Expanding Echo: Coordinated head articulations as nonmanual enhancements in sign language phonology

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Keywords: sign language phonology, echo phonology, head articulations, motor coordination

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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 a 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.

1. Introduction

The term *echo phonology* was coined in 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 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 in Figure 1, as the hands move to contact one another, so do the lips (MacSweeney et al., 2008). Likewise, in British SL THANK-GOD, the lips touch at the same time as the selected fingers come into contact (Woll, 2001).

Figure 1: TRUE in British SL (Figure 8b in 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 are coordinated. One such commonly cited example consists of finger trilling while the mouth articulates a sibilant, as in British SL EXIST (Woll, 2014) and German SL

[1] Sign languages also have obligatory mouth actions that do not echo manual movements. Since our focus will not be on mouth actions, we list them here only 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 BSL sign APPLE (Woll, 2001). Lastly, there are non-manual 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.

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 et al., 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. However, 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 ASL signers coordinate the onset and offset of hand and mouth movements in mouthing-accompanied fingerspelling, and they further coordinate the degree of opening or closing of both articulators. Signers do so even when the hands and the 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 moving 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, p. 173). She goes on to illustrate the phenomenon with a variant of the ASL sign PERPLEXED, in which the backwards path movement of the dominant hand in front of the forehead is copied by a backwards movement of the head:

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

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 two per cent 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 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 (as we outline below) 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 et al., 1996; Rizzolatti & Craighero, 2004). 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 (Gentilucci et al., 2001; Corballis, 2002; Gentilucci & Corballis, 2006; Gentilucci & Dalla Volta, 2008; Gentilucci et al., 2008), Gentilucci and Campione (2011) speculate that hand or arm gestures which historically formed 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 shared by many, 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 phonology. 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 a spoken language phonology (we thank Jay Keyser for confirming this intuition, p.c. 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 DUMM 'stupid' has a lateral mandibular echo articulation, as seen in Fig. 3.[3]

Figure 3: DUMM 'dumm' in German SL 

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 zig zag line downwards. 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.

[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.

Figure 4: KAUM ‘barely’ and AB-UND-ZU ‘every once in a while’ in German SL

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.

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

[5] Again, there’s 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.

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 BSL 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 axis (or 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, splenus 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 et al., 2015; Sanders & Napoli, 2016a; Östling et al., 2018; Börstell et al., 2019). 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 that 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 in some languages have 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

[6] http://www3.gallaudet.edu/clerc-center/info-to-go/asl/learning-asl-books_media_classes.html

[7] On spreadthesign.com, the same signers/signs 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.

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 et al., 2007), we further excluded signs with gaze-aligned head movement as attested in several SLs for the concept ‘rocket’. It is unclear whether upward head movement in these instances 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, then, we see information on the dictionary entries across the remaining 36 languages. English word forms that could be either nouns or verbs are verbs, unless specifically labeled as nouns with “(N)”.

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[9], rain, see-saw, sink, sit, snow, submarine, wave (N)

[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 upwards even when the hand does not rise higher than eye level).

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

circular movement	ferris wheel, washing machine

These entries offered a total of 115 tokens of head echoes[10] from 30 languages (that is, 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[11]
- 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 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.

[10] 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.
[11] 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.

Figure 5: PENDULUM in British SL

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.[12] 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 from left to right according to the token count of head echoes exhibited by them. Two lexical items had head echoes in eight languages; eleven 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 et al., 2008) as well as findings on the frequency of head echoes in Finnish SL (Puupponen et al., 2015).

[12] 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.

