Headshakes in NGT: Relation between Phonetic Properties & Linguistic Functions

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Abstract

Non-manual markers (such as facial expressions and head movements) have been shown to fulfil a wide range of grammatical functions across sign languages (Pfau and Quer, 2010). One nonmanual marker that is very wide-spread is headshake used to express negation (Oomen and Pfau, 2017). While negation and headshake have been studied for a variety of sign languages, phonetic/kinematic research on headshake has been mostly absent. In this paper, we conduct a phonetic analysis of headshake in Sign Language of the Netherlands using a Computer Vision solution, namely OpenFace (Baltrusaitis et al., 2018). We specifically analyze whether linguistic properties of headshake (e.g. spreading and the type of signs co-occurring with the headshake) influence its phonetic form.

Keywords: headshake, negation, OpenFace, Sign Language of the Netherlands

1. Introduction

Non-manual markers (such as facial expressions and head movements) have been shown to fulfil a wide range of grammatical functions across sign languages (SLs) (Pfau and Quer, 2010; Wilbur, 2021). Moreover, it has been observed that one and the same non-manual may display different properties depending on whether it is used grammatically or as a co-speech gesture. Zooming in on grammatical uses, a certain non-manual may also fulfil various grammatical functions within a given SL (e.g., brow raise; Wilbur and Patschke 1999). Yet, to date, very few studies have addressed the question whether subtle phonetic differences might also distinguish between various functions of a multifunctional marker. In the present study, we address this question for the headshake, as used in SL of the Netherlands (NGT), using naturalistic corpus data and Computer Vision processing technology.

2. Background

2.1. Manual and Non-Manual Negation in Sign Languages

The expression of clausal negation is one of the best-studied domains of grammar for sign languages: negation has been described for a considerable number of both urban and rural SLs, there are some comparative studies available (Pfau and Quer, 2002; Zeshan, 2004, 2006; Pfau, 2016), and handbook chapters provide convenient overviews of the phenomenon (Quer, 2012; Gökgöz, 2021). These studies reveal that all SLs studied to date employ manual and non-manual markers of negation, i.e., negative elements that are manually expressed, and head movements or other non-manual elements that are articulated simultaneously with (strings of) signs. However, the ways in which manual and non-manual negators interact within a clause has been shown to be subject to interesting cross-linguistic variation.

On the one hand, there are SLs in which the use of a manual negator is obligatory; this negator is then commonly, but not obligatorily, accompanied by a headshake – or, in some geographical areas, by a backward head tilt (e.g., in Turkish SL; Makaroğlu 2021).[1] However, the non-manual does not usually spread onto neighboring constituents. Such SLs are labeled *manual dominant* SLs (Zeshan 2004).

An example from Inuit SL is provided in (1a); here, the manual particle NEG occupies a clause-final position and is accompanied by a headshake ('hs'). The example in (1b), without NEG, is ungrammatical, irrespective of the scope of the headshake (Schuit, 2013, 48,50).

(1) a. WOLVERINE EAT $\overline{\text{NEG}}^{\text{hs}}$
'I don't eat wolverine.'

b. *$\overline{\text{POLAR.BEAR SEE}}^{\text{hs}}$
'I didn't see a polar bear.'

In contrast, in other SLs, it is possible – and actually common – to encode clausal negation by means of only a headshake. Manual negative particles do exist but their use is optional. Moreover,

[1] Further non-manual markers of negation have been described in the literature, e.g., a 'negative facial expression' (Yang and Fischer 2002 for Chinese SL) and tongue protrusion (Lutzenberger et al. 2022 for Kata Kolok).

in such *non-manual dominant* SLs, the headshake may spread over parts of the clause, e.g., the verb or the entire verb phrase (Zeshan 2004). NGT has been shown to belong to this typological group. We will provide examples in the next section.

It remains to be emphasized that recent studies suggest that the dichotomy (originally put forward in Zeshan 2004) may not be sufficient. Some SLs present us with a hybrid picture in that they require the use of a manual negator, but still spreading of the headshake beyond the negative particle is possible (e.g., Rudnev and Kuznetsova 2021 for Russian SL; Pfau et al. 2022 for Georgian SL).

