Phonetics of Negative Headshake in Russian Sign Language: A Small-Scale Corpus Study

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Abstract

We analyzed negative headshake found in the online corpus of Russian Sign Language. We found that negative headshake can co-occur with negative manual signs, although most of these signs are not accompanied by it. We applied OpenFace, a Computer Vision toolkit, to extract head rotation measurements from video recordings, and analyzed the headshake in terms of the number of peaks (turns), the amplitude of the turns, and their frequency. We find that such basic phonetic measurements of headshake can be extracted using a combination of manual annotation and Computer Vision, and can be further used in comparative research across constructions and sign languages.

Keywords: negative headshake, nonmanual marking, Computer Vision

1. Introduction

While the importance of nonmanual markers in sign language grammar is well understood (Pfau and Quer, 2010; Wilbur, 2021; Lackner, 2021), only a small number of studies so far focused on phonetic properties of nonmanual movements (Baker-Shenk, 1983; De Vos et al., 2009; Weast, 2011; Dachkovsky et al., 2013; Puupponen et al., 2015; Tyrone and Mauk, 2016; Harmon, 2017). An important reason for the scarcity of phonetic investigation of nonmanuals has been methodological: manual annotation of nonmanuals is difficult, time-consuming and not very reliable while more reliable methods like using Motion Capture are expensive and also very time-consuming in terms of analysis of the data (Puupponen et al., 2015).

Recent advances is Deep Learning lead to significant breakthroughs in Computer Vision (CV): currently, multiple instruments exist that allow automatic detection and tracking of the human body in video recordings, OpenPose being probably the most famous to date (Wei et al., 2016; Cao et al., 2017; Cao et al., 2018). CV has been applied to sign language data especially in the context of automatic sign language recognition and translation (Ko et al., 2018; Koller et al., 2016; Saunders et al., 2020). However, only a few studies have used CV for linguistic analysis of sign language data, and especially for analyzing phonetic properties of nonmanuals (Kimmelman et al., 2020). At the moment, it is not well understood whether existing CV instruments are even suitable for linguistic analysis of sign languages, but it is already clear that extensive testing and adjusting of CV solutions is necessary before they can be applied to sign languages at scale (Kuznetsova et al., 2021).

In this paper, we report the results of an initial investigation of phonetics of nonmanual headshake in Russian Sign Language (RSL). We use naturalistic corpus data from the online corpus of Russian Sign Language (Burkova, 2015). We attempt to identify all neg-

ative utterances in the corpus, and then manually select the utterances containing negative headshakes. Consequently, we apply a CV instrument OpenFace (Baltrusaitis et al., 2018) to extract information about head rotation in these video files in order to further analyze phonetic properties of these movements quantitatively. The aim of the study is thus two-fold. First, we describe basic phonetic properties of negative headshake in RSL, which can be a first step towards more detailed research on phonetics of headshakes in this and other sign languages. Second, we test and discuss the applicability of CV-tools for phonetic analysis of headshake.

2. Negative Headshake in SLs

One of the most common linguistic nonmanuals cross-linguistically is the side-to-side negative headshake (Zeshan, 2006; Pfau, 2008; Oomen and Pfau, 2017).[1] In different sign languages, the headshake can accompany the negative sign alone or spread across parts or the whole sentence; in some sign languages (often called *non-manually dominant*), the headshake alone can express the negative polarity, without any manual negative sign. Recent studies based on corpus data have shown that, in naturalistic data, negative headshake can be frequent but by no means obligatory (Johnston, 2018; Kuder et al., 2018).

In a recent study (Rudnev and Kuznetsova, 2021), RSL has been classified as a manually-dominant sign language: negative sentences must contain a manual negative sign. The negative signs almost always occur in the clause-final position, as in (1). Negative headshake is also extensively used, and can also spread, as in (1).

(1) $\overline{\text{INDEX}_1 \text{ THINK } \overline{\text{NOT}}}^{\text{neg}}$
'I did not think.'

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[1]In some sign languages, backward head tilt is also used to mark negation, but the negative headshake is typically also attested (Zeshan, 2006).

