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Agreement or no agreement.

ERP correlates of verb agreement violation in German Sign Language

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Abstract

Previous studies on agreement violation in sign languages report neurophysiological responses similar to those observed for spoken languages. In contrast, the two current event-related potential studies (ERP) on agreement violations in German Sign Language sentences present results that allow for an alternative explanation. In experiment A, we investigated the processing of agreement verbs ending in an unspecified location different to the location associated with the referent. Incorrect agreement verbs engendered a posterior positivity effect (220-570 ms post *nonmanual cues*) and a left anterior effect (300-600 ms post the subsequent *sign onset*). In experiment B, we investigated a violation of morphologically modified plain verbs. Incorrect plain verbs, articulated to express third person object agreement, engendered a broadly distributed positivity effect (420-730 ms post *mismatch onset*). We discuss the results under the perspective of enhanced costs for context updating, and argue that sign language agreement is based on phonological and pragmatic principles.

Keywords: Sign language, Agreement, German Sign Language, Event-related potentials, P600, Late positivity

1. Introduction

Whether or not the phenomenon that is called "agreement" [1] in sign languages follows the

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[1] Several terms have been used to label the phenomenon described here. To highlight the modality-specific aspects, the term "directionality" has been commonly used. This points to the fact that verbs (and also pronouns) change their direction in order to refer to distinct referents located in the signing space. The term

same grammatical principles as agreement between the verb and its argument(s) in spoken languages, is a deeply discussed question (cf. Lillo-Martin & Meier, 2011). Besides the linguistic discussion, little is known about the dependency relations of agreement in sign languages from a neurocognitive perspective. The neurophysiological level of processing sign language agreement violations has only been investigated by two previous studies with distinct violation parameters (Capek et al., 2009; Hänel-Faulhaber et al., 2014). As sign language agreement is expressed via spatial locations associated with referents in a three-dimensional signing space, agreement violations in sign languages might be more than a mere morpho-syntactic violation of feature checking/sharing. In the two present studies, we look in more detail into the complex linguistic aspects of sign language agreement and its electrophysiological correlates.

1.1 Sign language agreement

Verb agreement in sign languages is mainly expressed by a location overlap in the signing space between the beginning or the end point of a verb's path movement and the location that is associated with the verb's arguments, i.e. subject and/or indirect object (cf. Steinbach & Onea, 2016). Moreover, sign language agreement can also be conveyed by directing the hand orientation towards the location of the respective referent. For example, in the sentence IX_1 GRANDMA IX_{3a} ${}_1\text{HELP}_{3a}$ ('I help grandma')[2] in German Sign Language (DGS), the verb's path

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"agreement" rather emphasizes the modality-independent aspects. We will use both terms synonymously, depending on which aspect we want to focus on.

[2] By convention, signs are glossed in small caps. IX represents an INDEX sign, used for referentially locating a referent. IX is directed towards the location indicated by the subscript number. 1 marks the signer, 3a marks a location on the ipsilateral side, whereas 3b marks a location on the contralateral side of the signer.

movement directs from the signer's chest towards the location associated with the third person object, which is the referential locus or "R-locus" labelled with "3a" (Aronoff, Meir, & Sandler, 2005; Lillo-Martin & Klima, 1990). For third person referents, this is typically an area on the ipsilateral or contralateral side of the signing space. The direction of the verb changes accordingly when grandma becomes the subject/agent and the signer the object. Then the movement starts at location 3a and ends at the chest of the signer, as in the sentence GRANDMA IX_{3a} ${}_{3a}HELP_{1}$ ('Grandma helps me'). The two forms of HELP are depicted in Figure 1.

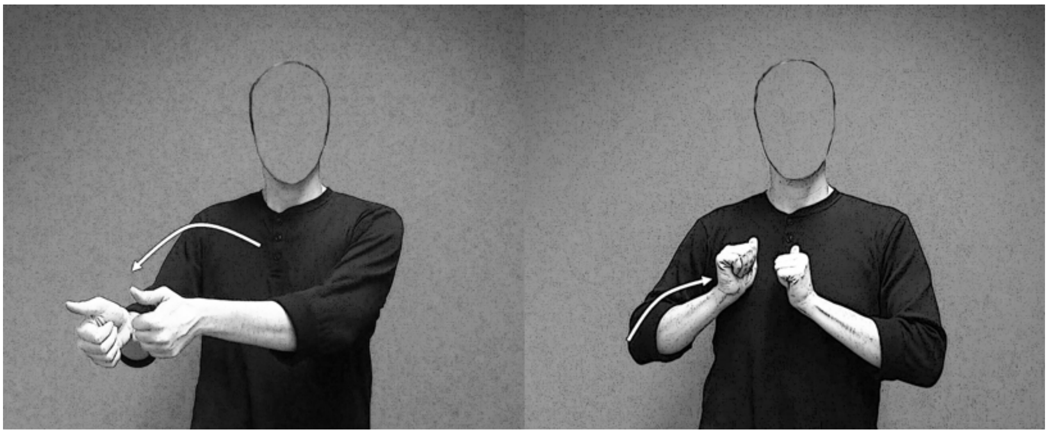

Figure 1. Pictures of the sign HELP. Left: from the signer to a 3rd person referent as in ${}_{1}HELP_{3a}$ ('I help him/her'). Right: from a 3rd person referent to the signer as in ${}_{3a}HELP_{1}$ ('he/she helps me').

Verb agreement in sign languages has modality independent as well as modality-specific characteristics, which leave its linguistic status as well as the neurocognitive aspects of its processing not yet established (Lillo-Martin & Meier, 2011 and the commentaries on this target article). On the one hand, sign language agreement can be observed in all sign languages investigated so far (Mathur & Rathmann, 2012), and analogous to spoken language agreement, it marks the grammatical features *person* and *number* (Lillo-Martin & Meier, 2011; Rathmann & Mathur, 2002, 2008). In addition, it shows similar tendencies of grammaticalization as agreement in spoken languages (Pfau & Steinbach, 2011; Steinbach, 2011). On the other hand, agreement in sign languages is restricted to only a subset of verbs (namely to *agreement verbs* and not to *plain verbs*), which may change path movement and/or hand orientation depending on the verbs' arguments. Furthermore, the actual location associated with subject and/or object can depend on the physical position of the referent. This latter aspect brings in a discourse specific gestural component, which queries the mere syntactic nature of sign language agreement (Liddell, 1995, 2011). With regard to the crucial role of these modality-specific aspects for the present studies, we will discuss them in a little more detail before reporting previous neurophysiological experiments on sign language agreement.

In most documented sign languages, a difference between verbs that agree and verbs that do not agree has been confirmed so far (Mathur & Rathmann, 2012). The basic distinction between *plain verbs* and *agreement verbs* is found in the specification for directionality: Plain verbs constitute a separate verb class as they are lexically specified and cannot undergo a phonological change of their path movement and/or orientation features. For example, the transitive verb LIKE in German Sign Language (*Deutsche Gebärdensprache*, DGS) has a lexically specified downward movement on the signers' chest. Plain verbs do not necessarily have to be body-anchored, as there are plain verbs articulated in neutral signing space such as BUY and PLAY in DGS. See Figure 2 for pictures of these plain verbs.

