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The Phonetics of Head and Body Movement in the Realization of American Sign Language Signs

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Abstract

Background/Aims: Because the primary articulators for sign languages are the hands, sign phonology and phonetics have focused mainly on them and treated other articulators as passive targets. However, there is abundant research on the role of nonmanual articulators in sign language grammar and prosody. The current study examines how hand and head/body movements are coordinated to realize phonetic targets. ***Methods:*** Kinematic data were collected from 5 deaf American Sign Language (ASL) signers to allow the analysis of movements of the hands, head and body during signing. In particular, we examine how the chin, forehead and torso move during the production of ASL signs at those three phonological locations. ***Results:*** Our findings suggest that for signs with a lexical movement toward the head, the forehead and chin move to facilitate convergence with the hand. By comparison, the torso does not move to facilitate convergence with the hand for signs located at the torso. ***Conclusion:*** These results imply that the nonmanual articulators serve a phonetic as well as a grammatical or prosodic role in sign languages. Future models of sign phonetics and phonology should take into consideration the movements of the nonmanual articulators in the realization of signs.

Introduction

Sign languages are the natural languages of members of the deaf community. As natural human languages, sign languages have syntactic, morphological and phonological structure, as well as stylistic and dialectal variation. Unlike spoken languages, sign languages use the hands and arms as their primary articulators. As a result, studies of sign phonetics and phonology tend to focus on the configuration, position, and movements of the hands and arms during signing. The earliest work on the phonology of American Sign Language (ASL) focused almost exclusively on the hands,

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with parts of the head and body listed as locations at which signs can be articulated (Stokoe, 1960).

The head, mouth and body are referred to in the sign language literature as nonmanual articulators, and their actions (often referred to as 'nonmanuals') are treated as having a separate function, or acting as a separate channel through which linguistic content can be conveyed (Baker and Padden, 1978; Herrmann and Steinbach, 2013; Sutton-Spence and Boyes Braem, 2003). In many cases, researchers have suggested that the hands produce lexical content during signing, while the head, eyebrows, mouth, and upper torso produce co-occurring prosodic or intonational content (and in some cases, morphemic content; Sandler and Lillo-Martin, 2006; Wilbur, 2000).

In their influential early work on nonmanuals in ASL, Baker and Padden (1978) examined videotapes of free conversation and of ASL productions elicited from English glosses. The glosses were designed to include grammatical structures with nonmanual features: conditionals, negation, yes-no questions. Baker and Padden (1978) focused on the role of nonmanuals in conveying linguistic information and analyzed the sign production data in terms of the number of separate channels of nonmanual activity. Their goals were to describe the functions of different nonmanual articulators and to determine how many independently controlled information channels must be coded in order to fully represent the content of the ASL productions. Importantly, they raise the possibility that separate information channels might be systematically coordinated, but the details of the physical coordination are not the focus of their research.

More recently, many other researchers have investigated the actions of the head and body during signing (Herrmann and Steinbach, 2013; Neidle et al., 2000; Sandler and Lillo-Martin, 2006), but rarely in terms of sign phonetics [see, however, Wilbur (2009) and Weast (2008)]. A central question in the research on nonmanuals and, in particular, on head and eyebrow movement, is whether they are fundamentally syntactic or prosodic in nature. Neidle et al. (2000) proposed that the ASL nonmanual movements that mark wh-questions, negation and topicalization are a component of ASL syntax. By contrast, Sandler and Lillo-Martin (2006) argued that these head and eyebrow movements are an aspect of ASL prosody rather than syntax. Similarly, some researchers have argued that nonmanual markers for negation and wh-marking are syntactic in some languages but morphological in others (Pfau, 2002; Pfau and Quer, 2010). Other studies have focused less on the syntactic versus prosodic nature of nonmanual grammatical markers and instead examined the functions of specific nonmanuals in greater detail (Antzakas and Woll, 2002; Gökgöz, 2013; Wilbur, 1999).

Wilbur (2000) carried out a broad analysis of the functions of many different nonmanuals and contrasted the specificity of nonmanual grammatical markers in ASL with the variability of facial expression that co-occurs with speech. She described how different nonmanual markers have different scopes and functions, and analyzed how they are timed relative to each other when they co-occur (e.g. an adverbial mouth gesture with a syntactic eyebrow rise). While Wilbur (2000) examined the interaction of phonology with morphosyntax in the realization of nonmanual markers, she did not address how nonmanuals might serve a function in facilitating production of signs. In addition, Wilbur (2000) proposed that the upper face and head in particular, and nonmanual articulators more generally, provide information equivalent to intonation in speech. In Wilbur's analysis, like in the early research by Baker and Padden (1978), nonmanuals are described as conveying information along multiple channels, simultaneously with manual actions, but without any apparent interaction between the manual

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and nonmanual channels. In contrast to this, the goal of the current study is to specifically examine the interaction between nonmanual head/body movement and the manual movements that occur during or between signs.