Our knowledge of phonetic properties of negative head-shake across sign languages is very limited.[2] In a recent small-scale study, Harmon (2017) described some aspects of phonetics of headshake in American Sign Language (ASL). She argued that ASL has two main types of headshake: canonical nonmanual negation, which begins with a wide arc and continues with smaller and smaller arcs, and intense negation, which has the same general shape, but with shorter (by 30-50%) arcs of movements. Both types of nonmanual negation can spread, and are generally temporally aligned with sign and sentence boundaries. Despite employing quantitative and CV-related techniques for data extraction, the paper does not report any quantitative results concerning phonetic properties of the headshake, and thus it is impossible to compare it to our findings below.

3. Methodology

In order to study phonetic properties of negative head-shake in RSL, we applied the following steps, which we describe in more detail below: (1) Searching for negative signs and sentences in the online corpus of RSL (Burkova, 2015); (2) Manual identification of segments containing negative headshake; (3) Manual annotation of the boundaries of negative headshake and negative manual signs in ELAN (Crasborn and Sloetjes, 2008); (4) Extraction of head rotation measurements using OpenFace (Baltrusaitis et al., 2018); (5) Quantitative analysis of a subset of the measurements.

3.1. Corpus Data

The online corpus of RSL is a collection of over 230 video recordings produced by 43 RSL signers of different ages and from different regions, filmed mostly between 2010 and 2012 (Burkova, 2015). The total duration of the video recordings is approximately 4 hours 30 minutes, and it contains around 20 000 sign tokens. The corpus is fully available on-line, but registration is required to access the data. For more details and a case study, see Bauer and Kyuseva (2022).

Most recordings in the corpus are narrative monologues, although some dialogues are also included. Each recording is annotated on 3 tiers: right hand glosses, left hand glosses, and sentence translation, in Russian. The annotations were created in ELAN, but are also accessible and searchable via the on-line interface of the corpus.

In order to identify negative structures in the data, we searched in the ELAN annotation files for words that are used to express negation in Russian, including negative particles (most prominently *ne* 'not'), negative adverbs and negative pronouns. We then watched the found segments in order to identify (1) whether they

were indeed negative structures and (2) whether they contained negative headshake.

3.2. Boundary Annotation

As mentioned above, the RSL corpus does not contain annotations of the nonmanual component. Because the horizontal position and the head movement along the horizontal plane are not exclusively associated with negation, we do not see an obvious way of automatically detecting negative headshake in the data. It might be possible to develop an ML solution, but we do not yet have sufficient data to train a model for automatic identification of headshake (see also a discussion in Section 5.3). Thus, we decided to manually annotate the boundaries of headshake in the segments that we selected before proceeding to further analysis of the data. We used the following criteria. We consider the onset of the headshake to occur on the first frame of leftward or rightward turn of the head from the position that was maintained in the previous context. We consider the offset of the headshake to occur on the last frame of the leftward or rightward turn before the head is maintained in some position afterwards. Note that, in both cases, the maintained position is not always forward-facing, as head turns can be used for functions not related to negation (see further discussion in Section 5.2). This procedure is subjective and based on laborious visual inspection of the data. In fact, in order to test reliability, the two authors independently annotated 65 instances of headshake, and only found 68% of raw overlap between the annotations. However, if manual annotations are combined with visual inspection of the results of CV data extraction, it is possible to identify the boundaries more reliably (Section 5.2).

We also annotated the boundaries of the manual negative signs to explore alignment with the boundaries of the headshake. We used commonly accepted criteria (as used for example in the corpus of Sign Language of the Netherlands (Crasborn et al., 2008)): the sign starts in the frame where the (initial) handshape is fully formed and the initial location is reached, and ends in the frame where the hand starts moving away from the final location and/or the handshape starts to change from the (final) handshape.

