under the phonology of sign language since there is no *phōnē* part? According to (Stokoe 1960; Battison 1978), every sign consists of five phonological components, namely handshape, location, movement, orientation, and non-manuals. One of the first phonological theories for sign languages suggests that each sign consists of holds and movements, where movements can be derived from the knowledge of holds or in other words positions without movement. Therefore, handshape, location and orientation are specified for each hold, under this theoretical framework. However, when a sign has a complex movement, for instance, a combination of path movement and local movements (RSL, WAVE – path movement + several changes in orientation), then this movement cannot be predicted from the knowledge of two holds. Since the linear structure of sign in the Movement-Hold model is not descriptive, other phonological theories exploit the idea of the hierarchical organization of five phonological components. However, the movement-hold dichotomy persists. For instance, in the currently most influential phonological theory, the Prosodic model of phonology (Brentari 1998) each sign can be represented as a tree (see Fig. 1 for an example), which has two main nodes: the prosodic features node (i.e. everything related to movement and manner of movement) and the inherent features node (i.e. handshape, location, orientation features). In addition to that, the Prosodic model of phonology (Brentari 1998) proposes that orientation feature is lower in the hierarchy than handshape and place of articulation features. This is explained by the fact that there are only a few minimal pairs based only on the orientation distinction. However, this assumption was made mostly on American SL (ASL) data, so it would be interesting to add more languages in the analysis.

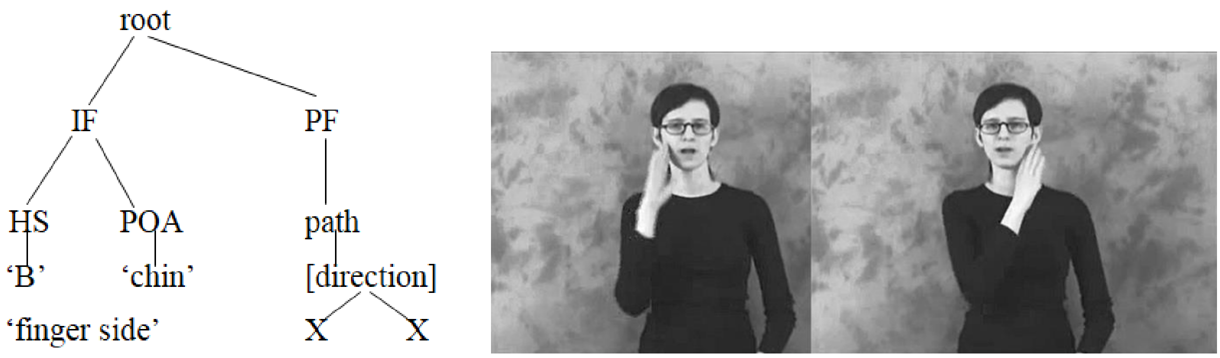


Figure 1. Movement-hold dichotomy in the Prosodic model (sign MOTHER): a tree structure on the left, the sign itself on the right

In order to get insight into hierarchy of phonological features in sign languages in general, Channon and Hulst (2011) suggest to describe separately phonemic inventories of locations, handshapes, and orientations for a sign language and then analyze how those features interact.

Many previous papers already pursued building phonemic inventories of handshapes ((van der Kooij 2002) for NGT, (Marsaja 2008) for Kata Kolok, (Schuit 2014) for Inuit SL, and (Bauer 2012) for Auslan) or handshapes and locations ((Nyst 2007) for AdaSL in Africa). However, all of them made their inventories using solely elicitation and manual annotation in their methodology. This research aims at describing phonemic inventory of the handshapes only for Russian Sign Language (RSL) using automatic methods.

The automatic method developed for this work is an implication of the movement-hold dichotomy in the phonological theories of sign languages. The idea is that in order to get an inventory of phonetic handshapes of a language it is sufficient to annotate them only in the positions without movement (aka. holds) (Liddell & Johnson 1994). Therefore, the script basically retrieves holds (i.e. positions without movement) from the video. Then the retrieved pictures with holds are manually annotated for the handshapes (and in the future perspective for locations, and orientations).