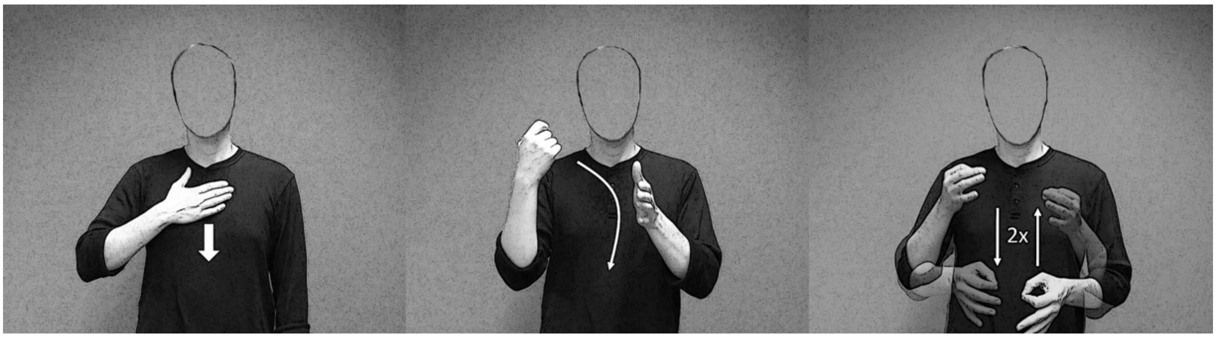

Figure 2. Pictures of the DGS plain verbs LIKE, BUY, and PLAY (from left to right) that display a lexically specified movement.

In contrast to plain verbs, agreement verbs have an underspecified path movement and/or hand orientation features that are only specified within the sentence in order to express agreement with subject and/or indirect object. While the manner of the movement is lexically specified (i.e. circular, straight or arc movement, etc.), the initial and the final position of the movement are determined by the referential indexes, manifested in the referential loci of the arguments. Thus, agreement verbs move from the location of the subject towards the location of the object (*double agreement*) or from a lexically specified location towards the location of the object (*single agreement*).[3]

The second modality-specific characteristic of sign language agreement regards the potential unambiguity of referential loci (R-loci). Outside of a specific discourse, a pronoun like *he* in English or like IX_{3a} in DGS is *per se* ambiguous, because it is referentially “empty”. It is unclear as to what a pronoun refers to, until it is anaphorically linked to a discourse referent. Unlike spoken language agreement, sign language agreement is realized through the

[3] Spatial verbs are realized in a topographic use of space and agree with locative arguments. They are prototypically verbs of action and location (LAY, STAND, GO, SIT, BE-AT, etc.) and did not occur in the two present studies. For a detailed description on spatial verbs, the reader is referred to Padden (1983) and Sandler & Lillo-Martin (2006).

use of a three-dimensional signing space in front of the signer. Once a discourse is set and the referents are introduced, sign languages seem to be less ambiguous with respect to pronoun resolution because discourse referents are associated with distinct R-loci in the signing space. Hence, pronouns can unambiguously identify a discourse referent by pointing towards the corresponding R-locus, as demonstrated in (1).

(1) a. The doctor and the scientist play tennis. **He** likes the game.

b. DOCTOR IX_{3a} SCIENTIST IX_{3b} TENNIS-PLAY. $\mathbf{IX_{3a}/IX_{3b}}$ GAME LIKE. (DGS)

The pronoun *he* in the English example (1a) is ambiguous as it can, in principle, take both noun phrases as its antecedent. In contrast, in the DGS sentence (1b), the two referents are assigned to two different R-loci in the signing space, locus 3a and locus 3b, respectively. The pronoun in the second sentence has an unambiguous phonological form in directing at one of the two loci. By that, it unambiguously refers back to either of the two referents. In this sense, the link between a specific R-locus and a particular referent within a discourse is less ambiguous than the link between a pronoun and its antecedent in spoken languages.[4] This aspect of a less ambiguous pronominal system might be explained by the assumption that sign language agreement systems have a gestural origin (Liddell, 1995, Pfau & Steinbach, 2006, 2011, and Steinbach & Pfau, 2007).

[4] For a discussion on the potential ambiguity of sign language pronouns and the issue of the *one referent to one R-locus* ascription, see Quer (2011) and Barberà Altimira (2015).

Based on the distinction between plain and agreement verbs, we investigate agreement violation with both verb types. In our first study (experiment A), we aimed to replicate Capek et al. (2009)'s design and test agreement verbs that incorrectly end in an unspecified R-locus where no discourse referent has been assigned to. In contrast to Capek et al., we analyse two trigger positions time-locked to crucial phonological changes in the continuous signing stream. Thus, we are able to analyse the ongoing processing of natural DGS sentences in more detail. In our second study (experiment B), we test agreement violation with plain verbs. As mentioned above, plain verbs are lexically specified for path movement and hand orientation, and cannot inflect for subject and/or object agreement. Hence, an agreement violation with plain verbs seems to be a clear violation of morpho-syntactic specifications. To our knowledge, there are no studies investigating the case of agreement violation with plain verbs so far.

1.2 Neurocognitive studies on sign language agreement

Neurocognitive investigations of sign language agreement provide a different perspective on the sign language agreement puzzle. The investigation of morpho-syntactic agreement violation in electrophysiological studies has – ever since Kutas & Hillyard (1983) – a long tradition in spoken language research (Molinaro, Barber, & Carreiras, 2011). Many of these studies investigated number agreement violations between a full subject NP and a verb, as in "The elected officials hopes* to succeed" (Osterhout & Mobley, 1995), or between a pronominal subject and a verb, as in "Every Monday, he mow* the lawn" (Coulsen, King, & Kutas, 1998). These agreement mismatches typically evoke a biphasic ERP pattern with a left anterior negativity (LAN) between 300-400 ms and a late positivity (P600/SPS) after 500 ms in spoken languages. In order to investigate agreement violations in sentences of American Sign Language (ASL), Capek et al. (2009) conducted an ERP study examining two types of agreement violations: “reversed verb agreement violation” and “unspecified verb agreement violation”. Similar to spoken languages, the authors report a biphasic ERP effect with an early anterior negativity followed by a late posterior positivity (P600) for these sign language agreement violations. However, Capek and colleagues reveal a difference between both types of agreement violation, in that the anterior negativity was larger over the right lateral frontal site in the unspecified agreement condition compared to the reversed agreement condition.

A second study on agreement violation during sign language sentence processing was conducted by Hänel-Faulhaber et al. (2014) in DGS. In contrast to Capek et al. (2009), they presented a different type of verb agreement violation, in which the verb incorrectly moved from an unspecified neutral location towards the signer, instead of from right to left, where subject and object were located. Measured EEG responses to incorrectly inflected verbs showed a negative potential with a left lateralized frontal distribution (LAN) and a late positivity with a posterior distribution (P600). Hence, Hänel-Faulhaber et al. (2014) similarly report a biphasic pattern for sentences with incorrect verb agreement. Both studies argue for agreement in sign languages to be a morpho-syntactic process similar to agreement in spoken languages.