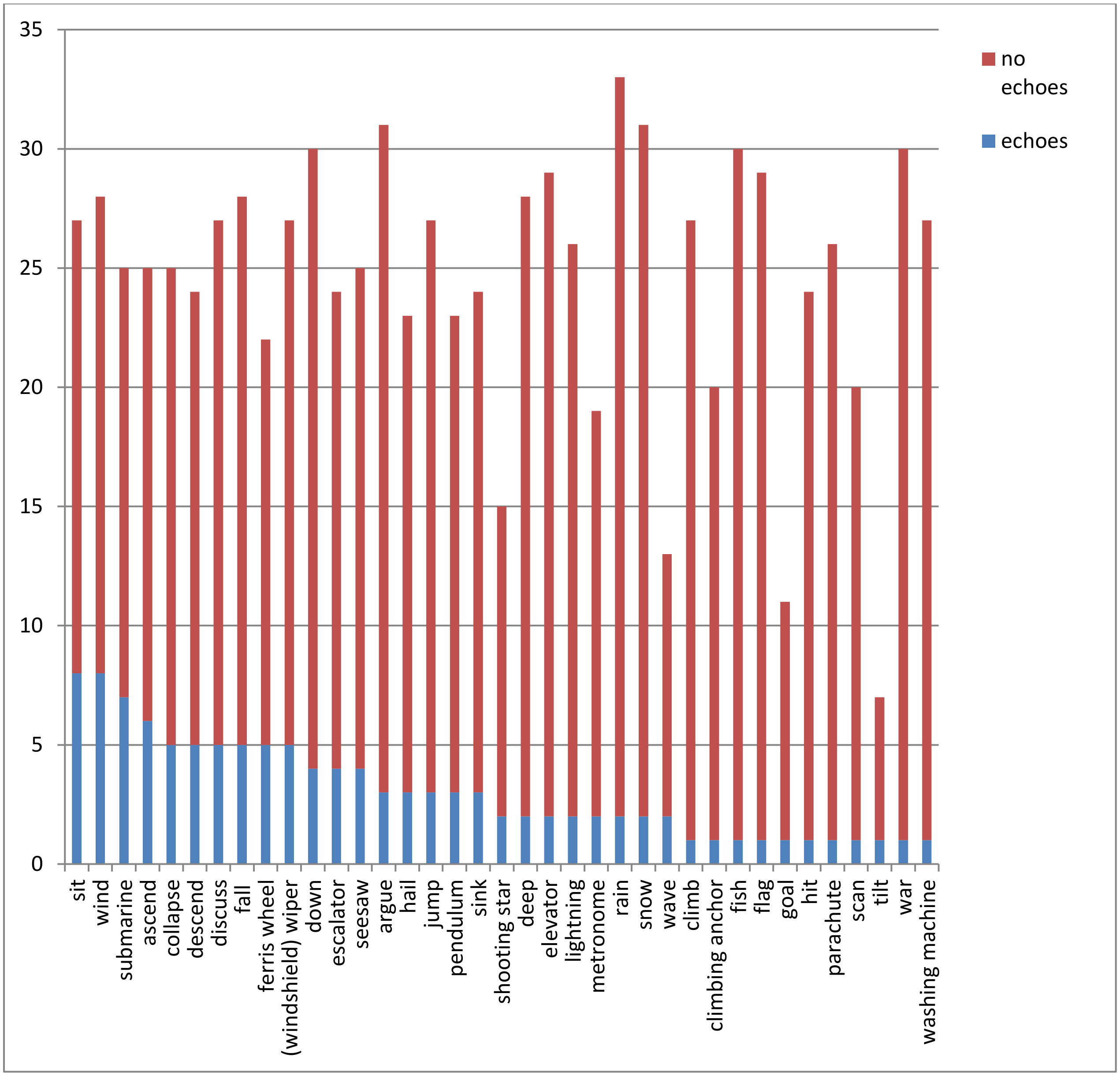


Figure 6: Lexical items listed by most to least head

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).[13] 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 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 displacement involves movement along the transverse axis. The examples we give here have the head moving in the opposite direction from that of the hands, as this was the case in nearly all our examples of lateral 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.

Figure 7: WIND in Polish SL 

[13] 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.

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 dominant hand (on this signer, the left hand) moves in a circle (transverse + vertical manual movement), arcing down first then to the side opposite of the moving hand, while the nondominant 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, not the vertical component.

Figure 8: FERRIS WHEEL in Italian SL

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 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 dimension along both the transverse and sagittal axes.[14] However, since that arc is slight – that is, people do not turn their heads 90 degrees to look over each shoulder, 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

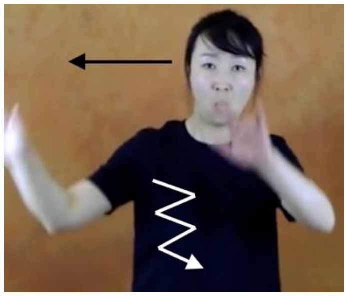
[14] Except for head rotation, our head movements are all described as movements along axes rather than some being described as movement around axes. In particular, we do not describe the two tilts in terms of pitch (for sagittal tilt), and roll (for lateral tilt), as some studies on head articulation 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.

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, the head 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 tilt and with lateral head displacement, here the torso moves side-to-side along with the head rotation.

Figure 9: WIND in Portuguese SL

As we saw with lateral displacement, sometimes not the entire manual movement is echoed by a head rotation. In Chinese SL FALL in Figure 10, the hands move downward in a left-right zig zag path while the head rotates once. 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. Again, head rotation only occurs 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.

Figure 10: FALL (the season) in Chinese SL 

4.2.3 Simple sagittal movement 3: 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).

Figure 11: GOAL in Pakistani SL

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 its un-displaced position, the torso goes to neutral position, the mouth relaxes, and the eyes shut.

Figure 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 movements 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.

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 Figure 13 we see an illustration of coordinated head tilt and hand movement in Greek SL.

Figure 13: (WINDSHIELD)WIPER 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 nondominant side, echoing only the vertical movement axis of the hands (Fig. 14).