To our knowledge, the current study is the first to systematically compare nonmanual head and torso movement to the phonetic realization of the co-occurring manual sign. While past studies have examined nonmanuals associated with, for example, wh-questions, negation, role shift, topicalization and emphatic stress (Pfau and Quer, 2010; Quinto-Pozos and Mehta, 2010; Sze, 2013; Weast, 2008; Wilbur, 1999), none has analyzed whether certain nonmanual actions tend to co-occur with specific phonological locations or location/movement combinations. Analyzing the phonetics of nonmanuals during signing will enable researchers to better identify the functions of specific nonmanual grammatical markers as well as to better differentiate meaningful nonmanuals from those that are purely phonetic or compensatory in nature. If phonetic studies of sign production show that phonological locations on the head (or on the body) move to accommodate the actions of the hands, then it may be worth revising models of sign phonology.

Based on extensive past research, it is clear that movements of the head and of other nonmanual articulators are used to mark prosodic and syntactic structure in sign languages. However, there is no a priori reason why researchers should hypothesize a one-to-one relationship between articulator and function in the sign modality. In the context of speech, suprasegmental features (e.g. pitch, loudness, voice quality) are directly associated with vocal fold function. Nevertheless, the vocal folds play a role in segmental aspects of speech, such as voicing and place of articulation. Moreover, pitch itself varies at a segmental level as well as being a component of prosody (Peterson and Barney, 1952). In this study, we seek to identify systematic phonetic patterns in head and torso movement so that those can be more clearly differentiated from grammatical or prosodic head and torso movement.

Researchers have identified different types of manual movement in the sign modality. Ormel and Crasborn (2011) compared the kinematics of lexical and transitional movements in Sign Language of the Netherlands. They describe transitional movements as the movements of the hands that occur between signs and lexical movements as those occurring within a sign, and this is the same operational definition that we will use in our analyses. Unlike the current study, Ormel and Crasborn (2011) were investigating only manual movements and not nonmanual movements. Their main finding was that transitional movements had lower velocities than lexical movements. Wilbur (1990) also compared lexical and transitional movements, in the context of a study on kinematic differences between stressed and unstressed signs in ASL. For a set of signs with a downward movement, she measured the displacements, durations and speeds of the transitional and lexical movements. One of the main findings of that study was that transitional movements had longer durations for stressed signs than for unstressed signs. Both studies emphasized the importance of distinguishing lexical and transitional movements for sign perception and for automatic sign recognition.

Based on earlier pilot research (Mauk and Tyrone, 2012), we hypothesize that the nonmanual articulators will move during signing to facilitate contact (or approximation) with the hand. Informal observations from the same study and general principles of movement physiology lead us to also predict that the head will move to facilitate hand contact to a greater extent than the torso does. Finally, research on the kinematics of lexical and transitional movements in signing (Ormel and Crasborn,

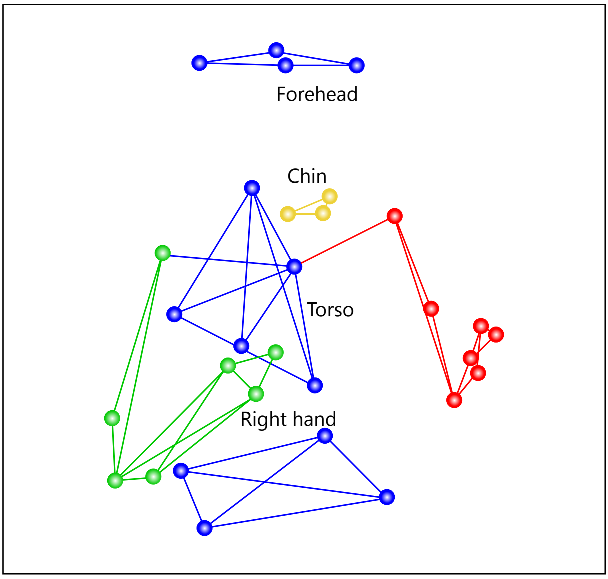

Fig. 1. Marker placement for the sign production task. Target sign locations and the dominant hand are labeled.

2011; Wilbur, 1990) leads us to expect a difference in the nonmanual movements that co-occur with those two types of manual movement. This final question has not been investigated previously, but it deserves attention, given that differences between lexical and transitional movements are likely to serve an important role, for example, in sign perception.

Methods

Data Collection

Five adult native signers (4 women and 1 man) participated in the experiment and produced ASL utterances from a script, while their movements were recorded by a Vicon motion capture system, with 6 infrared-sensitive cameras and a high-speed visible light camera. Data were collected from 30 reflective markers attached to the participants' hands, head, and body, and sampled at a rate of 100 Hz (fig. 1). A deaf research assistant presented written English glosses with accompanying illustrations to cue participants' productions (Tyrone et al., 2010).

The ASL utterances were developed in collaboration with a deaf ASL signer. The utterances were specifically designed to include target signs with either a lexical movement toward or a lexical movement away from a phonological location on the body. Note that in both of these cases, the hand must contact or approximate a location on the body, but in one case that movement is part of the sign (i.e. a lexical movement), and in the other case that movement is simply a repositioning of the hand to begin a new sign (i.e. a transitional movement). The three locations for the target signs were the torso, the chin, and the forehead. Thus, a total of 6 phrases were created (3 phonological locations × 2 movement types). The order of the utterances was randomized across recording trials. For each of the 6 phrases, 10 tokens were analyzed from each of the 5 participants. The total number of tokens considered was thus 300 (6 phrases × 10 tokens × 5 participants).

