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Expanding Echo: Coordinated Head Articulations as Nonmanual Enhancements in Sign Language Phonology

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Abstract

Echo phonology was originally proposed to account for obligatory coordination of manual and mouth articulations observed in several sign languages. However, previous research into the phenomenon lacks clear criteria for which components of movement can or must be copied when the articulators are so different. Nor is there discussion of which nonmanual articulators can echo manual movement. Given the prosodic properties of echoes (coordination of onset/offset and of dynamics such as speed) as well as general motoric coordination of various articulators in the human body, we expect that the mouth is not the only nonmanual articulator involved in echo phonology. In this study, we look at a fixed set of lexical items across 36 sign languages and establish that the head can echo manual movement with respect to timing and to the axis/axes of manual movement. We propose that what matters in echo phonology is the visual percept of temporally coordinated movement that repeats a salient movement property in such a way as to give the visual impression of a copy. Our findings suggest that echoes are not obligatory motor couplings of two or more articulators but may enhance phonological distinctions that are otherwise difficult to see.

Keywords: Sign language phonology; Echo phonology; Head articulations; Motor coordination

1. Introduction

The term *echo phonology* was coined by Woll and Sieratzki (1998) to capture the observation that the articulation of manual signs can sometimes be coordinated with semantically empty but obligatory movements of the lips, tongue, and jaw. The authors define echo phonology as a visual and motoric "echo" of manual articulations on the mouth (see also Woll, 2001, 2008, 2014).[1] Specifically, echoes copy some aspects of hand

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articulation: "onset and offset, dynamic characteristics (speed and acceleration) and type of movement (e.g., opening or closing of the hand, wiggling of the fingers)" (Woll, 2014, p. 4). For example, in British SL[2] TRUE (Fig. 1), as the hands move to contact one another, so do the lips (MacSweeney, Capek, Campbell, & Woll, 2008). And in British SL THANK-GOD, the lips touch at the same time as the selected fingers come into contact (Woll, 2001).

Woll and colleagues' definition of echo seems at once too minimal and too broad. Applying the single criterion of coordinated movement of onset and offset, in particular, overgenerates by classifying nonmanuals as echoes when only the timing of manual and nonmanual articulations is coordinated. One commonly cited example consists of finger trilling while the mouth articulates a sibilant, as in British SL EXIST (Woll, 2014) and German SL OWN (Pendzich, 2020). Another involves radioulnar rotation while the mouth articulates a voiceless pharyngeal fricative followed by a rounded front vowel or by [w], as in British SL WIN (Woll, 2014). Woll (2008) also cites British SL NOT-YET as an example of echo phonology. The sign has side-to-side forearm movement (achieved by shoulder rotation) accompanied by a sibilant, where it is not obvious that any mouth articulation (lip or tongue) mimics that of the forearm. Since nonmanual prosodic behaviors in general depend on manual production (Liddell, 1984; Nespor & Sandler, 1999), simple timing coordination cannot be a sufficient criterion for echoes.

At the same time, the relative brevity of the original definition of echo phonology leaves many questions open. What does it mean for a movement (type) to be coordinated? Part of the general assumptions about echo phonology seems to be that the manual and nonmanual articulators have matching features with regard to movement direction. Evidence from mouthing that accompanies fingerspelling shows that motoric coordination involving opposite features is possible as well. Using motion capture technology, Udoff (2014) shows that signers of American SL coordinate the onset and offset of hand and mouth movements in mouthing-accompanied fingerspelling, and

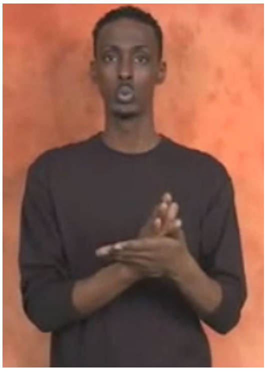

Fig. 1. TRUE in British SL (fig. 8b in Woll, 2001).

they further coordinate the degree of opening or closing of both articulators. Signers do so even when hands and mouth move in "opposite directions." Opposite direction may sometimes be interpreted in the mathematically obvious way, for instance the head moving backward as the hand moves forward, all along a straight line; but not, for example, the head tilting sideways as the hand moves forward. Other times, opposite direction is to be interpreted in a more physiological way. For example, when the hands produce the sequence of manual alphabet letters B-A, the base and interphalangeal knuckles of the fingers change from extended to flexed as the handshape changes from a flat hand with an opposed thumb (a B), to a closed fist with unopposed thumb (an A). At the same time, the mouth articulates as though it is producing [bɑ]; that is, the articulation starts with the lips closed and ends with them apart. Udoff thus shows that there are no motoric constraints on coordinating the movement of two articulators (here hand and mouth) in opposite directions. In light of the echo phonology literature, however, he hypothesizes that linguistic constraints prefer inter-articulator coordination in the same movement direction whenever that is possible. Coordination of movement between fingerspelling and mouthing is constrained by the phonology of the spoken language, and hence does not allow modifications of the movement direction of the mouthed articulations. Udoff claims that when mouth articulations are not thus constrained (because they are meaningless), there is a linguistic preference for them to match the hand movement with respect to direction. In this paper we present evidence from hand–head coordination that suggests that even with meaningless nonmanual articulations, coordination in opposite movement directions occurs.

In addition to wondering which components of the manual movement are copied in echo phonology and how, one might ask whether mouth movements are the only nonmanuals subject to echo phonology. If echo mouth articulations are an instantiation of prosodic nonmanual behaviors coordinated with manual articulations, then we might expect to find movement that echoes manual articulation on other nonmanual articulators as well (see the discussion in Pfau & Quer, 2010, p. 385). Already in 1998, Brentari observed non-mouth echo phenomena when she described that in some signs "the nonmanual behavior expresses the same type of movement as is expressed in the manual component" (1998). She goes on to illustrate the phenomenon with a variant of the American SL sign PERPLEXED in which the backward path movement of the dominant hand in front of the forehead is copied by a backward movement of the head (as shown in Fig. 5).

Likewise, Pendzich (2020) coins the term "mirroring nonmanuals" to refer to echo phenomena that include nonmanuals on the lower and upper face as well as the entire head. In a study on Finnish SL, Puupponen and colleagues note that about 2% of head movements in their data copied the manual path movement such that "the stroke in the head movement was produced simultaneously with a stroke in the manual movement" (2015, p. 33).

In this paper, we cast a typologically wide net to address the question of what counts as echo phonology. Our claim is that echo phonology may simply be one subtype of a much larger system of inter-articulator coordination that can involve (a) a range of

Fig. 2. PERPLEXED in ASL (from Brentari 1998, p. 174, reprint courtesy of the MIT Press)

nonmanual articulators, and (b) temporal and spatial coordination along one movement vector (in either the same or opposing directions). Following Brentari (1998), we further claim that the effect achieved by nonmanual echoing is to enhance the phonetic signal.

To investigate the possibility of echo articulators beyond the mouth, we look at head articulations in selected dictionary entries across 36 sign languages. We choose the head over other nonmanual articulators because of its size and resulting conspicuousness, as well as its range of motion; the neck area or cervical spine is the most flexible part of the spine (InformedHealth.org [Internet], 2006). If, as argued by Brentari (1998), phonological echoes serve to enhance the phonetic signal, then we are more likely to find echo phenomena in larger and therefore more visually salient nonmanual articulators, such as the head, than we are to find them on smaller articulators, such as the eyelids. In terms of which components of the manual articulation are copied in echo phenomena, we focus on one easily discernible feature of articulation that of movement along a particular axis or dimension.

The paper is structured as follows. Section 2 lays out the origins of the concept of echo phonology in the literature, which has led to favoring the mouth as the prime echo articulator. Section 3 describes the data set for this study and identifies the five basic head articulations involved in echo phonology. In Section 4, we describe the different echoes found in the data arranged by the type of head articulation. Section 5 provides an analysis of the data based on the relative incidence of different head articulations in the data set, correlations between manual and head movement in both simple (along a single axis) and complex (along more than one axis) movements, and the feature of movement direction. We offer a general discussion of the results and conclusions in Section 6.

2. Reviewing the prominence of hand–mouth coordination in the echo literature

Much of the early interest in echo phonology comes from the proposal that hand–mouth co-articulation may be evidence for an evolutionary route through which spoken language could have evolved in parallel with (or perhaps from) sign language. Thus, echo phonology might offer support for a motor-based evolution of speech, and would complement the proposals of others that the open–close mandible cycle (as in chewing, licking, and sucking) led to early vocalizations and babbling (MacNeilage, 1998; MacNeilage & Davis, 2000). This approach naturally places the focus on mouth echoes, and we will summarize it here.

The claim that the mouth moves in "sympathy" with the hands during language production did not originate in sign language studies; versions thereof can already be found in Charles Darwin's work (for a brief history of such claims, see Woll, 2008). More recently, neurobiological studies have confirmed the ubiquity of mouth–hand co-articulation in motor domains other than (sign) language production, including grasping tasks where people talk as they grasp (Gentilucci, 2003; Gentilucci & Campione, 2011). Interestingly, when people observe others grasping objects of different sizes with their fingers, their own speech production during this observation is similarly affected. Conversely, voicing vowels of different qualities has been shown to have an effect on hand posture. That is, mirror neurons fire (in the sense of Rizzolatti & Craighero, 2004; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). Undoubtedly, then, movements and postures of hand and mouth interact outside of language situations. The influence goes in both directions; the mouth can influence the manuals, and the manuals can influence the mouth.

Based on these and similar neurobiological findings (Corballis, 2002; Gentilucci, Benuzzi, Gangitano, & Grimaldi, 2001; Gentilucci & Corballis, 2006; Gentilucci & Dalla Volta, 2008; Gentilucci, Dalla Volta, & Gianelli, 2008), Gentilucci and Campione (2011) speculate that hand or arm gestures which historically were part of a manual communication system were accompanied by mouth articulation postures, which were then co-opted for speech. In modern humans, whatever system was responsible for that transfer is now responsible for controlling interactions between speech and co-speech gestures.

Woll (2014) assesses this position, arguing against the idea that gestural communication preceded oral communication and was supplanted by it. She argues in favor of the view that gesture developed in parallel with spoken language and was continually in use alongside it (a position many share, see e.g. Kendon, 2010). However, she does see echo phonology as a way that visually motivated gestures could have been transformed into the largely arbitrary words of spoken language. Evidence from functional imaging research locates echo phonology in an intermediate position in the brain between spoken words and manual signs.

Woll's conclusions are speculative, but suggestive of the idea that echo phonology served as a support for the development of spoken language. And it very well might have. However, hand-mouth echoes occur even when there is no possible relationship of mouth articulation to sound. Take mandible movement, for example. The literature on echo phonology discusses upward and downward mandible movement, but the mandible can also move forward and back, laterally, and even in a circle. Yet as far as we know, spoken language phonetic inventories include only vertical mandible articulations. Mandible position is never a distinctive feature used by the phonology (we thank Jay Keyser for confirming this intuition, personal communication, June 2018), probably because lateral mandibular movement does not change the auditory signal sufficiently. In contrast, we find at least lateral mandible movements in echo articulations across sign languages. For instance, an intensified variant of the German SL sign DUMM 'stupid' has a lateral mandibular echo articulation, as seen in Fig. 3.[3]

Here the B-handshape with an open thumb gradually closes into a flat-O-handshape as it moves down with radioulnar articulation making the hand rotate back and forth, where the closed fingertips move in a zigzag line downward. The mandible moves from side to side as the hand rotates back and forth. The mouth articulation mimics the line the fingertips would draw as the hand moves downward.

Other mouth articulations that occur in echoes but not in spoken language phonologies include the tongue pushing against the inside of one cheek. Pendzich (2020) shows that this mouth articulation occurs as an echo of hand articulation in German SL UNOFFICIAL-WAY. Additionally, the tongue may repeatedly flick out between the lips in German SL echoes.[4] This movement forms part of the signs KAUM "barely" and AB-UND-ZU "every once in a while," where each flick of the tongue aligns with a manual movement component of the signs, shown in Fig. 4.

In sum, even when considering only hand–mouth co-articulation, echo phonology must include articulation coordination that cannot be related to speech. We now turn to coordinated articulation between the hand and nonmanuals other than the mouth.

Fig. 3. DUMM 'stupid' in German SL.

Fig. 4. KAUM “barely” and AB-UND-ZU “every once in a while” in German SL.

3. Data collection: Echo phenomena involving the head

We begin by determining what should count as an echo and then describe the data selection and organization process. Throughout, we use the term "head articulation" to cover various articulations of the neck muscles.

