Brain Research 1691 (2018) 105–117

Contents lists available at ScienceDirect

Brain Research

journal homepage: www.elsevier.com/locate/bres

Research report

Subject preference emerges as cross-modal strategy for linguistic processing

Julia Krebs [a,b,*], Evie Malaia [c,d], Ronnie B. Wilbur [c], Dietmar Roehm [a,b]

[a] Research group Neurobiology of Language, Department of Linguistics, University of Salzburg, Erzabt-Klotz-Straße 1, 5020 Salzburg, Austria
[b] Centre for Cognitive Neuroscience (CCNS), University of Salzburg, Salzburg, Austria
[c] Linguistics Program, and Department of Speech, Language, and Hearing Sciences, Purdue University, West Lafayette, Lyles-Porter Hall, West Lafayette, IN 47907-2122, USA
[d] Freiburg Institute for Advanced Studies, Albertstrasse 19, 79104, Freiburg im Breisgau, Germany

ARTICLE INFO

Article history:
Received 24 September 2017
Received in revised form 30 January 2018
Accepted 24 March 2018
Available online 5 April 2018

Keywords:
Ambiguity resolution
Subject preference
Sign language processing
Event-related potentials
Cross-modality

ABSTRACT

Research on spoken languages has identified a "subject preference" processing strategy for tackling input that is syntactically ambiguous as to whether a sentence-initial NP is a subject or object. The present study documents that the "subject preference" strategy is also seen in the processing of a sign language, supporting the hypothesis that the "subject"-first strategy is universal and not dependent on the language modality (spoken vs. signed). Deaf signers of Austrian Sign Language (ÖGS) were shown videos of locally ambiguous signed sentences in SOV and OSV word orders. Electroencephalogram (EEG) data indicated higher cognitive load in response to OSV stimuli (i.e. a negativity for OSV compared to SOV), indicative of syntactic reanalysis cost. A finding that is specific to the visual modality is that the ERP (event-related potential) effect reflecting linguistic reanalysis occurred earlier than might have been expected, that is, before the time point when the path movement of the disambiguating sign was visible. We suggest that in the visual modality, transitional movement of the articulators prior to the disambiguating verb position or co-occurring non-manual (face/body) markings were used in resolving the local ambiguity in ÖGS. Thus, whereas the processing strategy of "subject preference" is cross-modal at the linguistic level, the cues that enable the processor to apply that strategy differ in signing as compared to speech.

1. Introduction

The phenomenon of subject preference, whereby the first-occurring noun in the sentence is assumed to be the grammatical subject, is attested for multiple spoken languages (Wekerly and Kutas, 1999; Bader and Meng, 1999; Tamaoka et al., 2005). Multiple psycholinguistic studies indicate that processing of sentences where the object precedes the subject – e.g. in flexible word order languages, or in relative clauses in fixed word order languages – induce a higher processing load during comprehension (Malaia et al., 2009, 2012a, inter alia). The reliability of this phenomenon in well-studied languages, however, does not mean that the phenomenon is universal. For example, examinations of languages with basic word order in which the object precedes the subject have shown an opposite effect – an increased cognitive load for subject-first sentences, indicating that sentence-processing load is conditional upon syntactic parameters of the language being processed (Yasunaga et al., 2015).

The present study further tests the assumptions behind the subject preference phenomenon by asking whether the cognitive load is indeed driven by the modality-independent representation of language in the human brain, or whether the cognitive load incurred might depend on the sensory processing pipeline. Testing of the subject preference prediction in sign language, in the visual modality, can help dissociate between the contribution of the two processing components.

The study of sign languages is a valuable tool to investigate how language modality may influence the structure and neural representation of language and thus provides important implications for spoken language processing. At the same time, the investigation of sign language processing enables us to identify processing mechanisms related to the modality in which a language is expressed. Sign languages are natural languages showing the same complexity, as well as language-specific differences, as spoken languages; however, they are expressed in the visual modality (Emmorey, 2002; Sandler and Lillo-Martin, 2006). Sign languages are produced by manual means (hands and arms) and non-manual means

* Corresponding author at: Research group Neurobiology of Language, Department of Linguistics, University of Salzburg, Erzabt-Klotz-Straße 1, 5020 Salzburg, Austria.
E-mail address: julia.krebs@sbg.ac.at (J. Krebs).

https://doi.org/10.1016/j.brainres.2018.03.029
0006-8993/

(e.g. brow raise, eye gaze, head/body/shoulder position), whereby non-manual cues function as relevant linguistic cues on all levels of the grammar: they can be a phonological part of lexical entries of signs, they can function as morphological markings (e.g. aspect marking, adverbial/adjectival marking), they differentiate specific sentence types on the syntactic level, function as discourse markers on the pragmatic level, and are also relevant prosodic cues (see e.g. Aran et al., 2009; Benitez-Quiroz et al., 2014, 2016; Cooper et al., 2011; Neidle et al., 2000; Parashar, 2003; Pizzuto et al., 1990; Wilbur, 2000, 2011; Xu et al., 2000; Pfau and Quer, 2010 for an overview).

The present study examined the processing of word order variations in Austrian Sign Language (ÖGS) by Deaf signers.[1] The investigation of the processing of word order variations is of particular interest because research on different spoken languages has identified a "subject preference" processing strategy, i.e. the processing system's tendency to interpret sentence-initial ambiguous argument NPs preferentially as the "subject" of a clause (see below for a more detailed description). The use of Austrian Sign Language is also especially telling because it, like spoken German, is verb-final and while fundamentally an SOV language, it allows variable constituent orders (e.g. SOV, OSV). This enables the construction of stimuli that parallel those used for spoken German, but with a twist. Whereas spoken German has an extensive case marking system for nominals, and thus can only offer locally ambiguous sentence initial nominals when the case marker is itself ambiguous, ÖGS (and other sign languages such as American Sign Language ASL; e.g. Sandler and Lillo-Martin, 2006) to the best of our knowledge has no case marking system, thus providing less distance between experimental results and more common natural online processing, supporting the generality of the subject processing strategy itself.

For example, German allows multiple orders of core arguments in transitive or ditransitive clauses. In addition, certain NPs (e.g. feminine/neuter nouns, proper names, bare plurals) show case syncretism between nominative and accusative (sometimes even dative). Together, case syncretism and relatively flexible word order can result in local ambiguity as to the syntactic function of an argument NP (i.e. whether subject or object), at least until further information permits resolution of the ambiguity (e.g. verb agreement marking on a finite verb) (e.g. Bornkessel et al., 2004). Thus, the human language processing system has to deal with such locally ambiguous word order variations. Studies on spoken language processing show that language is processed incrementally (Malaia et al., 2009). Thus, the language processing system does not wait until all information is provided, but integrates language input into previously established context as soon as possible. In cases of ambiguous input, the system must make very fast decisions for adopting one of available interpretation possibilities. One extensively investigated phenomenon with respect to this issue is the so-called "subject preference". Results of studies on different spoken languages with SO order, including English, German, Turkish, and Japanese, all reveal a general strategy for human parsers to interpret a sentence-initial ambiguous argument as the subject (e.g. Malaia and Newman, 2015b; Malaia et al., 2012a; Schlesewsky et al., 2000; Bornkessel et al., 2004; Demiral et al., 2008; Wang et al., 2009). For example in German, the singular noun *Prinzessin* (princess) and the bare noun plural *Frösche* (frogs) are case-ambiguous in the embedded clause in sentences (1) and (2).

(1) [SOV order] Ich glaube, dass die Prinzessin Frösche **küsst**.
[I believe that the princess$_{\text{NOM/ACC.SG}}$ frogs$_{\text{NOM/ACC.PL}}$ kisses$_{\text{SG}}$]
I believe that the princess kisses the frogs.

(2) [OSV order] Ich glaube, dass die Prinzessin Frösche **küssen**.
[I believe that the princess$_{\text{NOM/ACC.SG}}$ frogs$_{\text{NOM/ACC.PL}}$ kiss$_{\text{PL}}$]
I believe that the frogs kiss the princess.

Thus, their syntactic functions cannot be determined from morphological case information but remain fully ambiguous between possible SOV or OSV readings until the sentence-final main verb (*küsst* vs. *küssen*) resolves the ambiguity via number congruency information (Bornkessel et al., 2004). In an OSV sentence with ambiguous argument NPs (as in 2) the preferred subject-initial structure (SOV) does not match the actual order (OSV), which leads to a reanalysis towards a non-preferred object-initial construction when disambiguating information from the verb becomes available. This reanalysis results in increased processing costs that are reflected in longer reading times (Schlesewsky et al., 2000), lower acceptability ratings and longer reaction times (Bornkessel et al., 2004; Haupt et al., 2008), more regressions and longer fixations during reading (Kretzschmar et al., 2012) as well as different ERP effects for OSV sentences compared to SOV counterparts (Bornkessel-Schlesewsky and Schlesewsky, 2009 for overview). Interestingly, the preference towards subject-initial interpretation is observed not only for languages with accusative alignment but also with ergative syntactic alignment as in Hindi[2], and even languages which do not show any case marking (e.g. Chinese) (Bornkessel-Schlesewsky et al., 2008).

Different approaches attempt to explain the underlying source of the "subject preference". Traditionally, it is assumed to stem from specific structural properties of subjects, such as structural position (Frazier and Fodor, 1978; Crocker, 1994) or dependencies (Gibson, 1998), claiming that the language processing system makes use of these structural properties to reduce working memory costs (Newman et al., 2013). Although these theories can account for the subject preference in languages for which "subject" and subjecthood have been clearly defined (e.g. German or English), they cannot explain the fact that the subject preference is also observed in a language in which the status of the category "subject" and the applicability of grammatical relations (subject/object asymmetry) in general are controversial, such as Mandarin, which has relatively free word order, lacks verb agreement and case marking, and subject-related properties such as coordination in conjoined clauses (Li and Thompson, 1976). Thus, position- or dependency-based accounts of the subject preference seem not appropriate for Mandarin (Wang et al., 2009). The subject preference has also been observed in Turkish, a verb-final language that allows subject drop (Demiral et al., 2008). That is, in Turkish, object-initial sentences without a subsequent subject are perfectly acceptable. Thus, in Turkish an initial ambiguous argument can be analyzed as either the subject or the object in case of a dropped subject. Crucially, both orders are basic orders, i.e. associated with the same base-generated NP-V structure (a structure without filler-gap dependencies). Therefore, the subject preference observed in Turkish also cannot be explained by the subject-related accounts described above (Demiral et al., 2008).