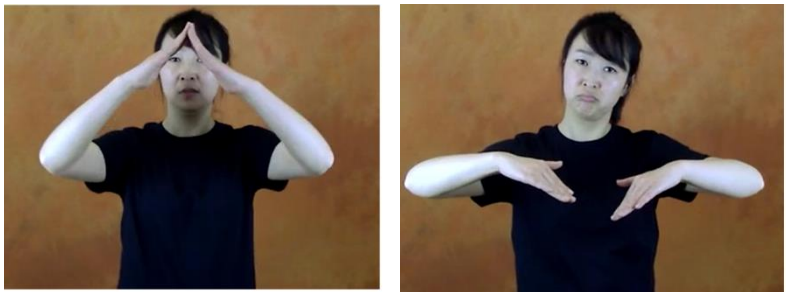


Figure 14: COLLAPSE in Chinese SL

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.

Figure 15: FLAG in Austrian 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.

Figure 16: DESCEND in Greek SL

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's 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 axis and 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 then in an arc forward and down as the head tilts backward and then 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.

Figure 17: FALL in Chilean SL 

We further find full sagittal tilt echoes of the following simple manual movements: downward, upward, and away-towards. 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.

Figure 18: Second part of CLIMBING ANCHOR in Spanish SL

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

Figure 19: ESCALATOR in Estonian SL 

Lastly, in the first part of DISCUSS in Indian SL (Fig. 20), the hands move away and back towards 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 (dominant) hand and the backward movement of the crown of the head corresponds to the sagittal backward movement of the dominant hand.[15]

Figure 20: First part of DISCUSS in Indian SL

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-towards: that is, sagittal displacement is awkward. Thus, again, a complex head echo is favored.

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, sideways, and outward as the head makes a sagittal tilt.

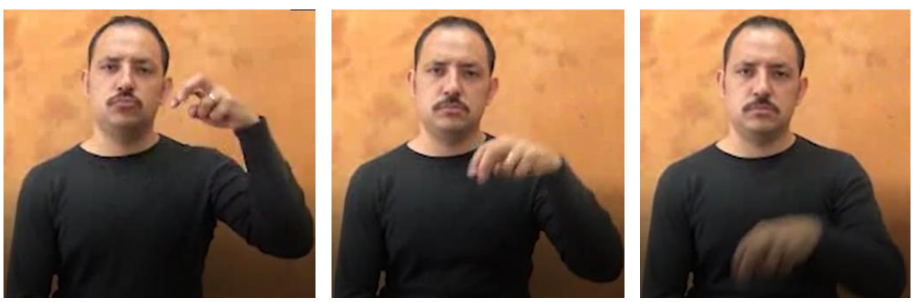


Figure 21: SINK in Italian SL

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

[15] 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.

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 when we combine the basic head articulations simultaneously. For example, circular movement of the head[16] is a combination of head rotation and sagittal tilt. The first part of Icelandic SL FERRIS WHEEL exhibits circular head movement echoing circular manual movement.[17] 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.

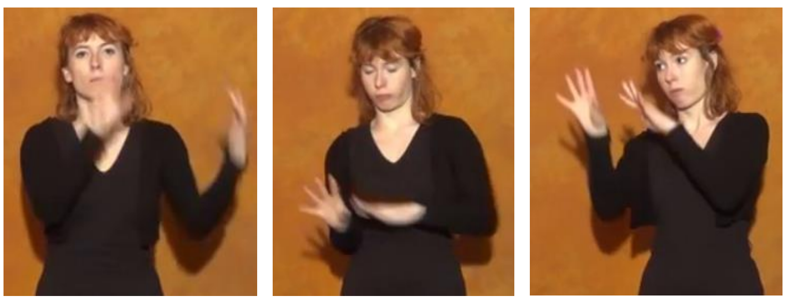


Figure 22: WAVE in French SL

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 zig-zag while moving upward, 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.

[16] Where the circle is visible on the vertical plane facing the signer.

[17] The movement is minimal and best observed on video at spreadthesign.com.

Figure 23: ASCEND in Estonian SL

4.2.7 Repetition. A last factor to be mentioned here is that repetition in a head echo is clearly determined by whether or not the sign demonstrates repetition of the manual movement. In 47 of our tokens, manual movement had repetition; 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 (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. Figure 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 Figure 24). 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 making them unless someone points them out. They contrast with involuntary movements (e.g. reflexes, tremors, certain tics), 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 et al., 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.