3.1. A note on obligatoriness and iconicity

Echo mouth articulations are claimed to be semantically empty and obligatory, and to occur only in the frozen lexicon (Schermer, 1990; Woll, 2008).[5] In other words, they were proposed as an unconscious and obligatory motor coupling of articulators not motivated by semantics. We accept the premise that (head) echo articulations are semantically empty since they seem to be tied to individual lexemes, rather than taking on the syntactic or discourse-structuring functions that have been observed for other nonmanuals (for such functions in head movements, see Puupponen et al., 2015). In contrast, the criterion of obligatoriness does not seem warranted. If we want to understand how and why echo phenomena occur, it is important that we look at all instances of echo rather than only the lexicalized ones. If echoes are involuntary motor couplings of two or more articulators, we would expect them to be obligatory and far more widespread than they are, but if they serve linguistic purposes such as enhancing the phonetic signal, there is no reason to assume that echoes are obligatory components of signs. In fact, some scholars suggest that optional mouth articulations are, indeed, echoes; Lewin and Schembri (2011) characterize British SL FALSE and NOTHING as having optional echoes, and Fontana (2008) claims an optional mouth echo for Italian SL DO-NOT-REALIZE.

Further, a note on iconicity is necessary. Woll distinguishes echo articulations from enactments, in which the nonmanual action corresponds to a part of the denotation of the sign. CHEW in Spanish SL, for instance, has the mouth engage in a stylized form of chewing. At the same time, the hands imitate a mouth chewing. The mouth articulation here is arguably not an echo of the manual movement but conditioned by the meaning of the sign. That does not mean that iconic signs cannot have nonmanual echoes, however. In fact, several of Woll’s examples of echo phonology feature a manually iconic sign: WIN in British SL seems to portray a hand waving a flag, DISAPPEAR shows an entity becoming smaller and then disappearing between the fingers. In WIN, the mouth exhales on the syllable /hy/, which does not enact a component of winning but, according to Woll, echoes the manual articulation. In other words, there is no motivation for excluding iconic manual articulations from consideration in echo phenomena, so long as the nonmanual articulation alone cannot be seen as iconic.

3.2. Data

Detecting instances of echo is complicated by the absence of sign language dictionaries and corpora that allow searches by nonmanuals. Since we are interested in which components of manual movement are likely to be echoed, including which movement axes, we needed to identify a number of signs with transverse (side-to-side), vertical, or sagittal (forward–backward) manual movements. As a thorough visual inspection of a wide range of sign language dictionaries would have been beyond the scope of this study, a shorthand was used: We compiled a list of signs that denote concepts and processes that prototypically involve movement along different axes and that might inspire iconic manual movement. We are not suggesting that iconic manual movement is more likely to have coordinated head movement than signs with arbitrary manual movement. Rather, our approach was merely a strategy for finding signs likely to be comparable across sign languages regarding the axes of manual movement.

We then fine-tuned the list to include only those signs where the possible manual articulations could easily be echoed by head movements. The neck is highly flexible and it allows a range of turning (rotation) and flexion/extension (tilting) as well as displacements of the head. We here offer a classification of head movements based on motion defined along the canonical axes—vertical, transverse (lateral), and sagittal—as a way to explore head echoes. We call these the basic head articulations.

1. ***Lateral tilt:*** The crown of the head draws an arc in the air from one side to the other.
2. ***Lateral displacement:*** The head moves laterally without tilting, so the neck cranes to one side or the other.
3. ***Rotation***: The nose draws an arc in the air from one side to the other.
4. ***Sagittal tilt***: The head tilts forward and backward, with the chin moving down and up.
5. ***Sagittal displacement***: The head moves back and forth without tilting, so the neck cranes backward or forward.

These movements are based on what one perceives visually; thus, they are not physiologically grouped. Tilting the head down (forward), for example, is done by the anterior fibers of the sternocleidomastoid muscle, while tilting the head up (backward) is done by the posterior fibers of the sternocleidomastoid as well as the semispinalis, splenius capitis, longissimus, and trapezius muscles. Since the two movements are visually perceived as paired down-up, we have paired them here as sagittal tilts. Continuing with visual coherence as the important criterion, we also discuss circular head movement as a combination of two basic head articulations (rotation + sagittal tilt).

The objects, concepts, and processes identified initially were entered as search terms in the online dictionary spreadthesign.com (Hilzensauer & Krammer, 2015). We chose this dictionary because it is easy to search and has an inventory of signs from many understudied languages. Dictionary entries are presented in whichever language the user has selected for reading the website (we selected American English). The authors are aware that the dictionary does not necessarily represent a given sign language vocabulary comprehensively and that usually only one phonological variant of any sign is represented. Further, the main entries do not reflect well-defined lexemes (as outlined in Sanders & Napoli, 2016a), a problem shared with many sign language databases (Johnston & Schembri, 1999). However, given that we are looking simply for head movement that echoes manual movement, these theoretical shortcomings do not affect our results. Please note that spreadthesign.com is on the list of dictionaries recommended by Gallaudet University[6] and serves as a database for several recent studies in linguistics and the cognitive sciences (e.g., Barboza, Campello, & Castro, 2015; Börstell et al., 2019; Östling, Börstell, & Courtaux, 2018; Sanders & Napoli, 2016a). As of October 2020, the online repository hosts dictionaries for 38 national sign languages[7] and contains approximately 15,000 signs per language. It further contains entries labeled "International Sign Language," which we did not consider here.

We generated a list of 45 concepts whose lexical realization could reasonably allow head echoes based on considering (a) what iconic manual movements might be for these concepts and (b) whether the five basic head articulations could possibly echo those manual movements with respect to direction and timing. We first checked whether cross-linguistically, the signs resulting from our query had a manual articulation that iconically depicts the relevant movement axis. Then we checked whether the manual movement is echoed by a non-iconic head movement. Concepts for which there were no entries on spreadthesign.com had to be excluded, for instance "merry-go-round."

To prevent overestimating the role of echo phonology in the languages of our data set, we avoided signs in which the head movement itself was iconic of the denotation of the sign or an enactment of that denotation—that is, signs with motivation for the head movement that was independent of the manual movement. For example, signs for "dance," "ballet," and "swing" were excluded since they consistently triggered enactment head articulations. These exclusions help us make the most cautious, conservative claims about head echoes that we can.

However, we included concepts such as "tilt" and "fall," which have some lexicalizations with enactment head movement, so long as there are also languages for which the head movement is clearly not enactment. Sometimes we turned to scientific studies in determining the likelihood of a head articulation being enactment. For example, we did not exclude signs with sagittal head tilts downward for DESCEND since a sagittal tilt alone would not be iconic for going down nor do people consistently tilt their head downward throughout a descent (Rosenbaum, 2009). Likewise, we did not exclude rotations or lateral tilts of the head for (WINDSHIELD) WIPER because a head rotation or lateral tilt alone is not iconic of a wiper, nor do people normally rotate or laterally tilt their heads when they are looking at a windshield wiper.

Since the head and eyes tend to move together in generating gaze (Kunin, Osaki, Cohen, & Raphan, 2007), we further excluded signs with gaze-aligned head movement, as attested, for example, for the concept "rocket." It is unclear whether upward head movement in this instance is the result of trying to keep the gaze on the hand (Sidenmark & Gellersen, 2019) or is an echo of manual movement. Accordingly, we excluded such signs from our study.[8] These exclusions left us with 40 concepts whose English lexicalizations we used to search spreadthesign.com. They are listed in Table 1 below. Two countries on spreadthesign.com did not have entries for any of these 40 concepts (Denmark and Cyprus). In Table 1 we see information on the dictionary entries across the remaining 36 languages on spreadthesign.com. English word forms that could be either nouns or verbs are verbs, unless specifically labeled as nouns with "(N)."

These entries offered a total of 115 tokens of head echoes[9] from 30 languages (i.e., six of the languages exhibited no head echoes). Each author analyzed all signs by eye independently, coding the following:

- whether or not the head moved in parallel with a manual movement[10]
- which of the five basic head articulations were involved in that movement
- the direction of head and manual movements
- the timing (onset and finish) of head and manual movements.

Signs on which we disagreed (roughly 10%) were watched repeatedly at reduced speed and, if necessary, presented to a third and fourth independent rater until agreement was reached on all tokens included in the final analysis. Disputed tokens mostly involved movement of the torso, making it difficult to immediately distinguish what the head was doing, or tokens in which the direction of head movement was the opposite from the direction of manual movement.

In analyzing whether head movement in a given sign in our data set is a potential echo or not, we caution the reader that there are many instances in which the head moves exclusively because of torso articulation, without any cervical (neck) articulation. These are not head echo candidates by our definition. For example, in British SL PENDULUM , the upper body displaces side-to-side repeatedly with a slight sagittal tilt, mirroring the

Table 1
Dictionary entry names for objects, concepts, and processes predicted to involve a specific manual movement type

Head Movement	Movement-Related Object, Concept, or Process
Lateral tilt or displacement	alarm clock, bell, metronome, pendulum, tail, tilt, (windshield) wiper
Rotation	argue, discuss, fish (N), flag, goal, hit, lightning, parachute, scan, shooting star, war, wind (N)
Sagittal tilt or displacement	ascend, climb, climbing hook/beak, collapse, deep, descend, down, elevator, escalator, fall, hail, jump[a], rain, see-saw, sink, sit, snow, submarine, wave (N)
Circular movement	ferris wheel, washing machine

[a]This concept is listed in the dictionary search options as JUMPING.

Fig. 5. PENDULUM in British SL.

hands' movement in the same direction (as shown in Fig. 5). This gives the impression that the head is echoing the hands, even though there is no articulation of the head. Often, however, both head and torso articulate, in which case the head articulations do qualify as potential head echoes.

4. Results

4.1. Number of head echoes in the data set

Of the 40 senses in Table 1, only three did not exhibit head echoes in any language.[11] In the chart in Fig. 6 we see the remaining 37 lexical items, with the number of languages that displayed an echo for them plus the number of languages that included this lexical item but without a head echo. The lexical items are arranged left to right according to the token count of head echoes exhibited by them. Two lexical items had head echoes in eight languages; 11 lexical items exhibited head echoes in only one language. Thus, the overall number of head echoes for the selected concepts in our database is low, which is in line with claims about the relative rarity of head echoes in sign languages (Crasborn, Van Der Kooij, Waters, Woll, & Mesch, 2008) as well as findings on the frequency of head echoes in Finnish SL (Puupponen et al., 2015).

4.2. Examples of head echoes for each basic type of head movement

In Section 3.2 we identified five basic types of head movement, two of which involve movement along more than one axis in space. Lateral displacement and head rotation move the head only along the transverse axis (left–right), and sagittal displacement moves it only along the sagittal axis (away–toward).[12] Lateral tilts, in contrast, have a transverse and a vertical (up–down) dimension, since the crown of the head lowers during a tilt and is located left or right of the center. Sagittal tilts have a vertical and a sagittal dimension: In a nod, the crown of the head goes forward and down, then to neutral again, then

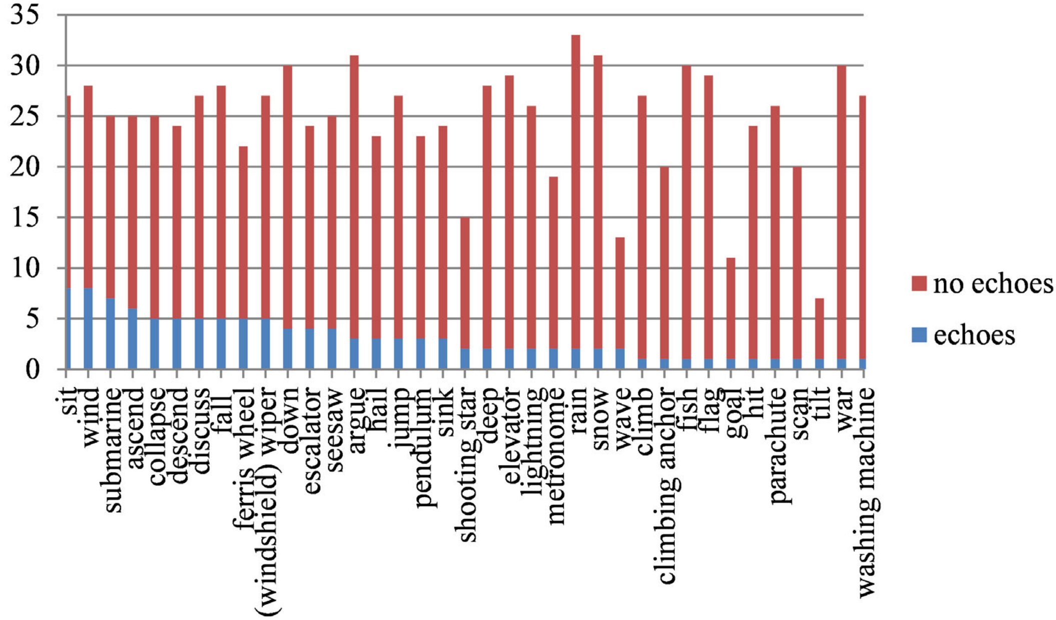

Fig. 6. Lexical items listed by most to least head echoes.

backward and down; at the same time the chin goes down and back, then to neutral, then upward and front. Circular movements combine head rotation and sagittal tilt and, thus, movement along the vertical and transverse axes. In the following subsections we provide examples of each of these head movements in turn and note whether they echo the manual movement in its entirety (full echo) or only parts of the manual movement (partial echo). We start with head movements that move along a single axis (simple head movements) and then consider those with movement along two axes (complex head movements). For complex head movements, we describe (a) whether they are full or partial echoes and (b) whether only one of their movement axes can be exploited as an echo. These descriptions will serve as the basis for a discussion of which kinds of head echoes are more prevalent and which correlations we find between head and manual movements.