An important assumption underlying both the above-mentioned investigations and the present study is that the headshake, as used in these sign languages, is indeed a grammatical marker. Of course, headshakes are also commonly used as co-speech gesture in spoken interactions (e.g., Kendon 2002; Harrison 2014). However, the fact that the use and distribution of headshake across sign languages has been shown to be subject to language-specific constraints suggests that it is not a mere gesture but rather functions as a linguistic non-manual marker (see Pfau 2015 on the grammaticalization of headshake). This does not exclude the possibility that in a given sign language, the headshake is not (yet) grammaticalized (as has been argued for Australian Sign Language by Johnston 2018).

2.2. Negation and Headshake in NGT

Oomen and Pfau (2017) present a corpus-based study on the realization of standard negation in NGT. The study is based on the analysis of 120 negative clauses, including clauses with non-verbal predicates, identified in the Corpus NGT (see Section 3.1 for details). Note that Oomen and Pfau additionally annotated clauses containing neg-words, such as NOTHING or NEVER, as well as clauses containing negative modals; however, these cases were excluded from the analysis as they were not considered standard negation.[2] The attested patterns clearly show that NGT can be classified as a non-manual dominant SL – thus confirming earlier observations by Coerts (1992) and Brunelli (2011): 47 clauses (39.2%) contain the negative particle NOT (2a, 2b) while 70 clauses (58.3%) are negated by headshake only (2c) (three clauses involve negative concord and were excluded). For the former group, they further observe that NOT may either follow the verb (which often is also the clause-final position), as in (2a), or precede the verb phrase (2b).

[2]For a general overview of NGT negation, see Klomp et al. in press; for negative concord in NGT, see Van Boven et al. 2023.

(2) a. IX$_1$ POINT $\overline{\text{UNDERSTAND NOT}}^{\text{hs}}$
'I don't understand/get the point.' [390-S019-00:53]

b. IX$_1$ ACTUALLY $\overline{\text{NOT LEARN}}^{\text{hs}}$
' I'm not going to learn (it).' [065-S006-01:25]

c. IX$_3$ SELF BASIS $\overline{\text{STRONG ENOUGH IX}_3}^{\text{hs}}$
'Their basis isn't strong enough.' [386-S019-00:22]

As for the headshake, Oomen and Pfau (2017) report the following observations:

- When NOT is present, it is always accompanied by a headshake.
- Predicates are accompanied by headshake in 94% of all negative clauses.
- Objects, when present, may or may not (2a) be accompanied by headshake, no matter whether they are nominal or pronominal.
- Subjects are only accompanied by a headshake if they are pronominal (only one exception in their dataset).
- Elements that follow the verb, like pointing signs (2c) or PALM-UP (3) may be accompanied by headshake.

Based on this distribution, they claim that in NGT, the headshake may fulfil up to three different linguistic functions within a single clause, as shown in (3): (i) for the manual negator, it is *lexically* specified (hs$_\text{L}$); (ii) when accompanying the predicate, it functions as a simultaneous *morphological* affix (hs$_\text{M}$); and (iii) it may optionally spread over additional elements in the clause for *prosodic* purposes (hs$_\text{P}$). The claim regarding prosodic spreading is motivated by the observation that prosodically light elements such as pronominal subjects and clause-final pointing signs and PALM-UP (3) are commonly accompanied by headshake. As indicated in (3), the headshake is not interrupted but rather is articulated as a continuous contour across multiple manual signs (Oomen et al., 2018, 45).