The full set of ASL utterances is listed in table 1 and images are presented in figures 2–7. In the interest of naturalness, the semantic content of the carrier phrase was adapted to each individual target sign. In order to control for phrase-level prosody, the target sign always occurred phrase-medially and was always followed by the lexical sign NOT.

Table 1. ASL utterances with English translations

ASL utterance	English translation	Movement type
KNOW *BOSS STRAIGHT* NOT. DRUNK.	You know the boss isn't sober. He's drunk.	Transitional
KNOW *MOTHER SICK* NOT. HEALTHY, OK.	You know mom isn't sick. She's healthy.	Lexical
KNOW *BOOK TRUE* NOT. MADE UP.	You know that book isn't true. It's made up.	Transitional
KNOW *FATHER DISAPPOINTED* NOT. PROUD.	You know dad isn't disappointed. He's proud.	Lexical
KNOW *NIECE WILLING* NOT. STUBBORN.	You know (my) niece isn't cooperative. She's stubborn.	Transitional
KNOW *CAR MINE* NOT. BORROWED.	You know the car isn't mine. It's borrowed.	Lexical

In each utterance, the target sign (in italics) is phrase-medial and immediately precedes the sign NOT.

Data Analysis

Changes in the positions of three markers were measured, one located at the right side of the forehead, one at the right side of the chin and one at the 10th thoracic vertebra (T_{10}), i.e. along the spine a few inches below the shoulder blades. The T_{10} marker was used instead of a marker on the front of the torso because markers on the front of the torso are often occluded by the movements of the hands and arms, and their stability is also limited in cases where the hands contact the torso and potentially jostle the markers. The T_{10} marker is a good approximation of a marker on the sternum, but in a more posterior position. For simplicity, we will refer to the T_{10} marker as the torso marker.

We were interested specifically in movements of the hand toward the body. As such, we chose sign sequences that contained such movements. To measure what the body was doing during the movement of the hand, we isolated the end point of one sign and the time when contact occurred between the hand and the body for the next sign. The change in the location of the body markers between the first and the second time points was measured.

The first location measurement took place at the end of the preceding sign. For signs like BOSS, MOTHER, and FATHER, the end of the preceding sign would be at the final contact between the hand and the body during that sign. That time was determined to be when the hand marker's movement was at a speed minimum (i.e. when the hand was essentially pausing) closest to the time when the hand reached a front-back minimum for MOTHER and FATHER, which both have forward and backward movements, and at a vertical minimum for the sign BOSS, which has a largely vertical movement. For the other signs, BOOK, NIECE and CAR, which do not involve contact with a body landmark, the end of the sign was determined by finding a speed minimum immediately preceding the movement of the hands toward contact with the body. The second location measurement took place when the Euclidean distance between a marker on the hand and a marker at the phonological location of the sign was smallest.

Data were coded for the phonological location of the sign, based on where contact between the hand and body would occur according to a phonological specification for the sign. SICK and STRAIGHT were coded as forehead-located signs, DISAPPOINTED and TRUE were coded as chin-located signs, and WILLING and MINE were coded as torso-located ones. Whether contact with the body location in question actually occurred is unknown, but visual inspection of the nonkinematic video did not look unusual in this regard.

Data were coded as to the type of movement measured. For some signs, the hand's movement is simply a transition from one sign to the beginning of the next sign (i.e. to the location where the

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Fig. 2. Sequence of ASL signs BOSS STRAIGHT.

next sign's movement will begin). Movements were coded as transitional for STRAIGHT, TRUE and WILLING, each of which has a forward movement from the body in its lexical representation. The other signs' lexical representations all include a movement of the hand to the body. For this type of sign, we measured the movement of the body from the end of the previous sign to the contact in the target sign. That means we in fact measured both the transitional movement from the previous sign's point of contact and the lexical movement of the target sign. In these cases, it is often hard to determine precisely the point at which the hand has completed its transition away from the body and begun its

Fig. 3. Sequence of ASL signs MOTHER SICK.

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Fig. 4. Sequence of ASL signs BOOK TRUE.

movement toward the body. There is rarely a pause between these movements, nor is there often a reliable speed minimum that could serve as an appropriate indicator. The signs SICK, DISAPPOINTED and MINE were all coded as including lexical movements. The average duration of data marked as transitional was approximately 90 ms shorter than the average of data marked as lexical, so we do not feel that durational differences are likely to be a major contributor to effects based on differences in movement type.

Linear mixed effects models were created in SPSS to determine the predictability of movements of the body markers. The Euclidean distance between a marker at the end of the preceding

Fig. 5. Sequence of ASL signs FATHER DISAPPOINTED.