4.2.1. Simple transverse movement 1: Lateral displacement

Lateral displacements are a good starting point, because they are highly unlikely to be enactments—few of our regular movements involve craning the head from side to side. Lateral displacements involve movement along the transverse axis. The examples we give here have the head moving in the opposite direction as that of the hands, as this was the case in nearly all our examples of lateral head displacement. WIND in the sign languages of Poland (in Fig. 7), Pakistan, and Argentina constitutes a full echo: The hands move sideways repeatedly as the head displaces to the opposite side repeatedly.

Fig. 7. WIND in Polish SL.

Fig. 8. FERRIS WHEEL in Italian SL.

As an example of a partial echo, we offer the first part of FERRIS WHEEL in Italian SL (Fig. 8), where a black arrow indicates the direction of head movement and a white arrow shows how the hands move. The left hand moves in a circle (transverse + vertical manual movement), arcing down first and then to the side opposite of the moving hand, while the right hand holds a wide baby-C handshape that references the size limit of the manual circle. The head displaces laterally, with the movement going in the opposite direction as the moving hand. The echo reflects only the lateral dimension of the hand movement.

In our data set, lateral displacement occurs only when there is a transverse dimension to the manual movement, whether the manual movement be simple or complex. This is as we expect if the head articulation is, indeed, an echo. For a discussion of similar examples involving lateral head displacement, please see Appendix S1.

4.2.2. Simple transverse movement 2: Rotation

Head rotation can consist of turning the head to face one direction, or the head can turn left to right repeatedly, resulting in a headshake. The tip of the nose traces an arc that has dimensions along both the transverse and sagittal axes.[13] However, since that arc is slight—that is, people do not turn their heads 90 degrees to look over each shoulder,

Fig. 9. WIND in Portuguese SL.

but seem to turn at most 10 degrees—the perception is of movement only along the transverse axis. The sagittal dimension that the tip of the nose negotiates is imperceptible to the onlooker. Given our overall hypothesis that enhancement is the motivation for head echoes, perception is our guide here and we characterize head rotation as movement along a single axis—the transverse.

Head rotations rarely coordinate with radioulnar articulation resulting in a hand rotation in our data (but see the final example in Appendix S2). Rather, they copy sideways displacement of the manual articulators, as in WIND in Portuguese SL (Fig. 9). Just as we found torso involvement sometimes with lateral head displacement, here the torso moves side-to-side along with the head rotation.

As we saw with lateral displacement, sometimes not the entire manual movement is echoed by a head rotation. In FALL in Chinese SL (Fig. 10), the hands move downward in a left–right zigzag path while the head rotates once in the opposite direction of the hands. The partial head echo here copies only the left–right displacement of the hands but not the vertical movement, and the head rotation coordinates with only the first movement of the hands to the right and then to the left.

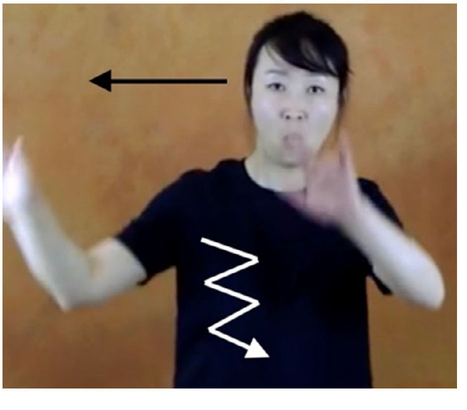

Fig. 10. FALL (the season) in Chinese SL.

Again, head rotation occurs only when there is a transverse dimension to the manual movement. This is as we expect if the head articulation in these examples is, indeed, an echo. Additional examples showing a range of other complexities are discussed in Appendix S2.

4.2.3. Simple sagittal movement: Sagittal displacement

Head movement along the sagittal axis that echoes manual movement is rare in our data set; it occurs in only four signs. GOAL in Pakistani SL has a component in which the hand moves forward in two bounces, and on the second bounce the head displaces forward (Fig. 11).

As an example of a partial echo, we offer ESCALATOR in American SL (Fig. 12). The dominant hand moves upward and outward as the head does a sagittal displacement. So only the sagittal dimension of the complex manual movement is echoed by the head. Note that other nonmanuals participate here. The torso tips forward (but the torso movement alone is not fully responsible for the forward displacement of the head) and the mouth shuts tight while the oral cavity fills with air, making the whole lower front of the face bulge forward. As the hand hits the final high position, the head immediately starts to fall. When the hand relaxes after the sign, the head goes back to un-displaced position, the torso goes to neutral position, the mouth relaxes, and the eyes shut.

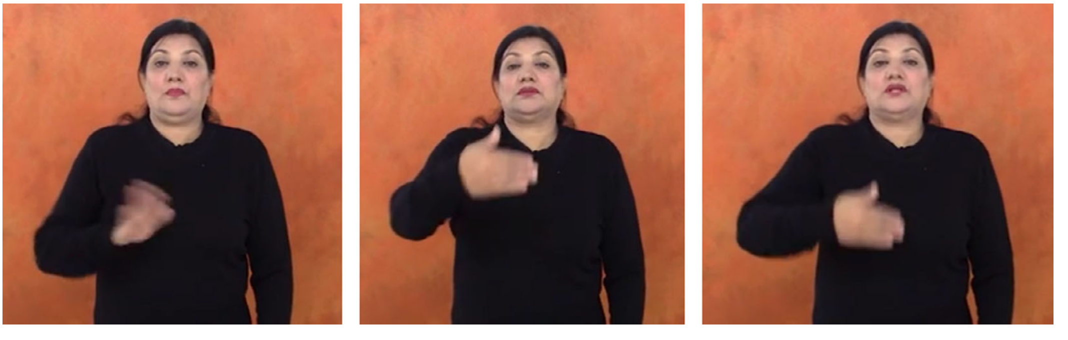

Fig. 11. GOAL in Pakistani SL.

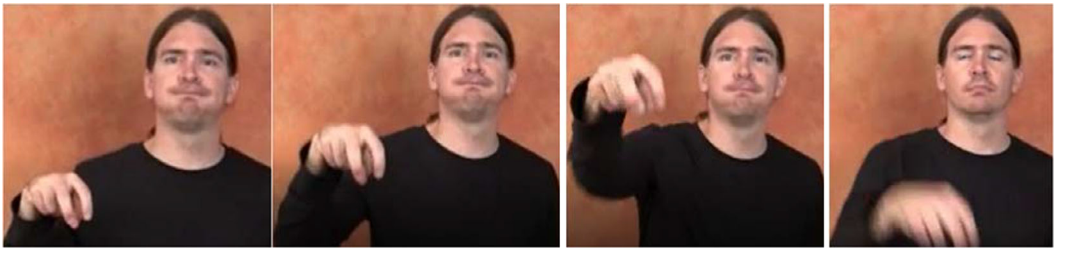

Fig. 12. ESCALATOR in American SL.

As expected for echo head articulations, sagittal displacement occurs only when there is a sagittal dimension to the manual movement, whether the manual movement be simple or complex. For descriptions of the remaining two examples of sagittal displacement, see Appendix S3.

4.2.4. Complex movement 1: Lateral tilt

At the end of a lateral tilt, the crown of the head is located both lower than its neutral position (vertical movement axis) and displaced further to the left or right (transverse axis). These two location differences can be exploited independently of each other as echoes, in addition to the arc movement traced by the head.

As an example of a full echo that copies a transverse and vertical manual movement, we provide (WINDSHIELD) WIPER in the sign languages of France and Greece. Here, the head tilts side-to-side in the same direction as the hands moving side-to-side in an arc. In Fig. 13 we see an illustration of coordinated head tilt and hand movement in Greek SL.

Simple manual movements can also be echoed by a lateral tilt. In those cases, either the vertical or the transverse movement axis of the head movement can serve as an echo. For example, COLLAPSE in Chinese SL has the hands move downward (but not sideways) as the head tilts to the side, echoing only the vertical movement axis of the hands (Fig. 14).

An example of transverse manual movement being echoed by a lateral head tilt is Austrian SL FLAG (Fig. 15). Here, the crown of the head moves laterally in the same direction as the hand movement. Further examples of lateral tilt echoes can be found in Appendix S4.

Fig. 13. (WINDSHIELD) WIPER in Greek SL.

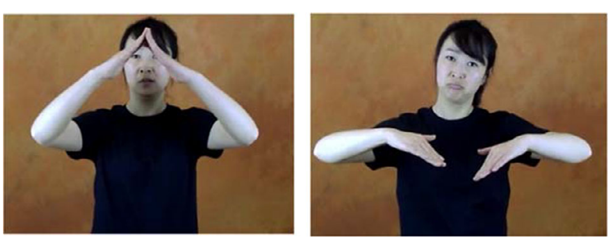

Fig. 14. COLLAPSE in Chinese SL.

Fig. 15. FLAG in Austrian SL.

Fig. 16. DESCEND in Greek SL.

Given that simple head articulations can partially echo complex manual articulations so long as the dimension of the head articulation is among the dimensions of the manual articulation (see Sections 4.2.1–4.2.3), we might expect a lateral tilt, which is T + V, to be able to echo a manual articulation that is T + V + S. And we do find that. In DESCEND in Greek SL (Fig. 16) the head makes a lateral tilt as the hand moves downward, to the side, and forward. The forward movement may be difficult to discern (as movement along the sagittal axis always is—a point we return to in Section 5.2), but it is there. Notice that the right arm begins with the elbow to one side, (close to) 90 degrees off center. The forearm appears to be close to orthogonal to the upper arm. From this starting position the shoulder joint rotates with a little lowering of the upper arm, as well. It is the rotation of the shoulder joint that contributes a sagittal dimension to the movement path of the forearm and hand. Meanwhile, the head tilts sideways but not forward.

4.2.5. Complex movement 2: Sagittal tilt

Sagittal tilts result in the head moving along the vertical and sagittal movement axes. The crown of the head moves forward as the head tilts down, or backward as the head tilts up. Sagittal tilts can therefore fully echo complex manual movement along both the vertical and the sagittal axis, or simple manual movements along one of those two axes. They can further partially echo a complex manual movement. We provide an example for each of these cases below.

FALL in Chilean SL exhibits a full echo of a complex manual movement. The dominant hand moves up and then in an arc forward and down as the head tilts backward and then

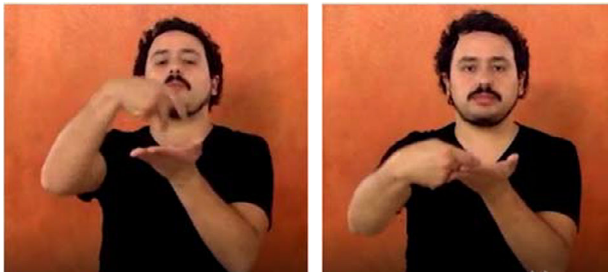

Fig. 17. FALL in Chilean SL.

Fig. 18. Second part of CLIMBING ANCHOR in Spanish SL.

forward (Fig. 17). So the backward tilt of the head echoes the upward manual movement while the forward tilt of the head (ending in neutral position) echoes both the forward and downward manual movements.

We further find full sagittal tilt echoes of the following simple manual movements: downward, upward, and away-toward. The second part of the sign CLIMBING ANCHOR in Spanish SL (Fig. 18) has the hands moving straight down and clamping into the grip of a climbing anchor's hook. At the same time, the head starts from a raised chin and tilts downward.

ESCALATOR in the sign languages of Britain, Portugal, and Estonia (Fig. 19) has both hand and head move upward, with the head tilting backward, lifting the chin.

Lastly, in the first part of DISCUSS in Indian SL (Fig. 20), the hands move away and back toward the signer repeatedly. While the hands move, the head does a repeated sagittal tilt, so that the forward movement of the crown of the head corresponds to the sagittal forward movement of the right hand and the backward movement of the crown of the head corresponds to the sagittal backward movement of the right hand.[14]

These partial echoes are expected, given what we found above with respect to lateral tilts. That is, the head cannot move simply downward or upward (that is, V) without introducing sagittal movement as well. Thus, there is no simple head echo available for simple V manual movements. Further, the head does not comfortably move only away-toward: That is, sagittal displacement is awkward. Thus, again, a complex head echo is favored.

