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Psycholinguistic Mechanisms of Classifier Processing in Sign Language

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Nonsigners viewing sign language are sometimes able to guess the meaning of signs by relying on the overt connection between form and meaning, or iconicity (cf. Ortega, Özyürek, & Peeters, 2020; Strickland et al., 2015). One word class in sign languages that appears to be highly iconic is classifiers: verb-like signs that can refer to location change or handling. Classifier use and meaning are governed by linguistic rules, yet in comparison with lexical verb signs, classifiers are highly variable in their morpho-phonology (variety of potential handshapes and motion direction within the sign). These open-class linguistic items in sign languages prompt a question about the mechanisms of their processing: Are they part of a gestural-semiotic system (processed like the gestures of nonsigners), or are they processed as linguistic verbs? To examine the psychological mechanisms of classifier comprehension, we recorded the electroencephalogram (EEG) activity of signers who watched videos of signed sentences with classifiers. We manipulated the sentence word order of the stimuli (subject–object–verb [SOV] vs. object–subject–verb [OSV]), contrasting the two conditions, which, according to different processing hypotheses, should incur increased processing costs for OSV orders. As previously reported for lexical signs, we observed an N400 effect for OSV compared with SOV, reflecting increased cognitive load for linguistic processing. These findings support the hypothesis that classifiers are a linguistic part of speech in sign language, extending the current understanding of processing mechanisms at the interface of linguistic form and meaning.

Keywords: Austrian Sign Language, sign language processing, sign language classifiers, subject preference, ambiguity resolution

Sign languages are natural, full-fledged, hierarchically structured languages, comparable in linguistic complexity to spoken languages and exhibiting similar grammatical structures. Sign languages are expressed in the visual-manual modality using the three-dimensional signing space, that is, the space in front of the signer, to convey linguistic information. In particular, sign languages are produced by manual (hands and arms) and nonmanual (facial expressions and head/upper-body positions/movements) means and are perceived by the visual system, in contrast to spoken languages, which are produced by the vocal tract and perceived by the auditory system.

In the present study, we focused on Austrian Sign Language (abbreviated as *ÖGS*).[1] ÖGS is the native language of approximately 8,000 Deaf people and was officially accredited by law in Austria as a nonethnic minority language in 2005.[2] 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 (Dotter, Krausneker, Jarmer, & Huber, 2019; Kramreiter & Krausneker, 2019). So far, relatively little is known about the syntactic structure of ÖGS, and very few researchers have discussed data on ÖGS

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[1] *ÖGS* is the abbreviation of the German translation of *Austrian Sign Language*: *Österreichische Gebärdensprache*.

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

from a theoretical viewpoint (e.g., Krebs, Wilbur, & Roehm, 2017; Schalber, 2006; Hunger & Schalber, 2001, Schalber & Hunger, 2008; Wilbur, 2002, 2005) or investigated the neural processing of ÖGS (Krebs, Malaia, Wilbur, & Roehm, 2018; Krebs, Malaia, Wilbur, & Roehm, 2020).

Despite the difference in modality, there are strong similarities between the processing of sign and spoken languages; for example, both are processed by a frontotemporal brain network within the dominant hemisphere (for an overview, see, e.g., Corina & Spotswood, 2012; Emmorey, 2002). In both sign and speech, different grammatical levels (e.g., syntax vs. semantics) draw on divergent brain mechanisms (e.g., Capek et al., 2009; Hänel-Faulhaber et al., 2014). However, modality does influence the neurocognitive processing of language in specific ways (for an overview, see, e.g., Campbell, MacSweeney, & Waters, 2008; Corina & Spotswood, 2012; Emmorey, 2002, 2007; MacSweeney, Capek, Campbell, & Woll, 2008). Recent advances in cross-modal research have shown that hearing nonsigners without any sign language experience can infer aspectual meanings of signs using the heuristic biases of event segmentation (Strickland et al., 2015) and that hearing persons who start to learn sign language can draw on experience with gestures when learning new signs (Ortega, Özyürek, & Peeters, 2020).

Sign languages have a class of words (signs) that appear to share properties of gesture and lexical signs: the classifiers. Classifiers provide a means of referring back to an already-mentioned referent using a pronominal form bound to the verb. Their categorizations may reflect particular grammatically relevant semantic or physical features of noun referent classes (e.g., persons; animals; vehicles; long, thin things; Wilbur, Bernstein, & Kantor, 1985). The hand movement and/or the location of the constructions containing these classifier handshapes represents the verb component (Shepard-Kegl, 1985) and can be used to express the movements (events, activities) and/or locations (states) of the referents (in relation to other referents) the classifiers refer to (Frishberg, 1975). Some classifier handshapes may also have an agentive interpretation, showing handling information about an object (e.g., picking up something small and round). Thus, sign language handshape classifiers can be divided into two major categories: (a) the "whole-entity classifiers", with nonagentive interpretation, and (b) the "handling classifiers", with agentive interpretation (Benedicto & Brentari, 2004). For ÖGS, a similar classifier system and classifier categories, that is, classifiers taking similar functions as those described for other sign languages, have been described as well (for more detailed information about ÖGS classifier handshapes and examples, see Skant et al. [2002]).

The form and meaning of classifier signs tend to be overtly related, that is, iconic. At the same time, classifiers differ from gestures in that they are linguistically controlled (governed by the internal rules of a specific sign language). For example, each sign language has a limited set of handshapes that may be used in classifiers; each sign language also determines a specific set of potential referents for a specific handshape. Although nonsigners use manual gestures that might look similar to sign language classifiers, gestures are not restricted in form and meaning in the same way that sign language classifiers are.