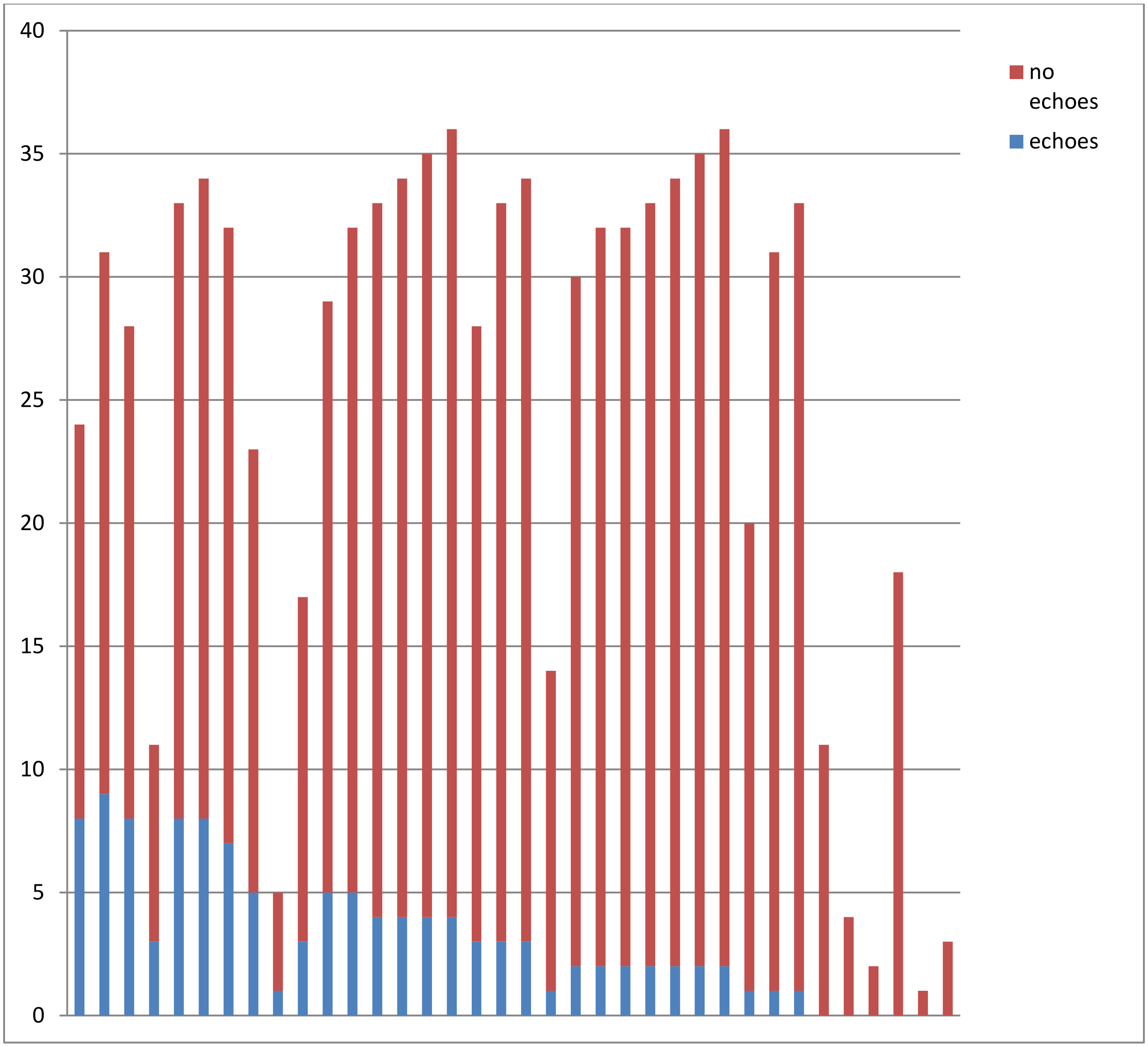


Figure 24: Countries arranged by number of dictionary entries they displayed with and without head echoes, from highest percentage of tokens with head echoes to lowest.

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 and for head movement. For example, hand movement away or toward the signer is labeled “S(agittal)”.

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

<table>
<tr><th>Head movement</th><th>lateral displ.</th><th>rotation</th><th colspan="2">lateral tilt</th><th colspan="2">sagittal tilt</th><th>sagittal displ.</th></tr>
<tr><td># head</td><td>16</td><td>19</td><td colspan="2">30</td><td colspan="2">56</td><td>4</td></tr>
<tr><td># hand</td><td colspan="3">32</td><td colspan="2">46</td><td colspan="2">3</td></tr>
<tr><td>Manual Axes</td><td colspan="3">T(ransverse)</td><td colspan="2">V(ertical)</td><td colspan="2">S(agittal)</td></tr>
</table>

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, there are only 3 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 a 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.

Table 3: Number of different directions in sagittal tilts

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

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,[18] 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 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 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 et al., 2005). That head echoes disfavor displacements is to be expected, then.

5.2 Correlations of head echoes to manual articulation types

[18] We use “language/ 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.

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 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 Figure 25.