Fig. 19. ESCALATOR in Estonian SL.

Fig. 20. First part of DISCUSS in Indian SL.

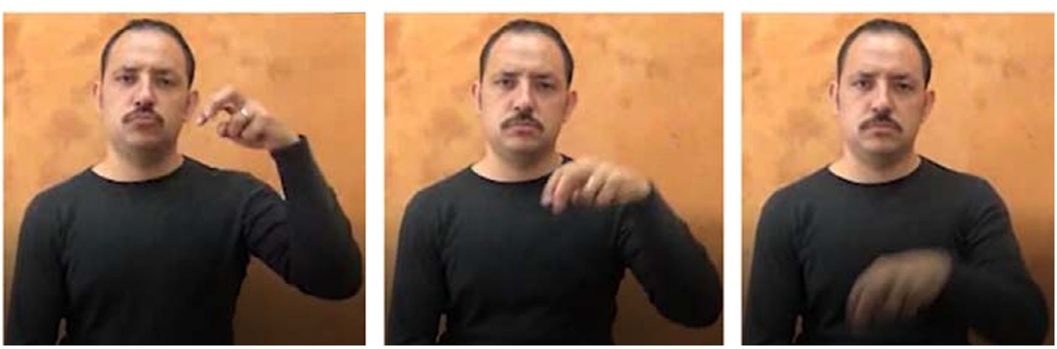

Fig. 21. SINK in Italian SL.

Lastly, sagittal tilts can partially echo a manual movement along all three dimensions. An example is SINK in Italian SL (Fig. 21), where the hand moves downward, sideward, and outward as the head makes a sagittal tilt.

Sagittal tilt behaves like our other head echoes in that it occurs only when one or both of its movement dimensions are found in the manual movement.

4.2.6. *Combining basic head articulations*

We have seen that lateral and sagittal tilts can serve as full echoes of complex manual movements. Even more echo possibilities arise if we combine the basic head articulations simultaneously. For example, circular movement of the head is a combination of head rotation and sagittal tilt.[15] The first part of Icelandic SL FERRIS WHEEL exhibits circular head movement echoing circular manual movement.[16]

A different kind of complex manual movement is seen in WAVE in French SL (Fig. 22). The hands trace the shape of a wave in a sideways up-and-down movement of both hands. The chin moves down and up (via sagittal head tilt) again in sync with the hands, while at the same time the head rotates toward the direction in which the hands move—that is, the head moves in a semicircle. Similar coordinated articulations are attested in WAVE in Lithuanian SL and in FALL in Brazilian SL.

We also find sagittal tilt upward (S + V) combining with lateral displacement (T), which allows echoing of manual movement along all three dimensions (S + V + T). In Estonian SL ASCEND (Fig. 23), the hands do a slight zigzag while moving upward,

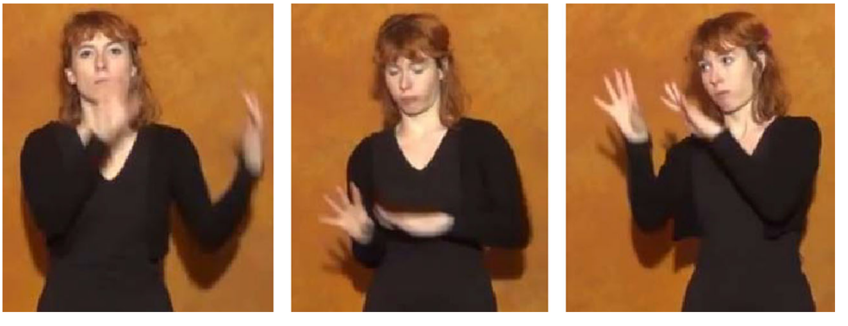

Fig. 22. WAVE in French SL.

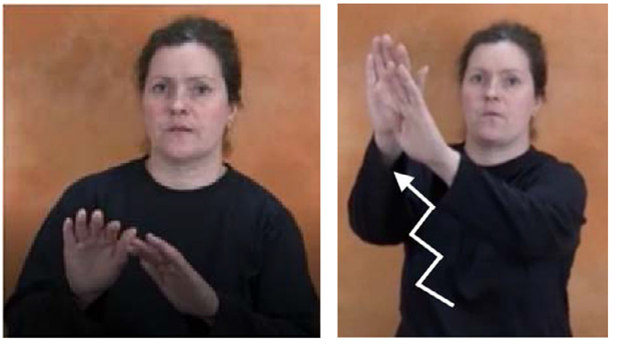

Fig. 23. ASCEND in Estonian SL.

outward, and sideways as the head displaces to the opposite side and tilts upward (and the torso also tilts side to side repeatedly). Other examples of complex head echo are described in Appendix S5.

4.2.7. Repetition

Looking at movement repetition in manual versus head movements, we note that the number of movements in head echoes is determined by whether or not the sign has repetition in the manual movement. In 47 of our tokens, manual movement was repeated; 46 (98%) of these exhibited a repeated head echo. Three signs have a repeated echo but do not have manual repetition. One of them has manual movement diagonally upward, but in a repeated zig zag motion (ASCEND in Estonian SL), and one of them has manual movement diagonally down, but with repeated radioulnar rotation (PARACHUTE in Swedish SL).

5. Analysis

We have seen that head echoes involve five different basic types of articulations and that they coordinate with a number of different simple and complex manual articulations. In this section we address which kinds of head echoes are more prevalent, look at correlations between head movements and manual movements, and explore factors that influence whether the direction of echo movement is likely to be the opposite of the direction of manual movement.

Two questions that arise but that cannot be answered on the basis of our data set are whether the likelihood of head echoes can be predicted from sense and whether some sign languages are more likely than others to exhibit head echoes. Given that 37 out of the 40 concepts selected for investigation had echo head articulations in at least one language, one might hypothesize that the meaning of a lexical item can predict whether or not a head echo will occur. However, the present study is not suited to address this question as we expressly selected concepts for which a head echo could be expected and did not have a control group of concepts for which no such head articulation was expected.

Addressing the second question, the languages in our sample exhibit different amounts of head echoes. Fig. 24 lists the 36 sign languages in our study arranged from left to right by percentage of head echoes, calculated by how many signs had at least one head echo. The highest percentage of signs accompanied by head echoes was found in Argentinian SL, where a third of the 37 lexical items in our study had a head echo. Six SLs exhibited no head echoes at all (Bulgarian through Slovakian SL in the table). Drawing any conclusions on language-based prevalence patterns for head echoes is complicated by the fact that some languages exhibited many more of our dictionary entries than others. New Zealand SL, for example, has only one of those entries, while British SL and French SL have 36 each. Secondly, each language is represented by only a small handful of signers on spreadthesign.com, allowing no generalizations about the entire community of users. This is an important fact. Head echoes are voluntary articulations (we can stop them if someone tells us not to move our head), but we are not usually conscious of

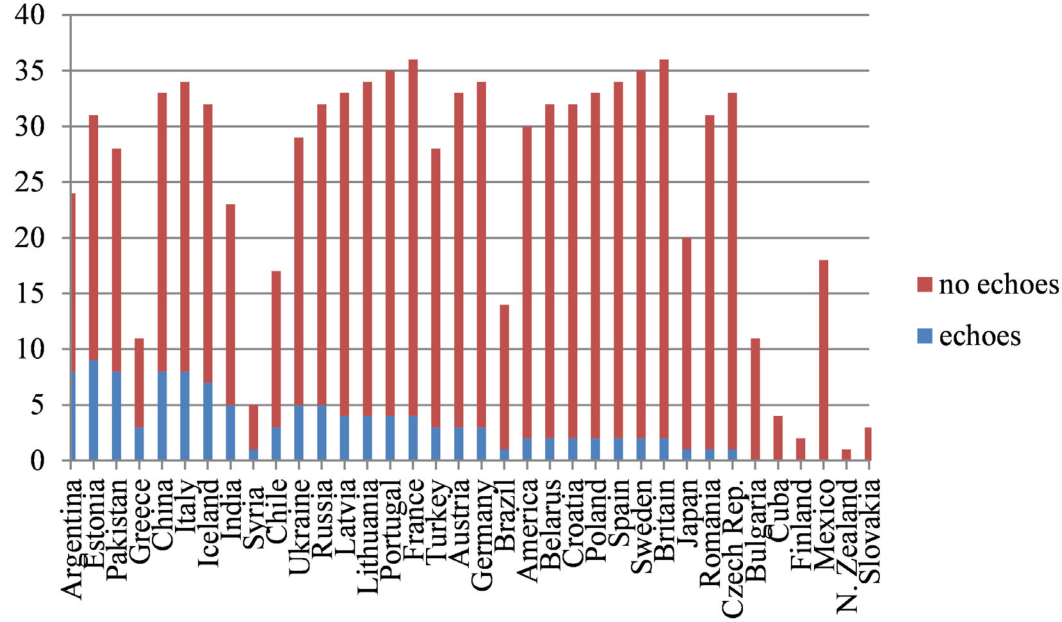

Fig. 24. Countries arranged by number of dictionary entries they displayed with and without head echoes, from highest percentage of tokens with head echoes to lowest.

making them unless someone points them out. They contrast with involuntary movements (reflexes, tremors, certain tics, and others), which we cannot control, whether or not we are conscious of them. As voluntary movements, head echoes can vary quite a bit from individual to individual (Peterson, Keshner, & Banovetz, 1989). Thus, the low number of signers for each language means that we cannot separate out language tendencies from idiosyncrasies of individual signers. But even if we were to ignore all these complications, we do not see a hint of any particular language propensity or any family (genetic or contact) propensity. We return to this question in Section 6.

5.1. *Inventory and percentage frequency distribution of particular head echoes*

For each of the five basic head articulations, Table 2 lists how often they occurred in our data ordered by the axis/es along which they move (# head). We also list how many signs have a simple manual movement along one of the three axes (# hand). For the sake of clarity of presentation, we use the same axis terminology for manual movement as for head movement. For example, hand movement away or toward the signer is labeled "sagittal."

Table 2 shows that sagittal tilts are by far the most commonly attested head movement, and sagittal displacements are the least common. These numbers have to be viewed against the number of signs with a compatible simple manual movement. For instance,

Table 2
Total number of head echoes listed by type of head echo and number of simple manual movements along a canonical axis

Head Movement	Lateral Displ.	Rotation	Lateral Tilt	Sagittal Tilt	Sagittal Displ.
# head	16	19	30	56	4
# hand	32	46	3		
Manual Axes	T(ransverse)	V(ertical)	S(agittal)		

there are only three signs in our data set with manual movement solely along the sagittal axis, offering opportunities for sagittal displacement and/or sagittal tilt head echoes. In contrast, there are 32 signs with manual movement only along the transverse axis, offering opportunities for lateral displacement, head rotation, and/or lateral tilt head echoes, and there are fully 46 signs with manual movement along only the vertical axis, offering opportunities for lateral tilt and or sagittal tilt. Thus, within the set of signs with only simple manual movement, the opportunities for sagittal head displacement echoes are 3; for lateral displacement and head rotations, 32; for sagittal tilts, 49; and for lateral tilts, 78. Therefore, the prevalence of sagittal tilt, particularly over lateral tilt, calls for explanation.

Considerations of physiology offer another possible account of the high occurrence of sagittal head tilt. As people age, they lose cervical range of motion, with sagittal tilt downward being the direction they maintain the most range of movement in (Kuhlman, 1993). Thus, we might reason that language exploits most the movement that people have fullest use of the longest. Complicating the matter, however, is the fact that sagittal tilt upward is the direction people lose range of motion in the most, followed by rotation (Kuhlman, 1993). Therefore, if a physiological account is responsible for the high occurrence of sagittal-tilt head echoes in our data, we might expect sagittal tilt upward to be less common than downward. This is the case. In our data set, there are 45 signs (or distinct parts of signs) with a head echo consisting solely of a sagittal tilt. In Table 3 we have assembled information on these signs, organized as to whether the sagittal tilt is upward, downward, or in both directions. Downward is by far the most prevalent, consistent with the physiological account.

Another possible explanation for the higher number of sagittal-tilt than lateral-tilt head echoes is linguistic in nature. Head gestures are used in many languages/cultures,[17] and the question arises as to whether such articulations can be separated from their gestural sense and coopted for use in head echoes. Sagittal tilts are used as affirmative and back-channeling gestures (nods) in many languages, while lateral tilts are less often used as

Table 3
Number of different directions in sagittal tilts

	Upward	Downward	Up- and Downward
Number of tokens	9	25	11

such. Perhaps the common usage of sagittal tilts as gestures is responsible for their frequent occurrence as head echoes in our data set. This explanation does not, however, account for the relative infrequency of head rotations in our data compared to sagittal tilts. Head rotations are used as negative gestures (head shakes) in many languages, but they occur much less often than sagittal tilt in our data set.