Fig. 6. Sequence of ASL signs NIECE WILLING.

sign and at the end of the movement toward the body was the dependent variable. Phonological location and movement type were included as independent variables, and their interaction was included in the modeling. Our prediction was that a particular phonological location would result in larger movement of the corresponding marker in a direction that supports convergence of the hand and the body than if the marker does not correspond to the phonological location. We did not have a specific hypothesis about the effect of movement type. Since the data cannot be easily analyzed in all three dimensions simultaneously, individual tests were run for each dimension of movement: front-back, left-right and up-down. Signer was included in the model as a subject variable, since data were not normalized and as such cannot be pooled. Differences between signers are not analyzed here.

Fig. 7. Sequence of ASL signs CAR MINE.

Results

The modeling was significant for each marker and for each dimension of movement. Tables in the Appendix list the 9 models and their significance levels. The regression analyses revealed that both the phonological location (forehead, chin or torso) and the movement type (lexical or transitional) were relevant predictors for how much the three markers moved during these sign phrases. Each dimension of movement for each marker is discussed separately, and then the results are considered as a set.

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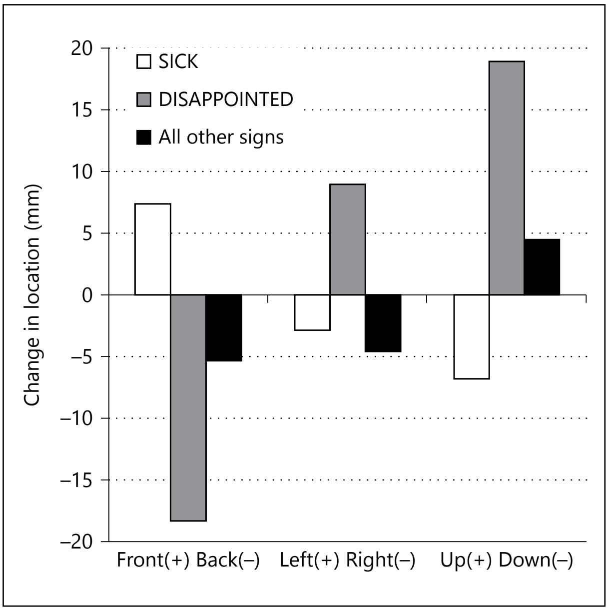

Fig. 8. Change in phonetic location for forehead marker.

Forehead Marker

For the front-back dimension, the degree of movement was found to be related to both phonological location ($p < 0.001$) and the interaction of phonological location with movement type ($p < 0.001$). On closer inspection, the interaction revealed that the chin location with a lexical movement (DISAPPOINTED) and the forehead location with a lexical movement (SICK) were different from the other signs and different from each other. In figure 8, these results are shown in the left grouping. The forehead moves forward by 7.44 mm (SE = 1.94 mm) for the forehead sign SICK, backward by 18.42 mm (SE = 2.09 mm) for the chin sign DISAPPOINTED and backward by 5.29 mm (SE = 0.91 mm) for all other signs combined.

For the left-right dimension, both phonological location ($p < 0.001$) and movement type ($p < 0.001$) and their interaction ($p < 0.001$) were found to be significant. Again the chin location with a lexical movement (DISAPPOINTED) and the forehead location with a lexical movement (SICK) were different from each other and from the other signs. The graph in figure 8 (middle grouping) shows that the forehead marker moved a small degree rightward (2.84 mm, SE = 1.81 mm) for the sign SICK, 8.95 mm leftward (SE = 1.72 mm) for the sign DISAPPOINTED and rightward by 4.62 mm (SE = 0.82 mm) for the other signs.

For the vertical dimension, the forehead marker movement was predicted by phonological location ($p < 0.001$) and the interaction of phonological location and movement type ($p < 0.001$; see the right grouping in fig. 8). The forehead marker was found to move down by 6.81 mm (SE = 1.08 mm) for the forehead sign SICK, up by 18.95 mm (SE = 1.58 mm) for the sign DISAPPOINTED and up by 4.56 mm (SE = 0.53 mm) for the other signs taken as a group.

It seems for the forehead signs that movement along all three dimensions served to assist achievement of the forehead location for the forehead sign SICK: the marker

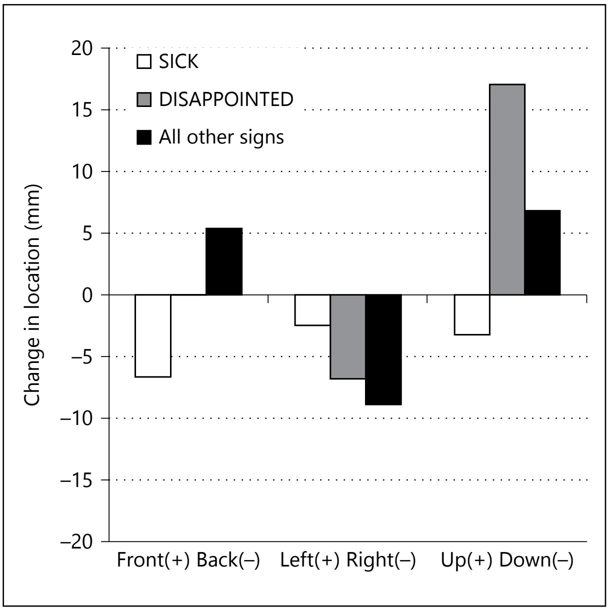

Fig. 9. Change in phonetic location for chin marker.

moved forward, rightward and downward. However, the forehead marker moved away from the hands for the chin-located sign DISAPPOINTED along all 3 dimensions. Forehead movements for the other 4 signs were not found to be significantly different and were generally small along each dimension.