What becomes apparent from both studies is that the neurophysiological response to processing agreement violations in sign languages is modulated by the type of agreement violation presented. This leads to the assumption that different types of agreement violations elicit different ERP responses. Furthermore, and this is new in the present study, it has not yet been investigated how the dependency relation between the subject/agent and the object/undergoer is realized in the processing of transitive plain verbs.

1.3 The two present studies

Experiment A on agreement violation with agreement verbs had the following objectives: The first aim was to test unspecified agreement violation for DGS and to replicate Capek et al.'s (2009) findings. A second aim was to investigate the time course of processing agreement violation in real time sentence processing in more detail. Therefore, we time-locked ERPs to different information sources available during the ongoing signing stream of the transition phase between the preceding sign and the critical verb sign. For the purpose of the first experiment, we defined "agreement violation" as incorrect object agreement. We presented videos of deaf native signers consisting of two consecutive sentences: The first sentence introduced two discourse referents, the 1^{st} person signer and a 3^{rd} person referent, which was unambiguously assigned to the right (i.e. ipsilateral) area of the signer at locus 3a. The second sentence continued the discourse topic and ended with the critical agreement verb. In the *match* condition, the verb agreed with the subject and object and thus moved from the R-locus of the signer (locus 1) to the R-locus associated with the 3^{rd} person referent (locus 3a). In the *mismatch* condition, the verb did not correctly agree with the object associated with 3a, but moved from the location of the signer (locus 1) towards an unspecified R-locus on the left (i.e. contralateral) side of the signer (locus 3b). Example (2) shows representative stimulus sentences with corresponding video stills of the final hold of the critical verb (Figure 3).

(2) a. *Match condition* (agreement verbs):

MY FATHER IX_{3a} SOCCER FAN. NEXT MATCH DATE $_{1}\textbf{INFORM}_{3a}$. (DGS)

'My father is a soccer fan. I will inform him about the date of the next match.'

b. *Mismatch condition* (agreement verbs):

MY FATHER IX_{3a} SOCCER FAN. NEXT MATCH DATE $_{1}\textbf{INFORM}_{3b}$. (DGS)

‘My father is a soccer fan. I will inform xxx about the date of the next match.’

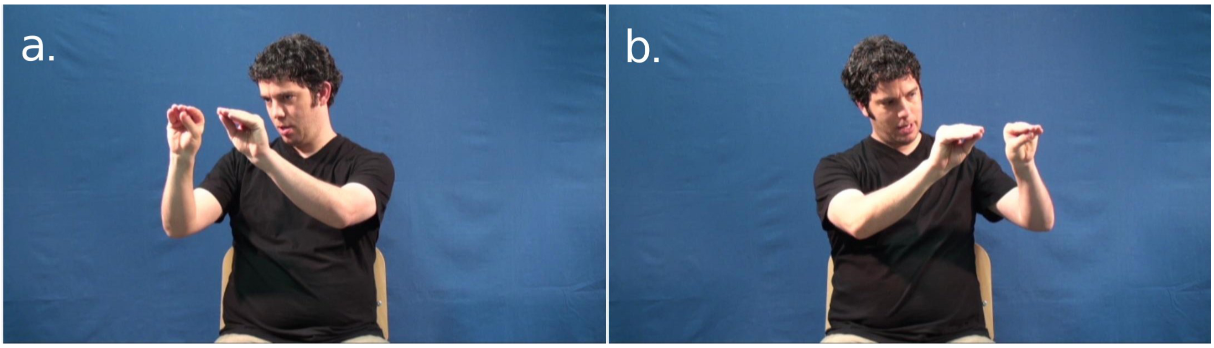

Figure 3. Original video stills of the final hold of the critical verb INFORM: (a) in the match condition, agreeing with the 3rd person referent ($_1$INFORM$_{3a}$); and (b) in the mismatch condition, ending at an unspecified R-locus on the contralateral side of the signer ($_1$INFORM$_{3b}$). The respective videos are available online in the supplementary material.

Note that this kind of agreement violation does not involve a phonologically incorrect form of the verb as it can correctly appear in sentences with a referent associated to R-locus 3b. If sign language agreement indeed constitutes a morpho-syntactic process of marking the features person and number of subject and object on the initial and final hold of the verb, we expect a similar ERP response as the well-investigated biphasic pattern of LAN and P600 for spoken language agreement violation. On the contrary, if the phenomenon of directionality in agreement verbs is rather a contextual (pragmatic) discourse phenomenon, e.g., a linking process of a previously introduced discourse referent to the subsequent proposition, we would expect to find a different ERP pattern compared to spoken language agreement violations.

Other than agreement verbs, plain verbs have a lexically specified path movement, that is, they cannot undergo a phonological change in order to mark subject and/or object agreement. Nevertheless, in experiment B we investigated a violation of this non-agreeing lexical specification of plain verbs. We transferred the agreement principle to plain verbs and manipulated them in the way to behave similar to agreement verbs, i.e. their final hold ended at locus 3a, in order to “agree” with a 3rd person referent. Hence, in the *match* condition, sentences comprised a subject, a 3rd person object, and a sentence final plain verb in its lexical form. In the *mismatch* condition, the plain verbs path movement was modified and directed at the R-locus 3a associated with the 3rd person referent. In any other respect, sentences were identical to their controls. Representative stimulus sentences with a correct (a) and an incorrect plain verb (b) are presented in example (3) and the corresponding video stills in Figure (4).

(3) a. *Match condition* (plain verbs):

IX$_1$ LAPTOP **BUY**. (DGS)

‘I buy a laptop.’

b. *Mismatch condition* (plain verbs):

IX$_1$ LAPTOP **BUY$_{3a}$**. (DGS)

‘I *buy a laptop.’

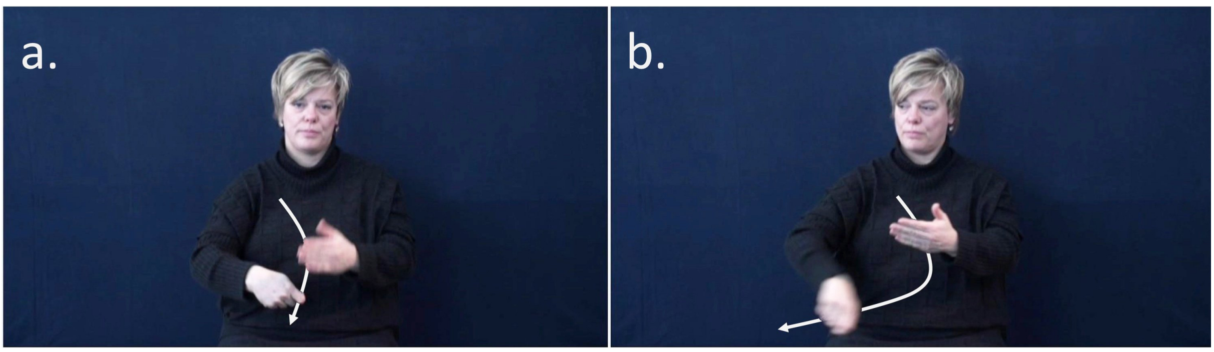

Figure 4. Original video stills of the critical plain verb BUY: (a) in the match condition; and (b) in the mismatch condition with the modified path movement directing towards locus 3a, in order to mark agreement with the 3rd person object. The respective videos are available online in the supplementary material.