However, the linguistic status of sign language classifier constructions has been called into question (e.g., Cogill-Koez, 2000) because of the differences between conventional lexical signs and classifiers, manifested in two ways: (a) the high degree of meaning variability in classifier constructions, as opposed to lexical signs, and (b) the grammatical and iconic role of handshape in classifiers. The variability of meaning in classifier constructions is similar to that of pronouns: Different classifiers can be used to represent one and the same entity, depending on which characteristic of an object is in focus. This many-classifiers-to-one-object relation is still, however, linguistically bound: The choice of a classifier is determined by the characteristics of the referent, discourse requirements, and phonological constraints (Wilbur et al., 1985). The grammatical status of the handshape, however, is what convinces many that classifiers are more similar to gestures than signs. In lexical signs, the handshape is learned as part of the sign, along with other phonological specifications (place of articulation and movement of a sign) and the sign's meaning (e.g., Lepic, 2015; Lepic, Börstell, Belsitzman, & Sandler, 2016; Padden, Hwang, Lepic, & Seegers, 2015). In contrast, the handshape of classifiers also functions as a meaningful unit—a morpheme. Classifiers allow for a wider range of handshapes to be assumed by the nondominant hand compared with lexical signs (Emmorey, 2002); for example, in a two-handed classifier construction involving two objects, each handshape has a separate morphological status and bears independent referential meaning, whereas two-handed lexical items are restricted with respect to the handshapes the nondominant hand can have (it can carry only phonological information even when providing a place of articulation as a base for articulation by the dominant hand; Battison, 1978; Malaia, Borneman, & Wilbur, 2018; Napoli & Wu, 2003).[3]

If classifiers are not processed as linguistic items by signers, the alternative that might account for classifier comprehension as gesture would be the gestural-semiotic processing strategy (Ortega et al., 2020). When the function of the classifier construction is to locate two referents with respect to each other (relative location of each), the resulting structures are often described as showing figure–ground relations, with the figure referring to the "locative subject" and the ground referring to the "locative object." Traditionally in figure–ground constructions, the figure is the more mobile of the two, although if both are equally mobile (e.g., two humans), then the figure is taken to be the one in focus (as noted by Liddell [1980] for American Sign Language [ASL] and by Coerts [1994] for the Sign Language of the Netherlands [NGT]). Two semantic factors relevant to the use of the figure–ground strategy in comprehension are mobility and animacy. Immobile, mostly bigger objects tend to be introduced first as ground, and mobile, often smaller referents represent figures and are produced later.

The question of whether classifier comprehension relies on linguistic processing or on a nonlinguistic gestural-semiotic processing strategy is relevant to multiple processing theories concerned with the relationship between cognition and language acquisition. If classifiers are processed as linguistic by Deaf signers, this would indicate high flexibility of the processing mechanism at the syntax–semantics–phonology interface, which can account for

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[3] Signs also consist of nonmanual components, such as specific nonmanual markings (e.g., specific brow or tongue position) and mouthing, which describes a (part of a) spoken language word that is silently produced by the lips. These nonmanual markings are expressed simultaneously with the manual components (e.g., Sandler & Lillo-Martin, 2006).

open-class items like classifiers via parallel processing. If, on the other hand, signers use nonlinguistic semiotic resources to understand the meaning of classifiers, it would suggest reliance on a general cognitive processing strategy that can be used by those learning sign language for the first time (cf. Ortega et al., 2020).

Neural Indices of Form and Meaning Reanalysis

Although there is a paucity of electroencephalogram (EEG) studies that consider sign language word classes, there are several L2 (sign language learning) studies that investigated the neural processing of gestures and signs (cf. Ibáñez et al., 2010; Ortega et al., 2020). Ortega et al. investigated the effect of visual similarity to typical gestures on sign learning in hearing nonsigners. Early in the training sessions, a P300a event-related potential (ERP) component was observed in nonsigners—a general novelty-driven effect between gesturally familiar and unfamiliar signs. This effect diminished with exposure of learners to the signs, disappearing entirely after a training session. This led Ortega et al. to conclude that nonsigners activate their gestural knowledge when generating expectations about the form of signs and that learners draw on any available semiotic resources (i.e., not only on their linguistic experience) when acquiring a second language.

Previous studies on argument-role reanalysis in speech or writing revealed different ERP patterns. Haupt, Schlesewsky, Roehm, Friederici, and Bornkessel-Schlesewsky (2008) provide an overview of ERP effects for subject/object ambiguity resolution in German, noting that compared with garden-path sentences, which showed a stable P600 effect, the results of processing subject/object ambiguities appeared to be more heterogeneous. In total, four different ERP effects were observed in the context of argument-role (i.e., syntactic) reanalysis in German verb-final structures: the P345, P600, N400, and the biphasic pattern of an N400 and a late positivity following it.

The ERP component that is known to respond to unpredicted information or information that was not preactivated on the basis of previous processing steps is the N400. It is a broadly distributed, negative-going component peaking at approximately 400 ms after word onset, the amplitude of which is sensitive to a number of linguistic parameters. One of these parameters is word frequency; familiar, but rare word forms elicit a stronger N400 compared with more frequently used lexical items (Van Petten & Kutas, 1990). The N400 is also sensitive to any type of linguistic priming—its amplitude is reduced when a target word is preceded by a semantically, morphologically, or orthographically similar word (in the same language or a different one). Ortega et al. (2020) originally hypothesized an N400 effect for signs with low overlap with gestures compared with signs with high overlap with gestures; or, alternatively, a reduced N400 would be identified for signs with high gestural overlap as a result of processing ease. Ortega et al. did not observe an N400 effect for sign learners (when first exposed to signs as well as after a training session). The authors suggested that the form-meaning mapping in the acquisition of a second language in sign might be facilitated by iconicity.

In a sentence context, sources of an N400 include a mismatch in meaning (Baggio & Hagoort, 2011; Kallioinen et al., 2016), as well as reanalysis as a result of local ambiguity resolution, such as argument-role reassignment in garden-path sentences (Malaia, Wilbur, & Weber-Fox, 2009; Osterhout, Holcomb, & Swinney, 1994; Philipp, Bornkessel-Schlesewsky, Bisang, & Schlesewsky, 2008). Another parameter that can strongly influence the N400 amplitude to a word in a sentence context is cloze probability. Cloze probability is the likelihood of the target word completing the specific sentence frame in which it occurs—in other words, the linguistic unexpectedness of word use given a specific sentence structure. Kutas and Hillyard (1984) demonstrated that the use of an unexpected word in a sentence resulted in an increased N400 relative to more expected words. Overall, the N400 effect is reliably observed in a sentence context in response to those words, which trigger reprocessing of previous linguistic material, whether with regard to their semantics (meaning) or syntax (word order or thematic role assignment). This particular property of the N400 ERP component was relied on in the experimental design of the present study.