Chin Marker

For the front-back dimension, both the phonological location ($p < 0.001$) and the interaction of phonological location with movement type ($p = 0.002$) were significant. In this case, the forehead-located sign with lexical movement, SICK, was different from all the other cases. Here the chin marker was found to move back by 6.61 mm (SE = 1.42 mm) for the sign SICK, while the other signs were found to move forward by 5.41 mm (SE = 0.61 mm). This result is shown in the cluster on the right side of figure 9. Note that no value is shown for the sign DISAPPOINTED not because its value was zero, but because it is grouped with the other signs in this test.

For the left-right dimension, it was found that both main factors ($p < 0.001$) and their interaction ($p < 0.001$) were significant predictors of the degree and direction of marker movement. Here the chin marker was found to move the shortest distance rightward for the forehead sign SICK (2.49 mm, SE = 2.04 mm), farther for the chin-located sign DISAPPOINTED (6.76 mm, SE = 2.29 mm) and farthest for the other signs as a group (8.91 mm, SE = 1.00 mm).

Finally, for the vertical dimension, we see that the phonological location ($p < 0.001$) and the interaction of phonological location and movement type ($p < 0.001$) were significant. The left cluster in figure 9 shows the significant differences found. This pattern was fairly similar to that of the forehead marker's movement, in that the chin marker moved downward by 3.25 mm (SE = 1.05 mm) for the forehead sign SICK, upward for the chin-located sign DISAPPOINTED by 17.10 mm

(SE = 1.29 mm) and upward to a lesser degree for the other signs (6.86 mm, SE = 0.49 mm).

Convergence between the hand and the chin was apparently not facilitated for the forehead sign SICK along the front-back dimension, but was assisted along the other dimensions. Surprisingly, while convergence with the hand during the chin-located sign DISAPPOINTED was assisted in the left-right dimension, it was not facilitated in the vertical dimension for that sign. This result will be discussed in more detail below.

Torso Marker

Movements of the torso marker are generally quite small. However, statistical modeling of movement of the torso marker was significant for each spatial dimension. These results are discussed below, but should be interpreted with caution due to their small size. Though differences were found to be significant for the torso marker, the greatest difference we observed between any two significantly different groups was less than 3.5 mm.

For the front-back dimension, phonological location ($p < 0.001$) and movement type ($p = 0.001$) are both significant predictors of torso movement, but their interaction is not. The regression model revealed specifically that the torso marker moved very little for forehead-located signs (0.12 mm, SE = 0.39 mm) but moved forward to a small degree for all other signs (3.27 mm, SE = 0.26 mm). For movement type, signs where the movement to the body was lexical (SICK, DISAPPOINTED and MINE) showed a 2.82-mm forward movement of the torso marker (SE = 0.35 mm), while those where the movement was transitional (STRAIGHT, TRUE and WILLING) showed a slightly smaller forward movement of 1.46 mm (SE = 0.30 mm).

For the left-right dimension, both main factors were significant ($p = 0.001$ for each) and their interaction was significant as well ($p < 0.001$). In this case, for the chin-located sign DISAPPOINTED, the torso marker was found to be unchanged (SE = 0.37 mm), while the marker moved rightward by 0.45 mm (SE = 0.55 mm) for the forehead sign SICK and rightward by 2.06 mm (SE = 0.27 mm) for the other signs, which were not significantly different from each other.

Finally, for the vertical dimension, both phonological location ($p < 0.001$) and movement type ($p < 0.001$) were found to be significant, but their interaction was not. The torso marker moved upward most for torso-located signs (1.56 mm, SE = 0.15 mm), to a smaller degree for chin-located signs (0.89 mm, SE = 0.17 mm) and downward for forehead-located signs (0.66 mm, SE = 0.16 mm). When considering movement type, the difference between groups was quite small, with movement for signs where the movement was lexical being 0.92 mm upward (SE = 0.16 mm) and where it was transitional being 0.28 mm upward (SE = 0.14 mm).