In contrast to previous ERP studies on agreement violation in sign languages, this experiment is the first to investigate agreement violation with plain verbs. If the artificial path movement towards the object is indeed processed as a form of agreement, we expect a left anterior negativity to reflect the violation of expectancy and a late positivity for some kind of mapping or integrating processes on the sentence level. Regarding neurophysiologic responses to agreement violations in sign languages, this experiment breaks new ground. The data of experiment A and experiment B have each been recorded together with a separate experiment that addressed an unrelated question and has been published elsewhere.

2. Experiment A: Agreement violation with agreement verbs

2.1 Experiment A: Materials and methods

2.1.1 Participants

In this experiment, a total of 20 congenitally deaf native signers of DGS (mean age: 36, range: 18-51) participated as paid volunteers (8 f, 12 m). All signers were born deaf, had deaf parents or DGS input before the age of three, and described DGS as their native language. All participants had normal or corrected-to-normal vision, were right-handed and had no history of neurological disorders. Due to excessive eye movement artefacts, two participants had to be excluded from the final data analysis.

2.1.2 Materials

The materials were created and recorded together with two deaf DGS informants (one male, one female) and checked for grammatical and semantic correctness, frequency and possible dialectical variation. We used 40 sentences for each of the critical conditions (*match* versus *mismatch*) as illustrated in example (2) and (3) in Section 1.3. The 40 sentences per condition were constructed using 10 verbs, thus resulting in 4 repetitions of each individual verb per condition; crucially, sentence contexts differed across repetitions. The verbs were frequent regular agreement verbs like HELP, ASK, VISIT, or GIVE, and selected for two animate arguments (subject and object).[5] The corresponding sentences in both conditions were identical, except for the critical final verb. Critical agreement verbs in the *match* condition started at the R-locus of the signer (i.e. the subject) and ended at R-locus 3a previously associated with the object referent on the ipsilateral (i.e. right) side of the signer. In contrast, critical agreement verbs in the *mismatch* condition also started at the R-locus of the signer, but ended on the contralateral (i.e. left) side of the signer at the unassigned R-locus 3b. Thompson, Emmorey, & Kluender (2006 and 2009) report for ASL that object agreement is also marked nonmanually by eye gaze towards the location of the object. Hosemann (2011) found similar results for DGS. Hence, we instructed our informants to produce manual agreement in co-occurrence with the nonmanual markers eye gaze and head tilt towards the direction of the final location (i.e., locus 3a for matching verbs and locus 3b for mismatching

[5] Although so-called backwards verbs (like PICK-UP or INVITE in DGS) also take two animate arguments and also agree with subject and object, they were not used as critical verbs in this experiment, because they move from the location of the object (or source) to the location of the subject (or goal) (Brentari, 1988; Meir, 1998, 2002).

verbs, respectively). In any other respect, nonmanual action like facial expressions or brow raise was kept to a minimum within the prospects of natural signing. A comprehensive list of stimulus sentences is provided in Appendix A.

The material was recorded on video with a HDR-XR 550E full-HD camera (25 frames per second) and processed with *Adobe Premiere Pro*. In total, videos had an average length of 8.27 seconds (sd 0.66). At the beginning and the end of each video, the signer was seen motionless for approximately 2000 ms before and after he/she signed the sentence in a natural manner. To ensure maximal naturalness of the signed sentences and the processing of it, videos were not cross-spliced, length adapted, or modified in any way. The 80 critical sentences resulting from this design were combined with 80 filler sentences, which were part of an unrelated separate experimental design. Altogether, the 160 sentences were presented in two different pseudo-randomized ordered lists, which were counterbalanced across participants. To familiarize participants with the procedure of the experiment, an additional set of 10 sentences were recorded in the same manner and presented twice as practice before the actual experiment started. These sentences were not part of the critical stimuli.

2.1.3 Procedure

After giving written informed consent, participants were seated approximately 1m in front of a 17 inch computer screen in a comfortable chair located in a dimly lit cabin. Participants watched an introductory video that explained the procedure in DGS at the beginning of the experimental session. Remaining questions were answered by the experimenter in DGS. Participants started with a short practice session. The following experimental session was subdivided into 4 blocks of 40 sentences each. Between blocks, participants had the opportunity to take short breaks. In each trial, participants had to perform two tasks after watching the critical sentence: an acceptability judgment of the sentence (Is the sentence correct? – answers: yes, no), and an evaluation judgment of their own decision (How sure are you? – answers: very sure, sure, not sure, not sure at all). The cue for the acceptability judgment task was a question mark in white Arial font (size 60) on a black screen, followed by a blank screen for 500 ms. Subsequently, the evaluation judgment task was cued by a short question in German ("wie sicher?", 'how sure?') in the same font. Maximal reaction times for the two tasks were 2000 and 3000 ms, respectively. The next trial began after an interval of 2500 ms with the next critical video. The experiment lasted for about 45 minutes.

2.1.4 EEG recording

We recorded the EEG data by means of 32 active electrodes placed according to the international 10-20 system (*ActiCAP 32*, Easycap GmbH, Herrsching, Germany). With a sampling rate of 500 Hz, the data was amplified by a BrainAmp amplifier (Brain Products GmbH, Gilching, Germany). Average impedances were kept below 10 kΩ. EEG recordings were referenced online to the right mastoid, and re-referenced to linked mastoids, whereas electrode AFz served as the ground electrode. In order to monitor the electrooculogram (EOG) for each participant, we placed electrodes above and below the right eye for the vertical EOG, and for the horizontal EOG at the outer canthi of each eye.

2.1.5 EEG data preprocessing and statistical analysis

Before analysis, the raw EEG was filtered with a 0.3-20 Hz band-pass filter in order to eliminate slow signal drifts. Epochs of the EEG corresponding from -200 to 1000 ms relative to two different trigger points (see below) were calculated per condition and electrode in the single subject ERP averages. Subsequently, grand averages were computed over all participants. The rejection threshold for trials with artefacts was 40 µV. Artefacts and EOGs were excluded from the averaging procedure.

Following the objective to investigate the processing of verb agreement in a natural sentential environment, trial videos were presented in an unsliced manner. Thus, trigger points for the analysis of the EEG signal were time-locked to two crucial points within the video: the moment of nonmanual changes and the subsequent sign onset of the critical verb. We thereby took into consideration that the processing of a target sign already begins during the preceding transition phase between the previous sign and the target sign (Hosemann, Herrmann, Steinbach, Bornkessel-Schlesewsky, & Schlesewsky, 2013). Each trigger point was identified individually for each video by two linguists with a high expertise in DGS. Conflicting classifications never differed by more than a single frame (40 ms) and were resolved by discussion. The critical moments for trigger setting were the following:

(a) *Nonmanual cues (nmc)*. Verb agreement was additionally marked by the nonmanual components of eye gaze and head tilt towards the final R-locus of the verb. This trigger point was defined as the first frame in which eye gaze towards the respective R-locus was clearly identifiable and/or in which the head left its neutral position. If eye gaze and head tilt did not change in the same frame, the first frame with a nonmanual deviation (either eye gaze change or head tilt change) was picked. On average, the nmc-trigger occurred 202 ms (sd 128 ms) prior to the sign onset trigger.