The Present Study

The present study focused on identifying the neural processing mechanism employed by proficient signers for comprehension of sentences with classifiers. We asked whether classifier constructions are processed as lexical verbs (showing interactions with other linguistic phenomena) or like spatial gestures. Stimuli sentences contained classifier constructions that indicated a spatial relationship between two arguments. The arguments used in the sentences belonged to the same semantic class, such that the classifier handshape could refer to either of the arguments. After the arguments were indexed in space, the direction of classifier motion disambiguated which argument moved toward which one (i.e., which argument could be semiotically interpreted as the figure and which as the ground or between the active and the passive argument). Thus, the direction of classifier motion also disambiguated the syntactic structure of the sentence: It identified whether the word order of the sentence was subject–object–verb (SOV), with the agent indexed first and the patient indexed second, or object–subject–verb (OSV), with the patient indexed first and the agent indexed second. The basic sign order of ÖGS is SOV (Skant et al., 2002; Wilbur, 2002, 2005), although in the context of agreeing verbs and plain verbs that are accompanied by an agreement marker, OSV orders are acceptable (Krebs et al., 2018; Krebs, Wilbur, Alday, & Roehm, 2019). The subject-first strategy (i.e., the subject preference) has been observed for sign and spoken languages (Haupt et al., 2008; Krebs et al., 2018, 2019, 2020; Wang, Schlesewsky, Bickel, & Bornkessel-Schlesewsky, 2009).

This strategy has already been observed for transitive argument structures involving typical lexical verbs in previous studies on ÖGS. Comparing SOV and OSV orders with lexical verbs in ÖGS, a subject preference is seen at the neurophysiological (ERP) and behavioral levels (Krebs et al., 2018, 2019, 2020). A negative-polarity ERP-reanalysis effect for OSV compared with SOV orders (i.e., the subject preference) was observed (Krebs et al., 2018, 2020). This effect was bound to a time point preceding the visual cue that was expected to indicate the argument structure, namely, before the path movement of the disambiguating sign. The transitional movement of the hand toward the disambiguating sign and/or nonmanual markings (body shift toward subject position and chin/face toward the object) appear to have disambiguated the structures. In line with previous studies testing subject/object ambiguities (i.e., the subject preference) in spoken languages (e.g., Haupt et al., 2008; Wang et al., 2009), we interpreted the observed negative effect as a reanalysis N400. In a follow-up gating study, locally ambiguous SOV and OSV orders were presented in successively prolonged gates (Krebs et al., 2019). After each gate, the signers had to identify the active referent in the sentence (i.e., make a choice between the argument introduced first or second). The first gate was the time span from video onset to the onset of the second argument. Each subsequent gate was prolonged by four frames. The majority of sentences were initially rated more likely to be SOV. This experiment confirmed the relatively early timing of ambiguity resolution in ÖGS. The gate at which the OSV order fell below 50% chance of being interpreted as SOV, taken to indicate the critical gate for disambiguation, was also observed before the predicted critical cue (path movement/hand orientation) of the disambiguating sign (for a discussion of the cues assumed to trigger reanalysis in sign language grammar, see Krebs et al. [2018, 2019, 2020]). Identification of a subject-preference phenomenon in ÖGS provides further evidence that signers and speakers draw on similar strategies during the processing of locally ambiguous argument structures, independent of language modality. This observation supports the assumption that the subject-preference phenomenon is a modality-independent, universal ambiguity-resolution processing strategy (cf. Bornkessel-Schlesewsky, Choudhary, Witzlack-Makarevich, & Bickel, 2008). Previous studies of ÖGS neurolinguistics, however, focused exclusively on structures containing lexical verbs. The present work examined classifier constructions that express motion in locative relations between arguments.

The experimental design contrasted two hypotheses about possible processing strategies for classifier predicates. First, if classifier processing is governed by linguistic (syntactic) rules in the same manner that is evident in the processing of lexical signs, then classifiers in the sentence-final position would be processed differently depending on whether the word order in the sentence is SOV or OSV. In this case, we would expect a subject-preference-driven broadly distributed N400 effect for OSV word order as a result of local ambiguity resolution at the point of classifier-predicate onset (similar to the one observed for lexical verb signs). Subject-preference effects on behavioral data, such as acceptability ratings or response times, can be subtle in either sign or spoken languages, even when neural processing differences manifest clear effects (Krebs et al., 2018; Malaia et al., 2009). For this reason, we did not expect to find significant differences between the SOV and OSV conditions in acceptability ratings or response times.

The alternative hypothesis is predicated on the findings that overt form-to-meaning mapping facilitates sign processing (Ortega et al., 2020). If classifier comprehension does not depend on the syntactic structure of the sentence—that is, if classifiers are processed using a gestural-semiotic mapping—no subject-preference effect (the N400 effect) would be expected for OSV compared with SOV sentences. Because spatial gestures would not be expected to interact with linguistic phenomena manipulated in the experiment (processing of word-order variation and resolution of a locally ambiguous argument structure), an absence of the N400 effect for the OSV condition as compared with the SOV condition would indicate that visual-spatial form-to-meaning mapping prevails over a linguistic processing strategy in classifier-predicate comprehension. The two hypotheses and their predictions are summarized in Table 1.

Method

Experiment Design

We presented participants with videos of signed classifier constructions in ÖGS in which we manipulated the word order (either SOV or OSV). A set of 40 sentences was presented in each condition (SOV or OSV). To avoid strategic processing, filler sentences were additionally included in the experiment, resulting in a total of 280 videos. The fillers consisted of (a) SOV and OSV sentences containing agreeing verbs, with or without topic marking on the first argument ($n = 160$), and (b) ÖGS videos presented in reversed video-frame order ($n = 40$). The reversed videos were included to ensure the reliability of the participants' ratings, that is, to check whether the subjects understood and correctly completed the rating task. The constructions involved only noncompound, frequent signs (the arguments MAN, WOMAN, GIRL, and BOY were used in the sentences). All the stimuli were signed by a right-handed Deaf woman who acquired ÖGS early in life, teaches ÖGS, uses ÖGS in her daily life, and is a member of the Deaf community.[4]

Stimuli

In the classifier constructions, both arguments were referenced by the same whole-entity classifier within one sentence (i.e., either the classifier for a sitting or a standing person) to ensure that only the direction of the classifier motion would disambiguate between the thematic roles of the arguments. The use of identical classifier handshapes in one sentence ensured that both arguments were equally likely to represent the active referent within the sentence. The same arguments were used within one sentence to avoid any semantic biases (e.g., "The man moves toward another man"). To create the 40 sentences for each condition, we used two classifier handshapes[5] (for sitting or standing person). We varied the spatial distance between the arguments (little vs. more distance between referents) as well as their orientation with respect to each other (sitting/standing opposite each other vs. next to each other), such that classifier signs expressed 40 different spatial movements/

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[4] Within the video material, the background color and the light conditions were kept constant among conditions.