3.3. Measurement Extraction and Analysis

We used a Python script to cut video fragments based on annotation boundaries extracted from ELAN annotation files. These fragments served as input to Open-Face, a toolkit for face landmark detection, head pose estimation, and facial action unit recognition. (Baltrusaitis et al., 2018). Importantly, this software reconstructs a 3D model of the face from 2D video recordings, and estimates not only facial landmark locations, but also head position along the 3 axes in radians. Most relevantly for us is the estimation of head position along the horizontal axis (also know as pitch), as negative headshake is rotation of the head on this axis.

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[2]See also Coerts (1992) for some information on negative headshake in Sign Language of the Netherlands. Some research has also been done on formal aspects of negative headshake in co-speech gesture (Harrison, 2014).

We used the *find_peak* function from the Python *scipy* model (Virtanen et al., 2020) to automatically detect peaks in the estimated horizontal rotation of the head. Because the data is noisy, and even minimal head movements clearly not classifiable as head turns were detected, we applied an empirically calibrated filter set to ignore any peaks which differed from the neighbors by less than 0.01 radians (see Figure 1 for an illustration of the process).
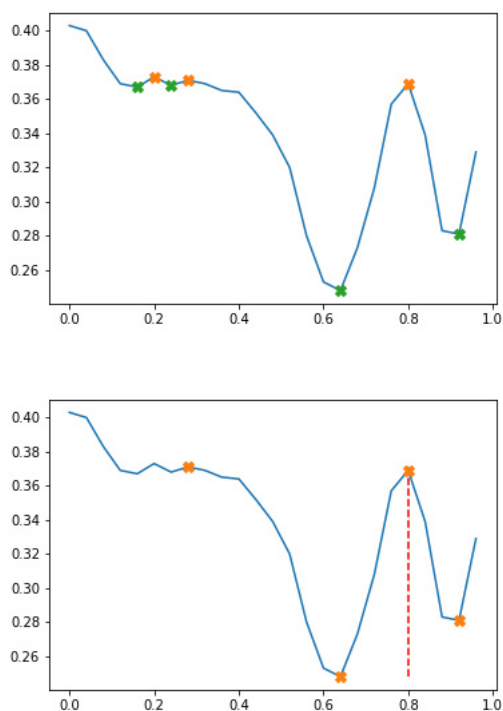

Figure 1: Top: peak identification before filtration. Bottom: peak identification after filtration and amplitude calculation.

For each headshake interval, we calculated the following measures:

- number of peaks;
- frequency: $((n_{peaks} - 1)/$duration between the first and last peaks);
- the maximal amplitude.

The amplitude was calculated as the difference between the maximal and minimal peak for the interval. This is illustrated as the red dotted line in Figure 1.

The script used for cutting video fragments and extracting measurements from the data can be found here: `https://github.com/nastyachizhikova/Negative_Headshake_Phonetics_RSL`.

For the quantitative analysis, we only focused on the headshake that co-occurs with the three most frequent manual negative signs (see Section 4). We explore the

distributions of the main phonetic measures above in these three types of constructions graphically and with basic descriptive statistics, using R and R Studio (R Core Team, 2019; RStudio Team, 2019).

4. Results

4.1. Basic Properties of RSL Negation

Using the methods discussed above, we found 663 potential instances of negative signs in the RSL corpus. However, unexpectedly, a vast majority of examples (476, 72%) did not contain visible headshake. This confirms earlier findings that RSL is a manually-dominant sign language, but it is still quite surprising that only a minority of negative sentences are also marked with headshake.[3]

Zooming in on the 187 examples that contain negative headshake, we can observe that a wide variety of manual negative markers are used in the data. The three most common types of manual negative signs are NEG, which is a side-to-side shaking of one or both palms used as the negative response sign 'no' or as a sentential negation (example 2, Figure 2, top line), NEG.EXIST which is the negative existential, but which can also be used as a sentential negation marker in combination with verbs (example 3, Figure 2, second line), and the class of irregular negative verbs (Zeshan, 2006), that is, verbs which have dedicated negative forms in RSL, such as NOT.KNOW and NOT.WANT (example 4, Figure 2, third line).

(2) ENTER $\overline{\text{NEG}}^{\text{neg}}$
    'Do not enter!'