(b) *Sign onset (so)*. The sign onset was defined as the first frame of the initial hold for the critical verb, when the target hand configuration reached the target location at body contact with the signer (in case of body anchored agreement verbs) or at the locus just in front of the signer (in case of non-body anchored agreement verbs). The average duration from sign onset to sign offset was 429 ms (sd 168) for *matching* agreement verbs and 461 ms (sd 174) for *mismatching* agreement verbs.

For the statistical analysis of the ERP data, four lateral topographical regions of interests (ROI) were computed: *left-anterior* (F3, F7, FC1, FC5, C3), *right-anterior* (F4, F8, FC2, FC6, C4), *left-posterior* (CP1, CP5, P3, P7, O1), and *right-posterior* (CP2, CP6, P4, P8, O2). The midline electrodes, FZ, CZ, CPZ, PZ, and OZ were each analysed as individual ROIs. The statistical analyses were conducted using R (Team, 2012) and the ez package (Lawrence, 2012) and carried out in a hierarchical manner. Repeated measures analysis of variance (ANOVAs) were calculated with the factor CONDITION (*match* vs. *mismatch*) and topographical region of interest (ROI). Only significant interactions ($p < 0.05$) were resolved. Probability values were Huynh-Feldt corrected when appropriate (Huynh & Feldt, 1970).

2.2 Experiment A: Results

2.2.1 Behavioural data

The statistical analysis of the behavioural data was calculated with a Bayesian regression model using the brms R-package (Bürkner, n.d.), in which individuals were included as random intercept. Responses to the acceptability judgment were evaluated with a binary regression model with logit link, whereas responses to the evaluation judgment were evaluated with an ordered logit model. Empirical probabilities for the acceptability judgment were as follows: sentences with correct agreement verbs (i.e. match): 92.9% acceptability; sentences with incorrect agreement verbs (i.e. mismatch): 44.7% acceptability. The estimated probability for accepting sentences in the match condition was 94.4% (with a 99% credible interval between 89.4-97.6%). The estimated probability for accepting sentences in the mismatch condition was 40.3% (with a 99% credible interval between 16.3-70.5%); Bayesian p-value: $p < 0.001$. The estimate probabilities for the evaluation judgment are illustrated in

Table 1 (95% credible interval shown in percentage in square brackets):

Table 1. Estimate probabilities for the evaluation judgment in experiment A.

	"not sure at all"	"not sure"	"sure"	"very sure"
Cond. match	23.6% [2.5, 66.5]	3.1% [4.5, 25.1]	21.8% [5.4, 45.6]	41.5% [9.5, 75.0]
Cond. mismatch	20.5% [2.9, 54.7]	17.1% [7.1, 29.9]	28.6% [7.4, 52.5]	33.8% [7.3, 68.1]

2.2.2 ERP data

Grand averages for sentences with agreement verb violation and for their matching control sentences are displayed in Figure 5, correlated to the preceding trigger *nonmanual cues*, and in Figure 6, correlated to the following trigger *sign onset*. As can be seen in both figures, agreement verbs ending at an unspecified locus different to the one associated with the introduced referent, engender two effects: A first *right posterior effect* that is most pronounced between 220-570 ms at trigger nonmanual cues, which appears at the right posterior electrodes P8, P4, CP6, and O2 (compare Figure 5); and a second following *left anterior effect* that appears at left lateralized anterior electrodes F7, F3, FC5, FC1, and the central electrode C3 between 300-600 ms relative to the later trigger sign onset (compare Figure 6).

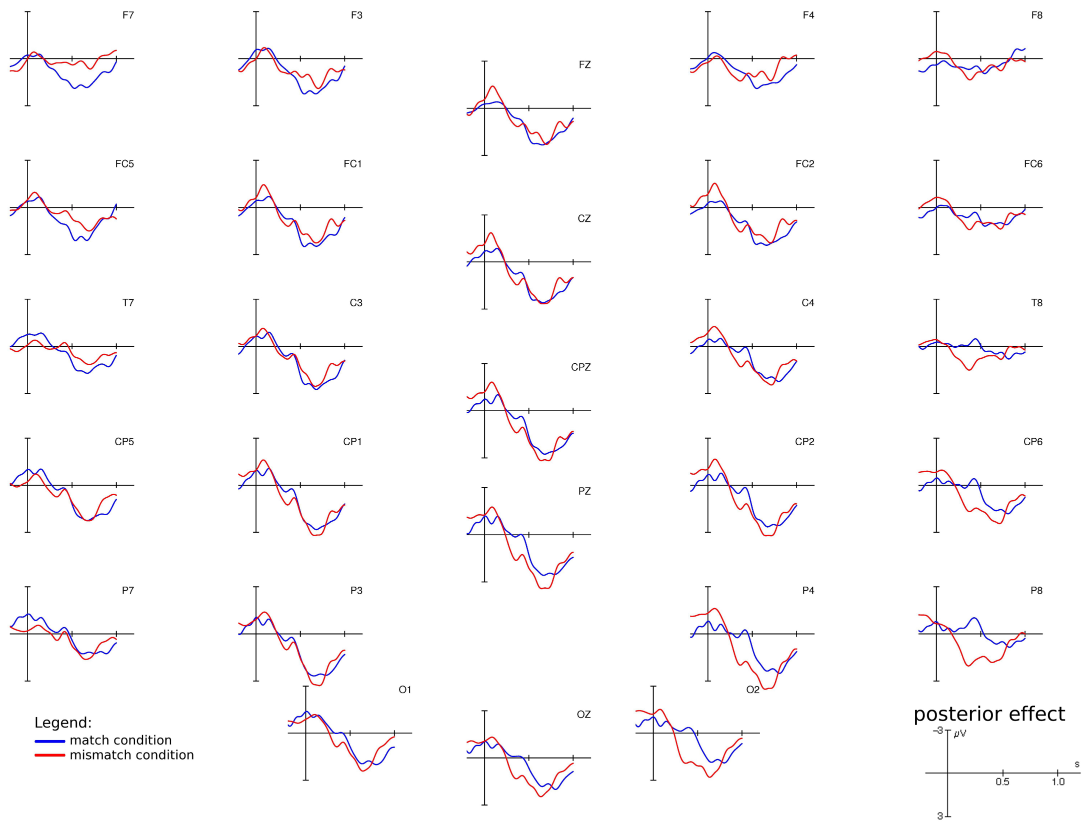

Figure 5. Grand average ERPs for matching (blue line) and mismatching (red line) agreement verbs, showing a right posterior effect time-locked to the trigger *nonmanual cues*. Negativity plotted upwards.