Another approach claims that the "subject preference" does not arise from any particular properties related to subjecthood but is an epiphenomenon of a general least-effort processing strategy. Within the so-called *Extended Argument Dependency Model (eADM)* (Bornkessel and Schlesewsky, 2006), this processing strategy is

[1] Per convention Deaf with 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 audiological status.

[2] The accusative vs. ergative alignment describes two different systems of case marking: In a language with (nominative)-accusative alignment the subject of the sentences bears nominative case and the object bears accusative case (e.g. German). In a language with ergative(-absolutive) alignment the subject of an intransitive structure and the object of a transitive structure show the same case marking (often noted as absolutive), but the subject of a transitive structure is marked by a different case which is called the ergative (e.g. Hindi) (e.g. Dixon, 1994).

explained in terms of minimality-based processing principles. Since the processing system attempts to generate less complex (minimal) structures, sentence-initial ambiguous arguments are preferentially interpreted as the single argument of an intransitive event, i.e. as subject. If an intransitive interpretation cannot be maintained, i.e. when a second ambiguous argument follows, extension towards a transitive event is necessary, leading to increased processing costs. In a transitive construction with a sentence-initial ambiguous object argument, an SOV reading is initially preferred and thus must be reinterpreted towards a non-preferred OSV structure. Since the subject preference only applies when the first argument is not unambiguously marked, Bornkessel-Schlesewsky et al. (2008) denoted the phenomenon as an "ambiguity resolution processing strategy". This minimality-based account makes the cross-linguistic prediction that the subject preference is a universal processing strategy that should be observable in all human languages.

Even though the subject preference prediction has been attested across multiple languages, including Basque (Erdocia et al., 2009), German (Rösler et al., 1998), Japanese (Ueno and Kluender, 2003), investigations of less-studied languages indicate that subject preference is constrained by the basic syntactic parameters of the language. For example, Yasunaga et al. (2015) has shown that in a language with free word order, but basic VOS structure (Kaqchikel, a Mayan language spoken in Guatemala), sentences in which subject precedes object, though frequent, incur a higher cognitive load than sentences with object preceding the subject. Thus, the minimal-effort processing strategy appears to be constrained by the basic syntactic structure of the language. However, with this limitation, subject preference is still predicted for SO languages. Since ÖGS is an SO language, subject preference prediction still holds.

However, the prediction for subject preference in SO languages can pertain either to the modality-independent representation of language in the human brain, or be conditioned by the cognitive load incurred in connection with sensory processing of the signal (e.g. phonological loop-based maintenance in spoken language). Testing of the subject preference prediction in sign language, in the visual modality, can help dissociate between the contribution of the two processing components to subject preference.

The present ERP study investigated the processing of word order variations in ÖGS by Deaf signers, with the goal to dissociate between modality- vs. language-based effects (such as subject preference) based on neural data. Although there are many studies on processing of word order variations for spoken languages, there are – to the best of our knowledge – no similar investigations focusing on the online processing of sign languages.

There are a number of descriptive and behavioral studies investigating word order phenomena in sign languages, including factors that may influence word order variation (e.g. Fischer, 1975 for ASL; Boyes Braem et al., 1990 for Swiss French Sign Language SFSL; Coerts, 1994 for Sign Language of the Netherlands NGT; Milković et al. 2006, for Croatian Sign Language HZJ; Kimmelman, 2012 for Russian Sign Language), or influence of age of acquisition on the memory processing of basic word order (e.g. Newport, 1990; Boudreault and Mayberry, 2006).

In sign languages, argument relations are expressed by other cues such as word order, animacy and/or verb modification ("verb agreement"). The term "verb agreement" and its applicability to the description of the process of indicating the argument structure in transitive signed sentences was and still is a point of debate. The mechanism has been analyzed from very different viewpoints (see Lillo-Martin and Meier (2011) for an overview). Although there have been some claims that the agreement process in sign languages is merely gestural (Liddell, 2003), there is a general agreement in sign language linguistics that the marking of argument structure in signing space is a linguistic process (Wilbur, 2013). For expressing verb agreement in sign languages, discourse referents (physically present and non-present referents) are associated with different specific locations, so-called R(eference)-loci, in signing space in front of the signer. These reference points may be established by (non-)manual cues (by index/pointing sign, eye gaze, head tilt, body shift towards a target location) (Padden, 1983). After referencing discourse participants, the path movement of an agreeing verb from the location associated with the subject to the object position indicates agreement. In addition, many agreeing verbs are signed with the palm and/or fingertips facing towards the object ('facing'). Thus, the path movement and/or facing of the agreeing verb indicates the relationship between the arguments.

The basic sign order in ÖGS transitive clauses seems to be SOV (Skant et al., 2002; Wilbur, 2005), but in some environments, such as sentences with agreeing verbs, (non-topicalized) object-initial constructions are also possible. Note that in ÖGS, as in many other sign languages, subject as well as object drop is possible (e.g. Lillo-Martin, 1986 for ASL; Milković et al., 2006 for Croatian Sign Language HZJ). To investigate how different word orders (SOV, OSV) are processed, our study used material comparable to constructions used for testing subject/object ambiguities in spoken languages. Independent of word order, the first argument was always referenced at the signer's left side in the stimuli. After both arguments were referenced in space by an index sign, the disambiguating agreeing verb either moves from the argument established first (from left to right in SOV) or from the argument referenced second (from right to left in OSV) (Table 1; Fig. 1).

Given that there are no studies on word order processing in ÖGS, hypotheses regarding the possible outcomes could only be made tentatively. However, ERP studies on (other) sign languages so far revealed similar ERP patterns as for spoken languages. For example, for spoken language it has been shown that semantic processing evokes N400 effects (effects with a negative polarity observable after around 400 ms after the onset of the critical stimulus which is topologically distributed in the centro-parietal area) as opposed to syntactic processing which elicited focal LAN effects (left anterior negativities appearing about 400 ms after presentation of the stimulus onset) and P600 effects (centro-parietal distributed positivities which reveal a maximum at approximately 600 ms after the presentation of the critical stimulus) (Bornkessel-Schlesewsky and Schlesewsky, 2009 for overview). Note however, that this description of ERP components displays the classical interpretation of the language-related ERPs but in certain circumstances particular ERP components may also occur in other contexts with which they are not associated in the "classical" functional interpretation. Thus, there is no one-to-one mapping of ERP components to specific functional interpretations. For example, the P600 may also occur in particular semantic violations (e.g. Kolk et al., 2003; Van Herten et al., 2005, 2006) and the N400 is also observed for grammatical reanalysis processes (e.g. Bornkessel et al., 2004; Haupt et al., 2008; Roehm et al., 2007; for an overview see Bornkessel-Schlesewsky and Schlesewsky, 2009).

N400 and P600 effects have been first formulated on the spoken language materials; however, similar effects have been elicited in some sign language research (Kutas et al., 1987 [American Sign

Table 1

Examples of the two experimental conditions. Agreeing verbs were presented in SOV and OSV orders. Signs are glossed with capital letters; IX = index sign; subscripts indicate reference points in signing space.

SOV	OSV
GIRL IX_{3a} GIRL IX_{3b} $_{3a}HELP_{3b}$ *The girl (left) helps the girl (right)*	GIRL IX_{3a} GIRL IX_{3b} $_{3b}HELP_{3a}$ *The girl (right) helps the girl (left)*

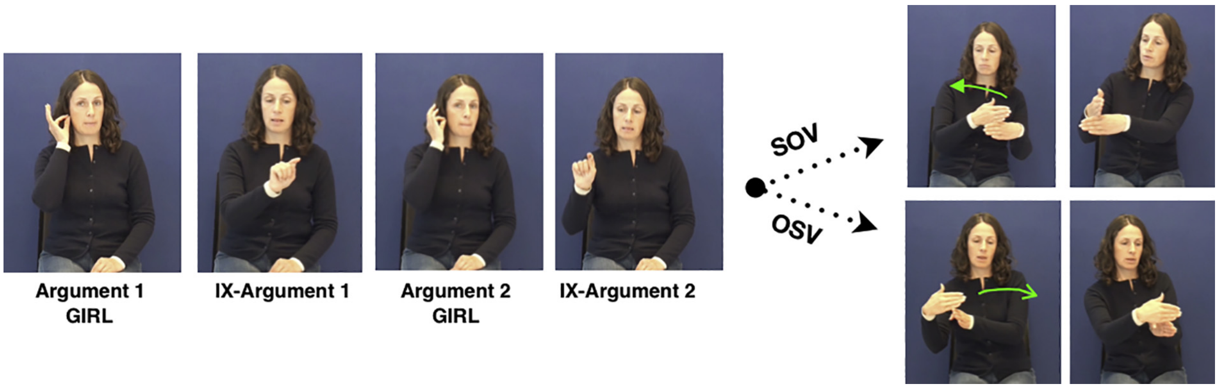

Fig. 1. Illustration of the two experimental conditions: In both constructions (SOV & OSV) the argument NPs (in this case GIRL) were signed in the same order and were referenced at the same points in space; i.e. the first argument was always referenced at the left side of the signer. The path movement of the sentence-final critical sign (agreeing verb HELP) unambiguously marks the argument structure.

Language, ASL; static image stimuli]; Neville et al., 1997 [ASL; static image stimuli], Capek et al., 2009 [ASL], Hosemann et al., 2013 [German Sign Language, DGS], Hosemann, 2015 [DGS], Hänel-Faulhaber et al., 2014 [DGS]). For instance, Capek et al. (2009) investigated the processing of semantic anomalies as well as verb agreement violations by Deaf signers in ASL. As has been revealed for spoken/written languages these two types of violations (semantic vs. (morpho-)syntactic) lead to different ERP patterns suggesting that different processing mechanisms are involved in the processing of semantic compared to (morpho-)syntactic processing. In particular, whereas the semantic violation evoked an N400 effect, the verb agreement violation led to a biphasic ERP pattern consisting of a left anterior negativity (LAN) followed by a P600 effect. Similar to Capek et al. (2009), Hänel-Faulhaber et al. (2014) investigated the processing of semantic and morpho-syntactic violations in DGS. Thereby, Hänel-Faulhaber et al. (2014) presented semantic as well as morpho-syntactic (verb agreement violations) to Deaf signers and observed a similar pattern as observed by Capek et al. (2009), namely an N400 effect for the semantic violation and a biphasic LAN-followed by a P600 effect for the verb agreement violation (but see also Hosemann (2015) for an ERP study investigating verb agreement violations in DGS revealing different results). These findings suggest that there are similar processing correlates in signed and spoken languages. Thus we hypothesized that ÖGS should also show a subject preference to support the claim that subject preference represents a modality-independent ambiguity resolution processing strategy. Under the assumption that sign languages (and therefore also ÖGS) do not have any form of case marking on the arguments indicating their syntactic function, we hypothesized an effect for OSV compared to SOV sentences in the disambiguating area, i.e. at the time point when the agreement information is provided by the disambiguating verb by path movement and/or facing.