(3) CLOSE ALSO NOTHING $\overline{\text{NEG.EXIST}}^{\text{neg}}$
    'In the one close by, there also was nothing.'

(4) INDEX$_1$ $\overline{\text{NOT.KNOW}}^{\text{neg}}$
    'I don't know.'

Another frequent negative marker is the negative particle NE, which almost always expresses sentential negation, and directly follows the verb, often cliticizing to it, as in example (example 5, Figure 2, bottom line). It formally resembles the NEG sign, but contains only a single movement of the hand.

(5) $\overline{\text{NOBODY MEET NE}}^{\text{neg}}$
    'Nobody is meeting me.'

As also discussed in earlier research, negative headshake can accompany the negative manual sign, but it also optionally spreads, as in (1). In our data, the

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[3]This is not to say that all the cases without negative headshake were unmarked nonmanually. Other nonmanuals associated with negation, such as furrowed eyebrows and lowered mouth corners did occur, but we did not analyze them further.

Figure 2: RSL signs NEG, NEG.EXIST, NOT.KNOW, NE from the examples.

spreading of the headshake was quite rare: it occurred in only 13% of the analyzed cases.

In the cases where there is no spreading, we observed remarkably precise alignment between the headshake and the manual negative sign. If we look in detail at the alignment between the headshake and the phases of the manual sign (Kita et al., 1998), the most common pattern is the following. The onset of the headshake coincides with the onset of the preparation phase of the negative sign, that is, when the hands start a transitional movement from a resting position or a preceding sign towards the negative manual sign, and the offset of the headshake coincides with the end of the stroke of the negative manual sign.

Consider Figure 3 which contains several screenshots from example (4). The first frame shows the last frame of the sign INDEX$_1$, and the head is in the neutral position. The second frame shows the retraction phase of this sign, initiating the transitional movement towards the manual negative sign, and the head starts a turning movement to the left. The third frame is in the middle of the transitional movement: the handshape of the negative sign NOT.KNOW is visible but not fully formed, and the initial location of the sign is not yet reached, while the head continues the turn. The fourth frame is the initial frame of the stroke of the negative sign, where the handshape and the initial location are fully formed, and the head starts a movement to the right. The fifth frame is the last frame of the stroke of the negative sign: the hands are still in the final location, and the head continues the turn from the headshake. Finally, in the sixth frame, the hands start moving towards the next sign, so this again is transitional movement, and the head starts another movement, a combination of turning and tilting, that is not a part of the negative headshake.

Figure 3: Selected frames from example (4), see the text for details.

In some cases the onset of the headshake is synchronized with the onset of the stroke of the manual sign, but this is less common.

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4.2. Phonetic Properties of Negative Headshake

For the quantitative analysis of the phonetic properties of negative headshake, we focused on the three most common types of manual negative signs demonstrated in (2)-(4) above. In total, we analyzed 68 sentences negative headshakes.

The first measure that we considered is the number of peaks, that is, the number of turns of the head, where a turn towards one side is counted as a single turn. Most frequently, the negative signs were accompanied with 1 or 2 turns, although 3-5 turns were also quite common, and one instance contained 14 turns.

Looking at the three types of manual negative signs, some tendencies can be observed.[4] Specifically, while both NEG and NEG.EXIST most often co-occurred with a single turn of the head, irregular negation most often co-occurred with two turns, and never with one.

Concerning the amplitude of the turns, again, the three types were very similar. In general, the mean amplitude is 0.279 radians (16 degrees), and the median amplitude 0.23 radians (13.5 degrees), so the turns are relatively small. Irregular negation seems to be accompanied by headshake of a lower amplitude than the other groups, although the difference is not significant.

The final measurement we looked at was the frequency of turns, measured as the number of turns per second. The mean frequency was 7.9 turns per second. While no significant differences between the groups were found, the average frequency for the headshake co-occurring with the NEG.EXIST sign was slightly higher than for the other two types.