[5] The findings can be generalized to other whole-entity classifiers used as verbs in transitive constructions involving animate arguments (expressing the meaning "move/go [to/toward]"). For example, the verb WALK, which is decomposable into the verb GO and the classifier TWO-LEGS, does generalize to other, animate move-classifier verbs. Shepard-Kegl (1985) provided the analysis of GO as underlyingly FROM_TO when starting and ending locations are specified (as they are in the present study). Likewise, GIVE and PUT are underlyingly GO, wherein the agent causes a theme (object) to GO_FROM_one_location_TO_another. Thus, WALK is a very good representative of such movements, and we would expect generalization to other spatial-classifier forms that express motion in locative relations between animate arguments.

Table 1
Processing Hypotheses and Their Predictions

Classifier-processing strategy	SOV word order	OSV word order
Linguistically governed processing	Baseline	Enhanced N400 compared with SOV
Gestural-semiotic processing	Baseline	No enhanced N400 compared with SOV

Note. SOV = subject–object–verb; OSV = object–subject–verb.

relations in each condition. The sentence-initial argument was always referenced at the left side of the signer.[6] After the arguments were referenced in space, the classifier predicate indicated the movement of one of the referents, who either walked, jumped with small successive jumps, or jumped with one big jump toward or away from the other referent.[7] Thus, either the classifier referencing the first argument indicated motion in relation to the argument referenced second (in SOV orders) or the classifier referencing the second argument indicated motion in relation to the argument referenced first (in OSV orders; Figure 1). At the end of the movement of the active referent, the active referent either stood beside/opposite the other (passive) referent or sat beside/opposite/in front of or behind the other referent (see the Appendix for the list of nouns and verbs used in the study).

Participants

Of the 25 persons who participated, 20 (9 females) were included in the final analysis (mean [*M*] age = 39.37, standard deviation [*SD*] = 10.19; range = 28–58). Four participants were excluded because of EEG artifacts (less than 70% of critical trials remaining after artifact rejection); one participant was excluded because of behavioral noncompliance (giving high acceptability ratings to reversed videos). All participants were born Deaf or lost their hearing early in life. Three had Deaf parents; the others had hearing parents. Half acquired sign language starting between 4 and 7 years, five participants between 0 and 3 years, and five subjects at a later age: one signer between 13 and 17 years, another between 18 and 22 years, and three after the age of 22. Participants came from different areas of Austria (Salzburg, Vienna, Upper Austria, Lower Austria, Styria). The language proficiency of all participants was confirmed by a professional ÖGS interpreter during the informed consent procedure. Informed consent was obtained in written form by a certified interpreter in accordance with the declaration of Helsinki. Fifteen participants were right-handed, four were left-handed, and one did not have a dominant hand preference (tested by an adapted German version of the Edinburgh Handedness Inventory; Oldfield, 1971). At the time of the study, none showed any neurological or psychological disorders. All had normal or corrected vision and were not influenced by medication or other substances that may affect cognitive ability.

Procedure

The videos (sized 35.3 × 20 cm) were presented on the computer screen, and the participant sat 1 m away from it. The material was presented in 14 blocks, each containing 20 sentences. Every trial started with the presentation of a fixation cross, which remained on the screen for 2000 ms, and was followed by an empty black screen for 200 ms. A stimulus sentence (video) was then presented in the middle of the screen. Each trial ended with a rating task, and a green question mark remained on the screen for 3000 ms after each stimulus. Participants had to rate the videos on a scale from 1 to 7, indicating whether, in their opinion, the stimulus was an acceptable ÖGS sentence (1= *that is not ÖGS*; 7 = *that is good ÖGS*). Ratings were given by button-press on a keyboard. Prior to the experiment, a training block of sentences was presented to familiarize participants with the task requirements and permit them to ask questions. The duration of breaks after each block was determined by the participants' wishes.

EEG Recording

The EEG was recorded from 26 electrodes (Fz, Cz, Pz, Oz, F3/4, F7/8, FC1/2, FC5/6, T7/8, C3/4, CP1/2, CP5/6, P3/7, P4/8, O1/2) fixed on the participant's scalp by an elastic cap (Easy Cap, Herrsching-Breitbrunn, Germany). Horizontal eye movements (HEOG) were registered by electrodes at the lateral ocular muscles, and vertical eye movements (VEOG) were recorded by electrodes fixed above and below the left eye. All electrodes were referenced against the electrode on the left mastoid and rereferenced later offline to the average of the left and right mastoids. The AFz electrode functioned as the ground. The EEG signal was recorded using a Brain Products amplifier (high pass 0.01 Hz) with a sampling rate of 500 Hz; electrode impedances were kept below 5 kΩ.

Data Analysis

Behavioral data. Acceptability ratings and reaction times (RTs) per participant (subject) and per item were assessed using repeated-measures analysis of variance (ANOVA). The fixed factor ORDER (SOV vs. OSV) and the random factors SUBJECTS (F_{Subj}) and ITEMS (F_{Item}) were included. Absent or late responses were not counted. The statistical analysis was carried out hierarchically; only significant interactions ($p \leq .05$) were resolved using a step-down approach.

ERP data. The signal was corrected for ocular artifacts using the Gratton and Coles method (Gratton, Coles, & Donchin, 1983)

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[6] Note that at the moment, there is no evidence of any default referencing (i.e., in that subjects are always referenced at the ipsi- or contralateral side of the signer) in ÖGS.

[7] In ÖGS, discourse referents can also be located in signing space by manual index/pointing signs as well as by nonmanual cues (e.g., body shift and/or eye gaze toward a specific location in space).