2. Results

Of 25 tested participants, 20 were included in the final analysis. Four were excluded due to artifacts (<60% of critical trials remaining after artifact correction). One participant was excluded due to behavioral noncompliance. Only significant effects ($p \leq 0.05$) are reported.

2.1. Behavioral data

The behavioral data revealed that all conditions were rated as linguistically acceptable (mean ratings for both conditions at least 5.89 on a scale from 1 to 7). Table 2 provides an overview of the behavioral results of the acceptability ratings and reaction times (in ms).

Table 2
Mean ratings and mean reaction times for the two experimental conditions. Standard deviation (*sd*) is presented in parentheses.

Condition	Mean acceptability rating (*sd*)	Mean reaction time in ms (*sd*)
SOV	6.10 (0.90)	880.06 (459.81)
OSV	5.89 (1.07)	886.40 (442.82)

The ANOVA for acceptability ratings revealed a significant main effect of ORDER for the by-item analysis [F_{Item} (1, 39) = 8.99; $p < 0.01$], but not for by-subject analysis [F_{subj} (1, 19) = 1.17; $p = 0.29$]. Analysis of reaction time data did not show any significant effects.

With respect to the filler material, all of the ÖGS structures were rated as relatively good (all conditions ranging between a mean acceptability rating of 5.67–6.16 on a scale from 1 to 7). The videos presented in time-reversed manner were rated as bad (mean acceptability rating: *mean* = 1.70; *sd* = 0.83).

2.2. ERP data

2.2.1. Trigger: Handshape

With respect to Trigger "Handshape", visual inspection did not reveal any significant effects. This was confirmed by a statistical analysis of consecutive 50 ms time windows.

2.2.2. Trigger: Transition

With respect to Trigger "Transition", visual inspection revealed a more pronounced negativity for OSV compared to SOV sentences in the 200–400 ms time window (Mean amplitude values in μV and standard deviations per condition: SOV: $M = 1.34$; $sd = 1.99$; OSV: $M = 0.28$; $sd = 1.71$ (Fig. 2). Within the 200 to 400 ms time window, statistical analysis revealed a significant main effect of ORDER (more negative for OSV compared to SOV) [$F(1, 19) = 8.29$, $p < 0.01$, $\eta_p^2 = 0.30$].

2.2.3. Analysis without late learners

2.2.3.1. Trigger: Transition. With respect to Trigger "Transition", visual inspection revealed a more pronounced negativity for OSV compared to SOV sentences in the 200 to 400 ms time window (Mean amplitude values in μV and standard deviations per condition: SOV: $M = 1.23$; $sd = 1.94$; OSV: $M = 0.04$; $sd = 1.75$). Within the 200 to 400 ms time window, statistical analysis revealed a significant main effect of ORDER (more negative for OSV compared to SOV) [$F(1, 14) = 9.34$, $p < 0.01$, $\eta_p^2 = 0.40$].

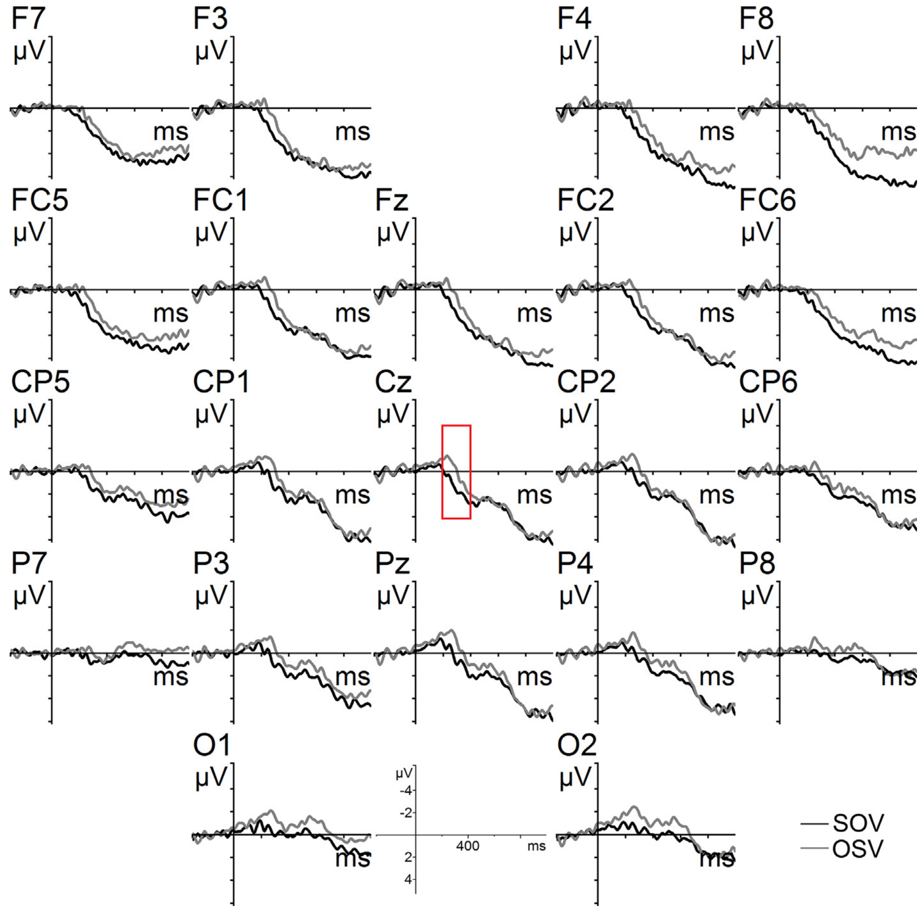

Fig. 2. Comparison of conditions SOV vs. OSV for Trigger "Transition". The vertical line represents the time point when the transitional movement towards the disambiguating verb was visible. Negativity is plotted upwards. The red square marks the time window in which the effect of ORDER became significant (200–400 ms time window).

3. Discussion

The present study aimed to investigate how word order variations in ÖGS are processed by Deaf signers. Data analysis revealed a widely distributed negativity for OSV compared to SOV structures which we interpret as indicating the subject preference. In line with Haupt et al. (2008) we interpret this effect as a reanalysis-related effect in the N400 family, reflecting the cost of syntactic reanalysis in OSV word order condition (i.e. subject preference). The observed negativity shows a similar broad scalp distribution as observed by Haupt et al. (2008; Experiment 2 in which subject/object ambiguities were tested with respect to isolated German sentences). Note that part of the effect (within the 300–400 ms time window at Trigger "Transition") overlaps with a period of time in the stimulus material for which a significant ORDER effect was revealed. The duration from the time point at which the verb handshape was established to the time point the verb movement starts was significantly shorter in OSV compared to SOV orders (average 30 ms shorter in OSV). However, since this duration difference is relatively small, it is unlikely that the observed effect is solely the product of a latency shift (see the methods section for an explanation of this difference in timing between conditions).

Interestingly, the ERP effect occurred earlier than expected, given traditional descriptions of sign onset as the beginning of path movement of the disambiguating sign (cf. Friedman, 1976). The reanalysis effect was observed for OSV in contrast to SOV orders with respect to the time point when the transitional movement towards the disambiguating verb of the index referencing the second argument was visible (i.e. preceding the production of the disambiguating path movement).

This transitional movement is a plausible cue for argument structure because it could indicate the direction of the subsequent path movement and thus serve as an earlier cue as to which argument is the subject. In fact, this transitional movement shows whether the index referencing the second argument moves back towards the position of the first-referenced argument (in SOV), or towards the handshape of the disambiguating sign (in OSV) (Fig. 3 in Methods).

However, additional non-manual cues preceding (i.e. during the referencing of the second argument) and/or accompanying the start of the transitional movement towards the disambiguating sign were observed in the stimuli and could also have resolved the ambiguity (possibly in addition to the transitional movement). In many OSV order stimuli the signer directed her body to the subject position (to the right) while referencing the second argument, which may have indicated the argument structure, i.e. where the movement of the verb sign would start. Also, the signer's face/chin was often directed towards the object position (to the left), i.e. the direction the disambiguating verb would move towards; the same direction to which the signer directs her eye gaze during the production of the target verb. In contrast, in SOV orders, a slight shoulder shift to the argument referenced second (the object), rather than a body shift, was often observed during referencing the second argument. Thereby, the body was positioned straighter (toward the camera) and the face/chin was often directed towards the object position (to the right in SOV). In some SOV orders, however, the body shift towards the subject position (to the left in SOV;

observable in the majority of the sentences during verb production as described in Section 4.2.) was sometimes already visible during referencing of the second argument (i.e. whereby the body was moving from a slightly right/central towards central/left position). A post hoc video analysis revealed that at least one of the described non-manual markings was present in all of the videos preceding and/or accompanying the start of the transitional movement, in the stimuli with both SOV and OSV orders.

The assumption that non-manuals may indicate grammatical functions is not new. For example, grammatical functions of body leans/body shifts have been reported for ASL and NGT (Sign Language of the Netherlands). Body leans can indicate contrastive meaning at the lexical, semantic, and pragmatic levels (Wilbur and Patschke, 1998 for ASL; Van der Kooij et al., 2006 for NGT). In addition, forward leans are used prosodically for marking information focus. While ASL makes use of backward/forward body leans as well as left/right body shifts, in NGT only left/right body shifts are used for contrastive focus marking (Van der Kooij et al., 2006). Body shifts may be used to reference discourse referents in signing space and for role-shift constructions (Lillo-Martin, 1995). Non-manuals as syntactic agreement markers have been described for ASL (Bahan, 1996; Neidle et al., 2000). According to Bahan (1996), in ASL transitive clauses, head tilt and sometimes body shift toward the subject can mark subject agreement and eye gaze marks object agreement independent of verb type. Further, body lean forward towards the object position can be another object agreement marker co-occurring with eye gaze towards the object, but can also mark object agreement on its own (Bahan, 1996). Crucially, it has been proposed that both head tilt towards the subject position and eye gaze towards the object position reach their target position before the onset of the verb sign movement and accompany the articulation of the verb movement and the direct object. One aspect of this proposed non-manual agreement marking – eye gaze – was tested empirically in an eye tracking study. Thompson et al. (2006) investigated whether eye gaze marks object agreement in ASL, showing that Neidle et al.'s observation holds only for agreeing verbs: with agreeing verbs, eye gaze always marks the lowest ranking argument (direct object in transitives and indirect object in ditransitives), but not in structures with plain verbs. In particular, for agreeing verbs object marking by eye gaze was observed to a very high degree (with regular agreeing verbs 98.4%). They further confirmed that eye gaze towards the object starts about 160 ms before the onset of the verb sign and may accompany objects which appear before or after the verb. In line with Neidle et al., Thompson et al. interpreted eye gaze as a marker for syntactic agreement. However, they analyzed the manual (movement/facing) and non-manual (eye gaze) components as two parts of one agreement morpheme. In contrast, Neidle et al. had proposed that eye gaze was an independent marker that should show up with plain verbs (those lacking manual agreement). It is plausible to assume that ÖGS might also have a form of non-manual agreement marking like ASL, which might indicate the argument structure before the disambiguating verb sign is established and possibly even before the manual transitional movement towards that verb sign starts.[3]