All in all, this work can be naturally split into ***two*** brunches of the research: (1) automatic holds extraction algorithm and (2) handshapes inventory in RSL. Since both of these brunches imply their own methodology and their own results and further implications, this preprint also has two parts. The first part of this paper (Chapter 2) describes the algorithm for holds extraction and discusses its efficiency and its implications on further research on phonetics of RSL and possibly other sign languages. The second part of this paper (Chapter 3) focuses on phonetic and phonemic handshape inventories in RSL starting with the methodology of this part of research and concluding with the results of the analysis. Chapter 4 provides a discussion on the implications of this work and future research directions.

2. Holds extraction algorithm

2.1. Algorithm description

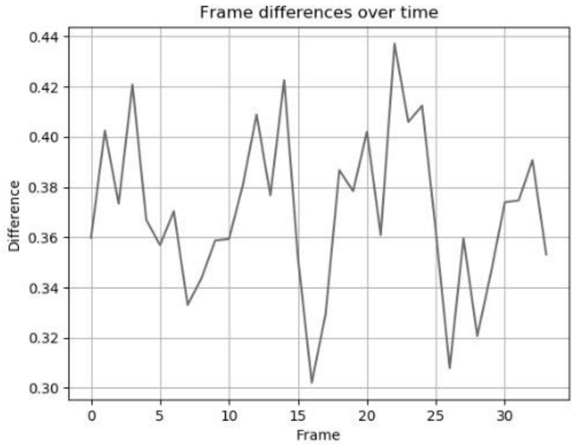
As for the core idea, the algorithm for holds extraction used in this research follows Börstell's (2018) *make-signs-still* script, although numeral significant adjustments were made and it was modified to be applicable to RSL data.

The idea is that in order to get an inventory of phonetic handshapes of a language it is sufficient to annotate them only in the positions without movement (aka. holds) (Liddell & Johnson 1994). As it was discussed before the linear structure of the Movement-Hold model (Liddell & Johnson 1994) does not account well for signs with a complex movement. However, in a case of handshapes investigation complex movements which entail aperture change do not ruin the analysis in a form of the linear structure. For example, consider the sign SUN from RSL (Fig. 2) which has an aperture change + path movement. Even though this sign has complex movement, there are still only two phonetic handshapes (closed fist in the starting position and opened fist in the ending position). The same logic goes for the situations where aperture change pairs with the orientation change. Similarly, if the complex movement does not have aperture change (e.g. path movement + orientation change), only two holds (the start of the path movement and the end of the path movement) are important for the analysis, because the handshape will still be the same in both holds regardless of the complex movement complications.

Figure 2. SUN, RSL

In this work I use videos of all RSL signs from Spreadthesign online dictionary (Hilzensauer et al. 2015) with phrases and compounds removed (3727 videos). For each video my algorithm cuts out setting frames without a moving object, i.e. hand(s), with the help of the movement detection algorithm (Rosebrock 2015). Then it calculates a histogram of color for each remaining frame, where X-axis corresponds to all 256 possible colors and Y-axis is the number of pixels of each color. Finally, it successively calculates differences between pairs of the adjacent frames with the help of B distance[3] from the *OpenCV* module for python. Consequently, I treat each video as a signal, or to be more specific as a relation between the difference between two consecutive frames' histograms of color and frame numbers (roughly speaking – time). Finally, each signal is smoothed with the help of moving average to make prominent peaks stand out (see Fig. 3). In the resulting signal, negative peaks correspond to positions without movement, and the algorithm takes one or at most two the highest negative peaks from each signal and returns snapshots of the corresponding frames with the holds. For instance, on the Fig. 3 (right) for the FALL-IN-LOVE sign the two negative peaks which contain holds would be the ones near 16th frame and near 27th frame.