(3) DEAF SELF IX$_3$ $\overline{\text{HAVE.PROBLEM}}^{\text{hs}_\text{M}}$ $\overline{\text{NOT}}^{\text{hs}_\text{L}}$ $\overline{\text{PU}}^{\text{hs}_\text{P}}$
'The deaf themselves don't have a problem (with it).' [387-S019-01:26]

2.3. Quantitative Analysis of Headshake

Not a lot of quantitative research on headshake in sign languages exists, to our knowledge. Harmon (2017) reports that ASL uses two types of headshake that differ in phonetic characteristics, but does not provide specific quantitative results. Chizhikova and Kimmelman (2022) previously conducted a study of negative headshake in Russian SL (RSL), using OpenFace (Baltrusaitis et al., 2018) to measure phonetic properties of headshake; the current study is partially an application of the same approach to NGT. In the quantitative analysis, the authors analyzed 68 instances of negative headshake from the online corpus of RSL (Burkova, 2015). For each instance, they calculated the number of peaks (reflecting the number of turns of the head), frequency and maximal amplitude, and the average measures they found in the data. Chizhikova and Kimmelman (2022) show that these measures do not correlate with the type of manual negative sign that is accompanied by the headshake.

It is important to note that RSL is quite different from NGT in terms of negative headshake, as it is clearly a manual-dominant language in the domain of negation; Chizhikova and Kimmelman (2022) found that headshake is clearly optional in negative sentences (only 28% of such sentences in the corpus had headshake). Furthermore, following the general typological trend for manual-dominant languages, while spreading of the headshake is possible (Rudnev and Kuznetsova, 2021), it is clearly rare (13% of the cases).

Given that NGT is a non-manual dominant language in which the headshake tends to spread beyond the manual negator (if present), it is reasonable to expect that the phonetic properties of headshake in NGT may be substantially different than in RSL. We therefore aim to explore possible correlations between the linguistic functions of headshake and its phonetics properties in NGT. Following Chizhikova and Kimmelman (2022), the properties we are analyzing include number of peaks, frequency, and maximal amplitude. We expect that the measures for these properties will differ depending on the predicted linguistic function of headshake, in line with Oomen and Pfau (2017). More precisely, we expect to find differences between lexical, morphological and prosodic spreading in terms of phonetic characteristics of the headshake.

3. Methodology

3.1. The dataset

For our study, we used the annotated dataset compiled by Oomen and Pfau (2017). The authors analyzed 35 video clips (amounting to approx. 95 minutes of data) from the Corpus NGT, which includes (partially) annotated video files of stories and conversations between deaf native signers of NGT (Crasborn et al., 2008). The selected videos involve 22 signers (14 female, 8 male), all from the Groningen region, with an age range between 18–50 years. As mentioned before, Oomen and Pfau analyzed 120 negative clauses from these videos, all involving standard negation. However, in contrast to them, we also include three instances of negative concord, as well as negated clauses involving negative modals (N = 21), the neg-words NOTHING and NEVER (N = 39), or the negative completive NOT-YET (N = 5), which they identified in the original data set but did not analyze further. Moreover, we coincidentally spotted one negated example that had apparently been overlooked by Oomen and Pfau. This leaves us with 220 instances of headshake for analysis.

3.2. Annotation

All 35 videos had previously been annotated in ELAN (Crasborn and Sloetjes, 2008) for manual signs (right and left hand on separate tiers for both signers) by the Corpus NGT team; most of the videos additionally included Dutch translations. Oomen and Pfau (2017) added a tier *Headshake*, on which they annotated the presence and the scope of the headshake. For the present study, we reviewed the annotations on the *Headshake* tier and made a few corrections. Furthermore, two additional tiers were created:

- *ManualNegation*: On this tier, we specified the type of manual negative sign(s) in the clause, if present. Four annotation values were distinguished – 'Neg' (for the standard clause negator), 'Neg.Mod' (for negative modals), 'Neg.Word' (for neg-words), and 'Neg.Comp' (for the negative completive NOT-YET). This tier allowed us to differentiate between clauses with standard negation and clauses involving other types of negation. Clauses with standard negation are those that (a) include the annotation 'Neg', or (b) do not include an annotation on this tier (but involve headshake only). Almost all clauses that include a manual negative sign also include a headshake (annotated on the main *Headshake* tier), although there are a handful of exceptions, typically involving manual negative signs other than the basic clause negator.