Because in sign languages many pieces of (manual and non-manual) information are presented in parallel, it cannot be determined exactly which visual cue(s) led to disambiguation (manual transitional movement or non-manual markings preceding/accompanying transitional movement). Thus, there is possibly not ONE visual cue which may lead to disambiguation in ÖGS, and that this may vary from sentence to sentence. It is highly plausible that combinations of (non-)manual markings may represent salient cues for disambiguation and in fact many of the articulators used for sign language production are not independent of each other anyway. Therefore, it is difficult to disentangle THE cue leading to disambiguation. This "trigger/effect assignment problem" is further complicated by the fact that it is not clear when a sign in a sentence (and even in isolation) starts, given that every movement is visible and it is not known at every given point in time whether a movement is (potentially) linguistically meaningful. Therefore, additional studies on the processing of sign languages are needed to get a clearer picture about the time course of sign language processing. In any case, the theoretical question of what constitutes the sign onset in a signed sentence and the presence of simultaneity of (non-)manual information in sign languages will always complicate the exact determination of cues with respect to certain ERP effects.

The observed relatively early time point of disambiguation in the ERP data is in line with the behavioral data (Krebs et al., submitted). A behavioral gating study showed that the signers are able to disambiguate syntactic structures before the path movement of the disambiguating element is visible, possibly based on inferences about the transitional movement to the point of articulation and handshape of it.

In spoken language, predictive processing has been attested for both auditory and visual input (i.e. reading), although ERPs that are observed in response to predictive processing depend on the level of linguistic information that is being predicted. For example, N400 has been observed as a result of prediction violations at the lexical level (Boudewyn et al., 2015); mismatch negativity (MMN) was reported as a result of violation of phonological predictions (Ylinen et al., 2016), and N1-P2 biphasic component has been observed as a result of violated expectations at the semantics-syntax interface (Malaia and Newman, 2015a). In sign language research, transitional movements have been clearly shown to contribute early cues for predictive processing (Hosemann et al., 2013; Hosemann, 2015), both at the lexical and syntactic levels (Ten Holt et al., 2009; Jantunen, 2010).

Furthermore, this study emphasizes that presentation of natural signing videos, despite some stimuli messiness, is preferable to artificially manipulated videos or sequences of still images for fully understanding online sign language processing. From the standpoint of information theory, the sign language signal provides continuous input for predictive processing (Malaia et al., 2016). During online sign language processing, transitional movements provide continuous input for the predictive processing systems at multiple levels (phonological, lexical, and syntactic), which restricts the number of possible points of articulation, handshapes, and trajectories that are compatible with prior signs and syntactic structures. It is important to include transitional movement windows in ERP analysis (see also Hosemann et al., 2013; Hosemann, 2015), because otherwise, early predictive processing effects might be included in the baseline interval. As a result, baseline correction could create artifacts within the post-stimulus interval.

One of the limitations of the present study is the fact that the participant group was heterogeneous with respect to age of sign language acquisition and handedness. While age of acquisition is an important factor that can influence sign language processing (e.g. Mayberry et al., 2002, 2011; Boudreault and Mayberry, 2006; Pénicaud et al., 2013; Malaia and Wilbur, 2010a,b), the

[3] The pointing direction of the index referencing the second argument may provide an additional hint to the argument structure: In OSV the index referencing the second argument was often directed inwards, whereas in SOV it often pointed outwards. Thus, index direction may indicate whether the hand will move back to the subject position (pointing outwards in SOV) or will start its transitional movement towards the verb right from the final position of the index referencing the second argument (pointing inwards in OSV). A post hoc video analysis revealed that during the referencing of the second argument and/or when the index referencing the second argument has reached its final position in 77,5% of the SOV and 65% of the OSV orders the described pointing direction was present.

ERP effect observed in the present study was not driven by the inclusion of the five late learners. A post hoc analysis of the behavioral and ERP data excluding the five late learners did not reveal any different results in comparison to the analysis including the late learners.

In spoken language research, handedness has been shown to interact with language processing strategies, specifically with the utilization of episodic memory for syntactic reanalysis (Newman et al., 2014). For sign language, no comparable studies exist; however, functional connectivity analyses of signers and non-signers resting-state connectivity (Malaia et al., 2014) have shown that signers recruit right hemisphere significantly more than non-signers even in resting state, possibly due the lifelong environmental influence of the visuospatial nature of sign language. An ancillary post hoc analysis only with the 4 left-handed participants did not reveal any differences between the total participant pool and the left-handed subgroup.

The observation of a reanalysis effect for OSV in contrast to SOV orders in ÖGS supports the assumption that the subject preference reflects a modality-independent processing strategy for languages with SO word order. The effect of visual modality on reanalysis due to subject preference was observed early (prior to onset of path movement in the disambiguating sign), and was marked by the widely distributed negativity. We propose that in the visual modality, syntactic reanalysis is triggered by early visual cues, such as the transitional movement of the hand towards the verb onset position, and/or specific non-manual cues preceding/accompanying the transitional movement towards the verb onset position. The status of these cues needs to be carefully considered in investigating the processing of natural sign language.

4. Materials and methods

4.1. Participants

20 participants (9 females) were included in the final analysis, with a mean age of 39.37 years (*sd* = 10.19; *range* = 28 to 58 years). All participants were born Deaf or lost their hearing early in life. Three have Deaf parents, the others 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. Fifteen participants are deaf from birth, three of them lost their hearing between 0 and 3 years, one between 3 and 4 and one between 4 and 7 years. The two participants who lost their hearing between 3 and 4 and 4–7 years respectively belong to the group of late ÖGS learners. All of the participants who took part in the study use ÖGS as their first language in daily life, and are members of the Deaf community. Language proficiency of all participants was confirmed by a professional ÖGS interpreter during the informed consent procedure. Participants came from different areas of Austria (Salzburg, Vienna, Upper Austria, Lower Austria, Styria). Fifteen were right-handed, four 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 which may impact cognitive ability. The participants received 30€ per session.

4.2. Materials and design

A 1×2 design with two-level factor ORDER involving SOV and OSV orders was used. 40 agreeing verbs were presented in each condition (80 critical sentences), with 200 fillers to distract from strategic processing (total 280 sentences). Filler sentences included different sentence structures: a) classifier constructions expressing spatial relations between arguments varying in word order (n = 80); b) ÖGS videos presented in time-reversed manner (n = 40) created from one of the critical conditions (OSV) to ensure reliability of participant ratings (to be sure that the participants understood the task); and c) a set comparable to the critical sentences (same SOV and OSV items) presented with non-manual topic marking on the sentence-initial argument (n = 80); this topic construction functioned as fillers for the experiment reported in this paper, but were included because the current critical sentences were also part of a larger experiment (Table 3).

Table 3
Summary of filler items included in the study.

Type of filler item	Number of items
Classifier constructions in ÖGS	80
Time-reversed videos (synthetically modified signing)	40
ÖGS sentences with non-manual topic markings	80

In the vast majority of stimuli, similar non-manual markings during production of the verb sign were observed. The signer's body was shifted towards the subject position and her chest, face and eye gaze were directed towards the object position. Almost half of the verbs were one-handed, the other two-handed (19 two-handed verbs; 21 one-handed verbs).

The sentence contexts used involved non-compound, relatively frequent signs (the arguments were MAN, WOMAN, GIRL and BOY). To avoid any semantic biases, we used the same arguments within one sentence (e.g. The man asks the man). The argument referencing in the sentences was kept constant within conditions in that sentence-initial arguments were always referenced at the signer's left side (see the Appendix for a list of the critical stimulus material). All material was 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.

4.3. Technical issues for studies using natural signing in video format

Unlike print stimuli, where no stimulus movement is involved, or acoustic stimuli, where synthetic speech can be used to control details that are otherwise less controlled in natural speech, signed stimuli involves movement in the stimulus itself. In most prior studies, attempts to control for this used sequences of still frame images taken from videos (e.g. Kutas et al., 1987; Neville et al., 1997), and only recently has actual video of natural signing been used as stimuli (e.g. Capek et al., 2009; Hosemann et al., 2013; Hosemann, 2015; Hänel-Faulhaber et al., 2014). To understand how this affects the data analysis, we need to review measures that are taken to provide confidence in the final results. Here we provide an overview of how the stimuli are checked for dynamic effects, such as durations and timing of onsets.

4.3.1. Checking the stimuli for dynamic effects

To check whether there were any systematic differences in timing in the stimuli, analyses of variance comparing specific time points within the structures and the durations between those time points were calculated (Table 4). ANOVAs involved the factor ORDER (levels SOV and OSV). In the following only significant effects ($p \leq 0.05$) are reported.

Comparison of time points did not reveal any significant differences. Comparison of durations between time points revealed significant differences for INT 8 (handshape to verb movement starts)

Table 4
Time points and intervals compared. TP = time point; INT = interval; IX = index; NP = noun phrase.