Looking at these results, it seems that the forehead and chin markers often moved to a greater degree when the phonological location of the sign was a head location and the movement included a lexical movement rather than only a transitional movement. However, it was not always true that the forehead marker moved to a greater extent when it was a forehead-located sign rather than a sign located at a different body location. The same was true for the chin marker. Regardless of the movement size, the forehead's movements seemed to be largely assisting convergence of the forehead location and the hand. For the chin, movements were sometimes assisting convergence, but not in all cases. To better understand these results, it is important to not consider the movement of the body during these signs alone, but also to examine the body's position

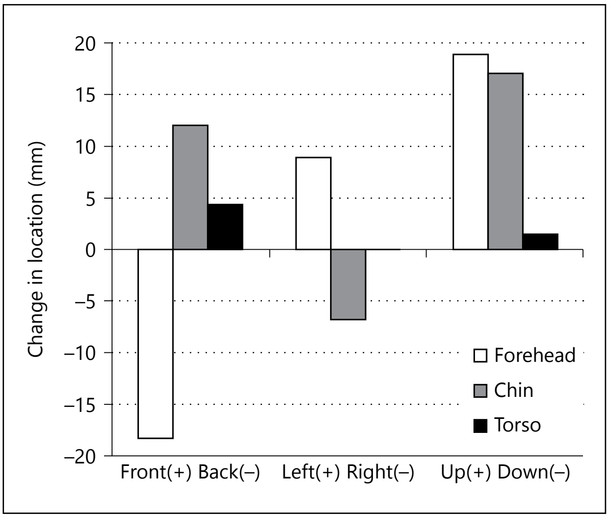

Fig. 10. Change in phonetic location for markers during FATHER DISAPPOINTED.

during a sequence of signs. The two signs SICK and DISAPPOINTED were repeatedly found to be distinct from the others and from each other. Detailed descriptions of each of these signs are given below to better elucidate how the markers were moving with respect to each other. This will give a clearer picture of the head's contribution to the achievement of convergence with the hand. Because movements of the torso marker were always quite small, we do not feel that further explication is needed.

The Sequence FATHER DISAPPOINTED

The sign FATHER would be described phonologically as being located at the forehead and the sign DISAPPOINTED located at the chin (fig. 5). The forehead and chin marker movements are essentially connected by virtue of both being attached to a fairly rigid body, the head. As a result, changes in the location of one marker are often reflected in changes in the location of the other marker. For the purposes of the descriptions below, the data reported above have been reorganized so that all data on movement of the forehead marker for DISAPPOINTED appear in figure 10.

In the movement from FATHER to DISAPPOINTED, as the forehead marker moves back, the chin marker moves forward. This is likely the result of the head pivoting at the neck. At the same time, the torso marker is moving forward to a smaller degree, likely assisting the forward movement of the chin marker. Notice that the relatively forward position of the forehead during the forehead-located sign FATHER and the relatively forward position of the chin during the chin-located sign DISAPPOINTED both indicate that the head shifted to assist the phonetic realization of the phonological location of these signs.

Similarly, the head seems to pivot such that the forehead marker shifts left as the chin marker shifts right, while the hand moves from FATHER to DISAPPOINTED. As in previous cases, the change in position indicates a body movement to facilitate achievement of the location. As noted above, all signers in this study were right handed, so a rightward position indicates that the body part was shifted in the direction of the dominant hand. The forehead is to the right during the sign FATHER and the chin is to

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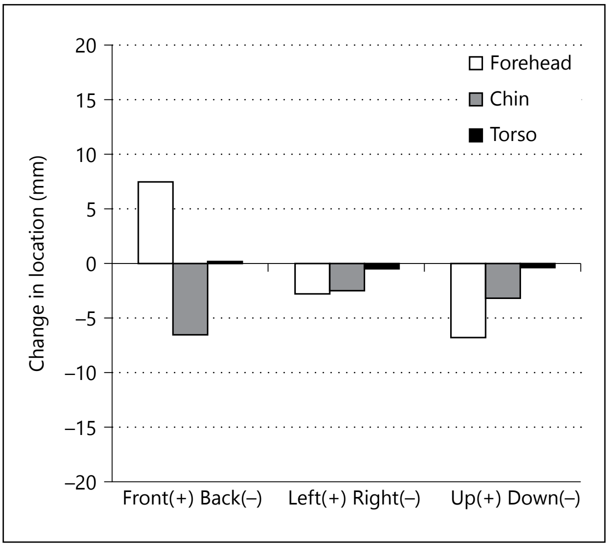

Fig. 11. Change in phonetic location for markers during MOTHER SICK.

the right for the sign DISAPPOINTED. The torso marker does not shift rightward or leftward.

Finally, the vertical dimension of the markers indicates facilitation of phonological location as well. The hand is high for the forehead-located sign FATHER and moves downward to shift into the sign DISAPPOINTED. As the hand moves down, the forehead and chin are both moving up. For the sign FATHER, the forehead was in a relatively low position, meaning that the hand did not have to rise as far as it might have otherwise. As the hand moves down, the chin moves up to reduce the distance the hand must move to achieve the next location. The torso also has a small upward movement, perhaps to facilitate the upward movement of the head.

The Sequence MOTHER SICK

Figure 11 shows the data for movements of the markers during the sequence MOTHER SICK. When considering the sequence of the chin-located sign MOTHER followed by the forehead-located sign SICK (fig. 3), first note that often the change in marker position is less than the analogous changes during the sequence FATHER DISAPPOINTED. It is not clear why that would be the case. Torso shifts during this sequence were found to be fairly minimal.

For the front-back dimension, we see an opposite pattern from FATHER DISAPPOINTED. That is, the forehead marker moves forward while the chin marker moves back. As before, this indicates that the chin was farther forward for the chin-located sign and the forehead was farther forward for the forehead-located sign.