[3] See the formula of Bhattacharyya distance here. The type of distance, namely Bhattacharyya was picked by the author on the same dataset experimentally in (Klezovich 2019) thesis.



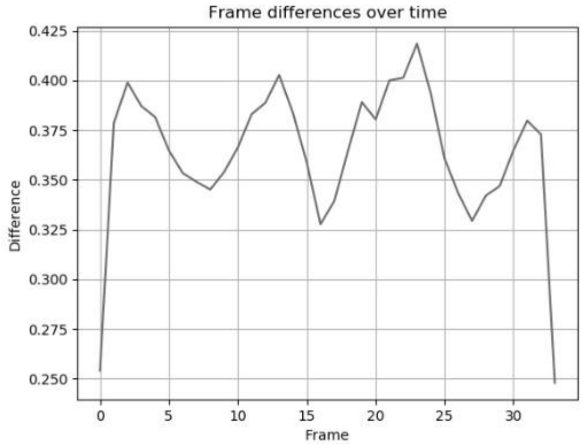


Figure 3. FALL-IN-LOVE (RSL) sign as a signal (left – before smoothing, right – after smoothing)

The core of the algorithm itself is significantly different from the script in (Börstell 2018). Firstly, it can be explained with the fact that it suits a different purpose: the Börstell's (2018) script was developed specifically for extracting hold positions from videos to make sign overlay pictures of NGT and SSL signs for respective dictionaries of these languages. Secondly, my algorithm compared to (Börstell 2018) uses moving average and highest peaks instead of continuous wavelet transform (Pan Du et al. 2006). Thirdly, it has additional cleaning from setting frames, which makes it more effective. And, finally, due to all these adjustments it is more interpretable.

2.2. Results and implications

Last but not the least, I manually estimated the accuracy of the algorithm for holds extraction by going through the first 493 signs of the dataset and checking whether estimated holds correspond to real hold positions. The estimated accuracy of the algorithm on my dataset is **76.7%**.

The algorithm was used to extract holds for all 3727 signs in the dataset. After that I went through all pictures in order to delete the ones which were obviously not hold positions in the corresponding signs. This resulted in a sample of 5189 pictures with hold positions.[4]

Crucially, there are several limitations to this algorithm. Firstly, since it takes into account only no more than two peaks (i.e. hold positions), it cannot take into consideration disyllabic signs. However, those signs are very rare typologically in general, and constitute less than 0.5% of my RSL dataset. Secondly, the algorithm is limited only to videos with one signer, because of the fact that it does not use neural networks or any complex multiple moving objects recognition. Thirdly, it does not work well with the signs that are produced too fast (e.g. the sign TO-ADAPT which is produced only for 1.44 seconds) due to the fact that moving average with the window of two frames

[4] All pictures of holds can be found here.

shortens the signal even more. If the sign is really short, the algorithm can smooth out the prominent peak so much, that it does not stand out anymore.

3. Phonetic and phonemic handshapes inventories

As it was described in the introduction, the main goal of this research is to not only extract phonetic handshapes of RSL, but also to estimate which of these phonetic handshapes can be allophones of each other.

According to van der Kooij's (2002) model of phonology, there are two main Phonetic Implementation rules which are used to derive phonemic handshapes from phonetic. The first one proposes that if handshape occurs only in iconic signs in a language, then it cannot be phonemic. The second rule says that if a handshape can be explained by the ease of articulation, i.e. phonetically, it cannot be postulated as a phonemic handshape. Although these two rules are not enough to postulate phonemic handshapes, because we also need to account for individual differences, this model suffices for preliminary findings on phonemic handshapes. So, firstly, I establish phonetic inventory of handshapes (section 3.1). Then I derive which of them could be allophones of each other using van der Kooij's (2002) model (section 3.2). I have also started to elicit the same set of words from the informants, but this discussion is out of the scope of this paper (section 4).