Onset Movement	Onset NP1	Offset IX-NP1	Onset NP2	Offset IX-NP2	Transition	Obvious transition	Handshape	Verb movement starts	Verb offset
TP 1	TP 2	TP 3	TP 4	TP 5	TP 6	TP 7	TP 8	TP 9	TP 10
INT 1	INT 2	INT 3	INT 4	INT 5	INT 6	INT 7	INT8	INT 9	

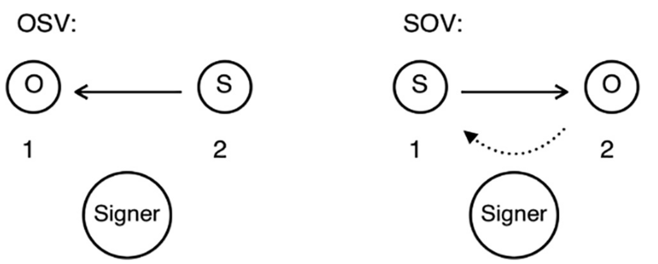

Fig. 3. Schematic of extra movement required in SOV (right picture, dotted line) compared to OSV (left picture). In both, the first argument is referenced on signer's left, second on her right (numbers). In both, argument structure shown by the disambiguating sign is expressed by path movement from subject (S) to object (O) (continuous arrows). In OSV (left) this is produced from argument referenced second (S) to argument referenced first (O). In SOV (right), prior to producing movement from S to O, the signer first must move from end position of reference to second argument (O) back to first argument (S) (dotted arrow).

and INT 9 (verb movement starts to verb offset). For INT 8 a significant main effect of ORDER [$F(1, 39) = 2.06$; $p < 0.05$] was observed [mean duration: SOV: 0.22 (0.10), OSV: 0.19 (0.09)].[4] Thus, the duration from the time point the verb handshape was established to the time point the verb movement starts was significantly shorter in OSV compared to SOV orders (on average 30 ms shorter in OSV). This shorter INT 8 in OSV can be explained by the fact that in OSV the dominant hand articulating the disambiguating verb immediately starts producing the verb movement from the reference locus associated with the second argument as soon as the target handshape has been established (it does not have to move back to where the first argument was located). In SOV, however, the dominant hand referencing the second argument has to move back to the subject position before the verb movement from subject to object position can start (Fig. 3). This additional trajectory movement back to the position associated with the first argument may have led to longer transitional movement in SOV.

For INT 9 a significant main effect of ORDER [$F(1, 39) = -2.20$; $p < 0.05$] was revealed [mean duration: SOV: 0.83 (0.18), OSV: 0.87 (0.19)]. Thus, duration from the time point the verb movement starts to the offset of the verb was significantly shorter in SOV compared to OSV (on average 40 ms shorter in SOV). Possibly this effect reflects some kind of compensation; given that the transition from the time point the verb handshape was established to the time point the verb movement starts is longer in SOV [INT8], the following duration from onset of the verb movement to the offset of the verb may have been shortened in SOV as a prosodic adjustment.

Thus, word order caused a slight latency shift between conditions: transition from the time point the verb handshape was established to the onset of verb movement lasted longer in SOV, but this difference was then compensated by shortening the duration from the verb movement onset to the offset of the verb in SOV. These differences in timing must be taken into account when interpreting ERP effects.

4.4. Procedure

Material was presented in 14 blocks, each with 20 sentences. Every trial started with presentation of a fixation cross to get the attention of the participants. The fixation cross, on the screen for 2000 ms, was followed by an empty black screen for 200 ms. Then a stimulus sentence (one video) was presented in the middle of the screen. Each trial ended with a rating task, indicated by a green question mark for 3000 ms after each stimulus. Participants had to rate the videos on a scale from one to seven as to whether the stimulus was good ÖGS or not (1 stood for 'that is not ÖGS'; 7 stood for 'that is good ÖGS'). Ratings were given by button press on a keyboard. Instructions were given by an ÖGS video signed by one of the authors. Prior to the actual experiment, a training block was presented to familiarize subjects with task requirements and permit them to ask questions in case anything was unclear. The duration of breaks after each block was determined by the subjects themselves. Subjects were instructed to avoid eye movements and other motions during the presentation of the video material and to view the sentences with attention.

4.5. EEG recording

The EEG was recorded from twenty-six 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 means of 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 bone and offline re-referenced against the averaged electrodes at the left and right mastoid. The AFz electrode functioned as the ground electrode. The EEG signal was recorded with a sampling rate of

[4] Mean durations are given in seconds; standard deviations are presented in parentheses.

500 Hz. For amplifying the EEG signal we used a Brain Products amplifier (high pass: 0.01 Hz). In addition, a notch filter of 50 Hz was used. The electrode impedances were kept below 5 kΩ. Offline, the signal was filtered with a bandpass filter (Butterworth Zero Phase Filters; high pass: 0.1 Hz, 48 dB/Oct; low pass: 20 Hz, 48 dB/Oct).

4.6. Data analysis

4.6.1. Behavioral data

An analysis of variance was calculated for mean acceptability ratings and mean reaction times per subject and per item. Absent or late responses were not considered. The statistical analysis was carried out hierarchically, that is, only significant interactions ($p \leq 0.05$) were resolved.

4.6.2. ERP data

Statistical evaluation of the ERP data was carried out by comparison of the mean amplitude of the ERPs within the time window (time windows were determined by descriptive analysis), per condition and per subject in seven regions of interest (ROIs). The factor ROI involved the levels 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; posterior right = P8, P4, O2; and midline = Fz, Cz and Pz (Fig. 4). The signal was corrected for ocular artifacts by the Gratton and Coles method (a method for off-line removal of ocular artifacts; Gratton et al., 1983) and screened for artifacts (minimal/maximal amplitude at −75/+75 μV). Data was baseline-corrected to −300 to 0. For each condition not more than 21% of the trials were excluded. The percentage of trials remaining after artifact rejection/correction per condition and per Trigger are presented in Table 5. Participants were excluded from analysis if <60% of the critical trials were left after artifact correction. All items were considered for ERP analysis. Statistical analysis was carried out in a hierarchical manner, i.e. only significant interactions ($p \leq 0.05$) were included in step-down analysis. For statistical analysis of the ERP data an analysis of variance (ANOVA) was computed including the factor of condition ORDER (SOV vs. OSV) and ROI. To correct for violations of sphericity, the Greenhouse-Geisser (1959) correction was applied to repeated measures with greater than one degree of freedom. Only significant ERP effects ($p \leq 0.05$) will be reported. Time windows were determined by visual inspection.

4.6.2.1. Trigger marking. In line with previous ERP studies (Capek et al., 2009) we defined stimulus onset and thus measured ERPs with respect to the time point when the verb handshape was established (Trigger "Handshape"). For signs with internal movement (i.e. handshape change), Trigger "Handshape" constituted the time point when the initial handshape was visible. For example, for the sign ÜBERFALLEN ("to attack someone") which starts with SCH-handshape and ends with S-handshape, Trigger "Handshape" was defined when the initial SCH-handshape was established (see Fig. 5). Additionally, in sentences with two-handed verb signs, Trigger "Handshape" was determined when both hands showed the target handshape. In addition, it has been shown that transitional movement trajectories between signs within a signed sentence, which are always visible during sign language comprehension, are relevant to sign language processing (Wilbur, 1990; Ten Holt et al., 2009; Jantunen, 2010; Hosemann et al., 2013; Hosemann, 2015; Wilbur and Malaia, 2008; Malaia et al., 2008, 2012b; McDonald et al., 2016; Malaia, 2014; for discussion see Krebs et al., submitted). For instance, it has been shown that transitional movement trajectories can take over properties typical for lexical movements to indicate stress marking in ASL (e.g. Wilbur, 1990), transitions provide a considerable amount of information with regard to sign recognition at both the sign and sentence-level (Ten Holt et al., 2009; Jantunen, 2010) and transitions have been claimed to present important information during predictive processing (Hosemann et al., 2013; Hosemann, 2015). Therefore, we also measured ERPs with respect to the time point when the transitional trajectory towards the disambiguating verb was visible (Trigger "Transition").

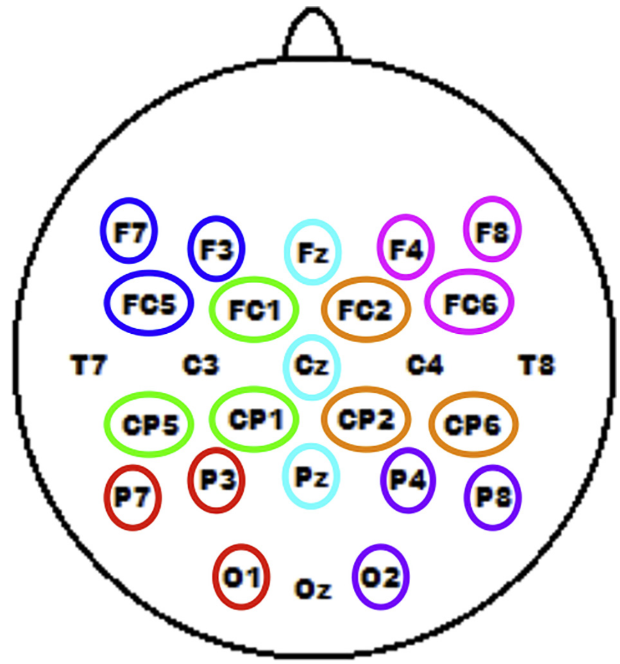

Fig. 4. Illustration of the scalp distribution of electrodes including marked ROIs. The factor ROI involved the levels anterior left = F7, F3, FC5 (blue); anterior right = F8, F4, FC6 (magenta); central left = FC1, CP5, CP1 (green); central right = FC2, CP6, CP2 (orange); posterior left = P7, P3, O1 (red); posterior right = P8, P4, O2 (violet); and midline = Fz, Cz and Pz (turquoise).

Table 5
Remaining trials after artifact correction/rejection per condition and per trigger marker.

	SOV	OSV
Trigger: transition	88%	82.5%
Trigger: handshape	85.5%	79%

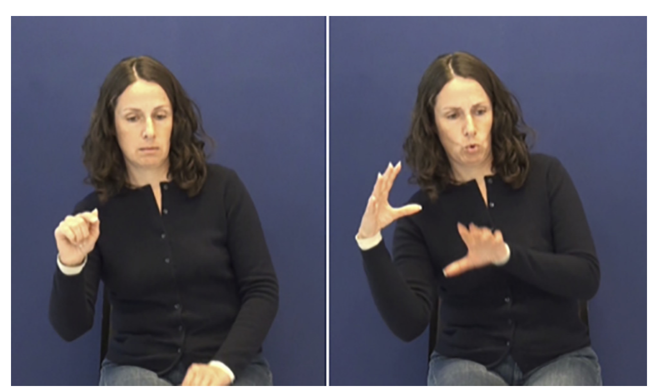

Fig. 5. Illustration of the two trigger markers, i.e. the time points at which ERPs were measured. On the left side the trigger "Transition" and on the right side the trigger "Handshape" are displayed; shown for the two-handed verb sign ÜBERFALLEN "to attack someone" which has an internal movement. Thus, Trigger "Handshape" was determined when both hands showed the initial handshape.

Acknowledgements

We want to thank all Deaf informants taking part in the present study. Special thanks to Waltraud Unterasinger for signing the stimulus material.

Funding

Preparation of the manuscript was funded by grant #1734938 from the U.S. National Science Foundation to RBW and EM, and European Union Marie S. Curie COFUND Fellowship Programme (FCFP) award to EM.

