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Title
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Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 43(43)

ISSN

1069-7977

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Publication Date

2021

Peer reviewed

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Event visibility in sign language motion: Evidence from Austrian Sign Language

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Abstract

This is the first kinematic investigation of articulator motion in Austrian Sign Language, which connects kinesiology of sign production and linguistic markers of *Aktionsart* in the native language of the Deaf[1] community in Austria. Our work used a 3D motion capture approach to sign language analysis to investigate the relationship between the semantics (event structure) of signed verbs, and kinematics of hand articulator movement. The data indicates that the underlying semantics of events in verb signs is reflected in sign duration and acceleration of the dominant hand during sign production. The finding that articulator dynamics (acceleration and deceleration of hand motion) characterizes the event structure in verb signs has significance for linguistic theory of visual communication, and understanding of the relationship between iconicity in sign language, and perceptual biases in meaning construction based on visual input.

Keywords: Austrian Sign Language; Sign language production; Motion Capture; Event Structure Hypothesis; Telicity; Kinematics

Introduction

One of the fundamental mechanisms underlying human cognition is that of parsing the continuous stream of sensory inputs into individualized events. In psychology, this ability to parse reality into distinct events is described by the Event Segmentation Theory (Zacks & Swallow, 2007; Zacks & Tversky, 2001). Additionally, there is a correlation between what one sees – the visual features of events - and how one conceptualizes, or interprets the scene. In general, kinematic parameters of motion (such as relative speed of moving agents, or motion of hands of a person engaged in an activity) undergird the interpretation of events (Sargent et al., 2013; Speer et al., 2007; Zacks et al., 2001).

Existence and etiology for universally accessible units of meaning is one of the major driving forces in linguistic research. As motion-based event segmentation appears to be a critical everyday mechanism for structuring reality, the question arises whether motion parameters might be interpretable in terms of event meaning. The notion that hand motion in sign language is distinct from that of everyday human motion in both temporal (variability over time) and spectral features (size and location of visual features relevant for communication) is well-established (Bosworth, Bartlett & Dobkins, 2006; Bosworth, Wright & Dobkins, 2019; Malaia, 2014; Malaia & Wilbur, 2012a). The question that necessarily follows is whether it might be possible to map specific linguistic features to their visual representation.

Sign languages are a unique testing ground on the existence of such features in the visual modality. Klima and Bellugi (1979) were among the first researchers who described the high degree of form-to-meaning mapping, or iconicity within American Sign Language (ASL). They described the rich repertoire of grammatical aspectual marking in ASL, whereby the event type of the verb determines which reduplicating movement can be used for the verb's aspectual marking. Wilbur (2003), in looking for

[1] Per convention, Deaf with an upper-case D refers to deaf or hard-of-hearing humans who define themselves as members of the sign language community. In contrast, deaf refers to the audiological status of an individual.

an explanation for why only a limited set of ASL verbs allow modification by aspect-denoting reduplication (Bellugi & Klima, 1979), observed that ASL lexical verbs can be analyzed as telic and atelic based on their phonological form. Specifically, telic verbs are characterized by a rapid ending deceleration of articulator motion, which reflects the semantic end-state of the affected argument (Wilbur, 2003).

This mapping between motion kinematics and linguistic features has been formulated as the Event Visibility Hypothesis (Wilbur, 2003, 2008), which proposes that visual features should be utilized by sign languages in a universal manner. Subsequently, it was found that when hearing non-signers classify verb signs (which are unknown to them), they rely on event segmentation heuristics. Strickland et al. (2015) demonstrated that when non-signers watch videos of sign language verbs differing in aspect (and motion signatures) and are given a forced choice between two written verbs (one with a bounded semantics, or telic, and another with a non-bounded semantics, or atelic), they select the verb the event structure of which matches that of the unfamiliar verb sign – in other terms, non-signers can accurately distinguish between atelic and telic signs and thus appear to be able to 'read off' event structure features from the kinematic parameters of the sign. This raises the question: when non-signers make these judgments, what kinematic features, exactly, do they base them on? What physical properties of signs can be used for making linguistic category judgements?

To advance in understanding of linguistic universals, it is necessary to examine multiple, unrelated languages. A number of sign languages appear to differ, according to qualitative descriptions, in the kinematic parameters of verb classes (e.g. the study by Strickland et al. (2015) used Italian Sign Language (LIS), Sign Language of the Netherlands (NGT), and Turkish Sign Language (TID) stimuli). For two sign languages, kinematic profiles of verb classes have been documented quantitatively, using motion capture: ASL and Croatian Sign Language (HZJ).