Finally, we visually explored the plots of the head position extracted from the video recordings. When looking at the cases with multiple peaks, we were interested whether we can observe the pattern previously reported for ASL, namely that the headshake starts with a wide arc, and that the following arcs decrease in amplitude. We indeed found many examples that conform to this pattern, as in Figure 4, upper panel. However, in some cases no decrease in amplitude was visible, and/or the first movement did not have the highest amplitude, as in Figure 4, lower panel.

5. Discussion and Outlook

5.1. Headshake in RSL

An important finding of this study is that headshake is a relatively infrequent marker of negation in RSL. Not only is headshake alone not enough to negate an utterance (a manual sign is required), but also under 30% of negative structures in the corpus contain headshake.

However, it is still important to be able to analyze phonetic properties of headshake, which we attempt to do

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[4]None of the comparisons discussed in this section are statistically significant based on mixed effect regression models with signers as random effects. Given the very small size of the data set it is not surprising; but it does mean that all the discussed tendencies are only indications for future research.
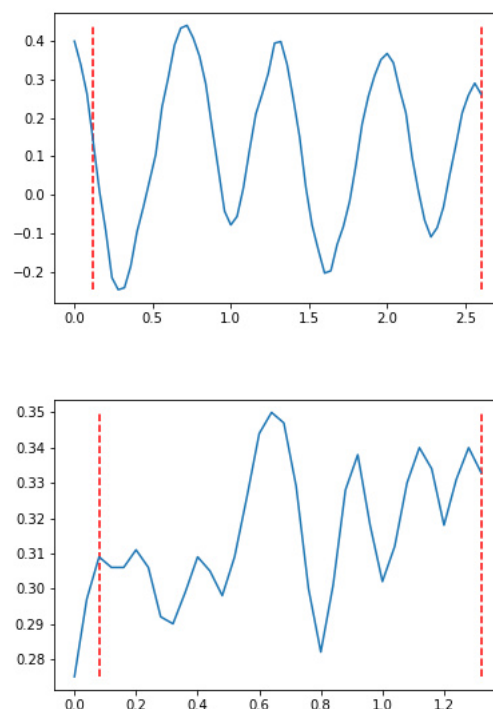

Figure 4: Example shapes of negative head movement in RSL. X-axis: time in seconds; y-axis: rotation in radians. Red lines: boundaries of the movement based on manual annotation.

in this study. We found that negative headshake in RSL most frequently contains only one or two turns of the head. This is also related to the fact that, in the majority of cases, the headshake does not spread from the negative manual sign.

On average, the head turns 16 degrees to the side when performing the headshake; the frequency of head turns in negative headshake is around 8/s. These measurements in isolation are not very useful. However, they open the perspective of comparative phonetic research. In a pilot follow-up, we looked at a small number of elicited RSL examples containing negation, and observed headshake with significantly larger amplitudes and number of peaks than in naturalistic corpus data. This is not completely unexpected, but should be investigated further.

Furthermore, while we did not find significant differences in phonetic properties of headshake accompanying the three types of negative signs, we observed some indications that there might be differences between them. For example, it seems that headshake with irregular negation typically has more peaks (at least two), and a smaller amplitude. It might be the case that different phonological types of negative headshake exist in RSL. Unfortunately we do not have a dataset that is sufficiently large to investigate this further.

Finally, similar measurements of phonetic properties of negative headshake can be conducted in future for

other sign languages with sufficiently large published corpora. Thus it will be possible to test whether phonetics of headshake varies cross-linguistically.

5.2. Applicability of CV

An important goal of this study was to test the applicability of CV to phonetic analysis of nonmanuals in sign languages, specifically, to headshake.

The measurements of head rotation extracted with OpenFace agree with our perception of head rotation in the recordings. In other words, whenever a head rotation is visible in the recording, it will be visible in the curve representing horizontal rotation of the head extracted from OpenFace. Whenever there is a peak in the movement (the head reaches the maximal degree of turning and starts moving in the opposite direction), this peak is also visible in the graph. Thus, OpenFace measurements can be used to identify the number of peaks and calculate the frequency of rotations.