- *HeadshakeType*: On this tier, we annotated the linguistic function of a headshake, taking the claims made by Oomen and Pfau (2017) as point of departure; three annotation values were distinguished – 'Lex' for lexically specified headshake (accompanying negative signs), 'Morph' for morphological headshake (accompanying the predicate), and 'Pros' for prosodic headshake (accompanying all other signs in a clause). The annotations were aligned with the scope of the annotations for the relevant manual signs, thus excluding the transition periods between signs.

3.3. Computer Vision Processing

We extracted the clips containing headshake based on the annotation for headshake described above, using the `split_elan_videos` script (Börstell, 2022) in R version 4.3.2 (R Core Team, 2022) with RStudio version 2023.12.1 (Posit team, 2024). The details can be found in the RMarkdown document following this link: https://osf.io/mxvre/.

The clips were then analyzed in OpenFace (Baltrusaitis et al., 2018). OpenFace is a toolkit for face landmark detection, head pose estimation, and facial action unit recognition. Most relevant for this project is that OpenFace measures per frame head rotation along three axes (pitch, roll, and yaw) in radians. Headshake is essentially yaw rotation, labeled as `pose_Ry` in OpenFace. We use the `pose_Ry` measure to measure headshake.

OpenFace also estimates confidence of the measurement (once per frame), which allowed us to filter out the data points with confidence below 0.8. We also excluded four examples of headshake which contain a turn in the middle of the headshake changing the base head position (e.g. because the signer is turning towards a different interlocutor), as these turns would incorrectly affect the phonetic measures. After the clean-up phase, 215 instances of headshake remain in the data set.

3.4. Phonetic measurements

Partially following the procedure from Chizhikova and Kimmelman (2022), we decided to explore a wide variety of phonetic measures of the headshakes, which can be divided into two major groups: those requiring peak identification, and those not requiring peak identification.

The measures without peak identification include duration, rough amplitude (the difference between the maximum and the minimum `pose_Ry`), mean velocity (measured as the average difference between two adjacent frames) and peak velocity (measured as the maximum difference between two adjacent frames).

The other measures require identifying the peaks (which reflect the maximally turned positions of the head). As discussed also by Chizhikova and Kimmelman (2022), peak identification algorithms have a sensitivity parameter that needs to be calibrated in order to not identify extremely small local peaks which are due to noise in the OpenFace outputs and do not reflect real changes in head movement direction. Using manual testing and graphical exploration of the data, we determined the appropriate sensitivity parameter at 0.02 radians. We also decided to include the first and last frames as peaks manually (if not already recognized as such by the algorithm) in order to measure the difference between these and adjacent peaks. Figure 1 illustrates a single headshake with peaks identified. For the details, please see https://osf.io/mxvre/.

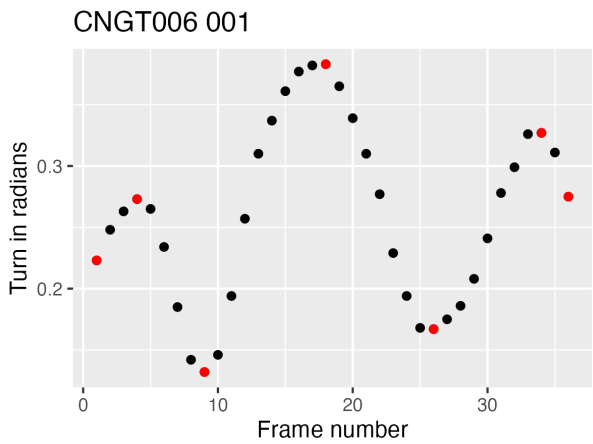

Figure 1: Results of peak identification in one headshake. Red dots are identified peaks.

Once we have the peaks identified, we can derive the following measures: peak number, frequency (number of peaks per second) and amplitude (measured as the average difference between adjacent peaks within a headshake).