The rarity of head displacements overall stems almost assuredly from physiological considerations. A sagittal displacement causes the lower cervical spine to go into hyperflexion and the upper cervical spine to go into hyperextension (Morrison, 2018). Hyperflexions and hyperextensions are unnatural and place stress on vertebrae, intervertebral discs, and facet joints. Further, because the bottom of the cervical spine hyperflexes forward while the top of the cervical spine hyperextends in the opposite direction, there is increased stretching and tension on the spinal cord and on surrounding nerve roots. Lateral displacement of the head is also not a natural movement, and activity that forces the head into this position is a cause of cervical spine injury in sports (Swartz, Floyd, & Cendoma, 2005). That head echoes disfavor displacements is to be expected, then.

5.2. *Correlations of head echoes to manual articulation types*

We now consider correlations between manual movement and head echoes with respect to axis of movement. We start with simple manual movements with single head echo articulations, then look at complex manual movements with single head echoes, and lastly examine complex manual movements with combinations of head echoes.

5.2.1. *Simple manual movement with a single head echo*

The data for (distinct parts of) signs with manual movement along only one axis accompanied by a single basic head articulation are presented in Table 4 and illustrated in a bar graph in Fig. 25.

We find that lateral displacements and rotations of the head occur only with manual movements along a transverse dimension, while sagittal displacement of the head occurs only with manual movement along a sagittal dimension. These results are predictable, given that these three head echoes articulate exclusively along a single axis, the precise axis of the manual movement that they echo.

Table 4
Distribution of head echoes over simple manual movement along the canonical axes

Head	**T**		**V**		**S**
Manual	**Lateral Displ.**	**Rotation**	**Lateral Tilt**	**Sagittal Tilt**	**Sagittal Displ.**
T	10	12	10	0	0
V	0	0	14	28	0
S	0	0	0	2	1

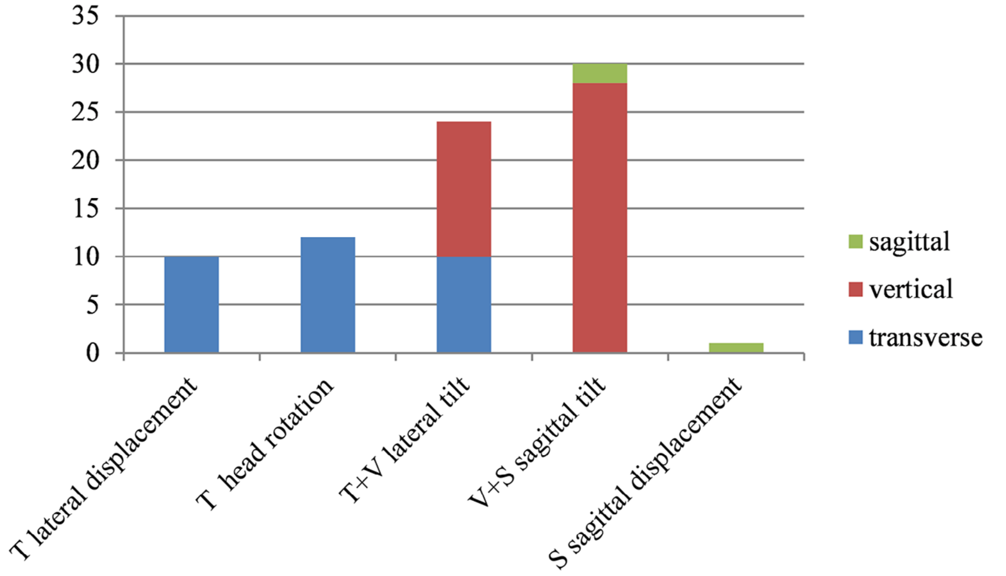

Fig. 25. Frequency of sagittal (green), vertical (red), and transverse (blue) manual movement accompanying each type of head echo.

Lateral tilts of the head move along the transverse and vertical axes, and they occur with simple manual movements along either of those two axes, but not with simple manual movement along the sagittal axis. The higher incidence of lateral tilts with simple vertical manual movement over simple transverse manual movement might reflect nothing more than the higher incidence of simple vertical manual movement over simple transverse manual movement in our data set. Sagittal tilts move along the vertical and sagittal axes, and they occur with simple manual movement along either of those two axes, but not with simple manual movement along the transverse axis. Again, the far higher incidence of sagittal tilts with vertical manual movement over sagittal manual movement may reflect nothing more than the extremely low incidence of simple sagittal manual movement in our data set.

We further observe that for each axis of manual movement there are at least two potential head echoes. In Table 4, transverse manual movement is echoed to (almost) equal amounts by lateral tilt, lateral displacement, and rotation. Sagittal manual movement is echoed by sagittal tilt or sagittal displacement to similar degrees, and vertical movement is echoed by lateral tilt or sagittal tilt. With regard to the two tilts and vertical manual movement, we find a clear preference for sagittal tilt: 28 out of the 42 instances (66.7%).

5.2.2. *Complex manual movement with a single head echo*

In our data set, we find a variety of simultaneous manual combinations of the canonical directions, such as transverse and vertical combining in zigzags or in diagonal upward or downward movement. We also have signs in which the manual movement is complex because of sequential combinations of the canonical directions; that is, the axis of movement changes. Sometimes the axis changes continuously, such as the hands moving in an arc or circle (as in FERRIS WHEEL in Italian SL). Other times that axis changes abruptly, for instance when the hands move downward and then forward in SUBMARINE in Argentinian SL.[18]

We find a total of 22 tokens for which the manual movement combines a vertical dimension with a transverse (9) or a sagittal one (12) or both (1), and that are accompanied by a single head echo. Table 5 conflates simultaneous and sequential manual movement and shows which dimensions of the manual movement are echoed on the head. In Fig. 26 we have arranged the data from Table 5 in a bar graph.

Few purely articulatory factors seem to influence which dimension of a complex manual movement a head articulation will echo. Each manual movement axis is echoed roughly equally (T = 13, V = 13, S = 9). It looks as if in manual V + T and V + S movements, the vertical axis is more likely to get dropped than the T or S axes, respectively. However, a closer look at Fig. 26 reveals that these facts likely fall out from a constraint against head echoes introducing a movement dimension that is not present in the manual movement. V + T manual movements are echoed either by a T or a V + T head echo, but never by a V + S one. Likewise, V + S manual movements are echoed by S or V + S head movements, but not by V + T ones. In each case, the missing V + S or V + T head echo would introduce a movement axis that is not present in the manual movement. Since there are no simple V head echoes, it therefore appears as if a manual vertical movement is more likely to be dropped from an echo. A likely motivation for omitting the V dimension in a head echo is to avoid introducing an S or T dimension that is not present in the manual movement.

Additionally, iconicity does not reliably indicate which dimension will be echoed. In some signs with complex manual movement, there is one axis that is clearly iconic in the manual movement. For example, in ASCEND the iconic axis is vertical, but in Ukrainian SL the sign also has a non-iconic transverse axis. In SCAN, on the other hand, the iconic axis is transverse. For other signs, the two axes of the manual movement are equally involved in the iconicity. For example, in FERRIS WHEEL the vertical and the transverse axes are equally involved in the circular iconic path. Now let us consider the three signs that have V + T manual movement and a lateral displacement head echo (which is T) in

Table 5
Distribution of head echoes over complex manual movement along the canonical axes

Head		T		V		S
Manual		Lateral Displ.	Rotation	Lateral Tilt	Sagittal Tilt	Sagittal Displ.
V +	T	3	4	2	0	0
S	0	0	0	10	2	
T + S	0	0	0	1	0	

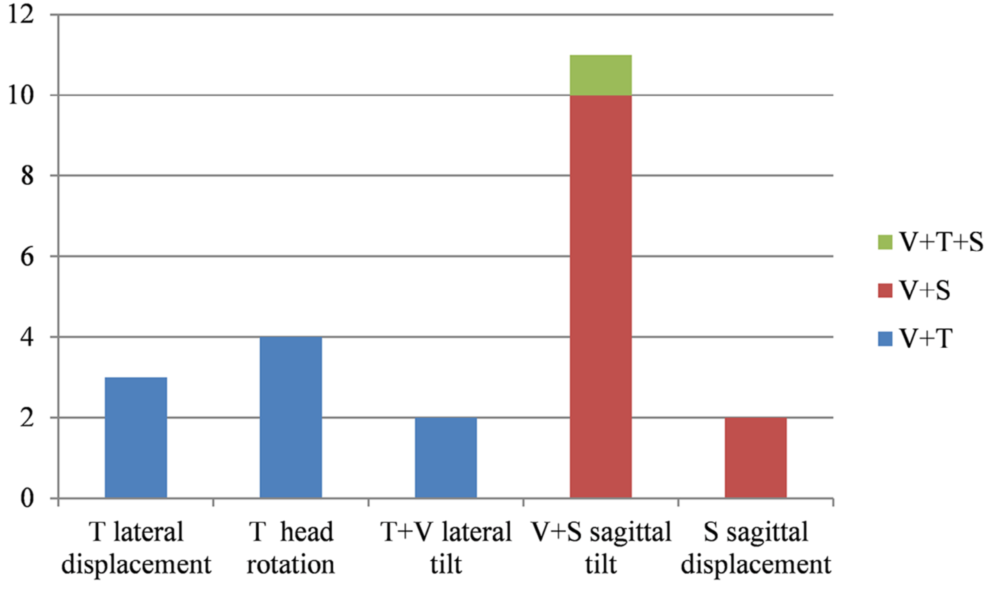

Fig. 26. Frequency of transverse and vertical (blue) hand movement versus vertical and sagittal (red) hand movement versus hand movement along all three dimensions (green) accompanying each type of head echo

Table 5. In two of them the iconic manual movement dimension is vertical (ASCEND in Ukrainian SL and DESCEND in Argentinian SL) while in the remaining one it is arguably transverse (SHOOTING STAR in Estonian SL). So in only one of the three tokens does the dimension of the head articulation match the iconic dimension of the manual movement. Rotation head echo, which is also T, fares no better. In the four V + T manual movement signs with rotation head echo, the iconic manual movement dimension is V in two of them (FALL in Chinese SL and PARACHUTE in Swedish SL). In none of these echoes does the dimension of the head articulation match the iconic dimension of the manual movement. Lateral tilt is V + T, so when it echoes manual movement that is V + T, the question of which axis is iconic is moot. The same is true for sagittal tilt (which is V + S) when it echoes V + S manual movement. Sagittal displacement is S and it echoes V + S manual movement; here both examples are arguably equally V and S. Finally, the one example of V + T + S manual movement is SINK in Italian SL (in Fig. 21), where only the V dimension is iconic. The head, however, echoes both the V and S dimensions. In sum, the iconicity of the manual movement dimension seems not to be a decisive factor in the dimension(s) of the head echo.

Another issue that arises with complex manual movement that is complex is whether there is a tendency for the head to echo all dimensions of that movement whenever possible. That does not seem to be the case. In Table 5, 12 head articulations echo all dimensions of the complex manual movement, while the remaining 10 head articulations echo some but not all dimensions of the complex manual movement. Also note that 10 of the head articulations that provide a full echo are sagittal tilts, and sagittal tilts are overall the most common type of head echo in our data set. The frequent occurrence of sagittal tilts seems to be motivated independently, partly by physiological reasons disfavoring displacement and partly due to the fact that sagittal tilts occur so often as gestural elements (nods) across languages.

5.2.3. Combining head echoes

Ten head echoes in our data set combine two of the basic head movements and may occur with either simple (four tokens) or complex (six) manual movements. Table 6 shows which manual movement axes they echo, conflating simultaneous and sequential manual movement.

Within our data set, sagittal tilt is the only basic head articulation that combines with the other head articulations, and it can combine with all four of them. This is not due to physiological limitations; rotation, for example, can be combined with the other basic head articulations, but such combinations do not occur in our data set. As for manual movement dimensions, Table 6 shows that they always include a vertical dimension; that is, there is no combined head echo in our data that accompanies a sign with T + S manual movement unless V is also involved (in the two instances in Table 6). Again, this is not due to any obvious limitation; generally, all three dimensions combine in manual movement in many signs.