The creators of OpenFace (Baltrusaitis et al., 2018) report that the absolute mean error for head rotation in their model is 2.4 degrees. It is useful to relate this to the mean headshake amplitude detected in our data, which is 16 degrees, and the standard deviation, which is 11.2. The mean error for amplitude is thus around 0.2 SD of the headshake we found. This means that OpenFace measurements can be used to estimate amplitude of headshake to this degree of certainty. However, if very small differences in amplitude are to be investigated, the measurement error can become an obstacle. We do not know of any research indicating that very minimal differences in headshake amplitude in sign languages can be meaningful, but the lack of such findings can also be due to the lack of research at that level of precision.

Finally, while OpenFace seems to produce good measurements of head rotation for video recordings, these measurements cannot be easily applied to detect negative headshake in the data. As mentioned above, head position can be used for many different purposes in addition to expressing negation; thus, a non-neutral position or even a sequence of non-neutral positions do not necessarily mean a headshake. This is illustrated in Figure 5, which shows a large amount of horizontal head movements, but only a small part of the utterance actually contains headshake. The initial part of the head movement is in fact due to the signer imitating a person looking for something.

However, it appears that one can combine measurements extracted with OpenFace and manual inspection of video recordings. Manual inspection can help identify roughly where headshake occurs, and OpenFace measurements can be used to more precisely detect its boundaries and to measure the amplitude.

5.3. Comparison to Other Types of Headshake

An issue related to the applicability of CV is comparing negative headshake to other types of headshake in
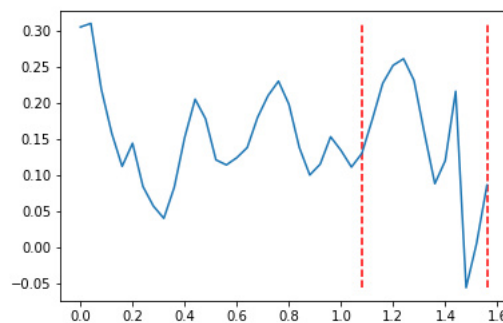

Figure 5: Example of head rotation in RSL. X-axis: time in seconds; y-axis: rotation in radians. Red lines: boundaries of the negative headshake.

RSL signers, and also comparing headshake produced by RSL signers to gestural headshake produced by e.g. speakers of Russian, in terms of phonetic characteristics. Such a comparison is necessary for quantitatively testing the claim in the literature that negative headshake in sign languages is different from gestural headshake, and that it is more grammaticalized (Pfau, 2008). Some recent corpus-based studies in fact directly question this conclusion, and argued that headshake produced by signers can be formally and functionally similar to headshake produced by non-signers (Johnston, 2018).

For the current study, we did not have the resources to compare negative headshake in RSL to headshake with other functions, or to headshake produced by non-signers. However, we think that the general methodology of using OpenFace to extract measurements of head rotation is fully applicable to conduct such a comparison in future. Furthermore, it seems conceptually possible and realistic to use output of OpenFace and Machine Learning to detect headshake in the data automatically, as the task of detecting headshake (vs. lack of headshake) is intuitively easier than distinguishing negative headshake (vs. other uses) based on measurements of head rotation alone. This automatic detection will likely need to be followed up by manual classification of the headshake detected, but this can still increase the speed of data collection and therefore sample sizes in future studies.

6. Bibliographical References

Baker-Shenk, C. L. (1983). *A microanalysis of the non-manual components of questions in American Sign Language*. Doctoral dissertation, University of California, Berkeley.

Baltrusaitis, T., Zadeh, A., Lim, Y. C., and Morency, L.-P. (2018). Openface 2.0: Facial behavior analysis toolkit. In *2018 13th IEEE International Conference on Automatic Face & Gesture Recognition (FG 2018)*, pages 59–66. IEEE.

Bauer, A. and Kyuseva, M. (2022). New Insights Into Mouthings: Evidence From a Corpus-Based Study of Russian Sign Language. *Frontiers in Psychology*, 12:779958. DOI: `10.3389/fpsyg.2021.779958`.