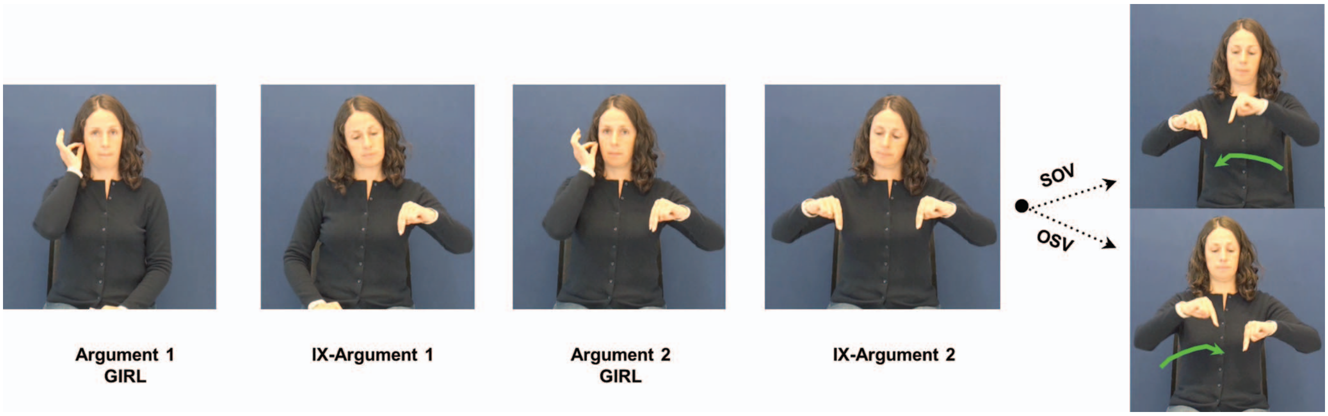

Figure 1. Example representing the two experimental conditions: Both arguments were referenced in space by a classifier handshape (in this case, the two referents are placed in space in a way indicating that they are standing opposite each other, with more distance between them). Then, either the hand representing the first referent (signer's left hand in subject–object–verb [SOV] orders) or the second referent (signer's right hand in object–subject–verb [OSV] orders) started to move—that is, indicating the active referent. The sentence shown means, "Two girls stand opposite each other, and one of them (either the one on the left or the one on the right side) jumps toward the other." Signs are glossed with capital letters. The photographs are published with the consent of Waltraud Unterasinger. See the online article for the color version of this figure.

and screened for artifacts (minimal/maximal amplitude at -75/$+75$ μV). The raw EEG signal was bandpass-filtered (Butterworth Zero Phase Filters; high pass: 0.1 Hz, 48 dB/Oct; low pass: 20 Hz, 48 dB/Oct). Data were baseline-corrected to -300 to 0. The percentage of trials remaining after artifact rejection (per condition at the time/first frame at which the hand referencing the subject started to move) is presented in Table 2. Participants were excluded from analysis if less than 70% of the critical trials remained after artifact rejection.

Statistical analysis of the ERP data compared mean amplitudes per time window per condition per subject in six lateral regions of interest (ROIs) and in three midline electrodes (MIDs). ROIs included the following electrodes: anterior left = F7, F3, FC5; anterior right = F8, F4, FC6; central left = FC1, CP5, CP1; central right = FC2, CP6, CP2; posterior left = P7, P3, O1; and posterior right = P8, P4, O2. The factor MID included three electrodes: Fz, Cz, and Pz. The statistical analysis was carried out in a hierarchical manner; that is, only significant interactions ($p \leq .05$) were resolved. For the statistical analysis of the ERP data, an ANOVA was computed, including the factor of condition ORDER (SOV vs. OSV) and the factors ROI or MID. To correct for violations of sphericity, the Greenhouse and Geisser (1959) correction was applied to repeated measures with greater than 1 degree of freedom.

Table 2
Remaining Trials After Artifact Rejection (per Condition at Time/First Frame at Which the Hand Referencing the Subject Started to Move)

SOV	OSV
87%	86%

Note. SOV = subject–object–verb; OSV = object–subject–verb.

Results

Behavioral Data

Acceptability ratings. Sentences with both SOV and OSV orders were rated high in acceptability (at least 5.67 on a scale from 1 to 7). Acceptability ratings for the two critical conditions did not differ significantly from each other, $F_{\text{subj}}(1, 19) = 1.23$, $p = .28$; $F_{\text{item}}(1, 19) = 2.25$, $p = .14$. Mean acceptability ratings for the reversed-video filler condition ($M = 1.70$, $SD = 0.83$) differed significantly from both the mean acceptability ratings for the SOV stimuli, $F_{\text{subj}}(1, 19) = 255.85$, $p < .001$, and the OSV stimuli, $F_{\text{subj}}(1, 19) = 252.71$, $p < .001$.

Reaction times. The mean RTs for stimuli did not differ significantly, $F_{\text{subj}}(1, 19) = 2.49$, $p = .13$; $F_{\text{item}}(1, 19) = 2.46$, $p = .13$. The mean RT for the reversed-video filler condition ($M = 909.34$, $SD = 446.39$) did not differ significantly from the mean RTs for classifier sentences ($F < 1$).

Table 3 provides an overview of the acceptability ratings and RTs for both critical conditions (SOV and OSV). These were also compared with acceptability ratings and RTs for the reversed-video fillers. Only significant effects ($p \leq .05$) are reported.

Table 3
Mean Ratings and Mean Reaction Times for the Two Experimental Conditions

Condition	Mean acceptability (*SD*)	Mean reaction time in ms (*SD*)
SOV	5.76 (0.92)	870.18 (446.90)
OSV	5.67 (0.90)	896.84 (460.53)

Note. SOV = subject–object–verb; OSV = object–subject–verb.