Appendix 1

List of stimulus material

Notation conventions: Signs are glossed with capital letters; IX = manual index sign; Subscripts indicate reference points within signing space

---

1.
A) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3a}$HIT$_{3b}$ (SOV)
The man (left) hits the other man (right)
B) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3b}$HIT$_{3a}$ (OSV)
The man (right) hits the other man (left)

2.
A) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3a}$CONTROL$_{3b}$ (SOV)
The man (left) controls the other man (right)
B) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3b}$CONTROL$_{3a}$ (OSV)
The man (right) controls the other man (left)

3.
A) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3a}$LOOK-FOR$_{3b}$ (SOV)
The man (left) looks for the other man (right)
B) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3b}$LOOK-FOR$_{3a}$ (OSV)
The man (right) looks for the other man (left)

4.
A) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3a}$DOMINEER-OVER$_{3b}$ (SOV)
The man (left) domineers over the other man (right)
B) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3b}$DOMINEER-OVER$_{3a}$ (OSV)
The man (right) domineers over the other man (left)

5.
A) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3a}$SUPPORT$_{3b}$ (SOV)
The man (left) supports the other man (right)
B) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3b}$SUPPORT$_{3a}$ (OSV)
The man (right) supports the other man (left)

6.
A) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3a}$THREAT$_{3b}$ (SOV)
The man (left) threats the other man (right)
B) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3b}$THREAT$_{3a}$ (OSV)
The man (right) threats the other man (left)

7.
A) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3a}$KILL$_{3b}$ (SOV)
The man (left) kills the other man (right)
B) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3b}$KILL$_{3a}$ (OSV)
The man (right) kills the other man (left)

8.
A) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3a}$ATTACK$_{3b}$ (SOV)
The man (left) attacks the other man (right)
B) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3b}$ATTACK$_{3a}$ (OSV)
The man (right) attacks the other man (left)

9.
A) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3a}$COMPLIMENT$_{3b}$ (SOV)
The man (left) compliments the other man (right)
B) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3b}$COMPLIMENT$_{3a}$ (OSV)
The man (right) compliments the other man (left)

10.
A) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3a}$CRITICIZE$_{3b}$ (SOV)
The man (left) criticizes the other man (right)
B) MAN IX$_{3a}$ MAN IX$_{3b}$ $_{3b}$CRITICIZE$_{3a}$ (OSV)
The man (right) criticizes the other man (left)

11.
A) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3a}$EXAMINE$_{3b}$ (SOV)
The woman (left) examines the other woman (right)
B) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3b}$EXAMINE$_{3a}$ (OSV)
The woman (right) examines the other woman (left)

12.
A) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3a}$CONGRATULATE$_{3b}$ (SOV)
The woman (left) congratulates the other woman (right)
B) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3b}$CONGRATULATE$_{3a}$ (OSV)
The woman (right) congratulates the other woman (left)

13.
A) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3a}$TEACH$_{3b}$ (SOV)
The woman (left) teaches the other woman (right)
B) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3b}$TEACH$_{3a}$ (OSV)
The woman (right) teaches the other woman (left)

14.
A) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3a}$CARE-FOR$_{3b}$ (SOV)
The woman (left) cares for the other WOMAN (right)
B) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3b}$CARE-FOR$_{3a}$ (OSV)
The woman (right) cares for the other woman (left)

15.
A) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3a}$INFORM$_{3b}$ (SOV)
The woman (left) informs the other woman (right)
B) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3b}$INFORM$_{3a}$ (OSV)
The WOMAN (right) informs the other woman (left)

16.
A) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3a}$RESPECT$_{3b}$ (SOV)
The woman (left) respects the other woman(right)
B) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3b}$RESPECT$_{3a}$ (OSV)
The woman (right) respects the other woman (left)

17.
A) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3a}$TRUST$_{3b}$ (SOV)
The woman (left) trusts the other woman (right)
B) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3b}$TRUST$_{3a}$ (OSV)
The woman (right) trusts the other woman (left)

18.
A) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3a}$GREET$_{3b}$ (SOV)
The woman (left) greets the other woman (right)
B) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3b}$GREET$_{3a}$ (OSV)
The woman (right) greets the other woman (left)

19.
A) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3a}$EYEBALL$_{3b}$ (SOV)
The woman (left) eyeballs the other woman (right)
B) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3b}$EYEBALL$_{3a}$ (OSV)
The woman (right) eyeballs the other woman (left)

20.
A) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3a}$ADORE$_{3b}$ (SOV)
The woman (left) adores the other woman (right)
B) WOMAN IX$_{3a}$ WOMAN IX$_{3b}$ $_{3b}$ADORE$_{3a}$ (OSV)
The woman (right) adores the other woman (left)

21.
A) GIRL IX$_{3a}$ GIRL IX$_{3b}$ $_{3a}$KISS$_{3b}$ (SOV)
The girl (left) kisses the other girl (right)
B) GIRL IX$_{3a}$ GIRL IX$_{3b}$ $_{3b}$KISS$_{3a}$ (OSV)
The girl (right) kisses the other girl (left)

22.
A) GIRL IX_{3a} GIRL IX_{3b} $_{3a}$WAKE-UP$_{3b}$ (SOV)
The girl (left) wakes up the other girl (right)
B) GIRL IX_{3a} GIRL IX_{3b} $_{3b}$WAKE-UP$_{3a}$ (OSV)
The girl (right) wakes up the other girl (left)
23.
A) GIRL IX_{3a} GIRL IX_{3b} $_{3a}$HUG$_{3b}$ (SOV)
The girl (left) hugs the other girl (right)
B) GIRL IX_{3a} GIRL IX_{3b} $_{3b}$HUG$_{3a}$ (OSV)
The girl (right) hugs the other girl (left)
24.
A) GIRL IX_{3a} GIRL IX_{3b} $_{3a}$CONSOLE$_{3b}$ (SOV)
The girl (left) consoles the other girl (right)
B) GIRL IX_{3a} GIRL IX_{3b} $_{3b}$CONSOLE$_{3a}$ (OSV)
The girl (right) consoles the other girl (left)
25.
A) GIRL IX_{3a} GIRL IX_{3b} $_{3a}$OBSERVE$_{3b}$ (SOV)
The girl (left) observes the other girl (right)
B) GIRL IX_{3a} GIRL IX_{3b} $_{3b}$OBSERVE$_{3a}$ (OSV)
The girl (right) observes the other girl (left)
26.
A) GIRL IX_{3a} GIRL IX_{3b} $_{3a}$THANK$_{3b}$ (SOV)
The girl (left) thanks the other girl (right)
B) GIRL IX_{3a} GIRL IX_{3b} $_{3b}$THANK$_{3a}$ (OSV)
The girl (right) thanks the other girl (left)
27.
A) GIRL IX_{3a} GIRL IX_{3b} $_{3a}$ADDRESS$_{3b}$ (SOV)
The girl (left) addresses the other girl (right)
B) GIRL IX_{3a} GIRL IX_{3b} $_{3b}$ADDRESS$_{3a}$ (OSV)
The girl (right) addresses the other girl (left)
28.
A) GIRL IX_{3a} GIRL IX_{3b} $_{3a}$INFLUENCE$_{3b}$ (SOV)
The girl (left) influences the other girl (right)
B) GIRL IX_{3a} GIRL IX_{3b} $_{3b}$INFLUENCE$_{3a}$ (OSV)
The girl (right) influences the other girl (left)
29.
A) GIRL IX_{3a} GIRL IX_{3b} $_{3a}$HELP$_{3b}$ (SOV)
The girl (left) helps the other girl (right)
B) GIRL IX_{3a} GIRL IX_{3b} $_{3b}$HELP$_{3a}$ (OSV)
The girl (right) helps the other girl (left)
30.
A) GIRL IX_{3a} GIRL IX_{3b} $_{3a}$PROTECT$_{3b}$ (SOV)
The girl (left) protects the other girl (right)
B) GIRL IX_{3a} GIRL IX_{3b} $_{3b}$PROTECT$_{3a}$ (OSV)
The girl (right) protects the other girl (left)
31.
A) BOY IX_{3a} BOY IX_{3b} $_{3a}$ANNOY$_{3b}$ (SOV)
The boy (left) annoys the other boy (right)
B) BOY IX_{3a} BOY IX_{3b} $_{3b}$ANNOY$_{3a}$ (OSV)
The boy (right) annoys the other boy (left)
32.
A) BOY IX_{3a} BOY IX_{3b} $_{3a}$SCARE$_{3b}$ (SOV)
The boy (left) scares the other boy (right)
B) BOY IX_{3a} BOY IX_{3b} $_{3b}$SCARE$_{3a}$ (OSV)
The BOY (right) scares the other boy (left)
33.
A) BOY IX_{3a} BOY IX_{3b} $_{3a}$HATE$_{3b}$ (SOV)
The boy (left) hates the other boy (right)
B) BOY IX_{3a} BOY IX_{3b} $_{3b}$HATE$_{3a}$ (OSV)
The boy (right) hates the other boy (left)
34.
A) BOY IX_{3a} BOY IX_{3b} $_{3a}$RESPOND$_{3b}$ (SOV)
The boy (left) responds to the other boy (right)
B) BOY IX_{3a} BOY IX_{3b} $_{3b}$RESPOND$_{3a}$ (OSV)
The boy (right) responds to the other boy (left)
35.
A) BOY IX_{3a} BOY IX_{3b} $_{3a}$INFECT$_{3b}$ (SOV)
The boy (left) infects the other boy (right)
B) BOY IX_{3a} BOY IX_{3b} $_{3b}$INFECT$_{3a}$ (OSV)
The boy (right) infects the other boy (left)
36.
A) BOY IX_{3a} BOY IX_{3b} $_{3a}$CATCH$_{3b}$ (SOV)
The boy (left) catches the other boy (right)
B) BOY IX_{3a} BOY IX_{3b} $_{3b}$CATCH$_{3a}$ (OSV)
The boy (right) catches the other boy (left)
37.
A) BOY IX_{3a} BOY IX_{3b} $_{3a}$LOOK-AT$_{3b}$ (SOV)
The boy (left) looks at the other boy (right)
B) BOY IX_{3a} BOY IX_{3b} $_{3b}$LOOK-AT$_{3a}$ (OSV)
The boy (right) looks at the other boy (left)
38.
A) BOY IX_{3a} BOY IX_{3b} $_{3a}$ASK$_{3b}$ (SOV)
The boy (left) asks the other boy (right)
B) BOY IX_{3a} BOY IX_{3b} $_{3b}$ASK$_{3a}$ (OSV)
The boy (right) asks the other boy (left)
39.
A) BOY IX_{3a} BOY IX_{3b} $_{3a}$SCOLD$_{3b}$ (SOV)
The boy (left) scolds the other boy (right)
B) BOY IX_{3a} BOY IX_{3b} $_{3b}$SCOLD$_{3a}$ (OSV)
The boy (right) scolds the other boy (left)
40.
A) BOY IX_{3a} BOY IX_{3b} $_{3a}$VISIT$_{3b}$ (SOV)
The boy (left) visits the other boy (right)
B) BOY IX_{3a} BOY IX_{3b} $_{3b}$VISIT$_{3a}$ (OSV)
The boy (right) visits the other boy (left)

References

Aran, O., Burger, T., Caplier, A., Akarun, L., 2009. A belief-based sequential fusion approach for fusing manual and non-manual signs. Pattern Recogn. 42 (5), 812–822. https://doi.org/10.1016/j.patcog.2008.09.010.