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

head / **manual**	**T**		**V**		**S**
	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

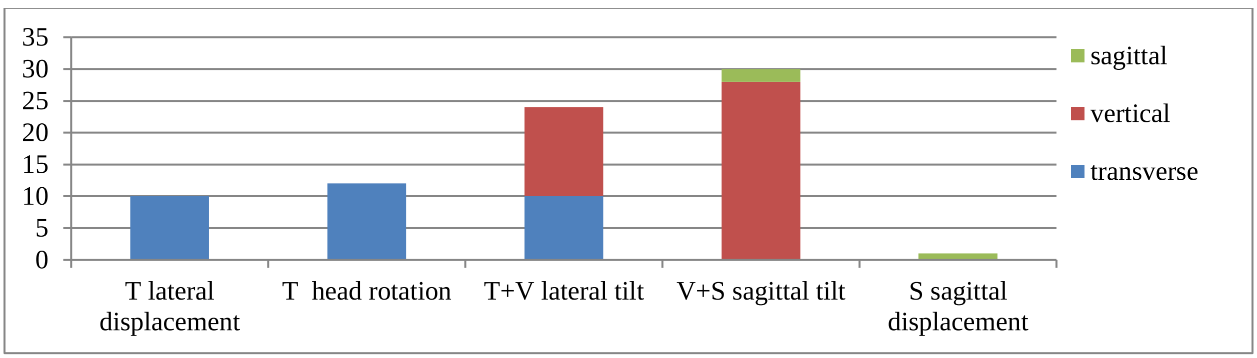


Figure 25: Frequency of sagittal (green), vertical (red), and transverse (blue) manual movement accompanying each type of head echo

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 movements 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.

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, or 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 zig zags 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 the axis changes abruptly, such as the hands moving downward and then forward (as in SUBMARINE in Argentinian SL).[19]

We find a total of 22 tokens for which the manual movement combines a vertical dimension with a transverse (9) or a sagittal (12) one or both (1), and that are accompanied by a single head echo. Table 5 conflates simultaneous and sequential manual movement and shows

[19] 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.

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.

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

manual \ head		T			V	S
		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

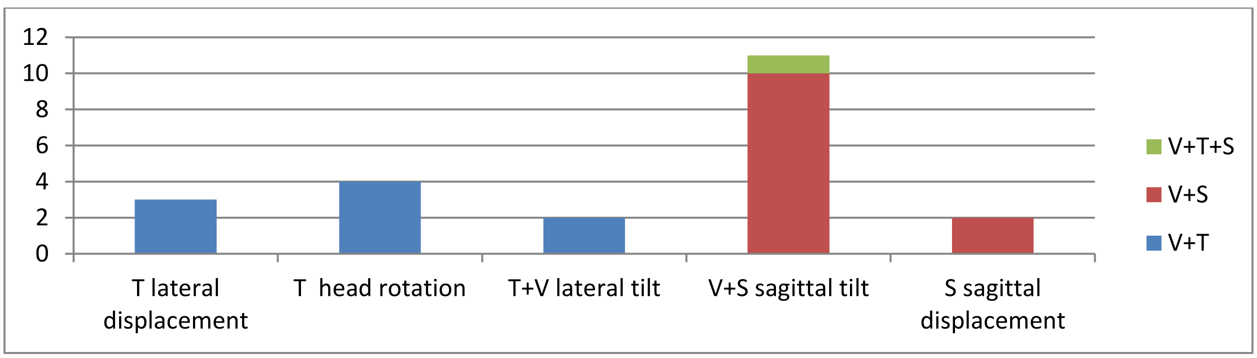


Figure 26: Frequency of transverse and vertical (blue) hand movement vs. vertical and sagittal (red) hand movement vs hand movement along all 3 dimensions accompanying each type of head echo (green)

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 Figure 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 either echoed 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's consider the three signs that have V+T manual movement and a lateral displacement head echo (which is T) in 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 (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 movements 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, twelve head articulations echo all dimensions of the complex manual movement, while the remaining ten head articulations echo some but not all dimensions of the complex manual movement. Also note that ten 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 displacements, 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 tokens) manual movements. Table 6 shows which manual movement axes they echo, conflating simultaneous and sequential manual movement.

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

head / **manual**	**sagittal tilt +**			
	T		**V**	**S**
	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

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 included a vertical dimension, i.e., there was no combined head echo that accompanied a sign with T+S manual movement unless V was 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 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, i.e. 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 the manual movement is simple or complex and whether the head echo is simple or combined.

When manual movement is simple, the head echo may be basic or combined. A simple echo will always copy 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 the dimension of the manual movement and the additional one will be physiologically motivated. When manual movement is complex but the head echo is simple (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. 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, but 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 extraneous dimensions (dimensions not present in the manual articulation).

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 to 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 towards 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, therefore, going away from or toward the signer) will require the addressee to indirectly infer the direction of that movement from other cues (Regan et al., 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.[20] 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.

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

[20] In two of these tokens we have a complex manual movement involving all three dimensions and a combination of two head echoes.

(V+S) sagittal tilt	1	51	2
(S) sagittal displacement	0	5	0

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 opposition 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 Figure 27. In this sign the direction of head movement matches the direction of manual movement (sagittally forwards and backwards), 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).