3.1. Phonetic handshapes inventory

After extracting holds from the dataset and manual cleaning from incorrect hold estimations, I got 5189 holds and annotated them manually for the handshapes with the help of HamNoSys (Hamburg Notation System; Hanke, 2004). Appendices 1 and 2 depict all handshapes which occur in the RSL dataset, therefore, they appear to be phonetic handshapes of RSL.

Annotation of holds resulted in 115 unique (i.e. phonetic) handshapes. 102 out of this handshapes occurred on both active and secondary hands. Only one handshape, namely №106 (see Appendix 2), does not occur on the active hand, while fourteen phonetic handshapes do not appear on the secondary hand.

The top-5 handshapes for both types of hands are represented in Tab. 1 below. The first five most frequent handshapes describe 42.8% of the whole dataset. Interestingly, these handshapes appear to be unmarked cross-linguistically, according to Battison (1978) on the basis of ASL and Nyst (2007) on the basis of AdaSL. This fact could explain why they are the most frequent in RSL.

In addition to that, according to van der Kooj (2002), “the relative frequencies of the most frequent handshapes of the dominant hand are highly similar in unrelated sign languages (van der Kooij 2002: 92 cited by Nyst 2007: 61)”. This statement holds for RSL too. Table 2 shows that ten out of the fourteen proposed by van der Kooij (2002) cross-linguistically most frequent handshapes appear to be the among the top-15 most frequent handshapes in RSL.

Table 1. Top-5 frequent handshapes

	1	**2**	**3**	**4**	**5**
handshape № in Appendix 2	71	69	14	87	1
frequency	11%	10.1%	9.8%	7.3%	4.6%

Table 2. Relative frequency of handshapes in the dominant hand in RSL compared with AdaSL, NGT, ASL, BSL, ISL (from Nyst, 2007: 61 and from van der Kooij, 2002: 93 cited by Nyst, 2007: 61)

Handshape (№ in Appendix 2)	**RSL**	**AdaSL**	**NGT**	**ASL**	**BSL**	**ISL**
B (i.e. 69, 71, 70, 72)	15%	25%	22%	23%	24%	20%
1 (i.e. 14, 13, 15, 18, 19)	16%	19%	15%	14%	15%	14%
S (i.e. 2)	2.1%	14%	10%	9%	9%	10%
bO/closed bB (i.e. 137)	1.8%	6%	5%	?	3%	8%
(Lax) O (i.e. 133)	0.4%	4%	<1%	4%	2%	6%
5 (i.e. 87)	7%	3%	13%	7%	7%	8%
A (i.e. 3)	3%	2%	4%	3%	5%	3%
V (i.e. 50, 51, 55)	2.2%	2%	3%	4%	3%	4%
X (i.e. 21)	2.1%	2%	1%	4%	?	1%

F (i.e. 144, 152, 160)	4%	<1%	5%	4%	3%	6%
H (i.e. 33, 34, 35, 39)	3%	<1%	1%	4%	4%	4%
(Lax) C (i.e. 136, 135, 134)	1.1%	1%	2%	7%	2%	3%
bC (i.e. 110, 108, 109)	1.6%	0%	1%	<1%	1%	5%
C+spr (i.e. 97)	2.1%	0%	3%	?	4%	?

3.2. Phonemic handshapes inventory

Inference from van der Kooij's (2002) model resulted in 23 phonemic handshapes on my RSL data. This is the list of all phonemic handshapes for RSL in the order of decreasing frequency (summed frequencies of their allophones) (refer to Appendix 2):

- 14 ("1"-handshape), 87 ("5"-handshape), 71 ("В"-handshape), 1 ("А"-handshape), 144 ("О"-handshape), 3, 34 ("П"-handshape), 21 ("Х"-handshape), 51 ("2"-handshape), 75, 137, 59, 30 ("У"-handshape), 68, 110 ("Э"-handshape), 125 ("Ч"-handshape), 111, 136 ("С"-handshape), 79, 29, 61, 53, and 83.