The earlier right posterior effect is a more positive deflection for mismatching agreement verbs ending at an unspecified locus compared to matching agreement verbs. Statistical analyses were conducted relative to the nonmanual cue trigger for the time window 220-570 ms post trigger onset. These resulted in a CONDITION to ROI interaction: $F(1,17) = 18.28$, $p < 0.000001$, and in a condition effect for the right-posterior ROI: $F(1,17) = 15.99$, $p < 0.001$ for lateral electrodes. For midline electrodes the CONDITION to ROI interaction ($F(1,17) = 5.94$, $p < 0.001$) lead to significant effects at electrode Pz: $F(1,17) = 6.41$, $p < 0.05$, and electrode Oz: $F(1,17) = 16.84$, $p < 0.001$. Thus, this identifies as the right posterior effect. By contrast, the later left anterior effect is evident between 300-600 ms relative to the sign onset trigger, which occurred on average 202 ms after the nonmanual cue trigger. The effect appears at left lateralized anterior electrodes F7, F3, FC5, FC1, and the central electrode C3 and displays a more negative-going wave for mismatching verbs (ending at locus 3b instead of 3a) compared to their matching controls (ending at 3a, i.e. the locus associated with the referent). The statistical analysis was conducted for the time window 300-600 ms relative to trigger sign onset and resulted in a CONDITION to ROI interaction: $F(1,17) = 13.16, p < 0.001$, and in a condition effect for the left-anterior ROI: $F(1,17) = 16.38, p < 0.001$ for lateral electrodes. Midline electrodes did not become significant after Huynh-Feldt correction (ps > 0.08).

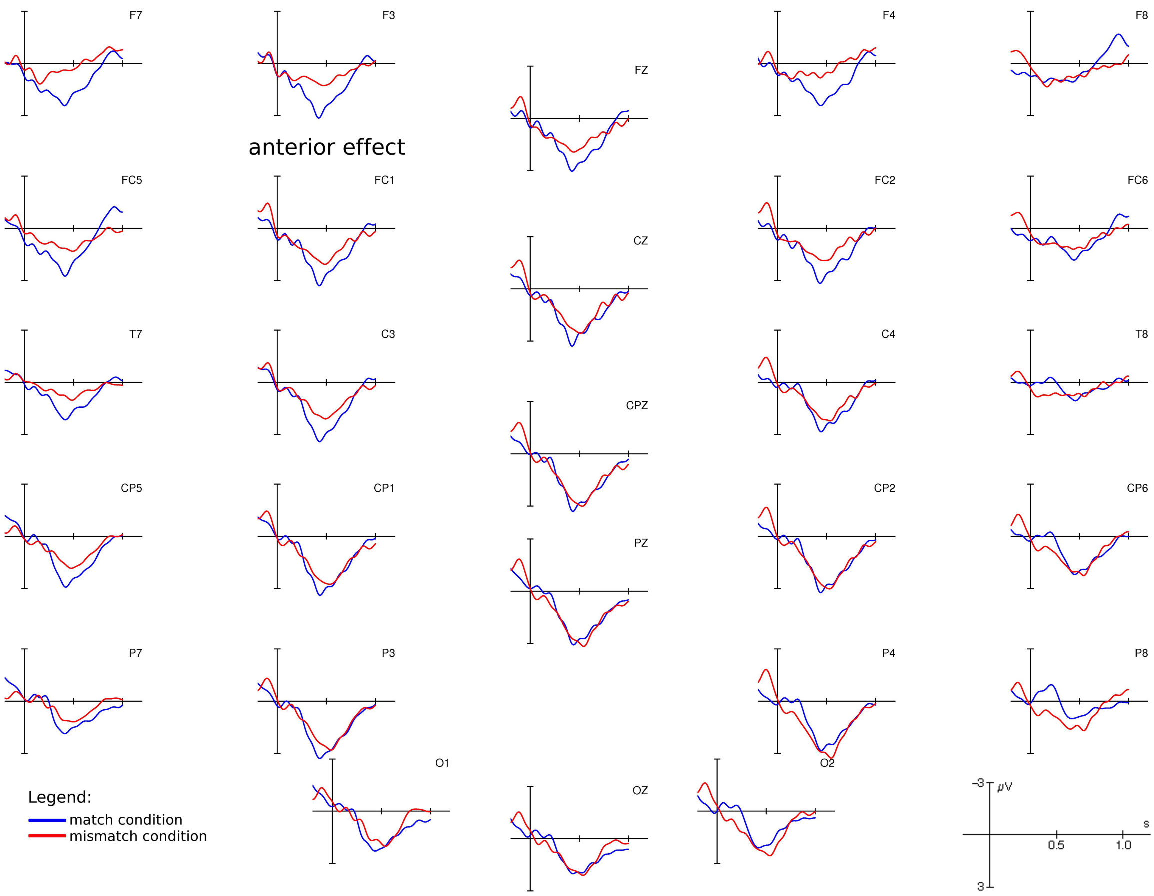

Figure 6. Grand average ERPs for matching (blue line) and mismatching (red line) agreement verbs, showing a left anterior effect time-locked to the trigger *sign onset*. Negativity plotted upwards.

In summary, agreement verbs ending in an unspecified R-locus 3b in contrast to agreement verbs ending in the R-locus 3a associated with a previously assigned referent engendered two ERP effects: a right posterior effect followed by a left anterior effect. Interestingly, the right posterior effect was related most prominently to the first visual indication of a nonmanual deviation, i.e. either a change in eye gaze and/or in head tilt. The second, left anterior effect was elicited at the moment of sign onset, which followed the moment of nonmanual cue change by a mean of 202 ms. This indicates that both effects seem to be unrelated and do not reflect a biphasic pattern of LAN and P600. The polarity of both effects and their functional interpretation remains uncertain at first sight. Whereas the right posterior effect is a more positive deflection for mismatching verbs, the left anterior effect seems to be a more negative deflection for mismatching verbs. However, both effects also allow for an alternative interpretation, in which the effect is engendered by the match condition. A possible interpretation of the results as a reflection of a violation of well-formedness or as a process of context updating, is presented in the following discussion.

2.3 Experiment A: Discussion

The earlier study by Capek et al. (2009), who investigated unspecified verb agreement violation – i.e. an agreement verb ending in an unspecified locus 3a – reports an anterior negativity distributed most prominently over the right hemisphere followed by a broadly distributed P600 over posterior sites. In contrast, in Experiment A we observed two ERP effects for the same type of agreement violation that seem to be unrelated to one another:

First, a right-posterior effect, which is most pronounced in a time window of 220-570 ms relative to the preceding trigger nonmanual cues; second, a left-anterior effect that appears 300-600 ms post trigger sign onset. Since the moment of sign onset was time-locked on average 202 ms (sd 128 ms) after the nonmanual cue trigger, it appears that the posterior effect at right lateral sites temporally evolved approximately 200-300 ms before the anterior effect evolved at left lateral sites. This indicates that both effects are not causally related and should thus be interpreted separately. Note that at this point of investigation, none of the interpretations can be favoured.

2.3.1 Interpretation of the right-posterior effect

The polarity of the effect displays a more positive-going waveform for the mismatch condition (red line) relative to the control condition (blue line). Since the number of ERP studies with unspecified verb agreement violation in sign languages is limited, three theoretical approaches based on ERP studies with spoken languages set the frame in which this effect can be explained.