Figure 27: DISCUSS in Argentinian SL 

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 directions 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 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.[21]

6. General discussion and conclusions

The present work enriches inquiry into echo phonology and 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 is attested outside of language; for example, wrist and ankle muscles coordinate leading to a preference for the same directional movements of hand and foot (Baldissera et al., 2002; Borroni et al., 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 et al., 2015), and flexion of hand muscles and/or foot muscles can trigger mandible (lower jaw) articulation so that e.g. a fist clench goes together with a jaw clench (Komeilipoor et al., 2017). Since coordination of hand articulations with other articulators in the body are well-documented, it would be surprising if a manual language did not exploit hand-head coordinations. In fact, the neuroscience literature establishes motoric hand-head coordination (Tao et al., 2018; Reppert et al., 2018). There is evidence of hand-eye coordination,

[21] However, biomechanics might not be the only factor. In shooting start in Russian SL (Appendix S5 Fig. 1) the opposite transverse movement of the head enhances the visual perception of a diagonal manual movement.

as well (Abrams et al., 1990; Miall et al., 2001), which shows that hand-head coordination need not be connected to hand-eye coordination (Pelz et al., 2001; Reppert et al., 2018). Both hand-head and hand-eye coordination are important to language development (Iverson, 2010; D'Souza et al., 2017). 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 9 have a simple 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.

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.

Figure 28: CLIMBING ANCHOR in Spanish SL

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 (that is, 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 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 hands are the same, but whether the visual percept for the viewer is one of coordinated movement that repeats some salient property of the 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, /ɘ/ 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 (Stevens & Keyser, 1989, 2010; Keyser & Stevens, 2006; 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 ASL. 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 that tilt, which cues us in to the manual sagittal dimension, since the tilt obligatorily includes a sagittal dimension that is easily observed. With an enhancement analysis, it is not surprising that some nonmanual articulations have been claimed to be obligatory echoes. Enhancements in spoken language 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/

expected under 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 of enhancement is. The head represents fully six per cent 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 looked at head articulations (because the head is a large nonmanual articulator, so it is easy to see), studies are needed to search for echo phenomena involving other nonmanuals, including studies of true mouth articulations as well as of the eyes, nose, eyebrows, and torso as potential echo articulators.

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 gestures include 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 a correlation between the various types of echo head articulations and particular head gestures, 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.

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Appendix S1: Further examples of lateral displacement head echoes

ARGUE in Italian SL (Appendix S1 Fig. 1) and WAR in Indian SL have the hands move side to side, while the head (and slightly the torso) displaces in the opposite direction, and the first part of HAIL in Chinese SL has quick side-to-side manual movement coordinated with lateral head displacement in the opposite direction.

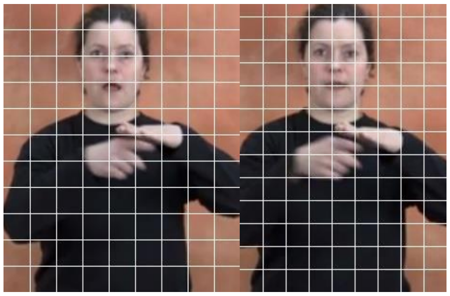
Appendix S1 Figure 1: ARGUE in Italian SL

Likewise, DISCUSS in Austria and Italy has the head displace sideways as the hands move side-to-side in the opposite direction, with the torso also moving.

ARGUE in Indian SL has two parts. In the second part, the hands move side-to-side once while the head (and torso) displaces laterally (Appendix S1 Fig. 2) in the opposite direction from the manuals. Then the hands move side-to-side a second time while the head rotates once side-to-side, again in the opposite direction from the manuals. Rather than analyze this sign as having three parts, we analyze the head articulation change from lateral displacement to rotation as a reduction of movement, since lateral displacement is a more physiologically unnatural movement than rotation (see the discussion in Section 5.4). This analysis is supported by the fact that the sideways manual movement path is shorter on the repeat – so there seems to be an overall reduction of effort on the repeat.

Appendix S1 Figure 2: ARGUE in Indian SL

The sign for SCAN (as in a machine scanning a sheet of paper) in Estonian SL has the dominant hand moving repeatedly side-to-side below the non-dominant hand while the head displaces laterally in the opposite direction and the torso rocks in the same direction that the head displaces (Appendix S1 Fig. 3).



Appendix S1 Figure 3: SCAN in Estonian SL

There are two more signs with lateral displacement in our data base. SHOOTING STAR in Estonian SL has the hand move in a very sharp diagonal forward and to the opposite side while the head displaces to the same side as the moving hand displaces (importantly without the gaze following the hand movement) and ever so slightly forward. DESCEND in Argentinian SL has the hand go down at a sideways diagonal in steps, while the head displaces laterally toward the same side the manual is going. These are the only two signs with lateral displacement in which the movement of the head is in the same direction as the manual movement.