Bader, M., Meng, M., 1999. Subject-object ambiguities in German embedded clauses: an across-the-board comparison. J. Psycholinguist. Res. 28, 121–143.

Bahan, B.J., 1996. Non-Manual Realization of Agreement in American Sign Language (Ph.D. thesis). Boston University.

Benitez-Quiroz, C.F., Gökgöz, K., Wilbur, R.B., Martínez, A.M., 2014. Discriminant features and temporal structure of nonmanuals in American Sign Language 101371/journal.pone.0086268 PLoSOne 9 (2). e86268.

Benitez-Quiroz, F., Wilbur, R.B., Martínez, A., 2016. The Not face: a grammaticalization of facial expressions of emotion. Cognition 150, 77–84. https://doi.org/10.1016/j.cognition.2016.02.004.

Bornkessel, I., McElree, B., Schlesewsky, M., Friederici, A.D., 2004. Multi-dimensional contributions to garden path strength: dissociating phrase structure from case marking. J. Mem. Lang. 51 (4), 495–522.

Bornkessel, I., Schlesewsky, M., 2006. The extended argument dependency model: a neurocognitive approach to sentence comprehension across languages. Psychol. Rev. 113 (4), 787–821.

Bornkessel-Schlesewsky, I., Choudhary, K.K., Witzlack-Makarevich, A., Bickel, B., 2008. Bridging the gap between processing preferences and typological distributions: initial evidence from the online comprehension of control constructions in Hindi. In: Malchukov, A., Richards, M. (Eds.), Scales (Linguistische Arbeitsberichte 86). University of Leipzig, Leipzig, pp. 397–436.

Bornkessel-Schlesewsky, I., Schlesewsky, M., 2009. Processing Syntax and Morphology. A Neurocognitive Perspective. Oxford University Press, Oxford.

Boudewyn, M.A., Long, D.L., Swaab, T.Y., 2015. Graded expectations: predictive processing and the adjustment of expectations during spoken language comprehension. Cog. Affect. Behav. Neurosci. 15 (3), 607–624. https://doi.org/10.3758/s13415-015-0340-0.

Boudreault, P., Mayberry, R.I., 2006. Grammatical processing in American Sign Language: age of first-language acquisition effects in relation to syntactic structure. Lang. Cogn. Process. 21 (5), 608–635. https://doi.org/10.1080/01690960500139363.

Boyes Braem, P., Fournier, M., Rickly, F., Corazza, S., Franchi, M., Volterra, V., 1990. A comparison of techniques for expressing semantic roles and locative relations in two different sign languages. In: Edmondson, W.H., Karlsson, F. (Eds.), SLR '87: Papers from the Fourth International Symposium on Sign Language Research. Signum, Hamburg, pp. 114–120.
Capek, C., Grossi, G., Newman, A.J., McBurney, S.L., Corina, D., Roeder, B., Neville, H.J., 2009. Brain systems mediating semantic and syntactic processing in deaf native signers: Biological invariance and modality specificity. Proc. Natl. Acad. Sci. U.S. A. (PNAS) 106 (21), 8784–8789.
Coerts, J., 1994. Constituent order in sign language of the Netherlands. In: Brennan, M., Turner, G.H. (Eds.), Word order issues in Sign Language: Working papers (presented at a workshop held in Durham 18-22 September 1991). International Sign Linguistics Association (ISLA), Durham, pp. 47–71.
Cooper, H., Holt, B., Bowden, R., 2011. Sign language recognition. In: Moeslund, T.B., Hilton, A., Krüger, V., Sigal, L. (Eds.), Visual Analysis of Humans. Springer, London, pp. 539–562.
Crocker, M.W., 1994. On the nature of the principle-based sentence processor. In: Clifton, C., Frazier, L., Rayner, K. (Eds.), Perspectives on Sentence Processing. Erlbaum, Hillsdale, pp. 245–266.
Demiral, Ş.B., Schlesewsky, M., Bornkessel-Schlesewsky, I., 2008. On the universality of language comprehension strategies: evidence from Turkish. Cognition 106 (1), 484–500.
Dixon, R.M.W., 1994. Ergativity. Cambridge University Press, Cambridge.
Emmorey, K., 2002. Language, Cognition, and the Brain. Insights from Sign Language Research. Lawrence Erlbaum Associates, Mahwah, New Jersey.
Erdocia, K., Laka, I., Mestres-Missé, A., Rodriguez-Fornells, A., 2009. Syntactic complexity and ambiguity resolution in a free word order language: Behavioral and electrophysiological evidences from Basque. Brain Lang. 109 (1), 1–17. https://doi.org/10.1016/j.bandl.2008.12.003.
Fischer, S., 1975. Influences on word order change in American Sign Language. In: Li, C.N. (Ed.), Word Order and Word Order Change. University of Austin Press, Austin, pp. 1–25.
Frazier, L., Fodor, J.D., 1978. The sausage machine: A new two-stage parsing model. Cognition 6 (4), 291–325.
Friedman, L.A., 1976. The manifestation of subject, object, and topic in the American Sign Language. In: Li, C.N. (Ed.), Subject and topic. Academic Press, New York, pp. 125–148.
Gibson, E., 1998. Linguistic complexity: Locality of syntactic dependencies. Cognition 68 (1), 1–76.
Gratton, G., Coles, M.G., Donchin, E., 1983. A new method for off- line removal of ocular artifact. Electroencephalogr. Clin. Neurophysiol. 55, 468–484. https://doi.org/10.1016/0013-4694(83)90135-9.
Greenhouse, S.W., Geisser, S., 1959. On methods in the analysis of profile data. Psychometrika 24 (2), 95–112.
Hänel-Faulhaber, B., Skotara, N., Kügow, M., Salden, U., Bottari, D., Röder, B., 2014. ERP correlates of German Sign Language processing in deaf native signers. BMC Neurosci. 15 (62), 1–11.
Haupt, F.S., Schlesewsky, M., Roehm, D., Friederici, A.D., Bornkessel-Schlesewsky, I., 2008. The status of subject-object reanalyses in the language comprehension architecture. J. Mem. Lang. 59 (1), 54–96.
Hosemann, J.A., 2015. The processing of German Sign Language sentences: Three event-related potential studies on phonological, morpho-syntactic, and semantic aspects (PhD. thesis). University of Göttingen.
Hosemann, J., Herrmann, A., Steinbach, M., Bornkessel-Schlesewsky, I., Schlesewsky, M., 2013. Lexical prediction via forward models: N400 evidence from German Sign Language. Neuropsychologia 51 (11), 2224–2237.
Jantunen T. (2010). On the role of transitions in signed language. Presentation at the "Theoretical Issues in Sign Language Research conference (TISLR)", Purdue.
Kimmelman, V., 2012. Word order in Russian Sign Language. Sign Language Studies 12, 414–445. https://doi.org/10.1353/sls.2012.0001.
Kolk, H.H., Chwilla, D.J., Van Herten, M., Oor, P.J., 2003. Structure and limited capacity in verbal working memory: a study with event-related potentials. Brain Lang. 85 (1), 1–36.
Krebs J., Wilbur R.B., Alday P.M. & Roehm D. (submitted). The impact of transitional movements and non-manual markings on the disambiguation of locally ambiguous argument structures in Austrian Sign Language (ÖGS).
Kretzschmar, F., Bornkessel-Schlesewsky, I., Staub, A., Roehm, D., Schlesewsky, M., 2012. Prominence facilitates ambiguity resolution: On the interaction between referentiality, thematic roles and word order in syntactic reanalysis (Studies in theoretical psycholinguistics, Vol. 40). In: Lamers, M.J.A., de Swart, P. (Eds.), Case, word order, and prominence. Interacting cues in language production and comprehension. Springer, Dordrecht, pp. 239–271.
Kutas, M., Neville, H.J., Holcomb, P.J., 1987. A preliminary comparison of the N400 response to semantic anomalies during reading, listening and signing. In: Ellingson, R.J., Murray, N.M.F., Halliday, A.M. (Eds.), Electroencephalography and Clinical Neurophysiology Supplement 39, The London Symposia. Elsevier, Amsterdam, pp. 325–330.
Li, C.N., Thompson, S.A., 1976. Subject and topic: A new typology of language. In: Li, C.N. (Ed.), Subject and topic. University of Texas Press, Austin, pp. 457–461.
Liddell, S., 2003. Grammar, gesture and meaning in American Sign Language. Cambridge University Press, Cambridge.
Lillo-Martin, D., 1986. Two kinds of null arguments in American Sign Language. Nat. Lang. Linguist. Theory 4 (4), 415–444.
Lillo-Martin, D., 1995. The 'Point of View' predicate in American Sign Language. In: Emmorey, K., Reilly, J. (Eds.), Language, gesture, and space. Lawrence Erlbaum Associates, Hillsdale, NJ, pp. 155–170.
Lillo-Martin, D., Meier, R.P., 2011. On the linguistic status of 'agreement' in sign languages. Theoret. Lingu. 37, 95–141. https://doi.org/10.1515/thli.2011.009.
Malaia, E., 2014. It still isn't over: Event boundaries in language and perception. Lang. Linguist. Compass 8 (3), 89–98.
Malaia, E., Newman, S., 2015a. Neural bases of syntax–semantics interface processing. Cognit. Neurodyn. 9 (3), 317–329.
Malaia, E., Newman, S., 2015b. Neural bases of event knowledge and syntax integration in comprehenion of complex sentences. Neurocase 21 (6), 753–766.
Malaia, E., Wilbur, R.B., 2010a. Early acquisition of sign language: what neuroimaging data tell us. Sign Lang. Lingu. 13 (2), 183–199. https://doi.org/10.1075/sll.13.2.03mal.
Malaia, E., Wilbur, R.B., 2010b. Sign languages: Contribution to neurolinguistics from cross-modal research. Lingua 120 (12), 2704–2706.
Malaia, E., Borneman, J., Wilbur, R.B., 2008. Analysis of ASL motion capture data towards identification of verb type. In: Proceedings of the 2008 Conference on Semantics in Text Processing. Association for Computational Linguistics, pp. 155–164.
Malaia, E., Wilbur, R.B., Weber-Fox, C., 2009. ERP evidence for telicity effects on syntactic processing in garden-path sentences. Brain Lang. 108, 145–158. https://doi.org/10.1016/j.bandl.2008.09.003.
Malaia, E., Wilbur, R.B., Weber-Fox, C., 2012a. Effects of verbal event structure on online thematic role assignment. J. Psycholinguist. Res. 41 (5), 323–345. https://doi.org/10.1007/s10936-011-9195-x.
Malaia, E., Ranaweera, R., Wilbur, R.B., Talavage, T.M., 2012b. Event segmentation in a visual language: Neural bases of processing American Sign Language predicates. Neuroimage 59 (4), 4094–4101.
Malaia, E., Talavage, T.M., Wilbur, R.B., 2014. Functional connectivity in task-negative network of the Deaf: effects of sign language experience. PeerJ 2, e446.
Malaia, E., Borneman, J.D., Wilbur, R.B., 2016. Assessment of information content in visual signal: analysis of optical flow fractal complexity. Vis. Cogn. 24 (3), 246–251. https://doi.org/10.1080/13506285.2016.1225142.
Mayberry, R.I., Lock, E., Kazmi, H., 2002. Development: Linguistic ability and early language exposure. Nature 417 (6884), 38. https://doi.org/10.1038/417038a.
Mayberry, R.I., Chen, J.K., Witcher, P., Klein, D., 2011. Age of acquisition effects on the functional organization of language in the adult brain. Brain Lang. 119 (1), 16–29. https://doi.org/10.1016/j.bandl.2011.05.007.
Milković, M., Bradarić-Jončić, S., Wilbur, R.B., 2006. Word order in Croatian Sign Language. Sign Lang. Lingu. 9, 169–206. https://doi.org/10.1075/sll.9.1-2.10mil.
McDonald, J., Wolfe, R., Wilbur, R.B., Moncrief, R., Malaia, E., Fujimoto, S., Stec, J., 2016. A new tool to facilitate prosodic analysis of motion capture data and a data-driven technique for the improvement of avatar motion. In: Proceedings of the 7th Workshop on the Representation and Processing of Sign Languages: Corpus Mining, 7. Language Resources and Evaluation Conference (LREC), pp. 2016, May–461.
Neidle, C., Kegl, J., MacLaughlin, D., Bahan, B., Lee, R.G., 2000. The syntax of American Sign Language: Functional categories and hierarchical structure. MIT Press, Cambridge.
Neville, H.J., Coffey, S.A., Lawson, D.S., Fischer, A., Emmorey, K., Bellugi, U., 1997. Neural systems mediating American Sign Language: Effects of sensory experience and age of acquisition. Brain Lang. 57, 285–308.
Newman, S., Malaia, E., Seo, R., Cheng, H., 2013. The effect of individual differences in working memory capacity on sentence comprehension: and fMRI study. Brain Topogr. 26 (3), 458–467.
Newman, S., Malaia, E., Seo, R., 2014. Does degree of handedness in a group of right-handed individuals affect language comprehension? Brain Cogn. 86, 98–103. https://doi.org/10.1016/j.bandc.2014.02.002.
Newport, E.L., 1990. Maturational constraints on language learning. Cog. Sci. 14 (1), 11–28. https://doi.org/10.1207/s15516709cog1401_2.
Oldfield, R.C., 1971. The assessment and analysis of handedness: The Edinburgh inventory. Neuropsychologia 9, 97–113.
Padden, C., 1983. Interaction of morphology and syntax in American Sign Language. PhD thesis, University of California, San Diego [published 1988, New York: Garland Press].
Parashar, A.S., 2003. Representation and interpretation of manual and non-manual information for automated American sign language recognition (PhD thesis). University of South Florida, Tampa.
Pénicaud, S., Klein, D., Zatorre, R.J., Chen, J.K., Witcher, P., Hyde, K., Mayberry, R.I., 2013. Structural brain changes linked to delayed first language acquisition in congenitally deaf individuals. Neuroimage 66, 42–49. https://doi.org/10.1016/j.neuroimage.2012.09.076.
Pfau, R., Quer, J., 2010. Nonmanuals: Their grammatical and prosodic roles. In: Brentari, D. (Ed.), Sign Languages (Cambridge Language Surveys). Cambridge University Press, Cambridge, pp. 381–402.
Pizzuto, E., Giuranna, E. Gambino, G., 1990. Manual and nonmanual morphoogy in Italian Sign Language: Grammatical constraints and discourse processes. Sign language research: Theoretical issues, pp. 83–102.
Roehm, D., Bornkessel-Schlesewsky, I., Rösler, F., Schlesewsky, M., 2007. To predict or not to predict: Influences of task and strategy on the processing of semantic relations. J. Cognit. Neurosci. 19 (8), 1259–1274. https://doi.org/10.1162/jocn.2007.19.8.1259.
Rösler, F., Pechmann, T., Streb, J., Röder, B., Hennighausen, E., 1998. Parsing of sentences in a language with varying word order: Word-by-word variations of processing demands are revealed by event-related brain potentials. J. Mem. Lang. 38 (2), 150–176. https://doi.org/10.1006/jmla.1997.2551.
Sandler, W., Lillo-Martin, D., 2006. Sign Languages and Linguistic Universals. Cambridge University Press, Cambridge.