The first approach assumes the right-posterior effect to reflect extra costs for discourse updating as reported by Baumann & Schumacher (2011) and Hung & Schumacher (2012, 2014). Baumann & Schumacher (2011) presented German monolinguals auditory sentences that varied with respect to information status of an entity (given versus new) and prosodic realization (accented versus deaccented). In the critical sentence, the information status of the 3rd person target NP ("the winegrower") was varied by the previously set context sentence. The target NP was *given*, when it has already been introduced in the preceding context sentence. In contrast, the target NP was *new*, when it was not mentioned in the preceding context sentence (cf. Baumann & Schumacher 2011: p. 366-367). ERPs time-locked to the noun elicited a biphasic N400 – late positivity pattern for new information compared to given information. The authors argue that the N400 reflects enhanced costs for linking new information to the previous discourse, and that the late positivity is caused by the listener's effort to update their discourse model. These effects were independent of an appropriate or inappropriate prosody and occurred for accented as well as deaccented nouns. Hung & Schumacher (2012, 2014) also found a biphasic N400 – late positivity pattern for a topic shift in sentence-medial and sentence-final position in Mandarin Chinese. Thus, a new topic in sentence-final position in the answer of a question-answer pair elicited a late positivity for context updating processes. With regard to the present study, the posterior positivity effect could have been caused by additional processing costs for context updating. Agreement verbs do not only anaphorically agree with the location of a previously introduced referent, they can also mark the location of a new referent that is cataphorically introduced later in the discourse. Thus, in the mismatch condition, a discourse referent X was introduced and associated with locus 3a in sentence one. However, in sentence two, the agreement verb ended at an unspecified locus 3b, thereby introducing a new discourse referent Y that would need to be explicated in a continuing context. Sentence two thus introduced a topic shift from referent X to a potential new referent Y. The example of an incorrect sentence in experiment A, such as MY FATHER IX_{3a} SOCCER FAN. NEXT MATCH DATE $_{1}$INFORM$_{\mathbf{3b}}$, could lead to an alternative interpretation. The incorrect agreement verb could be (re-)interpreted in the sense that the signer will inform another person (that needs to be specified) about the date of the next match. In contrast to plain verbs, agreement verbs in incorrect forms can have an alternative interpretation and the posterior positivity could thus reflect enhanced processing costs for updating the situation model.

A second explanation of the posterior positivity assumes that the kind of agreement violation is in fact a case of presupposition violation. The agreement verb ending at locus 3b presupposes a discourse referent that the verb can be linked with (cf. Steinbach & Onea, 2016). The failure of this linking process in the mismatch condition caused the enhanced processing costs. ERP studies on spoken language pronoun resolution typically show a widely distributed negative deflection for ambiguous referents (van Berkum, Brown, & Hagoort, 1999a, 1999b; van Berkum, Koornneef, Otten, & Nieuwland, 2007; and Nieuwland & van Berkum, 2008) and a P600 for no available referent. Sentences with unambiguous and ambiguous pronouns such as the following were tested: (a) “David shot at Linda as *he* jumped over the fence” versus (b) “David shot at John as *he* jumped over the fence” versus (c) “Anna shot at Linda as *he* jumped over the fence”. For referentially ambiguous nouns or pronouns as in sentences (b) compared to (a), van Berkum et al. (1999a, 1999b) and van Berkum, Zwitserlood, Bastiaansen, Brown, & Hagoort (2004) found a widely distributed negative deflection, emerging at about 300 ms after noun/pronoun onset, dubbed the “Nref effect”. However, for sentences like (c) with no available referent of the correct gender, van Berkum et al. (2004) found no Nref effect but rather a P600. Although the agreement violation in our experiment A is not a violation of gender, it can be compared to van Berkum et al.’s (2004) findings. Like in many spoken languages, pronouns and verb agreement in sign languages are two related phenomena (Pfau & Steinbach, 2006, 2011). Both are expressed by a location overlap with a R-locus assigned to the corresponding discourse referent. A verb ending at an unspecified R-locus (like 3b in our mismatch condition) presupposes a referent that has not been introduced in the discourse model. Thus, the reference of the verb ending is “empty” because there is no adequate referent available. In this third frame of explanation, this violation led to the posterior positivity effect in our results. Furthermore, van Berkum, Brown, Hagoort, & Zwitserlood (2003) showed for pronouns during sentence processing that subjects check their situation model already at a very early stage whether an adequate referent is available or not (see also van Berkum et al., 2007). This could explain the early latency of the posterior positivity effect at 220-570 ms relative to the trigger nonmanual cues prior to the sign onset. As has been argued in Hosemann et al. (2013), the verification of top down expectations and bottom up information already takes place during the relatively long transition phases prior to the onset of a lexical sign. Thus, in the current study, the expectation on the agreement verb was a direction towards R-locus 3a in accordance with the location of the object. The very early nonmanual cues of eye gaze and head tilt either confirmed this expectation in the match condition or violated it in the mismatch condition, when gaze and head tilt were directed towards the R-locus 3b.

A third approach could explain the right-posterior effect in terms of violating a more general well-formedness. Following the *extended Argument Dependency Model* (eADM) by Bornkessel & Schlesewsky (2006) of comprehending core constituents (i.e. verbs and their required arguments), the incremental comprehension processes follow three phases: In phase one, the currently processed item is identified as verb or noun phrase argument. In phase two, the prominence of an NP is computed (as actor or undergoer) according to morphological information, and further agreement information is assigned. If the computed item is a verb, its logical structure and agreement information are established and it is linked to arguments that have already been established. In phase three, core relations and noncore relations are mapped, and the NP/verb-structure is evaluated in terms of well-formedness or for possible repair processes (under the consideration of world knowledge, plausibility, and prosodic information of pitch accents, stress patterns, etc.) (cf., Bornkessel & Schlesewsky, 2006: p. 789-790). The concept of *well-formedness* focusses on the evaluation of the overall construction. It is a mechanism that gradually appraises the acceptability of an item in relation to its sentential and contextual environment. In this rather global perspective of the eADM, the interpretation of the effect would be as follows: In experiment A, we presented sentences like MY FATHER IX_{3a} SOCCER FAN. NEXT MATCH DATE $_{1}\text{INFORM}_{\mathbf{3b}}$, in which the final agreement verb does not end at the R-locus associated with the object, but at an unspecified R-locus. A well-formed expression of verb agreement would be a verb ending at the same R-locus as the one associated with the object. But as Quer (2011) points out, the *one referent to one R-locus* ascription is not as straightforward in everyday sign language use as it is in theoretical terms. Quer (2011) refers to observations in Catalan Sign Language, in which, within a connected discourse, one referent can be referred to by the use of different R-loci, probably restricted by pragmatic principles of accessibility. Hence, an agreement verb not ending at the R-locus associated with the referent but at a different R-locus could not be interpreted as a grammatical mistake but rather as a violation of pragmatic well-formedness.

However, the posterior positivity was not broadly distributed as it is characteristic for late positivity effects. This could be the result of an interference with the left anterior effect evolving approximately 200-300 ms after the right posterior effect.