The comparison of these two languages (i.e. ASL and HZJ) is especially interesting from the standpoint of cross-linguistic analysis, because these languages are unrelated, and the distinction between telic and atelic verb classes is realized differently. The grammars of the two languages have a very different structure. In ASL lexical verbs are divided into classes based on their phonological form (Wilbur, 2003): *telic* verbs, such as ARRIVE, which have an inherent endpoint in their semantics, and *atelic* verbs lacking an endpoint (e.g. the sign ANALYZE).[2] End-states in telic verbs can be marked by 1) a change of handshape aperture, 2) a change of hand orientation, and 3) an abrupt stop at a location in space or contact with a body part; thus, telic and atelic verbs differ in semantics/event structure, as well as phonological features/syllable structure (Malaia et al., 2012). In ASL, telic verbs are marked by significantly greater deceleration at the end of the verb, compared to atelic verbs (Malaia & Wilbur, 2012b). Duration and peak velocity of sign production also correlate with verb type (telic sign duration is shorter, and is marked by higher velocities); however, these parameters are also affected by prosodic processes, such as phrase-final lengthening. Sign-end deceleration, in ASL, is a robust marker of event type, regardless of the verb's position in a sentence.

In HZJ, with its Slavic substrate, event structure and aspect are conflated and, for the most part, productive: for most verbs, it is possible to identify two variants which differ simultaneously in telicity and perfectivity (telic-perfective; atelic-imperfective). In HZJ a regular morphological process can be observed that is used to produce an alternation between two forms of a verb from one stem. Milković (2011) reports that a large group of verbs in HZJ can be altered in this way (i.e. by a modification of movement), whereby the same root would appear with shorter, sharper movement for telic as compared to atelic signs[3]. A motion capture study of HZJ verbs (Malaia, Wilbur & Milković, 2013) confirmed that differences in event structure of the verbs are reflected in the kinematic features of verb signs. HZJ showed significant differences in deceleration between verb types. Peak velocity was greater in telic signs as compared to atelic signs; this effect was robust to the effects of verb position (e.g. phrase-final lengthening). In HZJ, both the peak velocity and deceleration features appeared to function as morphemic markers of event structure/aspect. In the present study we investigate motion profiles of telic and atelic verb signs in Austrian Sign Language (ÖGS).[4] ÖGS is especially interesting as a testing case, because, though unrelated to ASL, it patterns with ASL on lexical distinction between telic and atelic verb signs. ÖGS and HZJ, on the other hand, have a historic relationship: there was intense language

[2] Notation conventions: signs are glossed with capital letters.

[3] A majority of HZJ verbs allow for telic-perfective/atelic-imperfective alterations. However, there are signs that cannot be modified to alternate between expressing telic and atelic events. In such cases, unrelated verb roots can be used for expressing telic/atelic meaning in the predicate, or phrasal sequences (verb plus a separate aspectual sign, quantified internal argument, or verbal complement (Milković, 2011)).

[4] ÖGS is the abbreviation of the German translation of Austrian Sign Language: "Österreichische Gebärdensprache". ÖGS is the native language of about 8.000 Deaf people and has been officially accredited by law in Austria as a non-ethnic minority language in 2005. However, the implementation of this legitimate foundation - involving accessible admission to community and education - has not taken place so far. For example, ÖGS is not the language of teaching and is not taught as a separate subject in Austrian Deaf schools. So far, relatively little is known about the syntactic structure of ÖGS. Most of the existing literature on ÖGS is purely descriptive and very few researchers have discussed data on ÖGS from a theoretical viewpoint (e.g. Krebs, Wilbur & Roehm, 2017, 2020; Schalber, 2006a; Schalber & Hunger, 2008; Wilbur, 2002, 2005).

contact between the two languages in the 19th century due to the organization of the educational system: before the first school for the deaf opened in Zagreb in 1880 (Šarac Kuhn et al., 2007; Schalber, 2006b), Croatian Deaf students and teachers were sent to the deaf institute in Vienna.[5]

ÖGS differs from both ASL and HZJ with respect to basic sign order: ÖGS uses Subject-Object-Verb (SOV) as its basic word order, while ASL and HZJ are Subject-Verb-Object (SVO) languages. As the relative position of the verb and its object (i.e. OV vs. VO languages) is a fundamental syntactic relationship that can affect other syntactic and prosodic features within the interrelated structure of a language (Dryer, 1991; Haider, 2005; Nespor et al., 2008), quantitative characterization of event structure kinematics in ÖGS is of special interest for cross-linguistic analysis.