In order to explain how the allophones were established I will give an example of the inference from the van der Kooij's (2002) Phonetic Implementation rules for the phonemic handshape "1" or №14 in Appendix 2, i.e. index finger extended. All other phonemic handshapes were established in a similar way.

"1"-handshape is the most frequent phonemic handshape in RSL. It has four allophones – handshapes № 13, 18, 15, and 19 (see Appendix 2). The only difference between 14 and 13 is a position of a thumb: in 13 it is neutral, on the side of three non-selected fingers, while in 14 a thumb is covering non-selected fingers. The position of the thumb in a realization of this phoneme is phonetically motivated or dictated by a signer's preference. As for the other allophones, handshape 18 is the same as 14, but with index finger flattened. This handshape is phonetically motivated. Consider the sign VOICE (see Fig. 4 below), where a signer points at her throat, and it takes more joints to point at the throat with 14 handshapes, than with 18. In addition to that, "1"-handshape has allophones 15 and 19. Both of them differ from other allophones, because they have an extended thumb. Handshape 19 differs from 15, because its selected finger is flattened. Handshape 15 is almost always iconic (e.g. in a sign TO-THREATEN this handshape refers to a gun). It can also appear in initialized signs which start in spoken Russian with letter "Г", e.g. WARRANTY. Handshape 19 occurs only in one sign – GEOMETRY – and is phonetically predicted. It is basically handshape 15 but pointing down, and it is easier to point down with just flattening of the selected finger, without any movements in farther joints. All in all, "1"-handshape with all of its allophones has a total frequency of 23%.

Figure 4. VOICE, RSL

During the derivation of allophones I discovered three significant tendencies. Firstly, thumb position (extended or not) is often explained by individual differences. For example, this is the case for phonemic "B"-handshape. On the Fig. 5 there is a sign TO-BALANCE, which is produced with a non-extended thumb, while Fig. 6 depicts similar sign BALANCE, which is produced by a different signer with an extended thumb. One might say that this could be the way to express the difference between nouns and verbs. However, verbs in RSL are distinguished from nouns with the help of reduplication or some other movement pattern. That makes this difference pure phonetic and explained by individual differences. Interestingly, the position of the thumb is not phonologically distinctive not only in RSL, but in many other sign languages too, such as in Inuit SL (IUR) (Schuit 2014). Secondly, flattened fingers, like in handshapes №14 Vs. 18 (see Appendix 2), are usually explained by the simplicity of articulation, therefore, by phonetics. Here we could refer again to an example with "1"-handshape and Fig. 4 above for the sign VOICE. Finally, fingertips connection mostly depends on iconicity (e.g. handshape №152 compared to 144 usually refers to holding some flat object between one's fingertips) and sometimes on individual differences. On the Fig. 7[5] a signer shows sign PERFECT with simple fingertips connection as in handshape №144 (see Appendix 2), while another signer (Fig. 8) uses so-called hitchhiker fingertips connection as in handshape №152 for the same sign.

These three parameters of a handshape usually form allophones in hand configurations, and are, therefore, not phonemic.

[5] This data was elicited for research on individual differences and was not taken into account for holds extraction.

Figure 5. TO-BALANCE, RSL

Figure 6. BALANCE, RSL

Figure 7. PERFECT, RSL, first signer

Figure 8. PERFECT, RSL, second signer

3.3. Results and implications

As a result, I propose that RSL has at least 116 phonetic handshapes and at most 23 phonemic handshapes.

As for the phonetic handshape inventory, RSL appears to be typologically unusual, because Schuit (2014) proposed an idea that it is highly unlikely to find a sign language with more than 80 handshapes. However, probably this is an effect of using a bigger dataset, namely *Spreadthesign* dictionary, because most of the works on other sign languages used only elicitation getting smaller datasets.