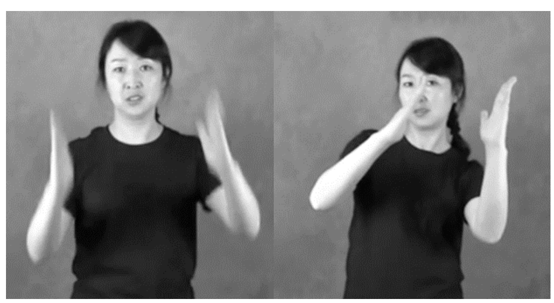
Appendix S2: Further examples of rotation head echoes

FISH in Italian SL has the hand move from one side to the other, while the head does a very slight rotation in the direction of the hand movement.

We also commonly find movement of the hands in one direction with rotation of the head in the opposite direction; so, while the hands move to the right, the head rotates to the left. We find this opposing movement in WIND across several sign languages; in the sign languages of France (Appendix S2 Fig. 1) and Iceland only the head is involved, in the sign languages of Britain and Germany, both head and torso move.

Appendix S2 Figure 1: WIND in French SL

Opposite movement direction of head and hands is also attested in (WINDSHIELD) WIPER in Ukrainian SL (which has no torso movement) and Lithuanian SL (which has very slight torso movement in the same direction as the manual movement). And it is attested in TILT in Chinese SL (Appendix S2 Fig. 2) with torso movement in the direction of the manual movement.



Appendix S2 Figure 2: TILT in Chinese SL

COLLAPSE in Argentinian SL has the hands first move upward in a zig-zag path and then sharply downward, while the head rotates repeatedly, but then stops moving when the hands move downward. LIGHTNING in Ukrainian SL also has the hand move downward in a zig zag while the head rotates only one time, starting at the side that the zig-zag of the hand started at and ending at the side that the zig-zag of the hand ended at. So, the beginning and end of the head movement are coordinated with the beginning and end of the hand movement in a muted echo. Here we see another way in which not the entire movement is copied but only its initial and final locations.

In the second part of DISCUSS in Indian SL (Appendix S2 Fig. 3), the head stays in a displaced position forward (which is not an echo, simply a pose) as the hands move away and back toward the signer repeatedly while also moving from one side of the signer to the other and back. At the same time, the (displaced) head rotates toward the side that the hands move toward, echoing only the sideways movement of the manuals.

Appendix S2 Figure 3: The second part of DISCUSS in Indian SL

We found one (close to exact) instance of coordination of head rotation with side-to-side manual rotation caused by radioulnar articulation, in PARACHUTE in Swedish SL (in Appendix S2 Fig. 4). Radioulnar articulation itself, however, does not yield a movement path. In this sign, there is also manual movement downward and to one side (that is, along the vertical and transverse axes). As the hands move downwards diagonally, the dominant wrist wiggles repeatedly sideways – resulting in a slight zig zag path. At the same time, the signer's head rotates repeatedly.

Appendix S2 Figure 4: PARACHUTE in Swedish SL

Appendix S3: Further examples of sagittal displacement head echoes

There are two more instances of sagittal displacement head echoes in our data: SUBMARINE in German SL and in Croatian SL. In both, the dominant hand moves downward and then forward, tracing an L-shape, while the head does a sagittal tilt and then a sagittal displacement. The head echoes one movement component of the hands (downward) and then echoes another movement of the hands (forward). The signs in both languages are accompanied by mouthing. In Appendix S3 Fig 1 we see the German word *U-boot* mouthed, where the lip positions for the syllable [bo:] are coordinated to coincide with the onset of the manual forward movement.

Appendix S3 Figure 1: SUBMARINE in German SL

Appendix S4: Further examples of lateral head tilt echoes

METRONOME in the sign languages of Estonia and Russia has lateral head tilt as the hand moves in an arc from side-to-side (Appendix S4 Fig. 1):

Appendix S4 Figure 1: METRONOME in Russian SL

Note that we do not include the token from Spanish SL here. In Spanish SL, the head moves down and up as the index finger of the dominant hand rocks side-to-side on the nondominant hand via radioulnar movement. The hand movement hits an abrupt stop with each rock, as does the head with each downward movement. Thus, both hand and head keep time, but not as echoes of one another.

FERRIS WHEEL in Russian SL has the hands move in an arc, as though they are on a steering wheel, while the head tilts in the same direction as the arc. DESCEND in Pakistani SL repeats the hand descending in a slight tilt with the head repeatedly tilting in the same direction.

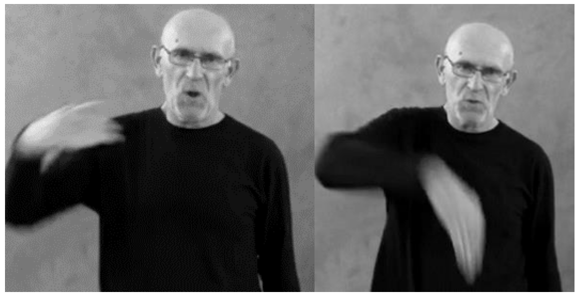
In the sign language of Argentina, HIT has the dominant right hand move leftward a single time as the head tilts in the same direction together with a slight torso movement (in Appendix S4 Fig. 2).