For ÖGS, qualitative differences of end-state and non-manual markings for distinguishing event types have been identified. Schalber (2006a) reported that ÖGS telic verbs show an end-state marking by a rapid deceleration to a complete stop which is realized in changes of orientation, changes of handshape, or changes of setting; such marking of end-state is not found in atelic signs. Additionally, ÖGS uses specific non-manual markings for distinguishing predicate event types. Specifically, Schalber (2004, 2006a) described a correlation between event structure and two adverbial mouth nonmanuals, noting that transitional-mouth nonmanuals (involving change in mouth position) are present only in telic predicates scoping over the semantic endpoint, while posture-mouth nonmanuals (posture is held for the duration of the sign) occur with both telic and atelic verbs modifying the entire event. The present study extends the investigation into event structure representation in ÖGS verbs by quantifying production differences between telic and atelic verbs using motion capture.

Methods

Stimuli

ÖGS patterns with ASL in that the semantic distinction between telic and atelic verb signs is primarily manifested at the lexical level, such that a lexical entry for a verb sign is associated with a specific *Aktionsart* (event structure). Unlike ASL, ÖGS allows for a number of verb class alternations (cf. Levin, 1993), such that a verb sign can be associated with two or more types of event structure without incurring the need for morphological alterations/changes in signing kinematics (as, for example, does HZJ – see Milković, 2011). For the purposes of this study, two standard tests for telicity - the "almost"-test and the conjunction test[6] were used to identify signs with telic and atelic event structure (Borik, 2006; Smith, 2007). Four Deaf signers were interviewed about the use and semantic interpretation of a set of 119 ÖGS verb signs. From these, the signs which contained a time-reference point (as determined by the 'almost' – modification test), and could not be interpreted as one long (not repeated) event, as determined by the conjunction test, were identified as telic. The set of 20 signs (10 telic, 10 atelic) for testing were selected based on consistency of production/lack of dialectal variation among informants.

The following verb signs were used in the study:
Telic verbs: THROW, CATCH-UP, TAKE, DISAPPEAR, CHANGE, ARRIVE, DIE, RELAX, STEAL, SUGGEST
Atelic verbs: TRAVEL, COLLECT, SHAVE, CHASE, WRITE, PAINT, SEW, EXAMINE, ANALYZE, SWIM

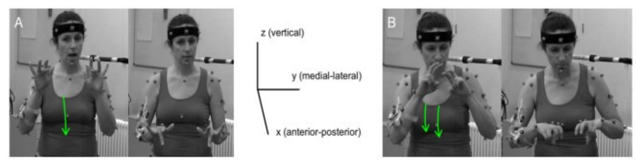

Figure 1. Examples of telic and atelic verbs investigated in our study. A. The telic verb ARRIVE is presented showing a single downward path movement (i.e. movement is not repeated) reflecting endpoint marking. B. The atelic verb ANALYZE shows repeated downward movement lacking endpoint marking. Between both pictures the global coordinate system is illustrated; x-axis represents anterior-posterior motion; y-axis represents medio-lateral motion; z-axis represents vertical motion.

Data acquisition and analysis

A Deaf signer who acquired ÖGS early in life, uses ÖGS in her daily life and is a member of the Deaf community was asked to produce telic and atelic verbs, one by one, in isolation/vocabulary form (N=10 per category). The signer stood in the center of the motion capture system reflecting x-axis of the global coordinate system to be anterior-posterior, the y-axis to be medio-lateral and the z-axis to be vertical motion (Figure 1). The signer was facing a screen, at which the verbs to be captured were displayed in written German. Each verb sign started and ended with both arms held at each side in a resting position (arms extended,

[5] It is an open question, to what extent ÖGS might have influenced the development of HZJ.

[6] The conjunction test examines verb meaning in temporal contexts such as "she/he did something on Sunday and on Monday". If the sentence can only be interpreted as denoting two discrete events, the verb is considered telic. If the sentence is ambiguous and can be interpreted as either denoting two discrete events or one uninterrupted event, the verb is considered atelic.

The "almost" modification test in sign languages consists of combining the sign verb and the adverb "almost" (Smith, 2007). The combination of "almost" with an atelic verb has a single interpretation - the process/state did not commence ("one did not begin doing X"). The combination of "almost" with a telic verb might mean either that the event did not commence, or that the event was not completed /carried out ("one did not complete doing X").