At the very least, we can say that in the signs in Table 6 the vertical dimension is echoed consistently. In fact, all manual dimensions are echoed in the head articulations for the signs in Table 6, whether the manual movement has two or three dimensions. This finding recalls our speculation at the end of Section 5.2.2 that there is a tendency for the head to echo all dimensions of manual movement whenever possible. While we could not find firm footing for that speculation there, perhaps the findings on signs with combined head echoes suggest that this possibility be reconsidered on a larger data set. Additionally, we note that combined head echoes can also echo a single manual dimension: Four signs have only vertical manual movement and combine lateral and sagittal tilts to echo this movement. Note that both head tilt movements have a vertical dimension and their

Table 6
Distribution of combined head echoes over manual movement along the canonical axes

Head		**Sagittal Tilt +**			
		T		**V**	**S**
Manual		**Lateral Displacement**	**Rotation**	**Lateral Tilt**	**Sagittal Displacement**
V +		0	0	4	0
	T	0	3	0	0
	S	0	0	0	1
	T + S	1	1	0	0

additional dimension is there by physiological necessity, since we have no head echoes that are strictly vertical.

5.2.4. Conclusions about echoing of movement axes

We conclude that the articulation of a head echo is determined by the dimension(s) of manual movement. Transverse manual movements can be echoed by head movements with a transverse dimension, that is, lateral tilts, lateral displacements, and rotations. Vertical manual movements can be echoed by lateral tilts or sagittal tilts since both have a vertical movement component. Sagittal manual movements can be echoed by a sagittal tilt or sagittal displacement. These statements hold whether manual movement is simple or complex and whether head echoes are single (basic) or combined.

When manual movement is simple, the head echo may be basic or combined. A single echo will always copy at least one of the movement axes of the hands. When two head articulations are combined in an echo, one of the dimensions of each basic head movement will correspond to a dimension of the manual movement and the additional one will be physiologically motivated. When manual movement is complex but the head echo is single (in Table 5), we find no reliable way to predict which dimension the head will echo, although we note a possible hierarchy of echoing the vertical dimension more than the transverse and sagittal dimensions. When manual movement is complex and two head movements are combined, the head echoes all the manual dimensions.

In sum, the head has a tendency to echo all manual dimensions. However, we hold back from concluding that there is a tendency to find the best fit of head echo to manual movement since the head sometimes introduces dimensions that are not present in the manual articulation "(e.g. collapse in Chinese SL (Fig. 14), where the lateral tilt has a transverse dimension not present in the manual component)".

Finally, we note that sagittal manual movement occurs in 20 tokens in the data set. The ratio of sagittal displacement echoes to sagittal tilt echoes for this movement is 4:16. Certainly, displacements are less natural physiologically than tilts, as we noted. However, the predominance of sagittal tilt to echo sagittal manual movement may also point toward perception as a determining factor in echo phonology, just as perception may be in other areas of sign phonology (Sanders, 2018). Signers generally face each other when signing one-on-one. Human vision perceives the three-dimensional world as a composite of only two dimensions—the vertical and the horizontal. So manual movement that goes toward or away from the addressee (which is also going away from or toward the signer) will require the addressee to indirectly infer the direction of that movement from other cues (Regan, Erkelens, & Collewijn, 1986; Regan & Kaushal, 1994). Therefore, movement along the sagittal axis is in need of extra cues to help the addressee properly interpret the sign. A sagittal displacement of the head cannot provide additional cues, since it also moves only along the sagittal axis. But a sagittal head tilt, because of its additional vertical dimension, may well provide the extra cue.

5.3. Opposite directions of manual and head movements

In almost a quarter of the tokens in our data set (27 out of 115; 23.5%) the head moves along the same axes as the hand(s) but in the opposite direction.[19] For instance, while the hands move to the right, the head rotates to the left. In Table 7 we organize the data regarding opposite direction of manual and head movements according to the five basic head articulations, where we calculate the percentage of echoes with opposite direction of manual and head movement with respect to all echoes of the same type (including combined ones). Take lateral tilts, for example. There are 26 signs with only a lateral tilt as head echo in our data set (see Tables 4 and 5), and five of them tilt in the opposite direction from the manual movement. Four further lateral tilts occur in combined echoes (see Table 6), so a total of five out of 30 lateral tilt echoes (16.7%) move in the opposite direction from the manual movement.

The likelihood of opposite movement directions of manuals and head is greatest for lateral displacements. That likelihood is still relatively high when the head echo is rotation or a combination that includes rotation; in other words, when the head moves only along the transverse axis. But the likelihood of opposite movement direction drops precipitously when the head echo is lateral tilt—the T + V articulation. Almost no opposite direction echoes are attested in head movements that do not involve the transverse axis. We conclude that the head and manuals going in opposite directions is mostly a transverse phenomenon.

A biomechanical explanation offers itself. The opposing direction of head movement helps to ameliorate the force of torque generated by the hands moving together to the same side, thereby reducing the amount of reactive effort needed to resist the torque. Lack of counteractive measures could lead to spinning around the vertical axis that passes down through the body from head to feet (Sanders & Napoli, 2016a, 2016b). In favor of this account is the fact that in 11 out of the 18 signs with only transverse manual movement the torso moves in parallel with the head. Together head and torso move in the opposite direction from the hands and thus balance the biomechanical effect of the manual movement and help the signer maintain stability.

Additional support for this account can be found by looking at DISCUSS in Argentinian SL shown in Fig. 27.

In this sign the direction of head movement matches the direction of manual movement (sagittally forward and backward), and so it is not one of the signs included in Table 7. However, the torso moves in the opposite direction of hands and head. The movement of both hands and the head forward and backward together generates torque, and the opposite movement direction of the torso reduces the amount of reactive effort needed to resist falling forward or backward (Sanders & Napoli, 2016a, 2016b).

Finally, we note that head and hands sometimes perform opposing movements even when the torso does not move—here in 10 out of the 28 total tokens. These facts indicate that echo phonology can involve opposite movement direction regardless of biomechanical concerns. Rather, movement of the head and hand(s) in opposite directions might be linguistically motivated as well: The sign's movement is enlarged, thereby creating an

Fig. 27. DISCUSS in Argentinian SL.

Table 7
Percentage of opposite direction movement arranged by type of head articulation

	# With Opposite Direction	Total # of All Head Echoes	%
(T) lateral displacement	13	14	85.7
(T) rotation	8	20	40
(T + V) lateral tilt	5	30	16.7
(V + S) sagittal tilt	1	51	2
(S) sagittal displacement	0	5	0

overall larger phonetic signal. This finding confirms previous proposals by Brentari (1998) and Puupponen and colleagues (2015), who view echoes in general as a way of enhancing the phonetic signal.

6. General discussion and conclusions

The present work enriches inquiry into echo phonology and into phonological theory in general. First, echo phonology is not limited to hand–mouth coordinations; the head and hands also coordinate. This is not a surprising conclusion. Coordination between the hand and other body parts that do not involve language is attested outside of language; for example, wrist and ankle muscles coordinate leading to a preference for the same directional movements of the hand and foot (Baldissera, Borroni, Cavallari, & Cerri, 2002; Borroni, Cerri, & Baldissera, 2004; Byblow et al., 2007; Mcintyre-Robinson & Byblow, 2013). Further, digit muscles coordinate leading to a preference for simultaneous flexion or extension of fingers and toes (Muraoka, Sakamoto, Mizuguchi, Nakagawa, & Kanosue, 2015). Flexion of hand muscles and/or foot muscles can trigger mandible articulation so that, for example, a fist clench goes together with a jaw clench (Komeilipoor et al., 2017). Since coordination of hand articulations with other articulators in the body is well-documented, it would be surprising if a manual language did not exploit head–

hand coordinations. In fact, the neuroscience literature establishes motoric hand–head coordination (Reppert et al., 2018; Tao, Khan, & Blohm, 2018). There is evidence of hand–eye coordination, as well (Abrams, Meyer, & Kornblum, 1990; Miall, Reckess, & Imamizu, 2001), which shows that hand–head coordination need not be connected to hand–eye coordination (Pelz, Hayhoe, & Loeber, 2001; Reppert et al., 2018). Both hand–head and hand–eye coordination are important to language development (D'Souza, D'Souza, & Karmiloff-Smith, 2017; Iverson, 2010). Thus, articulatory coordination in language need not and should not privilege the hand–mouth relationship, and, as we have shown, it does not.

Second, the present study challenges the notion of what an echo really is. Importantly, we focus on bodily articulation that echoes another bodily articulation. In past studies of echo phonology, not just lip or tongue articulation, but air flow characteristics were pointed to as echoes of manual articulation. With this paper we hope to reposition the discussion of echo phonology so that it fits within the overall study of motor coordination among body parts.

Third, this study opens up questions about what the parameters might be on an echo when the two articulators involved are so different. The manuals, for example, have a wider range of movement possibilities than the head does, so an echo cannot be an exact copy. Instead, it looks like the axis or axes of movement are the most relevant factor. But even when we consider only axes of movement, the echo may not be perfect. Sometimes, a head echo can come close, as we saw with side-to-side manual movement being echoed by lateral tilts, lateral displacements, or rotations. Head echoes can even closely match complex manual movements such as circles, but they do not do so consistently. In the 28 tokens of complex manual movement in our data (see Tables 5 and 6), 19 (67.9%) have more than one movement direction echoed by a head movement. The remaining nine have a single head echo that copies only one manual movement direction. Overall, we note that if only one dimension of a complex manual movement is to be echoed, vertical is the most likely.

Fig. 28. CLIMBING ANCHOR in Spanish SL.

Additionally, direction of head movement is usually the same as that of hand movement, but biomechanical considerations and/or phonetic enhancement strategies can favor head movement in the opposite direction to hand movement.

An interesting question arises from looking at signs with alternating manual movement. Take for instance the first part of the sign CLIMBING ANCHOR in Spanish SL (Fig. 28), which has repeating head rotation as the two hands alternate moving up and down, mimicking climbing.

Each time, the head rotates toward the hand that is moving up. We did not analyze this rotation as a head echo, since it is unclear what part of the direction of the manual movement could be echoed by this rotation. We further have four instances of the sign SEESAW in which the hands again alternate moving up and down. Here, the head does a lateral tilt toward the rising hand (i.e., the hand is going up but the head is going down). Looking at these signs together, we wonder if both rotation and lateral head tilt are, in fact, echoes, but of the alternating feature of the manual movement. That would mean that not only direction of movement but also movement alternation could be echoed by the head. We leave this matter for future investigation.

In sum, our study suggests that what matters in head echoes is not whether the articulations of head and hand are the same, but whether the visual percept for the viewer is one of coordinated movement that repeats some salient property of movement. That salient property is not simply a matter of timing coordination. Rather, as suggested by Brentari (1998), something about the manual movement type must be repeated by the head in such a way as to give the visual impression of a copy. In this paper, we have shown that the axes along which movement takes place matter, but the movement direction does not. We have identified which basic head movements are used in hand–head echoes, and which movement axes they can represent. Despite the fact that more basic head articulations include a transverse movement axis than any other axis, vertical manual movement was more likely to be echoed than transverse or sagittal manual movement. We have suggested that this may be partially due to the prevalence of sagittal tilt echoes. Aside from movement axes, we indicated that movement repetition and potentially alternating manual movement are features of the manual signal that echoes pick up on.

A fourth issue emerging from this study has to do with perception. The fact that sagittal head tilts are coopted to echo manual sagittal movement much more heavily than sagittal head displacements leads us to suggest that perception is a determining factor in echo phonology. Movement along the sagittal axis creates perception difficulties and needs to be shored up by additional cues (Sanders, 2018). The vertical dimension within a sagittal head tilt may well provide what is needed.

A fifth and major finding of our study has to do with the phonological notion of enhancement. Distinctive features of spoken language phonemes are often reinforced in their phonetic realization by added articulatory gestures that serve to enhance the auditory effects of those features so that the listener can more easily perceive the distinction (Stevens, Keyser, & Kawasaki, 1986). For example, the feature [-high] on the central mid vowel /ɘ/ can be enhanced by lowering it to [a], or the feature [-round] on the central high vowel /ɨ/ can be enhanced by fronting it to [i], or the feature [+voice] on an initial stop consonant can be enhanced by lowering the velum to add pre-nasalization. Additionally, entire articulations can be added for enhancement. For example, /ə/ can be inserted to enhance the perceptibility of the surrounding consonants, but it vies with prosodic boundary insertion (Cote, 2007). In spoken languages, enhancement of features that are in jeopardy of losing their perceptual salience occurs across languages (Keyser & Stevens, 2006; Stevens & Keyser, 1989, 2010; among many).