The size of the phonemic handshape inventory of RSL is, on the contrary, in line with previous findings. It is shown by Nyst (2012) that urban sign languages tend to have more phonemic handshapes than rural sign languages. In this respect RSL is quite similar to NGT (van der Kooij 2002) which has 31 phonemic handshapes. Additionally, both RSL and NGT stand out from AdaSL (Nyst 2007), which has only 7 phonemic handshapes. What is also important to notice is that the results on phonemic handshapes are preliminary and need to be proved with the data on individual differences between signers.

4. Discussion

All in all, this work presented: (1) a new tool for retrieving hold positions from videos with signs with the help of basic computer vision methods; (2) potentially exhaustive inventory of phonetic handshapes in RSL; (3) preliminary conclusions on which of these handshapes can be allophones of each other.

There are three directions which are going to be explored in the future perspective: (1) further development of the tool for holds extraction; (2) establishing phonemic inventory of handshapes in RSL, and (3) adding more phonological features into the analysis, such as locations, orientation, and movement. All of these directions have already started to be explored.

Firstly, there is an ongoing research on the corpus data for RSL, where we develop the existing algorithm to be suitable for the corpus video. Current algorithm is heavily dependent on the contrast between the color of the background and hands of a signer and work only for one signer. In addition to that, the corpus research gives us an opportunity to compare different signers and partially accounting for the individual differences between signers. This research will give us a more clear picture of which handshapes could be allophones of each other.

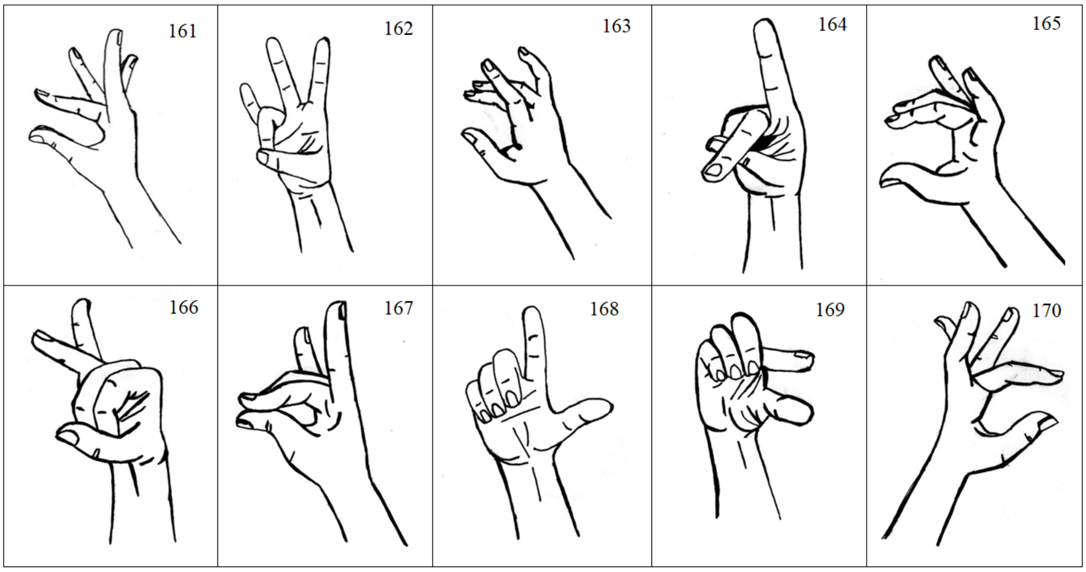
Secondly, I elicit data from different informants where the task is to name 536 words in RSL (all words are taken from the dataset in this paper). After more data is elicited it will be annotated again with the help of HamNoSys (Hanke 2004) and analyzed for agreement between the informants using Fleiss kappa (Fleiss 1971). In general, this elicitation-based research is mostly focused on the position of the thumb in different handshapes in RSL and whether it is mostly phonetic/iconic (our hypothesis) or phonemic. Since in this paper phonemic inventory of handshapes was estimated only on the basis of van der Kooij's (2002) Phonetic Implementation Rules (namely on the basis of whether a handshape can be phonetically predicted or iconically motivated), it is essential to account for individual differences between signers too. This ongoing research aims at filling in this gap.