Appendix S4 Figure 2: HIT in Argentinian SL

Note that neither this torso movement nor the manual movement constitutes enactment, since we don't prototypically assault with a sideways movement.

A very slight lateral head tilt can be combined with a more exaggerated torso tilt, giving an impression of strong diagonal downwards head movement, as in SINK in Croatian SL

(Appendix S4 Fig. 3), and DEEP in Belarus SL, where the downward hand movement is only slightly diagonal.



Appendix S4 Figure 3: SINK in Croatian SL

We find repeated lateral head tilts coordinating with side-to-side movement of one hand in PENDULUM in the sign languages of Italy (very slight), Ukraine, and China.

Now we move on to cases in which lateral head tilt copies only the endpoints of movement but not the type of movement (arched). First, the hands can perform a vertical movement whose upper and lower endpoints are matched by the initial and final location of the head, as in Fig. 14 in the text. COLLAPSE in Czech SL has the hand move downward while the head tilts to the side of the moving hand. In Pakistani SL COLLAPSE, both head and torso tilt toward the side of the moving hand as that hand moves downward with a little upward flourish of the hand at the end.

RAIN in Japanese SL and HAIL in Greek SL have the hands alternate an up-down movement coordinated with slight lateral head tilt. SIT in the sign languages of Germany, Romania, and Lithuania (where Lithuania also tilts the torso) has a single lateral head tilt coordinated with a single downward hand movement.

SEESAW in American SL coordinates down-up movement of one hand with head tilt toward that side, and the same on the other side, alternating which side is down. (Appendix S4 Fig. 4).

Appendix S4 Figure 4: SEESAW in American SL

The same happens with SEESAW in the sign languages of Estonia (Appendix S4 Fig. 5), Sweden, and Mexico (very slightly); the head tilts laterally towards the hand that moves upwards and thus in the opposite direction from the downward-moving hand.

Appendix S4 Figure 5: SEESAW in Estonian SL

This contrasts with SEESAW in the sign languages of Britain, Russia, and Spain, where we find coordinated downward movement of one hand and the corresponding side of the torso, and then the same on the other side, but no articulation of the head.

Similarly to Fig. 15 in the text but with a complication in direction, DISCUSS in Polish SL has the hands move sideways then return to neutral while the torso displaces to the side and the head does a lateral tilt. The torso displaces in the opposite direction of the hands and the head tilts toward the hands, then both return to neutral as the hands return to neutral, as seen in Appendix S4 Fig. 6.

Appendix S4 Figure 6: DISCUSS in Polish SL

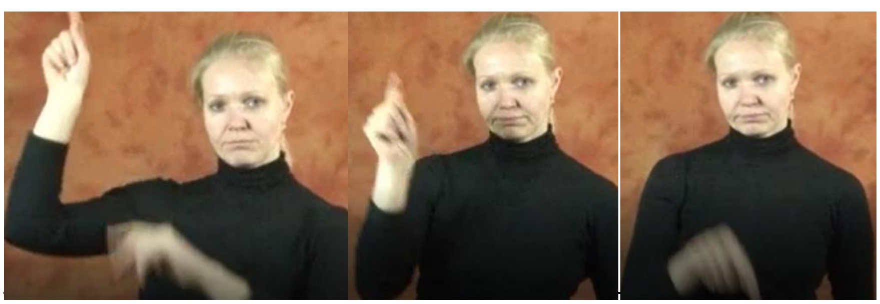
Appendix S5: Combination head articulations

Both lowering of the torso and sagittal head tilt downward plus lateral head tilt to one side coordinate with downward hand movement in SIT in Indian SL. Lateral head tilt as well as sagittal head tilt down coordinate with downward hand motion in SNOW in Italian SL.

DESCEND in Latvian SL has the hand move downward and forward in a diagonal as the head rotates to one side and does a sagittal tilt down (making the head fall forward), accompanied by torso tilt in the direction of the diagonal hand movement.

ASCEND in Chinese SL and Ukrainian SL has the hand move upward in a zig zag as the head tilts upward and rotates repeatedly. The eyes switch from looking forward to gazing at the hand as it reaches a high point in Chinese SL. In Ukrainian SL the eyes switch from gazing up toward the endpoint that the hand movement will eventually reach to looking straight ahead, but we include both as examples of echo since for much of the sign the head movement is independent of eye gaze.

SHOOTING STAR in Russian SL (Appendix S5 Fig. 1), has the dominant hand move downward, sideward, and outward as the head makes a sagittal tilt and a very slight rotation in the opposite direction of the manual T movement. Interestingly, the visual effect the opposite movement direction created here is one of the head and the hand forming parallel diagonal lines. So the opposing directions work together to make a visual consistency.



Appendix S5 Figure 1: SHOOTING STAR in Russian SL