"hanging" in a relaxed position). After the signer read the verb, the test-operator gave a visual signal and the signer brought her hands into position and signed the verb. When finished both arms return to the rest position and the next verb was presented. For each sign, the three dimensional (3D) position of a reflective marker attached to the right wrist was collected using an 8-camera infrared motion capture system with 200 Hz sampling rate (Miqus, Qualisys, Gothenbourg, Sweden). The right wrist marker was chosen, as the motion of the dominant hand has been shown to be the most informative (entropy-rich) part of the sign language signal (Malaia, Borneman & Wilbur, 2017).

Marker trajectory data were labelled and gap-filled using Qualisys Track Manager (QTM, Qualisys, Göteborg, Sweden) and analyzed using V3D-software (V3D (C-motion, Rockville, MD, USA)). 2D Video of each verb sign was linked to the respective trials and synchronously displayed in V3D. The 6 DOF model was used to create a pelvic, torso, head, right and left upper arm, lower arm and hand segment, which allowed the calculation of individual marker position, velocity and acceleration measures. The actual signing phase (as opposing to preparation and end phase) was determined by an experienced ÖGS signer, using the 2D-Video and the wrist marker velocity data (zero-velocity-threshold), and identified by START (sign onset) and STOP events (sign offset).[7] Sign onset was defined when the target handshape reaches target location from where sign movement starts (Wilbur & Malaia, 2008). Sign offset was defined when the hand changes its shape or orientation or when it moves away from final position.

Based on prior observations, we hypothesized that the movement pattern of telic and atelic verbs in ÖGS would show differences in velocity, acceleration (deceleration), and jerk (second derivative of velocity, reflecting the rate of change in acceleration over time) across linguistic contexts. For each sign, the following parameters were calculated: sign duration, maximal/peak velocity (max V), maximum acceleration within the sign (max A), minimum acceleration/maximal deceleration (max D), and the maximum jerk (the second derivative of velocity, i.e. the rate of change in acceleration within the sign, max J; for detail, see Wilbur & Malaia, 2008). 3D displacement in anterior-posterior, medio-lateral and transversal direction, calculated velocity in each dimension, and total (3D) velocity are presented for the telic sign ARRIVE and for the atelic sign ANALYZE in Figures 2 and 3. Unpaired *t*-tests were used to statistically compare the parameters of telic and atelic verbs.

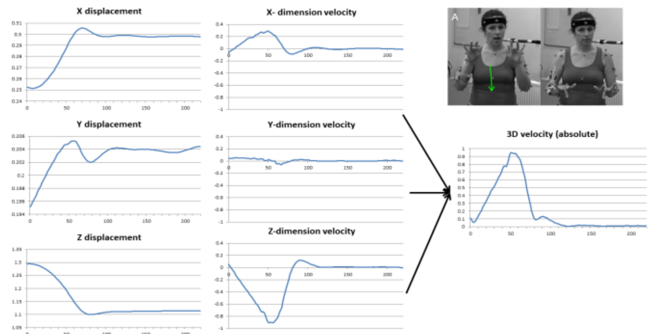

Figure 2. Sign ARRIVE: displacement along XYZ axes; calculated velocity in each dimension, and 3D velocity.

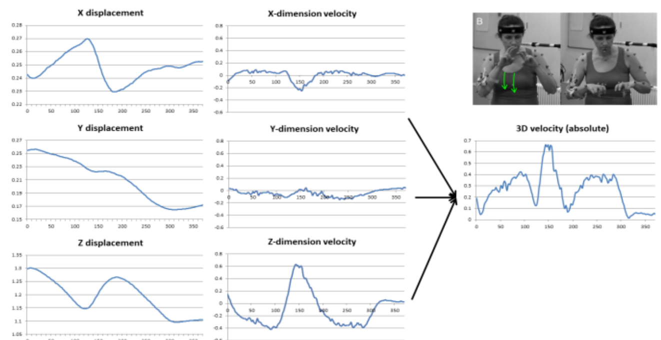

Figure 3. Sign ANALYZE: displacement along XYZ axes; calculated velocity in each dimension, and 3D velocity.

Results

Telic and atelic verbs differed significantly in duration, peak deceleration and acceleration of the dominant articulator, and maximum jerk in motion within the sign (see Table 1).