ERP Data

The first frame of the hand movement for the disambiguating classifier predicate was time-stamped as the onset of disambiguating motion. A pronounced negativity for OSV compared with SOV word order was observed in the 300- to 800-ms time window (see Figure 2). Statistical analysis revealed a significant main effect of ORDER for lateral ROIs, $F(1, 19) = 10.69$, $p < .01$, $\eta_p^2 = 0.36$, as well as a significant main effect of ORDER for MID electrodes, $F(1, 19) = 10.44$, $p < .01$, $\eta_p^2 = 0.35$. Significant interactions, ORDER × ROI, $F(5, 95) = 6.01$, $p < .01$, $\eta_p^2 = 0.24$, and ORDER × MID, $F(2, 38) = 4.07$, $p < .05$, $\eta_p^2 = 0.18$, were also observed. The resolution of the interaction ORDER × ROI revealed significant ORDER effects in the right anterior, $F(1, 19) = 9.88$, $p < .01$, $\eta_p^2 = 0.34$; left central, $F(1, 19) = 8.08$, $p < .05$, $\eta_p^2 = 0.30$; right central, $F(1, 19) = 13.42$, $p < .01$, $\eta_p^2 = 0.41$; and right posterior, $F(1, 19) = 26.03$, $p < .001$, $\eta_p^2 = 0.58$, ROIs. The resolution of the interaction ORDER × MID revealed a significant effect at the anterior, $F(1, 19) = 9.61$, $p < .01$, $\eta_p^2 = 0.34$; central, $F(1, 19) = 6.98$, $p < .05$, $\eta_p^2 = 0.27$; and posterior, $F(1, 19) = 12.30$, $p < .01$, $\eta_p^2 = 0.39$, midline electrodes.[8] Only significant ERP effects ($p \leq .05$) are reported.

The ERP data analysis revealed a significant negative ERP effect for OSV compared with SOV orders. This finding supports the hypothesis that the classifier sentences examined in the present study were not processed via a gestural-semiotic strategy by signers. Instead, the data support the hypothesis that sign language classifiers are processed in a manner that is similar to that in which lexical verbs are processed in sign language—that is, that their structure is linguistically controlled.

Discussion

We investigated the neural mechanisms underlying processing strategies for classifiers—a part of speech unique to sign languages that has both linguistic and gestural characteristics. The experimental design—use of sentences with classifiers that expressed the spatial relationship between two human referents—aimed to create an ambiguity that could be resolved by either of the two processing mechanisms (linguistic vs. gestural-semiotic). The behavioral data did not show any preference for one or the other word order in acceptability ratings, suggesting that we successfully created truly ambiguous and equally acceptable stimuli for both conditions. Although RTs did not differ between conditions, online EEG data from Deaf signers revealed a pattern of processing for classifiers that was indicative of linguistic, rather than gestural-semiotic, processing. The ERP analysis indicated enhanced processing costs (i.e., a broadly distributed N400 effect) for OSV (patient-first) word order compared with SOV (agent-first) word order, which we interpret as a reflection of the subject-first processing strategy that was reported previously for sign and spoken languages (Haupt et al., 2008; Krebs et al., 2018, 2020; Wang et al., 2009).

Classifier-processing mechanisms are a particularly interesting phenomenon from the standpoint of both psychological models and linguistic theory because classifiers as a part of speech straddle the divide between purely linguistic signs in the visual-manual modality and semantically meaningful gesture. The understanding of how classifiers are processed by native and nonnative signers bears on a larger question of the interface between perception, language, and cognition.

In theoretical linguistic research, the observation that most sign languages with locative classifiers show a preference toward a locative object/locative subject/locative predicate (OSV) order (despite their different basic sign orders) has led some researchers to suggest that this preference is not linguistically governed but is, rather, driven by the visual-manual modality. Kimmelman (2012) points out that hearing nonsigners use the same locative object/locative subject/locative predicate order when describing pictures expressing locative events nonverbally (pantomime/gesture), suggesting a cognitive "mental-map" approach to these relationships when using spatial/visual means of expression. Hearing nonsigners also prefer animate/agent arguments in the sentence-initial position, suggesting a modality-independent preference for what makes a good subject and how it should be expressed (e.g., Hall, Mayberry, & Ferreira, 2013; Laudanna & Volterra, 1991; Meir et al., 2017).

The claim that classifier signs are complex linguistic constructions is further supported by neuroimaging data, which indicate that language-specialized brain areas in the left hemisphere are involved during classifier processing (e.g., Emmorey, McCullough, Mehta, Ponto, & Grabowski, 2013; Hickok, Pickell, Klima, & Bellugi, 2009; Newman, Supalla, Fernandez, Newport, & Bavelier, 2015). Some studies on native signers, however, have also suggested that sign language classifiers are processed somewhat differently from lexical signs (e.g., Emmorey et al., 2002, 2005, 2013; Emmorey, McCullough, Mehta, & Grabowski, 2014; MacSweeney et al., 2002; McCullough, Saygin, Korpics, & Emmorey, 2012). Neuroimaging and lesion studies suggest that the processing of classifiers engages spatial-processing networks in the right hemisphere and in bilateral parietal brain areas to a greater extent than the processing of lexical signs (e.g., Atkinson, Campbell, Marshall, Thacker, & Woll, 2004, Atkinson, Marshall, Woll, & Thacker, 2005; Emmorey et al., 2002, 2005, 2013, 2014; Hickok et al., 1999, 2009; MacSweeney et al., 2002; Poizner, Klima, & Bellugi, 1987). Whether this evidence reflects enhanced (nonlinguistic) visual-spatial processing or whether it shows "spatially based syntactic processing" is still an open question.

Multiple neurophysiological and behavioral studies have indicated that the subject-preference processing strategy—the tendency to interpret the sentence-initial argument as the subject—elicits a reliable, broadly distributed reanalysis N400 effect in spoken and sign languages (e.g., Haupt et al., 2008;

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[8] That the observed effect was not driven by the inclusion of five late learners was shown by an additional ERP data analysis excluding the five late learners. This analysis revealed a significant main effect of ORDER for ROI, $F(1, 14) = 6.52$, $p < .05$, $\eta_p^2 = 0.32$, and a significant main effect of ORDER for MID, $F(1, 14) = 5.75$, $p < .05$, $\eta_p^2 = 0.29$. In addition, a significant interaction of ORDER × ROI, $F(5, 70) = 8.75$, $p < .001$, $\eta_p^2 = 0.38$, and a significant interaction of ORDER × MID, $F(2, 28) = 6.46$, $p < .01$, $\eta_p^2 = 0.32$, were observed. The resolution of the interaction ORDER × ROI revealed significant ORDER effects in the right anterior, $F(1, 14) = 5.50$, $p < .05$, $\eta_p^2 = 0.28$; right central, $F(1, 14) = 11.06$, $p < .01$, $\eta_p^2 = 0.44$; and right posterior, $F(1, 14) = 27.13$, $p < .001$, $\eta_p^2 = 0.66$, ROIs. The resolution ORDER × MID revealed a significant effect at the anterior, $F(1, 14) = 5.43$, $p < .05$, $\eta_p^2 = 0.28$, and posterior, $F(1, 14) = 8.21$, $p < .05$, $\eta_p^2 = 0.37$, midline electrodes.