With respect to sign languages, Brentari (1998, p. 173) first suggested that a head articulation might serve to enhance the phonetic signal in American SL. Pendzich (2020) and Puupponen et al. (2015) propose similar functions for nonmanual movement copies in German and Finnish SL. Head echoes and other nonmanual echoes may well be an example of a process that reinforces the perceptual salience of the features of the manual parameters of the sign. Head echoes would appear to enhance the dimension of manual movement, the repetition of it, and, usually, its direction. Here the fact that sagittal tilt is the favored head echo for sagittal manual movement is pertinent. The difficulty of perceiving movement along the sagittal axis is overcome by the vertical dimension of the tilt, which cues us in to the manual sagittal dimension. With an enhancement analysis, it is not surprising that some nonmanual articulations have been claimed to be obligatory echoes. Enhancements in spoken languages typically start out as optional additions, but sometimes are subsequently phonologized and, thus, become obligatory (as happened with aspiration of stops in Korean, see Kim & Duanmu, 2004). The fact that we found multiple ways for head articulation to enhance a particular direction of manual movement is compatible with an enhancement analysis, given that the effects of enhancement in spoken languages need not be uniform, can vary from language to language, and can vary within a language from one environment to another (Dresher, Hall, & Mackenzie, 2020). Head echoes also show us how strong the phonological tendency for enhancement is. The head represents fully 6% of total body weight (Szczygieł et al., 2015), and it is far less mobile than the mouth. Nevertheless, the head does what it can to enhance the signal.

This preliminary study opens the door to various possible others. Future investigations into what principles govern and what factors motivate echoes are called for. Given that echoes give redundant information, we might want to look for factors that increase their likelihood of occurring. And while this study focused on head articulations because the head is a large nonmanual articulator and therefore easy to see, studies are needed to search for echo phenomena involving other nonmanuals. Such studies might include true mouth articulations as well as echo articulations of the eyes, nose, eyebrows, and torso.

Additionally, one might look for influence on the relative incidence of head echoes from gestures that occur in the ambient spoken language, since sign languages incorporate several gestural components (Goldin-Meadow & Brentari, 2017). Further, co-speech includes head gestures that are common to many cultures (such as a sagittal tilt to show affirmation or a head rotation to show negation) or they may be particular to a given language/culture (such as a lateral tilt in the so-called Indian head wobble). While our limited study uncovered no hint of correlation between the various types of echo head articulations and particular head gesture articulations, one might want to check whether the prevalence of a particular head articulation is encoded in motor memory in such a way as to influence head echoes (see Förster & Strack, 1996, for a study of head tilts and rotations related to affirmation and negation).

Finally, the analysis provided in this paper is based on our own perceptions of movement in the video data provided on spreadthesign.com. This procedure is adequate for a preliminary study that aims to engender discussion about what echo phonology might truly encompass. But relying on movement detection technology would undoubtedly uncover movement that is not obvious to the eye. If the function of echoes is redundancy, then our own judgments of head movement are not only adequate, they are the more appropriate, since people in a conversation will be relying on their own perceptions to pick up redundant cues. But if echoes are motivated by something else, for instance a production factor, technology might uncover important evidence missed by the naked eye. Indeed, if there are more similarities between hand movement and head movement than the eye can detect, that would support the idea that echoing is a built-in physiological coordination matter involving much more than language.

Notes

1. Sign languages also have obligatory mouth actions that do not echo manual movements. Since our focus will not be on mouth actions, we only list them here briefly. They include mouthings, which are (partial or reduced) articulations of spoken words (Schermer, 1990), mouth components of multi-channel signs (Brennan, 1992) such as the articulation "pah" that forms an obligatory component of the sign REALISE in Australian SL (Johnston & Schembri, 2007), or the tongue protrusion in American SL NOT-YET. Mouth actions may also enact an aspect of the meaning of a sign; for instance, a biting action for the British SL sign APPLE (Woll, 2001). Lastly, there are nonmanual adverbs formed on the mouth, for instance "quickly" in Israeli SL, which consists of puffed cheeks with air hissing out (Meir & Sandler, 2007).
2. Throughout we refer to sign languages by a country-name adjective plus the abbreviation SL, since they are listed in our source dictionary by country-name.
3. When a sign comes from our own research, we gloss it in the ambient spoken language. Thus, this sign meaning 'stupid' is glossed DUMM because it is in German SL and these are our own photographs. Signs from other sources are glossed according to the source glossing conventions.
4. This tongue movement needs to be distinguished from a retroflex tongue flick, a tongue trill, or a velaric tongue movement internal to the oral cavity in many spoken languages.
5. Again, there is confusion over these criteria in the literature. For example, DRA "go away" in Norwegian SL is claimed to be an example of echo phonology (Vogt-Svendsen, 2001). Here the tips of the index finger and thumb come into contact

while the mouth closes. But this manual articulation is iconic (of something appearing smaller as it goes away). Further, the mouth articulation is optional.

6. http://www3.gallaudet.edu/clerc-center/info-to-go/asl/learning-asl-books_media_classes.html.
7. On spreadthesign.com, the same signs/signers appear under the language labels "English (India)" and "Hindi." We collapse these under the country label "India" and refer to this as Indian SL. Spreadthesign.com also has the language label "Urdu." Since Urdu is the official language of Pakistan, we list these entries under the country label "Pakistan" and refer to this as Pakistani SL.
8. However, we included concepts which in some languages have entries with similar movement of manuals, head, and gaze, so long as there are also entries for which head movement and gaze do not coincide for the entire duration of the sign. We also included entries for which maintaining gaze on the moving hand does not warrant head movement, such as a sagittal tilt upward even when the hand does not rise higher than eye level.
9. There are 115 head echoes distributed over 112 dictionary entries, because three entries have more than one head echo. All five basic types of head echoes plus circular movement are represented in the data set.
10. Manual movements that form part of the sign but do not co-occur with a head movement are not considered in the analysis. Thus, for example, ARGUE in Austrian SL has a side-to-side hand movement followed by a vertical one, but we analyze it as only vertical because the head movement (sagittal tilt) begins after the transverse manual movement has ended.
11. These three are ALARM CLOCK, BELL, and TAIL. A possible reason for the lack of head echoes may be the speed of manual movement in these signs. Signers very often produced rapid radioulnar rotations. If the head were to echo this movement, we might expect rapid cervical rotations. While cervical range of motion is not inhibited by speed (Bonnechere et al., 2014), we expect that head rotations (as well as lateral head tilts) even at their fastest are still slower than radioulnar rotations (although we have found no comparative studies). Since timing of head and hand movements generally matches in echoes, manual speed might preclude head echoes here.
12. Head rotation is a bit trickier to characterize. The nose, for example, moves in an arc that has dimension along both the transverse and sagittal axes. In Section 4.2.2 we explain why we analyze head rotation as movement along the transverse axis only.
13. Except for head rotation, our head movements are all described as movements *along* axes rather than some being described as movement *around* axes. In particular, we do not describe the two tilts in terms of pitch (for sagittal tilt), and roll (for lateral tilt), as some studies on head articulation do (such as Kunin et al., 2007). Rather, we maintain head rotation as distinct in type from the two head tilts, as other studies on head articulation do (such as Jampel & Shi, 2002). This approach facilitates capturing correlations between head movement and manual movement and is consistent with our emphasis on visual perception.

14. Throughout the production of the sign, the head stays in a displaced position forward and slightly rotated. This is not an echo but simply a pose.
15. This holds for circles drawn on the vertical plane facing the signer.
16. The movement is minimal and best observed on video at spreadthesign.com.
17. We use "languages/cultures" to allow for head nods that are entrenched in a linguistic system as well as those entrenched in a culture that might include multiple linguistic systems.
18. Note that three signs with abrupt manual direction change were included in Table 4 of Section 5.2.1, because each part of the sign has a distinct head echo—so the signs are made of two parts, where each part behaves like a complete mono-axial sign with a head echo.
19. In two of these tokens we have a complex manual movement involving all three dimensions and a combination of two head echoes.

References

Abrams, R. A., Meyer, D. E., & Kornblum, S. (1990). Eye-hand coordination: Oculomotor control in rapid aimed limb movements. *Journal of Experimental Psychology: Human Perception and Performance*, *16*(2), 248–267. https://doi.org/10.1037/0096-1523.16.2.248

Baldissera, F., Borroni, P., Cavallari, P., & Cerri, G. (2002). Excitability changes in human corticospinal projections to forearm muscles during voluntary movement of ipsilateral foot. *Journal of Physiology*, *539*, 903–911. https://doi.org/10.1113/jphysiol.2001.013282

Barboza, C. F. S., Campello, A. R., & Castro, H. C. (2015). Sports, physical education, olympic games, and Brazil: The deafness that still should be listened. *Creative Education*, *6*(12), 1386–1390. https://doi.org/10.4236/ce.2015.612138

Bonnechere, B., Salvia, P., Dugailly, P.-M., Maroye, L., Van Geyt, B., & Feipel, V. (2014). Influence of movement speed on cervical range of motion. *European Spine Journal*, *23*(8), 1688–1693. https://doi.org/10.1007/s00586-014-3249-3

Borroni, P., Cerri, G., & Baldissera, F. (2004). Excitability changes in resting forearm muscles during voluntary foot movements depend on hand position: A neural substrate for hand-foot isodirectional coupling. *Brain Research*, *1022*, 117–125. https://doi.org/10.1016/j.brainres.2004.07.003

Börstell, C., Jantunen, T., Kimmelman, V., de Lint, V., Mesch, J., & Oomen, M. (2019). Transitivity prominence within and across modalities. *Open Linguistics*, *5*, 666–689. https://doi.org/10.1515/opli-2019-0037

Brennan, M. (1992). The visual world of BSL: An introduction. In D. Brien (Ed.), *Dictionary of British Sign Language* (pp. 1–133). London: Faber and Faber.

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

Byblow, W. D., Coxon, J. P., Stinear, C. M., Fleming, M. K., Williams, G., Müller, J. F. M., & Ziemann, U. (2007). Functional connectivity between secondary and primary motor areas underlying hand-foot coordination. *Journal of Neurophysiology*, *98*, 414–422. https://doi.org/10.1152/jn.00325.2007

Corballis, M. (2002). *From hand to mouth: The origins of language*. Princeton, NJ/Oxford, UK: Princeton University Press. Available at: https://www.researchgate.net/publication/246251064_From_Hand_to_Mouth_The_Origins_of_Language. Accessed June 1, 2020.

Cote, M.-H. (2007). Rhythmic constraints on the distribution of schwa in French. In J. Camacho, N. Flores-Ferrán, L. Sánchez, V. Déprez, & M. J. Cabrera (Eds.), *Romance linguistics 2006* (pp. 81–96). Amsterdam: Benjamins. https://doi.org/10.1075/cilt.287.07cot

Crasborn, O. A., Van Der Kooij, E., Waters, D., Woll, B., & Mesch, J. (2008). Frequency distribution and spreading behavior of different types of mouth actions in three sign languages. *Sign Language & Linguistics*, *11*(1), 45–67. https://doi.org/10.1075/sl&U38;l.11.1.04cra

Dresher, B. E., Hall, D. C., & Mackenzie, S. (2020). The status of phoneme inventories: The role of contrastive feature hierarchies. Paper presented at the Congrès de l'ACL2020/ 2020 CLA Meeting. Accessed June 1, 2020.

D'Souza, D., D'Souza, H., & Karmiloff-Smith, A. (2017). Precursors to language development in typically and atypically developing infants and toddlers: The importance of embracing complexity. *Journal of Child Language*, *44*(3), 591–627. https://doi.org/10.1017/S030500091700006X

Fontana, S. (2008). Mouth actions as gesture in sign language. *Gesture*, *8*(1), 14–123. https://doi.org/10.1075/gest.8.1.08fon

Förster, J., & Strack, F. (1996). Influence of overt head movements on memory for valenced words: A case of conceptual-motor compatibility. *Journal of Personality and Social Psychology*, *71*(3), 421–430. https://doi.org/10.1037//0022-3514.71.3.421

Gentilucci, M. (2003). Grasp observation influences speech production. *European Journal of Neuroscience*, *17*, 179–184. https://doi.org/10.1046/j.1460-9568.2003.02438.x

Gentilucci, M., Benuzzi, F., Gangitano, M., & Grimaldi, S. (2001). Grasp with hand and mouth: A kinematic study on healthy subjects. *Journal of Neurophysiology*, *86*, 1685–1699. https://doi.org/10.1152/jn.2001.86.4.1685

Gentilucci, M., & Campione, G. C. (2011). Do postures of distal effectors affect the control of actions of other distal effectors? Evidence for a system of interactions between hand and mouth. *PLoS ONE*, *6*(5), e19793. https://doi.org/10.1371/journal.pone.0019793

Gentilucci, M., & Corballis, M. C. (2006). From manual gesture to speech: A gradual transition. *Neuroscience Biobehavioral Review*, *30*, 949–960. https://doi.org/10.1016/j.neubiorev.2006.02.004

Gentilucci, M., & Dalla Volta, R. (2008). Spoken language and arm gestures are controlled by the same motor control system. *The Quarterly Journal of Experimental Psychology*, *61*, 944–957. https://doi.org/10.1080/17470210701625683

Gentilucci, M., Dalla Volta, R., & Gianelli, C. (2008). When the hands speak. *Journal of Physiology*, *102*, 21–30. https://doi.org/10.1016/j.jphysparis.2008.03.002

Goldin-Meadow, S., & Brentari, D. (2017). Gesture, sign and language: The coming of age of sign language and gesture studies. *Behavioral Brain Sciences*, *40*, e46. https://doi.org/10.1017/S0140525X15001247

Hilzensauer, M., & Krammer, K. (2015). A multilingual dictionary for sign languages: Spreadthesign. In *ICERI2015 Proceedings* (pp. 7826–7834). Valencia, Spain: IATED. Available at: https://pdfs.semanticscholar.org/b382/b03f17aa1db2264ac52a98da9a146a2006a6.pdf

InformedHealth.org [Internet]. (2006). How does the spine work? Cologne, Germany: Institute for Quality and Efficiency in Health Care (IQWiG). Available at: https://www.ncbi.nlm.nih.gov/books/NBK279468/. Accessed February 9, 2020.