Table 1: Statistical differences between telic and atelic verbs in motion parameters

Variable	*t*	*p*	Cohen's d
Duration	3.346	.004*	1.49
Maximum velocity	-1.374	.186	-0.61
Deceleration (max)	3.194	.005*	1.43
Acceleration (max)	-2.647	.016*	-1.18
Jerk (max)	-2.189	.042*	-0.98

* $p < .05$

Telic verbs were significantly shorter than atelic verbs in duration (telic *M* =1.192 s, *SD* =.3 s; atelic *M* =1.688 s, *SD* =.35 s). Telic verbs, as compared to atelic ones, also evidenced significantly faster deceleration (telic *M* =12.3

[7] Sign offset definition differed slightly as compared to prior studies in ASL and HZJ. Previously, sign borders were defined on the basis of Green (1984): the first video frame of the sign-initial handshape as the beginning of each predicate was marked as sign onset; either the point of contact, or maximal distance traveled by the hand, was marked as the end of the sign. We defined sign onset in a similar way (i.e. when the target handshape reached the location from where sign movement started). Sign offset, however, was defined as the frame when the hand (after the sign movement was completed) changed its shape or orientation, or when it moved away from its final position. Thus, in the present study the final hold phase was included in data analysis.

m/s^2, *SD* = 5.2 m/s^2; atelic *M* =6.2 m/s^2, *SD* = 2.9 m/s^2), acceleration (telic *M* =11.7 m/s^2, *SD* =5.7 m/s^2; atelic *M* =6.4 m/s^2, *SD* =2.6 m/s^2), and jerk (telic *M* =1933 m/s^3, *SD* =1598 m/s^3; atelic *M* = 765 m/s^3, *SD* = 537 m/s^3).

Discussion

The overall findings support the Event Visibility Hypothesis - showing that the kinematics of dominant hand motion in articulation corresponds to the event structure (telic vs. atelic) of the verb sign. The data corroborate the prior observation that the telic-atelic distinction manifests in ÖGS vocabulary (Schalber, 2006a). Telic signs in ÖGS are produced with faster deceleration/acceleration and jerk, and are shorter in duration compared to atelic signs.

Similarly to ASL and HZJ, kinematic parameters in ÖGS differentiate between telic and atelic verb types. The list of those parameters differs somewhat: in HZJ, peak velocity is different between telic and atelic signs, whereas in ASL and ÖGS this does not appear to be the case. One possibility is that in HZJ, where the telic-atelic distinction is, for the most part, productive, grammaticalization of event structure makes the parameter of peak velocity robust to prosodic effects (Malaia et al., 2013). In ASL, peak velocity is used to indicate stress (Wilbur, 1999); one possibility is that velocity, then, has one circumscribed linguistic function in ASL grammar. Stress marking in HZJ is under-investigated - it may be marked by a different motion variable or a non-manual marking (face/head/body). The question of whether specific kinematic markers may be uniquely associated with a grammatical function within sign languages, and whether this holds for all sign languages, needs further investigation. One limitation of the present study is that verb signs were only tested in isolation, so the effects of prosody (e.g. phrase-final lengthening) on the kinematics of sign production are unclear. Future studies should examine telic and atelic ÖGS signs in different sentence positions.

The data provides experimental support for the Event Visibility Hypothesis (i.e. showing that kinematic features differentiate telic from atelic verb signs) in ÖGS, and contributes to typological cross-linguistic findings showing differences and similarities regarding the movement profiles of telic/atelic verb signs. Consistent with findings in ASL and HZJ, the motion capture data on ÖGS supports the notion that signers use universal means to denote event structure via mapping between sign semantics and dynamic visual form (motion).

The results should also be considered in the wider context of Event Segmentation Theory as applied to visual communication. The experimental analysis of sign language kinematics demonstrates that sign language motion is more varied in time than everyday human motion - it contains more information/entropy (Borneman, Malaia & Wilbur, 2018; Malaia, Borneman & Wilbur, 2016). This raises the question of whether fluctuations in the visual entropy might be used for parsing of sign language signal, drawing on the same cognitive mechanisms that underlie speech parsing, but in a different modality (Blumenthal-Dramé & Malaia, 2019; Malaia & Wilbur, 2020). If this is the case, then grammatical features in sign languages would be expected to be marked via kinematic dynamics. There is some empirical support for this conjecture: For instance, Wilbur, Malaia and Shay (2012) observed that the marking of end-state/endpoint is not restricted to predicates, but is also observed for adjectives in certain constructions. Specifically, scalar adjectives lacking closed upper boundaries (like *far*) are nonetheless end-marked in ASL when combined with degree modification with *too*, e.g. *too far to walk*. Thus, kinematic markers that result in visual entropy change in the signal (such as velocity, acceleration, and jerk; or other dynamic markers, such as handshape change) might be crucial for sign language perception.

Acknowledgements

We want to thank all Deaf informants who took part in the interview study. Special thanks to Waltraud Unterasinger for taking part in the motion capture study.

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