An important issue concerns the boundaries of the annotations for headshake types. During the annotation process, we aligned these boundaries with the boundaries of the corresponding manual signs. However, this means that some parts of the headshake overlapping with transitional movements are excluded. Therefore, we also recorded the data such that these parts of the headshake are split equally between the adjacent manual signs. We conducted the analysis described below using both approaches. The general trends are the same between the two approaches, but the effects are less pronounced with the extended annotations.

3.5. Statistical analysis

In order to investigate the influence of linguistic functions on the phonetic properties of headshake, we explore numerically and graphically the relation between the three linguistic functions and the phonetic measures, using R version 4.3.2 (R Core Team, 2022) with RStudio version 2023.12.1 (Posit team, 2024). In each case, we calculate the mean and sd estimates per group, create violin and boxplots to explore the relation, and build mixed effect linear regression models, with individual signers coded as random factors. The full script can be found following this link: https://osf.io/mxvre/.

An important disclaimer that we want to make is that the design of the study is inherently exploratory. We try out multiple phonetic measures as we do not have a solid reason to choose on of them beforehand. For example, both rough amplitude and amplitude are measures of amplitude (the size of movement), and mean and peak velocity both measure the speed of movement. There is therefore a higher chance that some of the findings which are reported as significant, are in fact accidental. We interpret the significant differences simply as indication of where effects might be, which need to be further investigated in the future.

4. Results

4.1. Overall results

Overall, the headshakes in the dataset are characterized by the following measures of central tendencies, reported in Table 1.

measures	mean	median	sd
duration (ms)	25.5	22	13.5
rough amplitude (rad)	0.25	0.21	0.16
mean velocity (rad/sec)	0.03	0.02	0.02
peak velocity (rad/sec)	0.08	0.06	0.06
N peaks	5.93	5.00	3.18
frequency (turns/sec)	6.25	6.06	1.86
amplitude (rad)	0.14	0.11	0.10

Table 1: Central tendencies of the phonetic measures of headshakes.

Thus we can see, for example, that the average duration of a headshake is around 25 frames (1s), the average number of peaks (turns) is almost 6, with an average frequency of 6 turns per second. For all the measures, the mean is higher than the median, so the distributions are positively skewed, with the majority of the data in the lower part of the distribution, and some outliers at the higher end.

Comparing the results with RSL (Chizhikova and Kimmelman, 2022), we can notice that the rough amplitude is comparable between the two languages (0.25 radians in NGT vs. 0.28 in RSL), but that frequency is lower in NGT (6.25 vs. 7.9 Hz). Note, however, that the methodologies used in the two studies are not identical.

4.2. Manual negation and spreading

Our NGT dataset includes sentences both with and without manual negative signs, and sentences with and without spreading of the headshake. Both of these factors can potentially influence the phonetic properties of the headshake.[3]

Not surprisingly, spreading significantly affects the duration of the headshake (headshakes with spreading are longer by an estimated 11 frames[4]), while the presence of a manual negative sign does not affect the duration (Figure 2).

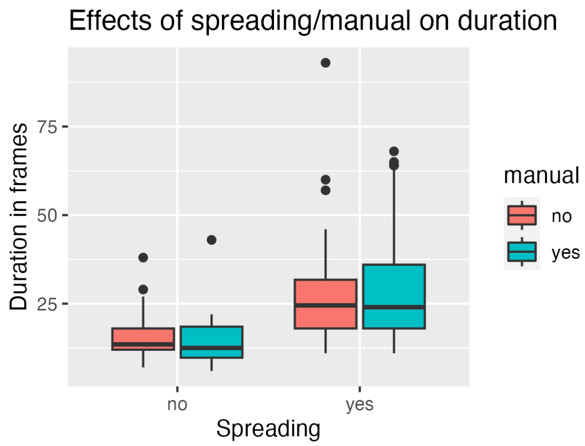

Figure 2: Effect of spreading and the presence of a manual negator on duration.

At the same time, rough amplitude, mean velocity and peak velocity are not affected by spreading or the presence of a manual negative sign.