For the left-right dimension, the forehead and chin markers both move to the right. Both signs tend to involve contact near the body's midline. For the chin-located sign MOTHER, the hand does not occlude the signer's face to a great degree, but for a forehead medial sign like SICK, it may. The rightward movement of the head markers may indicate a rotation of the head so that the sign SICK can still make contact near the midline, but the face is less obscured.

For the vertical dimension, the forehead marker was lower for the forehead-located sign. The chin was higher for the preceding chin-located sign. In isolation, one might expect that when the signer produces a chin-located sign like MOTHER, the hand would move up to the chin and the chin would move downward. It is not immediately clear why the chin would be in a relatively high position during the sign MOTHER in this case. However, considering the phrase in its entirety, a reason emerges. The forehead-located sign KNOW preceded MOTHER. As a result, the head may have been lowered while the hand was high for the sign KNOW, then as the hand moved down for MOTHER, the head moved up to bring the chin to the hand, and finally as the hand moved up again for SICK, the head shifted down again.

In summary, it seems that for these two sequences, MOTHER SICK and FATHER DISAPPOINTED, changes in marker position for the forehead and chin were indeed assisting convergence of the body and the hand, not only for the signs that we were focusing on (SICK and DISAPPOINTED), but also for the signs that preceded them.

Discussion

The main finding of this study is that the head moves to facilitate the realization of phonetic locations at the chin or the forehead, as predicted based on a previous study (Mauk and Tyrone, 2012). In addition, we found that both the forehead and the chin showed larger movement amplitudes during signs with locations on the head and a lexical movement toward the location. By contrast, the chin and forehead showed significantly less movement for signs located at the torso and for chin- and forehead-located signs that did not include a lexical movement toward the location. The torso did not move to facilitate contact with the hand for torso-located signs, even to a moderate degree, irrespective of the type of manual movement (i.e. lexical or transitional). Taken together, these findings suggest that not all sign locations should be viewed as equally static in models of sign phonology.

There are several reasons why we might expect to see more phonetic head movement than torso movement during signing. Compared to the head, the torso is much larger and heavier, and more subject to the effects of gravity and inertia, so it is less likely to move in order to facilitate contact or convergence with the hand. In addition, shifting the position of the torso requires the coordination of multiple muscle groups and would require additional effort to avoid causing shifts in the positions of the head, neck, and arms. For these reasons or others, it may be that torso movement during signing is used primarily for grammatical or pragmatic purposes and not to facilitate contact with the hand. It is worth noting that the participants in this experiment were all seated, which could well have limited the amount of torso movement that occurred during signing. This is a point that future studies comparing the contributions of different nonmanual articulators should take into account.

A few studies have examined kinematic differences between lexical and transitional movements in sign languages (Ormel and Crasborn, 2011; Wilbur, 1990). Models of sign phonology include movement as a structural primitive, but at a phonetic level, there is not a consistent, straightforward method for differentiating lexically specified movements from the transitional movements that occur as the hand moves from one sign to another. Ormel and Crasborn (2011) identified distinct kinematic signatures of lexical and transitional movements, based on movement trajectories of the fingers,

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as measured by a set of cybergloves. For two-sign sequences, they found that lexical movements had higher velocities than transitional movements. Similarly, Wilbur (1990) found that emphatic stress affected lexical and transitional movements differently. For signs with a phonological location on the head, we may have identified a kinematic distinction between these two types of movement in the form of compensatory head movement that facilitates contact with the hand. This finding illustrates the value in examining sign movement in relation to the nonmanual articulators, given that both manual and nonmanual articulators are active during sign production, and both contribute to the realization of manual signs.

In light of the many studies of head movement and negation, it is worth noting that all of the target signs in this study were negated. Because all the signs that were examined immediately preceded the lexical sign NOT and occurred phrase-medially, there is no reason to assume that sign-specific differences were related to negation marking. It is more likely that such differences are due to some aspect of the sign's structure, such as its location or movement. To our knowledge, the form of negation headshake in ASL is not influenced by the sign that is modified, and there is no theoretically sound way to speculate what form a negation headshake would take for one sign as opposed to another. Moreover, a systematic visual inspection of the videos of the experiment indicates that a negative headshake occurred in less than 10% of the productions analyzed. Finally, if negation and phonetic head movement were interacting, the likely effect would be to obscure our findings rather than contribute to the sign-specific differences we have identified. Further investigation would be needed to address specifically how these two types of head movements might interact.

This study suggests parallels between the sign and speech modalities at the level of phonetics and prosody. In particular, the type of compensatory head movements identified in the current study may be analogous to intrinsic f_0 in speech. In nontonal languages, f_0 variation functions mostly at a prosodic level, for example marking phrase boundaries and conversational turns. However, at the same time, precise measurements of f_0 show that different vowels vary systematically not just in their formant frequencies but also in their values for f_0 (Peterson and Barney, 1952). In the sign modality, head movement could operate similarly, where its most apparent function is prosodic, while it also varies in its realization at a purely phonetic level. This phonetic variation could be related to specific signs, or to specific sign locations.