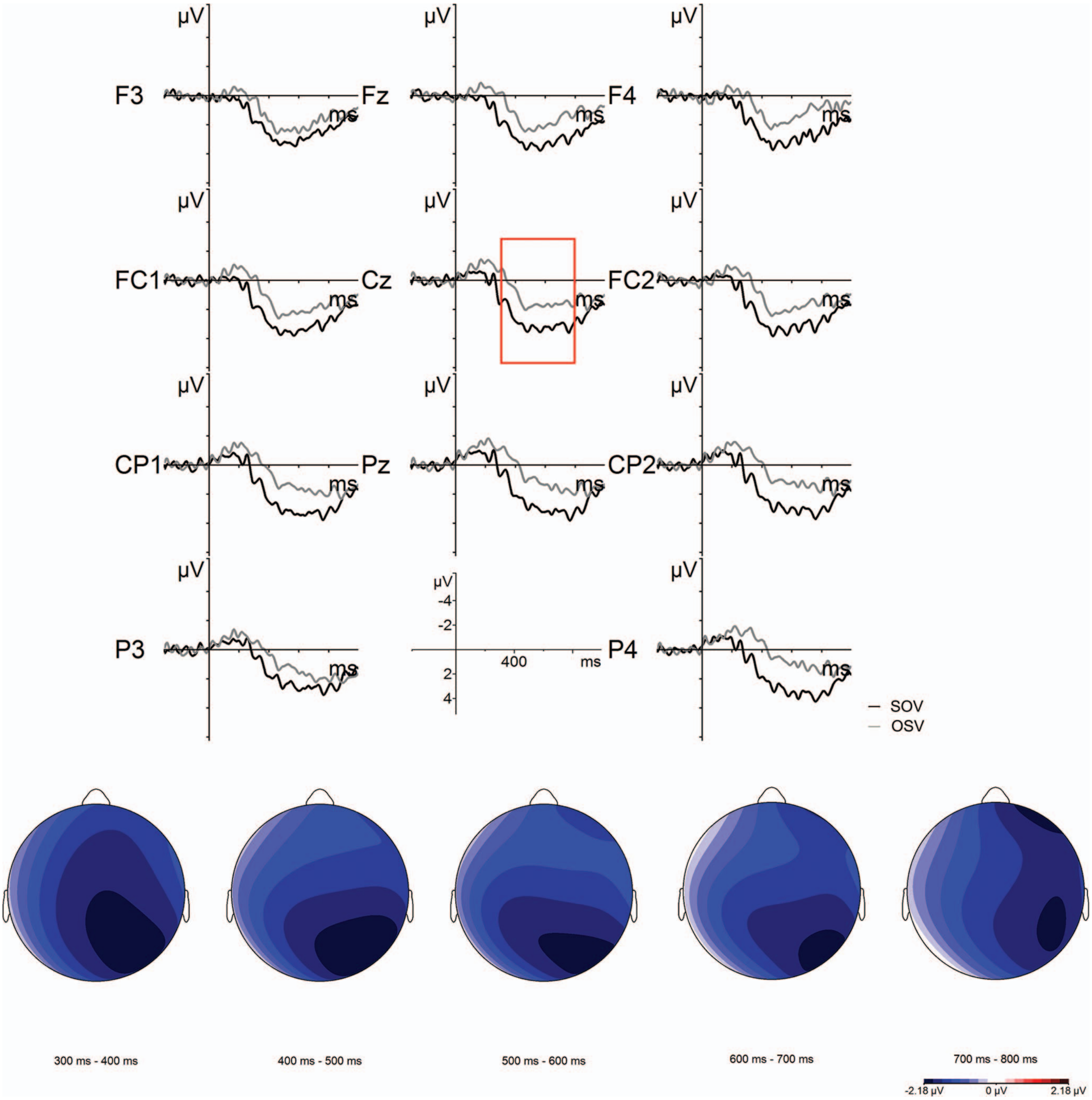

Figure 2. Top: Comparison of subject–object–verb (SOV) versus object–subject–verb (OSV) conditions with regard to the time point when the classifier predicate started its movement. The vertical line represents the time point at which the first frame when the hand referencing the subject starts to move was visible. Negativity is plotted upward. The rectangle marks the time window in which the effect of ORDER became significant (300- to 800-ms time window). Bottom: The topographic plots illustrate the corresponding voltage difference between the two conditions over the epoch of interest, that is, from 300 to 800 ms, showing the broad scalp distribution of the N400 effect. See the online article for the color version of this figure.

Krebs et al., 2018, 2020; Wang et al., 2009). The subject preference has also been described in terms of actor preference, whereby the actor is understood as the participant primarily responsible for the state of affairs that is described by the event (cf. proto-agents in Malaia, Wilbur, & Weber-Fox, 2012, 2013; Primus, 1999), which yields similar reanalysis and disambiguation effects in neural data (e.g., Alday, Schlesewsky, & Bornkessel-Schlesewsky, 2014; Bornkessel & Schlesewsky, 2006, 2009, 2013). Our results support and extend the observation that the subject preference is a preferred processing strategy of ÖGS, whether driven by syntactic word order or semantic parameters of arguments, such as animacy, or both.