Finally, another work in progress is to annotate the same dataset for location and orientation features with respect to HamNoSys in order to investigate relations between different phonological features on the RSL data. Location features have already been investigated for Adamorobe SL (AdaSL, Ghana) by Nyst (2007) and new RSL data on locations could be compared with Nyst's findings for AdaSL. But the most important goal of this work is to draw relations between handshape, orientation, and location features with the help of some dimensionality reduction technique. Many phonological theories of sign languages, such as the Prosodic model of phonology

(Brentari 1998), suggest that phonological features are organized in hierarchical structure. For example, the Prosodic model (Brentari 1998) proposes that orientation is lower in the hierarchical structure than handshape and location features. However, most of such theories are based either only on the American SL (ASL) data, or on the data of only a few languages, so it would be very fruitful to add the data from new sign language (Channon & Hulst 2011), in our case RSL, into the discussion of phonological structure of the sign in general cross-linguistically.

Appendices

Appendix 1. Additional phonetic handshapes which do not occur in Handshapes chart (Hanke 2010) (Appendix 2), but are present in RSL.



Appendix 2. Handshapes chart (Hanke 2010) numbered (black dots mark handshapes that occur in RSL).

HamNoSys 4 Handshapes Chart

Please note that this chart aims at demonstrating how HamNoSys handshape notations are constructed, by no means is this chart an exhaustive list of HamNoSys handshape notations.

Thomas Hanke, 2010-06-10, Drawings by Heiko Zienert, Olga Jeziorski, Andreas Hanß

References:

Battison, Robbin (1978). *Lexical borrowing in American sign language*. Silver Spring, MD: Linstok Press.

Bauer, Anastasia (2012). The use of signing space in a shared sign language of Australia. PhD Dissertation, Universität zu Köln.

Brentari, Diane (1998). *A prosodic model of sign language phonology*. Cambridge, MA: MIT Press.

Brentari, Diane (2002). Modality Differences in Sign Language Phonology and Morphophonemics. In: R. P. Meier, K. Cormier & D. Quinto-Pozos (eds.), *Modality and Structure in Signed and Spoken Languages*. Cambridge: Cambridge University Press, p. 35–64.

Brentari, Diane (2012). Phonology. In: R. Pfau, M. Steinbach & B. Woll (eds.), *Sign Language. An international handbook*. Berlin: Mouton de Gruyter, p. 21–54.

Bross, Fabian (2015). Chereme. In: T. A. Hall & B. Pompino-Marschall (eds.), *Dictionaries of Linguistics and Communication Science (Wörterbücher zur Sprach- und Kommunikationswissenschaft, WSK). Volume: Phonetics and Phonology*. Berlin, New York: Mouton de Gruyter.

Börstell, Carl (2018). Make signs still. Retrieved from https://github.com/borstell/make_sign_stills.

Channon, Rachel & Harry van der Hulst (2011). Introduction: Phonetics, Phonology, Iconicity and Innateness. In: R. Channon & H. van der Hulst (eds.), *Formational Units in Sign Languages*. Berlin: de Gruyter, p. 1–17.

Crasborn, Onno, Harry van der Hulst & Els van der Kooij (1998). Phonetic and phonological distinctions in sign languages. Paper presented at InterSign workshop on phonology, December 1998, Leiden, Manuscript.

Crasborn, Onno & Han Sloetjes (2008). Enhanced ELAN functionality for sign language corpora. In: O. Crasborn, T. Hanke, O. Efthimiou, I. Zwitserlood, H. Thoutenhoofd (eds.), *Proceedings of the Workshop on Representation and Processing of Sign Languages*. Paris: ELRA, p. 39–43.

Fleiss, J. L. (1971). Measuring nominal scale agreement among many raters. *Psychological Bulletin*, Vol. 76, No. 5, p. 378–382.