Schlesewsky, M., Fanselow, G., Kliegl, R., Krems, J., 2000. The subject preference in the processing of locally ambiguous wh-questions in German. In: Hemforth, B., Konieczny, L. (Eds.), German Sentence Processing. Kluwer, Dordrecht, pp. 65–93.
Skant, A., Dotter, F., Bergmeister, E., Hilzensauer, M., Hobel, M., Krammer, K., Okorn, I., Orasche, C., Orter, R. Unterberger, N., 2002. Grammatik der Österreichischen Gebärdensprache. Veröffentlichungen des Forschungszentrums für Gebärdensprache und Hörgeschädigtenkommunikation der Universität Klagenfurt (Vol. 4).
Tamaoka, K., Sakai, H., Kawahara, J., Miyaoka, Y., Lim, H., Koizumi, M., 2005. Priority information used for the processing of Japanese sentences: Thematic roles, case particles or grammatical functions? J. Psycholinguist. Res. 34, 281–332. https://doi.org/10.1007/s10936-005-3641-6.
Ten Holt, G.A., Van Doorn, A.J., de Ridder, H., Reinders, M.J.T., Hendriks, E.A., 2009. Which fragments of a sign enable its recognition? Sign Lang. Stud. 9 (2), 211–239. https://doi.org/10.1353/sls.0.0012.
Thompson, R., Emmorey, K., Kluender, R., 2006. The relationship between eye gaze and verb agreement in American Sign Language: An eye-tracking study. Nat. Lang. Linguist. Theory 24 (2), 571–604.
Ueno, M., Kluender, R., 2003. Event-related brain indices of Japanese scrambling. Brain Lang. 86 (2), 243–271. https://doi.org/10.1016/S0093-934X(02)00543-6.
Van der Kooij, E., Crasborn, O., Emmerik, W., 2006. Explaining prosodic body leans in Sign Language of the Netherlands: Pragmatics required. J. Prag. 38 (10), 1598–1614.
Van Herten, M., Kolk, H.H., Chwilla, D.J., 2005. An ERP study of P600 effects elicited by semantic anomalies. Cogn. Brain Res. 22 (2), 241–255. https://doi.org/10.1016/j.cogbrainres.2004.09.002.
Van Herten, M., Chwilla, D.J., Kolk, H.H., 2006. When heuristics clash with parsing routines: ERP evidence for conflict monitoring in sentence perception. J. Cognit. Neurosci. 18 (7), 1181–1197. https://doi.org/10.1162/jocn.2006.18.7.1181.
Wang, L., Schlesewsky, M., Bickel, B., Bornkessel-Schlesewsky, I., 2009. Exploring the nature of the 'subject'-preference: Evidence from the online comprehension of simple sentences in Mandarin Chinese. Lang. Cogn/ Process. 24 (7–8), 1180–1226.
Weckerly, J., Kutas, M., 1999. An electrophysiological analysis of animacy effects in the processing of object relative sentences. Psychophysiology 36 (5), 559–570. https://doi.org/10.1111/1469-8986.3650559.
Wilbur, R.B., 1990. An experimental investigation of stressed sign production. Int. J. Sign Lingu. 1 (1), 41–59.
Wilbur, R.B., 2000. Phonological and prosodic layering of nonmanuals in American Sign Language. In: Lane, H., Emmorey, K. (Eds.), The Signs of Language Revisited: Festschrift for Ursula Bellugi and Edward Klima. Erlbaum, Hillsdale, pp. 213–241.
Wilbur, R.B., 2005. Evidence from ASL and ÖGS for asymmetries in UG. In: DiScuillo, A.M. (Ed.), UG and External Systems: Language, Brain and Computation. John Benjamins, Amsterdam, pp. 193–210.
Wilbur, R.B., 2011. Nonmanuals, semantic operators, domain marking, and the solution to two outstanding puzzles in ASL. Sign Lang. Lingu. 14, 148–178. https://doi.org/10.1075/sll.14.1.08wil.
Wilbur, R.B., 2013. The point of agreement: changing how we think about sign language, gesture, and agreement. Sign Langu. Lingu. 16 (2), 221–258.
Wilbur, R.B., Patschke, C., 1998. Body leans and marking contrast in ASL. J. Pragm. 30, 275–303.
Wilbur, R.B., Malaia, E., 2008. Contributions of sign language research to gesture understanding: What can multimodal computational systems learn from sign language research. Int. J. Semantic Comput. 2 (1), 5–19.
Xu, M., Raytchev, B., Sakaue, K., Hasegawa, O., Koizumi, A., Takeuchi, M., Sagawa, H., 2000. A vision-based method for recognizing non-manual information in Japanese sign language. Adv. Multimodal Interf.-ICMI 2000, 572–581. https://doi.org/10.1007/3-540-40063-X_75.
Yasunaga, D., Yano, M., Yasugi, Y., Koizumi, M., 2015. Is the subject-before-object preference universal? An event-related potential study in the Kaqchikel Mayan language. Langu. Cogn. Neurosci. 30 (9), 1209–1229. https://doi.org/10.1080/23273798.2015.1080372.
Ylinen, S., Huuskonen, M., Mikkola, K., Saure, E., Sinkkonen, T., Paavilainen, P., 2016. Predictive coding of phonological rules in auditory cortex: A mismatch negativity study. Brain Lang. 162, 72–80. https://doi.org/10.1016/j.bandl.2016.08.007.