Cao, Z., Simon, T., Wei, S.-E., and Sheikh, Y. (2017). Realtime multi-person 2D pose estimation using part affinity fields. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*.

Cao, Z., Hidalgo, G., Simon, T., Wei, S.-E., and Sheikh, Y. (2018). OpenPose: realtime multi-person 2D pose estimation using Part Affinity Fields. In *arXiv preprint arXiv:1812.08008*.

Coerts, J. (1992). *Nonmanual Grammatical Markers. An Analysis of Interrogatives, Negation and Topicalisation in Sign Language of the Netherlands*. Doctoral dissertation, University of Amsterdam, Amsterdam.

Crasborn, O. and Sloetjes, H. (2008). Enhanced ELAN functionality for sign language corpora. In *Proceedings of the 3rd Workshop on the Representation and Processing of Sign Languages: Construction and Exploitation of Sign Language Corpora*, pages 39–43. ELRA, Paris.

Crasborn, O., Zwitserlood, I., and Ros, J. (2008). Corpus NGT. An open access digital corpus of movies with annotations of Sign Language of the Netherlands.

Dachkovsky, S., Healy, C., and Sandler, W. (2013). Visual intonation in two sign languages. *Phonology*, 30(02):211–252. DOI: `10.1017/S0952675713000122`.

De Vos, C., Van der Kooij, E., and Crasborn, O. (2009). Mixed signals. Combining linguistic and affective functions of eye brows in questions in Sign Language of the Netherlands. *Language and Speech*, 52(2/3):315–339.

Harmon, J. (2017). Simultaneous articulation as a window into structure: nonmanuals in ASL. In Nee, J., et al., editors, *Proceedings of the Forthy-Third Annual Meeting of the Berkeley Linguistics Society*, volume I, pages 121–144. Berkeley Linguistics Society, Berkeley.

Harrison, S. (2014). 112. Head shakes: Variation in form, function, and cultural distribution of a head movement related to "no". In Müller, C., et al., editors, *Handbücher zur Sprach- und Kommunikationswissenschaft / Handbooks of Linguistics and Communication Science (HSK) 38/2*, pages 1496–1501. De Gruyter Mouton. DOI: `10.1515/9783110302028.1496`.

Johnston, T. (2018). A corpus-based study of the role of headshaking in negation in Auslan (Australian Sign Language): Implications for signed language typology. *Linguistic Typology*, 22(2):185–231. DOI: `10.1515/lingty-2018-0008`.

Kimmelman, V., Imashev, A., Mukushev, M., and Sandygulova, A. (2020). Eyebrow position in grammatical and emotional expressions in Kazakh-Russian Sign Language: A quantitative study. *PLOS ONE*, 15(6). DOI: `10.1371/journal.pone.0233731`.

Kita, S., van Gijn, I., and van der Hulst, H. (1998). Movement phases in signs and co-speech gestures, and their transcription by human coders. In Wachsmuth, I. et al., editors, *Gesture and Sign Language in Human-Computer Interaction*, volume 1371, pages 23–35. Springer Berlin Heidelberg, Berlin, Heidelberg.

Ko, S.-K., Son, J. G., and Jung, H. (2018). Sign language recognition with recurrent neural network using human keypoint detection. In *Proceedings of the 2018 Conference on Research in Adaptive and Convergent Systems*, pages 326–328.

Koller, O., Ney, H., and Bowden, R. (2016). Deep hand: How to train a cnn on 1 million hand images when your data is continuous and weakly labelled. In *Proceedings of the IEEE conference on computer vision and pattern recognition*, pages 3793–3802.

Kuder, A., Filipczak, J., Mostowski, P., Rutkowski, P., and Johnston, T. (2018). What Corpus-Based Research on Negation in Auslan and PJM Tells Us About Building and Using Sign Language Corpora. In *Proceedings of the 8th Workshop on the Representation and Processing of Sign Languages: Involving the Language Community*, pages 101–106. ELRA, Paris.