Hanke, Thomas (2004). HamNoSys - representing sign language data in language resources and language processing contexts. In: O. Streiter & C. Vettori (eds.), *Proceedings of the Workshop on Representation and Processing of Sign Languages*. Paris: ELRA, 2004, p. 1–6.

Hanke, Thomas (2010). HamNoSys 4 Handshapes Chart. Drawings by H. Zienert, O. Jeziorski, A. Hanß. Retrieved from https://www.sign-lang.uni-hamburg.de/dgs-korpus/files/inhalt_pdf/HamNoSys_Handshapes.pdf

Hilzensauer, Marlene and Klaudia Krammer (2015). A multilingual dictionary for sign languages: ”spreadthesign”.

Kooij, Els van der (2002). Phonological categories in sign language of the Netherlands: the role of phonetic implementation and iconicity.

Liddell, Scott & Robert E. Johnson (1994). American Sign Language: The Phonological Base. *Sign Language Studies*, 64, p. 195–278.

Mak, Joe & Gladys Tang (2011). Movement types, repetition and feature organization in Hong Kong Sign Language. In: R. Channon & H. van der Hulst (eds.), *Formational Units in Sign Languages*. Berlin: de Gruyter, p. 315–337.

Marsaja, I. Gede (2008). *Desa Kolok. A deaf village and its sign language in Bali, Indonesia*. Nijmegen: Ishara Press.

Metaxas, Dimitris, Mark Dilsizian, & Carol Neidle (2018). Linguistically-driven Framework for Computationally Efficient and Scalable Sign Recognition. In: N. Calzolari, K. Choukri, Ch. Cieri, Th. Declerck, S. Goggi, K. Hasida, H. Isahara, B. Maegaard, J. Mariani, H. Mazo, A. Moreno, J. Odijk, S. Piperidis, T. Tokunaga (eds.), *Proceedings of the Eleventh International Conference on Language Resources and Evaluation (LREC 2018)*. Paris: ELRA.

Nyst, Victoria (2007). A Descriptive Analysis of Adamorobe Sign Language (Ghana). PhD Dissertation, University of Amsterdam.

Nyst, Victoria (2012). Shared sign languages. In: R. Pfau, M. Steinbach, & B. Woll (eds.), *Sign Language. An international handbook*. Berlin: Mouton de Gruyter, p. 552–574.

Östling, Robert, Carl Börstell, & Servane Courtaux (2018). Visual iconicity across sign languages: Large-scale automated video analysis of iconic articulators and locations. *Frontiers in Psychology*, 9, 725.

Pan Du, Warren A. Kibbe, & Simon M. Lin (2006). Improved peak detection in mass spectrum by incorporating continuous wavelet transform-based pattern matching. *Bioinformatics*, 22, 17, p. 2059–2065.

Rosebrock, Adrian (2015). Basic motion detection and tracking with Python and OpenCV. Retrieved from https://www.pyimagesearch.com/2015/05/25/basic-motion-detection-and-tracking-with-python-and-opencv/.

Sandler, Wendy (1989). *Phonological Representation of the Sign: Linearity and Nonlinearity in American Sign Language*. Dordrecht: Foris Publications.

Schuit, Joke (2014). Signs of the arctic: Typological aspects of Inuit Sign Language. PhD Dissertation, University of Amsterdam.

Stokoe, William (1960/2005). Sign Language Structure: An Outline of the Visual Communication Systems of the American Deaf. *Journal of Deaf Studies and Deaf Education*, 10, 1, p. 3–37.

Tang, Gladys (2007). *Hong Kong Sign Language: A trilingual dictionary with linguistic descriptions*. Hong Kong: the Chinese University Press.

Contact details and disclaimer:

Anna G. Klezovich
National Research University Higher School of Economics (Moscow, Russia). School of Linguistics. International laboratory of linguistic convergence. Intern-researcher;
E-mail: anna.klezovich@yandex.ru