To our knowledge, this is the first study of how phonetic head and body movements are affected by the phonetic form of a sign. Thus, our findings are preliminary and should be complemented by future research addressing similar research questions through the use of different methodologies. In particular, it would be informative to examine phonetic head and body movements in more naturalistic signing data, for example, semispontaneous or structured conversation or narrative production, in conjunction with precise phonetic data. This approach would allow future studies to examine a broader range of target signs and of phonetic contexts, while at the same time controlling for the large degree of individual variation reported in past research on sign phonetics. Conversely, future studies might broaden our understanding of phonetic head movement by more tightly controlling the phonetic environment in which target signs are produced, in order to minimize the coarticulatory effects of surrounding signs. Repeated use of the same carrier phrase in a single experiment can lead to an artificially formal signing style, but it also allows researchers to identify phonetic context effects in detail.

Conclusion

Based on past research, as well as casual observation, it is clear that head and body movements are used for prosodic and syntactic purposes in sign languages; however, this does not mean that the head and body only function at these levels in the sign modality. It is apparent from the current study that the head in particular moves in order to facilitate contact with the hand during signing.

All the target signs in our data set allowed (but did not necessarily require) contact at the sign's phonological location. It is not clear whether signs that include contact would show different patterns of head or body movements compared to signs that do not include contact. Moreover, it is unclear whether noncontacting signs at one location would show similar nonmanual phonetic movement to signs at other locations or in neutral space. It may be, for example, that the head moves to facilitate contact with the hand but does not move to facilitate head-hand approximation in the absence of contact, for example, in a sign such as WONDER in ASL.

This study only examined the productions of native ASL signers. It would be interesting to collect similar sign production data from nonnative or inexperienced signers. This type of research could help determine whether the patterns identified here are shaped more by early language exposure or by extralinguistic factors such as biomechanical or perceptual constraints. Past research on nonnative sign language acquisition suggests that bimanual coordination in signing takes many weeks to develop (Lupton and Zelaznik, 1990). Coordination between manual and nonmanual articulators may also be delayed in nonnative signers. Along similar lines, it is not clear whether the phonetic patterns in head and body movements identified here are specific to ASL or whether they also occur in other sign languages. Further research is needed to clarify whether the current findings reflect a universal phenomenon.

Since the earliest stages of sign language research, it has been recognized that signers use the nonmanual articulators in systematic, rule-governed ways. Thus, it should come as little surprise that nonmanual actions are coordinated with movements of the hands during sign production, as illustrated by the current study. As a central component of sign language structure, nonmanuals should receive more attention in future studies of sign phonetics.

Appendix: Linear Mixed Regression Models

Forehead front-back	F	d.f.	Significance
Corrected model	14.751	5, 294	$p < 0.001$
Phonological location	20.957	2, 294	$p < 0.001$
Movement type	0.008	1, 294	n.s.
Interaction	26.448	2, 294	$p < 0.001$

Forehead left-right	F	d.f.	Significance
Corrected model	29.686	5, 294	$p < 0.001$
Phonological location	25.923	2, 294	$p < 0.001$
Movement type	31.573	1, 294	$p < 0.001$
Interaction	32.505	2, 294	$p < 0.001$

Forehead vertical	F	d.f.	Significance
Corrected model	50.391	5, 294	$p < 0.001$
Phonological location	73.048	2, 294	$p < 0.001$
Movement type	1.269	1, 294	n.s.
Interaction	52.295	2, 294	$p < 0.001$

Chin front-back	F	d.f.	Significance
Corrected model	29.062	5, 294	$p < 0.001$
Phonological location	65.589	2, 294	$p < 0.001$
Movement type	1.544	1, 294	n.s.
Interaction	6.294	2, 294	$p = 0.002$

Chin left-right	F	d.f.	Significance
Corrected model	23.785	5, 294	$p < 0.001$
Phonological location	22.466	2, 294	$p < 0.001$
Movement type	14.634	1, 294	$p < 0.001$
Interaction	29.679	2, 294	$p < 0.001$

Chin vertical	F	d.f.	Significance
Corrected model	39.606	5, 294	$p < 0.001$
Phonological location	61.495	2, 294	$p < 0.001$
Movement type	1.273	1, 294	n.s.
Interaction	36.884	2, 294	$p < 0.001$

Torso front-back	F	d.f.	Significance
Corrected model	14.887	5, 294	$p < 0.001$
Phonological location	29.820	2, 294	$p < 0.001$
Movement type	10.700	1, 294	$p = 0.001$
Interaction	2.048	2, 294	n.s.

Torso left-right	F	d.f.	Significance
Corrected model	15.553	5, 294	$p < 0.001$
Phonological location	6.690	2, 294	$p = 0.001$
Movement type	10.731	1, 294	$p = 0.001$
Interaction	26.826	2, 294	$p < 0.001$

Torso vertical	F	d.f.	Significance
Corrected model	24.319	5, 294	$p < 0.001$
Phonological location	52.782	2, 294	$p < 0.001$
Movement type	12.522	1, 294	$p < 0.001$
Interaction	1.755	2, 294	n.s.

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