Iverson, J. M. (2010). Developing language in a developing body: The relationship between motor development and language development. *Journal of Child Language*, *37*(2), 229–261. https://doi.org/10.1017/S0305000909990432

Jampel, R. S., & Shi, D. X. (2002). The absence of so-called compensatory ocular countertorsion: The response of the eyes to head tilt. *Archives of Ophthalmology*, *120*(10), 1331–1340. https://doi.org/10.1001/archopht.120.10.1331

Johnston, T., & Schembri, A. (1999). On defining lexeme in a signed language. *Sign Language and Linguistics*, *2*(2), 115–185. https://doi.org/10.1075/sll.2.2.03joh

Johnston, T., & Schembri, A. (2007). *Australian Sign Language: An introduction to sign language linguistics*. Cambridge, UK: Cambridge University Press. https://doi.org/10.1017/CBO9780511607479

Kendon, A. (2010). Response: Gesture first or speech first in language origins? In G. Mathur & D. J. Napoli (Eds.), *Deaf around the world: The impact of language* (pp. 251–267). Oxford: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199732548.001.0001

Keyser, S. J., & Stevens, K. N. (2006). Enhancement and overlap in the speech chain. *Language*, *82*(1), 33–63. https://doi.org/10.1353/lan.2006.0051

Kim, M.-R., & Duanmu, S. (2004). "Tense" and "lax" stops in Korean. *Journal of East Asian Linguistics*, *13*(1), 59–104. https://doi.org/10.1023/B:JEAL.0000007344.43938.4e

Komeilipoor, N., Ilmoniemi, R. J., Tiippana, K., Vainio, M., Tiainen, M., & Vainio, L. (2017). Preparation and execution of teeth clenching and foot muscle contraction influence on corticospinal hand-muscle excitability. *Scientific Reports*, *7*(1), 1–9. https://doi.org/10.1038/srep41249

Kuhlman, K. A. (1993). Cervical range of motion in the elderly. *Archives of Physical Medicine and Rehabilitation*, *74*(10), 1071–1079. https://doi.org/10.1016/0003-9993(93)90064-h

Kunin, M., Osaki, Y., Cohen, B., & Raphan, T. (2007). Rotation axes of the head during positioning, head shaking, and locomotion. *Journal of Neurophysiology*, *98*(5), 3095–3108. https://doi.org/10.1152/jn.00764.2007

Lewin, D., & Schembri, A. (2011). Mouth gestures in British Sign Language (BSL): A case study of tongue protrusion in BSL Narratives. *Sign Language & Linguistics*, *14*(1), 94–114. https://doi.org/10.1075/sll.14.1.06lew

Liddell, S. (1984). THINK and BELIEVE: Sequentiality in American Sign Language. *Language*, *60*(2), 372–392. https://doi.org/10.2307/413645

MacNeilage, P. F. (1998). The frame/content theory of evolution of speech production. *Behavioral and Brain Sciences*, *21*(4), 499–511. https://doi.org/10.1017/s0140525x98001265

MacNeilage, P. F., & Davis, B. L. (2000). On the origin of internal structure of word forms. *Science*, *288*(5465), 527–531. https://doi.org/10.1126/science.288.5465.527

MacSweeney, M., Capek, C. M., Campbell, R., & Woll, B. (2008). The signing brain: The neurobiology of sign language. *Trends in Cognitive Sciences*, *12*(11), 432–440. https://doi.org/10.1016/j.tics.2008.07.010

Mcintyre-Robinson, A. J., & Byblow, W. D. (2013). A neurophysiological basis for the coordination between hand foot movement. *Journal of Neurophysiology*, *110*, 1039–1046. https://doi.org/10.1152/jn.00266.2013

Meir, I., & Sandler, W. (2007). *A language in space: The story of Israeli Sign Language*. New York: Lawrence Erlbaum Associates. https://doi.org/10.4324/9780203810118

Miall, R. C., Reckess, G. Z., & Imamizu, H. (2001). The cerebellum coordinates eye and hand tracking movements. *Nature Neuroscience*, *4*(6), 638–644. https://doi.org/10.1038/88465

Morrison, G. (2018). *Forward head posture's effect on the cervical spine*. Available at: https://www.spine-health.com/conditions/neck-pain/forward-head-postures-effect-cervical-spine. Accessed March 5, 2020.

Muraoka, T., Sakamoto, M., Mizuguchi, N., Nakagawa, K., & Kanosue, K. (2015). Corticospinal excitability modulation in resting digit muscles during cyclical movement of the digits of the ipsilateral limb. *Frontiers in Human Neuroscience*, *9*, 607. https://doi.org/10.3389/fnhum.2015.00607

Nespor, M., & Sandler, W. (1999). Prosodic phonology in Israeli Sign Language. *Language and Speech*, *42*(2–3), 143–176. https://doi.org/10.1177/00238309990420020201

Östling, R., Börstell, C., & Courtaux, S. (2018). Visual iconicity across sign languages: Large-scale automated video analysis of iconic articulators and locations. *Frontiers in Psychology*, *9*, 725. https://doi.org/10.3389/fpsyg.2018.00725

Pelz, J., Hayhoe, M., & Loeber, R. (2001). The coordination of eye, head, and hand movements in a natural task. *Experimental Brain Research*, *139*(3), 266–277. https://doi.org/10.1007/s002210100745

Pendzich, N.-K. (2020). *Lexical nonmanuals in German Sign Language (DGS). Empirical studies and theoretical implications*. Berlin: Mouton De Gruyter. https://doi.org/10.1515/9783110671667

Peterson, B. W., Keshner, E. A., & Banovetz, J. (1989). Comparison of neck muscle activation patterns during head stabilization and voluntary movements. In J. H. J. Allum & M. Hulliger (Eds.), *Progress in brain research: Afferent control of posture and locomotion* (Vol. 80, pp. 363–371). Edinburgh: Elsevier. https://doi.org/10.1016/s0079-6123(08)62231-1

Pfau, R., & Quer, J. (2010). Nonmanuals: Their grammatical and prosodic roles. In D. Brentari (Ed.), *Sign languages* (pp. 381–402). Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511712203.018

Puupponen, A., Wainio, T., Burger, B., & 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. https://doi.org/10.1075/sll.18.1.02puu

Regan, D., Erkelens, C. J., & Collewijn, H. (1986). Necessary conditions for the perception of motion in depth. *Investigative Ophthalmology & Visual Science*, *27*(4), 584–597.PMID: 3957578. Available at: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1089.3876&rep=rep1&type=pdf. Accessed 1 June 2020.

Regan, D., & Kaushal, S. (1994). Monocular discrimination of the direction of motion in depth. *Visual Research*, *34*(2), 163–177. https://doi.org/10.1016/0042-6989(94)90329-8

Reppert, T. R., Rigas, I., Herzfeld, D. J., Sedaghat-Nejad, E., Komogortsev, O., & Shadmehr, R. (2018). Movement vigor as a traitlike attribute of individuality. *Journal of Neurophysiology*, *120*(2), 741–757. https://doi.org/10.1152/jn.00033.2018

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience*, *27*, 169–192. https://doi.org/10.1146/annurev.neuro.27.070203.144230

Rizzolatti, G., Fadiga, L., Gallese, V., & Fogassi, L. (1996). Premotor cortex and the recognition of motor actions. *Cognitive Brain Research*, *3*, 131–141. https://doi.org/10.1016/0926-6410(95)00038-0

Rosenbaum, D. A. (2009). Walking down memory lane: Where walkers look as they descend stairs provides hints about how they control their walking behavior. *The American Journal of Psychology*, *122*(4), 425–430. https://www.jstor.org/stable/27784419

Sanders, N. (2018). Some issues in the perceptual phonetics of sign language: Motion-in-depth and the horizontal-vertical illusion. *Toronto Working Papers in Linguistics*, *40*. Special issue from the CRC-Sponsored Phonetics/Phonology Workshops. Available at: https://twpl.library.utoronto.ca/index.php/twpl/article/view/29190/21936. Accessed June 1, 2020.

Sanders, N., & Napoli, D. J. (2016a). A cross-linguistic preference for torso stability in the lexicon: Evidence from 24 sign languages. *Sign Language & Linguistics*, *19*(2), 197–231. https://doi.org/10.1075/sll.19.2.02san

Sanders, N., & Napoli, D. J. (2016b). Reactive effort as a factor that shapes sign language lexicons. *Language*, *92*(2), 275–297. https://doi.org/10.1353/lan.2016.0032

Schermer, T. (1990). *In search of a language: Influences from spoken Dutch on Sign Language of the Netherlands*. Delft: Eburon.

Sidenmark, L., & Gellersen, H. (2019). Eye & Head: Synergetic eye and head movement for gaze pointing and selection. In F. Guimbretière, M. Bernstein & K.. Reinecke (Eds.), *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology* (pp. 1161–1174). New York, NY: Association for Computing Machinery.

Stevens, K. N., & Keyser, S. J. (1989). Primary features and their enhancement in consonants. *Language*, *65*(1), 81–106. https://www.jstor.org/stable/414843

Stevens, K. N., & Keyser, S. J. (2010). Quantal theory, enhancement and overlap. *Journal of Phonetics*, *38*(1), 10–19. https://doi.org/10.1016/j.wocn.2008.10.004

Stevens, K. N., Keyser, S. J., & Kawasaki, H. (1986). Toward a phonetic and phonological theory of redundant features. In J. S. Perkell & D. H. Klatt (Eds.), *Invariance and variability in speech processes* (pp. 426–449). Hillsdale, NJ: Erlbaum. https://doi.org/10.4324/9781315802350

Swartz, E. E., Floyd, R. T., & Cendoma, M. (2005). Cervical spine functional anatomy and the biomechanics of injury due to compressive loading. *Journal of Athletic Training*, *40*(3), 155–161.PMID: 16284634; PMCID: PMC1250253.

Szczygieł, E., Węglarz, K., Piotrowski, K., Mazur, T., Miętel, S., & Golec, J. (2015). Biomechanical influences on head posture and the respiratory movements of the chest. *Acta of Bioengineering and Biomechanics*, *17*(2), 143–148.PMID: 26415553.

Tao, G., Khan, A. Z., & Blohm, G. (2018). Corrective response times in a coordinated eye-head-arm countermanding task. *Journal of Neurophysiology*, *119*(6), 2036–2051. https://doi.org/10.1152/jn.00460.2017

Udoff, J. A. (2014). Mouthings in American Sign Language: Biomechanical and representational foundations (Doctoral dissertation). San Diego, CA: University of California. Available at: https://escholarship.org/uc/item/6h02d9d9. Accessed June 1, 2020.

Vogt-Svendsen, M. (2001). A comparison of mouth gestures and mouthings in Norwegian Sign Language (NSL). In P. Boyes Braem & R. Sutton-Spence (Eds.), *The hands are the head of the mouth: The mouth as articulator in sign languages* (pp. 9–40). Hamburg: Signum.

Woll, B. (2001). The sign that dares to speak its name: Echo phonology in British Sign Language (BSL). In P. Boyes Braem & R. Sutton-Spence (Eds.), *The hands are the head of the mouth: The mouth as articulator in sign languages* (pp. 87–98). Hamburg: Signum.

Woll, B. (2008). Do mouths sign? Do hands speak?: Echo phonology as a window on language genesis. *LOT Occasional Series*, *10*, 203–224.

Woll, B. (2014). Moving from hand to mouth: Echo phonology and the origins of language. *Frontiers in Psychology*, *5*, 662. https://doi.org/10.3389/fpsyg.2014.00662

Woll, B., & Sieratzki, J. S. (1998). Echo phonology: Signs of a link between gesture and speech. *Behavioral and Brain Sciences*, *21*(4), 531–532. https://doi.org/10.1017/S0140525X98481263

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article:

Appendix S1. Further examples of lateral displacement head echoes.

Appendix S2. Further examples of rotation head echoes.

Appendix S3. Further examples of sagittal displacement head echoes.

Appendix S4. Further examples of lateral head tilt echoes.

Appendix S5. Combination head articulations.