Kuznetsova, A., Imashev, A., Mukushev, M., Sandygulova, A., and Kimmelman, V. (2021). Using Computer Vision to Analyze Non-manual Marking of Questions in KRSL. In *Proceedings of the 1st International Workshop on Automatic Translation for Signed and Spoken Languages (AT4SSL)*, pages 49–59, Virtual. Association for Machine Translation in the Americas.

Lackner, A. (2021). Nonmanuals in sign languages: a research desideratum. *Grazer Linguistische Studien*, pages 1–27. DOI: `10.25364/04.48:2021.93.1`.

Oomen, M. and Pfau, R. (2017). Signing not (or not): A typological perspective on standard negation in Sign Language of the Netherlands. *Linguistic Typology*, 21(1):1–51. DOI: `10.1515/lingty-2017-0001`.

Pfau, R. and Quer, J. (2010). Nonmanuals: their prosodic and grammatical roles. In Brentari, D., editor, *Sign Languages*, pages 381–402. Cambridge University Press, Cambridge.

Pfau, R. (2008). The grammar of headshake: a typological perspective on German Sign Language negation. *Linguistics in Amsterdam*, 1:37–74.

Puupponen, A., Wainio, T., Burger, B., and Jantunen, T. (2015). Head movements in Finnish Sign Language on the basis of Motion Capture data: A study of the form and function

of nods, nodding, head thrusts, and head pulls. *Sign Language & Linguistics*, 18(1):41–89. DOI: `10.1075/sll.18.1.02puu`.

R Core Team. (2019). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

RStudio Team. (2019). *RStudio: integrated development environment for R*. Boston, MA. tex.organization: RStudio, Inc.

Rudnev, P. and Kuznetsova, A. (2021). Linearization constraints on sentential negation in Russian Sign Language are prosodic. *Sign Language & Linguistics*, 24(2):259–273. DOI: `10.1075/sll.20007.rud`.

Saunders, B., Camgoz, N. C., and Bowden, R. (2020). Everybody Sign Now: Translating Spoken Language to Photo Realistic Sign Language Video.

Tyrone, M. E. and Mauk, C. E. (2016). The Phonetics of Head and Body Movement in the Realization of American Sign Language Signs. *Phonetica*, 73(2):120–140. DOI: `10.1159/000443836`.

Virtanen, P., Gommers, R., Oliphant, T. E., Haberland, M., Reddy, T., Cournapeau, D., Burovski, E., Peterson, P., Weckesser, W., Bright, J., van der Walt, S. J., Brett, M., Wilson, J., Millman, K. J., Mayorov, N., Nelson, A. R. J., Jones, E., Kern, R., Larson, E., Carey, C. J., Polat, L., Feng, Y., Moore, E. W., VanderPlas, J., Laxalde, D., Perktold, J., Cimrman, R., Henriksen, I., Quintero, E. A., Harris, C. R., Archibald, A. M., Ribeiro, A. H., Pedregosa, F., van Mulbregt, P., and SciPy 1.0 Contributors. (2020). SciPy 1.0: Fundamental algorithms for scientific computing in python. *Nature Methods*, 17:261–272. DOI: `10.1038/s41592-019-0686-2`.

Weast, T. (2011). American Sign Language Tone and Intonation: A Phonetic Analysis of Eyebrow Properties. In Channon, R. et al., editors, *Formational Units in Sign Languages*, pages 203–226. De Gruyter, Berlin, Boston. DOI: `10.1515/9781614510680.203`.

Wei, S.-E., Ramakrishna, V., Kanade, T., and Sheikh, Y. (2016). Convolutional pose machines. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, pages 4724–4732.

Wilbur, R. (2021). Non-manual markers: theoretical and experimental perspectives. In Quer, J., et al., editors, *The Routledge Handbook of Theoretical and Experimental Sign Language Research*, pages 530–565. Routledge, London; New York.

Zeshan, U., editor. (2006). *Interrogative and negative constructions in sign languages*. Number 1 in Sign Language Typology Series. Ishara Press, Nijmegen.

7. Language Resource References

Burkova, S. (2015). Russian Sign Language Corpus.