One of the limitations of the study is that we did not test for the effect of animacy on argument processing in sentences with classifiers. Argument animacy has also been shown to interact with thematic role assignment at early stages of processing (Malaia & Newman, 2015a, 2015b). For other sign languages, it has been shown that animacy can cancel out a figure–ground interpretation (Volterra, Laudanna, Corazza, Radutzky, & Natale, 1984), such that animate (i.e., most agent-like) arguments are preferred in the sentence-initial position, that is, before inanimate arguments, even in locative constructions (e.g., Coerts, 1994; Kimmelman, 2012; Leeson, 2001). It is, thus, possible that a combination of animate and inanimate arguments in the sentence might change the online processing strategy—it would be interesting to test whether the subject preference could be overridden by the figure–ground principle in sentences with inanimate arguments for which a figure–ground relation can be clearly established (e.g., a big/immobile vs. a small/mobile referent). The present findings also do not apply to the processing of locative classifier constructions that do not express a motion relation but only a locative relation between arguments (e.g., "The cat is on the fence").

Conclusion

The present study revealed an N400 reanalysis effect for sentences with OSV word order (in contrast to SOV) containing classifiers. These data indicate a linguistic, rather than a spatial gestural-semiotic, processing strategy for sign language classifiers: Locally ambiguous classifier constructions are processed using a linguistic strategy in transitive sentences (Krebs, 2017; Krebs et al., 2018, 2019, 2020). We show that the high iconicity of sign language classifiers does not affect processing mechanisms during ambiguity resolution/argument structure assignment for Deaf signers: In sign language, classifier constructions expressing motion in locative relations are linguistically controlled constructions rather than the suggested partially nonlinguistic gestures. These findings suggest that further work investigating how classifiers are acquired by signing children can be instrumental in understanding the interconnected development of language and cognition in the visuospatial modality.

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(*Appendix follows*)

Appendix

Information About the Stimulus Material

Notation conventions: Signs are glossed with capital letters; *CL* stands for *classifier*.

Nouns/Classifier Verbs Used in the Critical Stimulus Sentences

Nouns

MAN

WOMAN

BOY

GIRL

Classifier Verbs

CL-WALK-TOWARD

CL-JUMP-TOWARD (small successive jumps)

CL-JUMP-TOWARD (one big jump)

CL-WALK-AWAY

CL-JUMP-AWAY (small successive jumps)

CL-JUMP-AWAY (one big jump)

Figure A1. The photographs are published with the consent of Waltraud Unterasinger. See the online article for the color version of this figure.

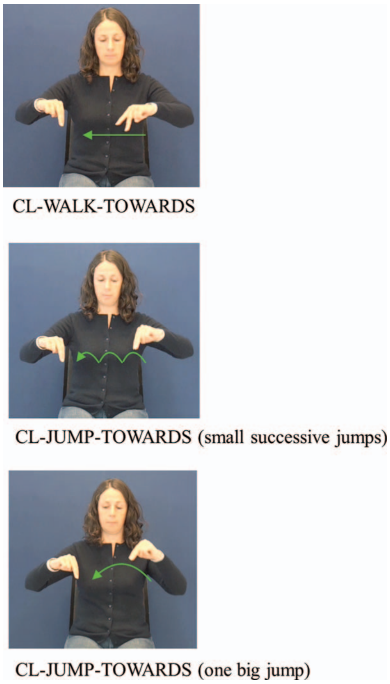

Figure A2. The photographs are published with the consent of Waltraud Unterasinger. See the online article for the color version of this figure.

In the classifier constructions, both arguments were referenced by the same whole-entity classifier within one sentence, that is, either with the classifier for a standing or a sitting person. To create a set of 40 sentences for each condition and thereby use two classifier handshapes (for sitting or standing person), we varied the spatial distance between the arguments (little vs. more distance between the referents) as well as their orientation with respect to each other (sitting/standing opposite to each other vs. next to each other). After the arguments were referenced in space by whole-entity classifiers, the classifier predicate indicated the movement of one referent, who either walked, jumped with small successive jumps, or jumped with one big jump toward or away from the other referent (for illustration, see the accompanying examples). After the movement of the active referent ended, the active referent either stood beside/opposite the other (passive) referent or sat beside/opposite/in front of or behind the other referent.

(*Appendix continues*)

Nouns/Verbs Used in the Filler Sentences

Nouns

MAN

WOMAN

BOY

GIRL

Verbs

HIT

CONTROL

LOOK-FOR

OPPRESS

SUPPORT

THREATEN

KILL

ATTACK

PRAISE

CRITICIZE

EXAMINE

CONGRATULATE

TEACH

CARE-FOR

INFORM

RESPECT

TRUST

GREET

LOOK-OVER/EYEBALL

ADORE

KISS

WAKE-UP

HUG

CONSOLE

WATCH

THANK

CONVEY-INFORMATION-TO

INFLUENCE

HELP

PROTECT

ANNOY

SCARE

HATE

ANSWER

INFECT

CATCH

LOOK-AT

ASK

SCOLD

VISIT

The fillers consisted of SOV and OSV sentences containing agreeing verbs, with or without topic marking on the first argument ($n = 160$). The content of the sentences encompassed transitive argument relations (Noun Phrase 1 [NP1]–Noun Phrase 2 [NP2]–verb). The arguments were referenced by manual index signs in the signing space in front of the signer. After referencing, the sentence-final verb showed verb agreement by movement (either from one indexed position to another and/or by hand orientation, i.e., palm and/or fingertips facing toward the object position). The preverbal part (i.e., noun phrases and their spatial referencing) was kept constant across conditions (i.e., the first argument in the sentence was always referenced at the left side of the signer). The SOV and OSV stimuli differed only in the movement and/or hand orientation of the sentence-final verb. In the SOV condition, the verb changed the initial-to-final location from the argument referenced first to the second argument. In the OSV condition, the verb changed the initial-to-final location from the argument referenced second to the argument referenced first. Half of the sentences were SOV orders; the other half were OSV orders. Half of the sentences

(*Appendix continues*)

were signed with topic marking on the sentence-initial argument (expressed by specific nonmanual markings accompanying the sentence-initial argument and a pause following the topic argument). The other half of the sentences were signed without topic marking. Each verb occurred in the same sentence context in the SOV and OSV conditions, as well as with and without topic marking. Approximately half of the verbs were one-handed; the others were two-handed (19 two-handed verbs; 21 one-handed verbs). The same arguments were used within one sentence (e.g., "The man asks the man").

In addition, ÖGS videos presented in reversed video-frame order ($n = 40$) were included in the filler material. These time-reversed videos were constructed from the OSV orders without topic marking (which were also part of the filler material described previously). In the fillers, no classifier signs were included.

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