Turning to the measures based on peak identification, again, not surprisingly, headshakes with spreading have higher number of peaks (turns), by an estimated 2.2 peaks, while the presence of a manual negator does not play a role. More surprisingly, headshakes with spreading have a lower frequency (estimated -1Hz), in comparison to those without spreading. This can be explained as follows: the cases of headshakes without spreading are quite short, but they still need to fit enough turns to be visually salient, and this leads to them having higher frequency. The peak-based amplitude measurement is not significantly affected by spreading or the presence of a manual negator.

4.3. Headshake types

Based on the framework discussed above, we divide the headshake into lexical, morphological, and prosodic parts, based on the type of sign it co-occurs with, cf. (3). We expect lexical and possibly morphological headshake to be more phonetically/prosodically prominent as these two types realize syntactic/semantic features; we do not have

[3]The nonmanual nonspreading case means that the headshake only accompanies the verb, that is, it is morphological headshake in our approach.

[4]The estimates here and below are based on the mixed effects model predictions.

a clear prediction on the lexical vs. morphological headshake.[5]

For the non-peak based measures, duration and mean velocity do not significantly correlate with the headshake types. However, both rough amplitude and peak velocity show a difference in the expected direction. When comparing prosodic headshake with the other two types combined, we observe a lower amplitude (by estimated -0.024 radians) and a lower peak velocity (by -0.007 radians per frame). Thus, we find evidence in favor of the hypothesis that prosodic headshake has a weaker realization. Note, however, that the differences, albeit significant, are very small. We do not find a significant difference between lexical and morphological headshake.

Turning to the peak-based measures, the number of peaks is not different for the different categories. However, prosodic headshake has a significantly higher frequency than the other two types (by estimated 2.2 Hz), and a significantly lower peak-based amplitude (by estimated -0.019 radians), which is in agreement with (and equally small as) the result for the rough amplitude measure above. We do not have a clear explanation for the higher frequency of prosodic headshake, but we can hypothesize that since the amplitude is decreased, a higher number of turns can be realized with the same effort in the same time period. We do not find a significant difference between lexical and morphological headshake.

4.4. Negative signs

The type of negative sign might also potentially correlate with phonetic measures of the headshake. Here, however, we do not have a clear prediction beforehand, and thus simply explore the phonetic properties of the four types. Note also that the Neg.Comp type only includes 5 cases, so any conclusions for this type are very tentative.

Of all the measures we applied, only duration and frequency produce significant results, and only for the Neg.Comp type (which is longer and has a lower frequency than standard negation Neg). However, given the extremely small number of data points, we have to conclude that we simply do not have enough data to seriously address this question. For the three types of negative signs with larger number of data points (Neg, Neg.Mod and Neg.Word), we do not see significant differences for any of the measures, resembling the findings from RSL (Chizhikova and Kimmelman, 2022).

[5]Here we report the results obtained using the boundaries aligned with the manual signs, and not the extended boundaries.

4.5. Overall amplitude development

When exploring the effects of the linguistic factors on amplitude, we also noticed a potential general trend of amplitude development over time. This trend is shown in Figure 3, where we plot the average amplitude difference between two adjacent turns (± 2 standard errors) for the turn positions. In other words, the figure shows how large the first, second, third, etc. turns are on average.

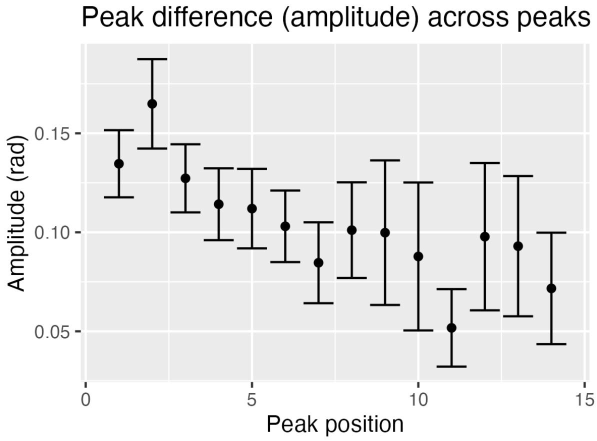

Figure 3: Mean difference in amplitude between adjacent peaks based on peak position. Error bars indicate ± 2 standard errors.

This figure indicates that the overall trend of amplitude development is as follows: the maximal turn happens at the second position, and then the amplitude goes down steadily (note that we count the neutral position in the beginning of the headshake as the first peak, and thus it is not surprising that the first turn, which is in fact a half turn, is smaller than the second).

It is possible to see a parallel here with downstep or declination of pitch in spoken languages (Pierrehumbert, 1980). Even though amplitude is apparently used for linguistic purposes (distinguishing headshake types), the overall trend is that the highest effort, and thus the highest amplitude, happens in the beginning of the utterance and declines toward the end. However, this issue needs to be studied in much more detail.

5. Discussion

5.1. Methodological aspects

Similar to Chizhikova and Kimmelman (2022), we show that it is possible to use OpenFace to measure headshake in sign languages, and to investigate the phonetic properties of these headshakes. However, it is important to realize that substantial data processing and semi-manual clean up is required.

First, it is necessary to identify the headshakes during the annotation phase. Second, cases where other non-negative head turns co-occur with the negative turns have to be excluded.

Third, the peak-identification algorithm needs to be manually calibrated. In addition, the same calibration might not work for 100% of the cases. We intend to further explore and improve the peak identification approach in future studies.

Finally, for the analysis of headshake types and other research questions involving overlap with annotations for manual signs, it is not clear how to identify the relevant region, specifically, whether the transitional movements should be included. In our data, it seems that including transitional movements leads to less clear results.

To explore phonetic properties of headshakes, we used a wide variety of measures, some of which are very similar (the two types of amplitude), and some of which are causally related to others (number of peaks, duration and frequency). From our exploration at least, we can conclude that the two measures of amplitude are pretty similar and produce similar results. Given that rough amplitude does not require peak identification, it might be a more practical measure. However, it is not usable for research question involving amplitude dynamics, as discussed in Section 4.5. Mean velocity and peak velocity are also quite similar, but peak velocity seems to be more sensitive (in our data).

5.2. Theoretical implications

Keeping in mind the exploratory nature of the study, we can still report some interesting and theoretically consequential findings.

First, we found that, unsurprisingly, spreading headshakes are longer and have a higher number of turns than non-spreading headshakes. More surprisingly, non-spreading headshakes have a higher frequency, which can be a compensatory mechanism in order to make the short non-spreading headshake more saliently visible.

It is also quite interesting that the presence or absence of a manual negative sign does not appear to play a role in any phonetic features of the headshake. This is not fully expected, as the manual sign in some sense renders the headshake superfluous. It might indicate that, in non-manual dominant sign languages like NGT, the non-manual marker is in fact primary, and thus, it is the manual sign that is superfluous and therefore less influential.

The potentially most exciting results concern the headshake types. In agreement with the theory presented in Section 2.2, headshake behaves differently depending on the manual sign it co-occurs with. Prosodic parts of headshake are realized with smaller amplitude and smaller peak velocity, in comparison to the morphological and lexical parts. This is a clear demonstration that syntactic factors affect the realization of the negative headshake, and, to our knowledge, the first demonstration of this type of effect for headshake in SLs. Note however, that the differences in amplitude and velocity are very small relative to the overall mean amplitude and peak velocity.

Given the methodological challenges and the exploratory nature of this study, we cannot be fully confident in our findings, but we think that the study provides a good indication that future studies on phonetic properties of non-manual markers using Computer Vision can be expected to lead to interesting discoveries.

Author Contributions

Vadim Kimmelman: Conceptualization, Funding Acquisition, Methodology, Investigation, Formal Analysis, Visualization, Software, Writing. **Marloes Oomen**: Conceptualization, Methodology, Investigation, Writing. **Roland Pfau**: Conceptualization, Methodology, Investigation, Writing.

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