2.3.2 Interpretation of the left anterior effect

The polarity of the left anterior effect – seen in Figure 6 – is unexpected in the sense that the match condition (blue line) is relatively distinct compared to the mismatch condition (red line) and is thus interpreted as a positivity effect for correct verb agreement. According to visual inspection, the left anterior effect displays a maximum positive peak for the match condition compared to the mismatch condition at electrode F3, approximately 400-450 ms relative to trigger sign onset. A possible explanation for the effect is that it was not caused by verb or agreement processing, but is rather task-related and thus falls into the P300 family. In a series of ERP studies with hearing participants, researchers investigated a positive deflection, typically peaking around 300 ms post stimulus onset, that is related to the given task and is not primarily caused by language processing costs (Kok, 2001; Polich, 2007; Squires, Squires, & Hillyard, 1975; Sutton, Braren, Zubin, & John, 1965). Whether or not the P300 composes a family of effects or comprises a solitary effect is still under debate. However, in the literature, two distinct effects have been classified: P3a and P3b (Squires et al., 1975; Polich, 2007). The P3a has a peak latency between 220-280 ms post stimulus onset and can be clearly differentiate from the P3b by its topographic distribution. While the P3a has a fronto-central distribution, the P3b originates from temporal-parietal activity and has a rather posterior distribution. The P3b is also a positive deflection with a peak amplitude at about 300 ms post stimulus onset. The P3b can be elicited by the awaiting of the target stimulus (Verleger, 1988, 1998). In an experiment where participants had to recall words from a list of several words, Karis, Fabiani, & Donchin (1984) observed a larger P300 component for recalled items. Thus, they argue that fundamental memory processes affect the P300 amplitude (see also Donchin, 1981). If we interpret the left anterior effect as a positivity for correct agreement verbs that match in their final location with the R-locus of the related object referent, we could assume the effect to be a task-related effect from the P300 family, with regard to memory processes. The first sentence introduced and located a referent within the signing space. This raises an expectation in the second sentence on the final verb to agree with the object and thus with the R-locus 3a, respectively. In the correct condition this expectation is affirmed. The positivity effect for the correct condition could thus reflect a confirmation of topic continuity or fundamental memory processes associated with the referent assigned to the corresponding R-locus. However, the positivity effect observed here, with a left-frontal distribution, certainly does not coincide with the classic observation of a posterior distributed P3b. Up to now, there are no reported ERP studies investigating the causes and the topographic distribution of a P300 during sign language processing. But, in studies observing N400 effects it is well documented that the topography of the effect can vary depending on the input modality (Domalski, Smith, & Halgren, 1991; Wolff, Schlesewsky, Hirotani, & Bornkessel-Schlesewsky, 2008). Hence, the interpretation of the left-anterior effect here can only be speculative until further research is conducted.

In summary, unspecified agreement violation in continuous sentence processing, as we have investigated here, did not elicit a biphasic pattern of LAN and P600 as typically found for morpho-syntactic agreement violation in spoken languages (cf. Molinaro et al., 2011) or as has been reported by Capek et al. (2009) and Hänel-Faulhaber et al. (2014) in sign languages. Instead, we observed a posterior positivity effect for the mismatch condition related to nonmanual cues prior to the actual sign onset. Subsequently, a left anterior effect emerged in relation to the sign onset that can be interpreted as a positivity for the correct condition, reflecting affirmation of topic continuity. From a neurolinguistic perspective, sign language agreement is not a mere morpho-syntactic phenomenon, but also has pragmatic facets. This might also explain the relatively high acceptance rate of incorrect sentences recorded in the behavioural data. The estimate probability for accepting sentences with mismatch agreement verbs was 40.3% (compared to 94.4% for accepting sentences in the match condition). One explanation for these results could be that participants did not interpret these sentences as grammatically or semantically incorrect, but rather as infelicitous; either because these sentences were pragmatically not well-formed, or because the incorrect agreement verb could be reinterpreted in the sense that another referent is introduced into the context. Another explanation comes from the fact that DGS is a social minority language with a high variability and no standardized form, which has not been used or taught at schools for the Deaf. Deaf signers, even native signers, are therefore not trained to evaluate their language on a meta level and they have a high tolerance for signs deviating from the signs they usually use. Hence, the high acceptability rates may come from a very tolerant attitude towards their native language.

In the following section, we discuss experiment B, where we aimed to examine a more far-reaching case of agreement violation by conducting an experiment on agreement violation with plain verbs that – against their lexically specified nature – “agreed” with a 3rd person object.

3. Experiment B: Agreement violation with plain verbs

As described in Section 1.1, plain verbs are lexically specified verbs with a certain path movement and a specified initial and final hold. In contrast to agreement verbs, they do not inflect for person or number features of the verbs’ arguments. In order to create a morpho-syntactic violation, we simulated object agreement with plain verbs in experiment B. We transferred the sign language agreement principle and manipulated the path movement of plain verbs so that they inflect for a 3rd person object.

3.1 Experiment B: Materials and methods

3.1.1 Participants

For experiment B, we evaluated the data of 14 deaf native DGS signers (3 female, 11 male; mean age: 29, range 16-52). Equivalent to experiment A, all signers had deaf parents or DGS input before the age of three and reported DGS to be their native language. They met the same requirements on normal or corrected-to-normal vision as in the previous experiment, were right-handed, and reported no history of neurological disorders. In total, 18 deaf native DGS signers participated in the experiment as paid volunteers. However, two participants had to be excluded from the final data analysis due to experimenter fault, whereas a further two participants had to be excluded due to excessive eye movement artefacts.

3.1.2 Materials

For the production of the stimulus material for experiment B, we worked with the same deaf informants and followed the same design as in experiment A. Thus, the materials also comprised 40 sentences for each critical conditions (*match* versus *mismatch*), as illustrated in example (3) in Section 1.3. Critical sentences consisted of three signs: a 1st person pronoun, a 3rd person referent, and a frequent plain verb, which was either a body anchored verb such as LIKE and KNOW in DGS or a non-body anchored verb such as PLAY and BUY in DGS. (A comprehensive list of stimulus sentences is provided in Appendix A.) The corresponding correct and incorrect sentences between conditions were identical, except for the critical plain verb in sentence final position. In the *match* condition, plain verbs were performed in their lexically specified manner, comprising a hold-movement-hold syllable structure (HMH). In the *mismatch* condition, plain verbs began in their lexically specified manner, but the path movement of the verb was manipulated so that it extended towards the R-locus 3a on the ipsilateral side of the signer. We did not violate the HMH syllable structure by adding an additional but separate movement. Instead, we instructed our informants to stretch the lexically specified movement into a deviant path towards the R-locus 3a. In light of the experimental manipulation, note that these constructed plain verbs do not exist in this phonological form. They have been created according to the agreement rule deduced from agreement verbs: A location overlap between the final-hold of the verb and the R-locus associated with a referent marks agreement with the object of the sentence.

Based on Hosemann (2011)'s findings and parallel to experiment A, informants were asked to express the manual "agreement" additionally with the nonmanual components eye gaze and head tilt. Hence, we instructed our informants to gaze towards the locus 3a with plain verbs in the mismatch condition. In the match condition, gaze was continuously directed towards the camera. In this type of violation, the initial hold and the beginning of the path movement were identical for verbs of both conditions, whereas the moment of mismatch appeared in the middle of those verbs with agreement marking. The moment of mismatch was indicated during the movement path by a change in hand orientation, path direction, and eye gaze towards the locus 3a. Figure 4 in Section 1.3 shows the two different path movements of a lexically specified plain verb (a) and the manipulated plain verb that agrees with the locus 3a.

The production of the materials with respect to recording and technical preparation was identical to experiment A, described in Section 2.1.2. In total, the videos had an average length of 5.26 seconds (sd 0.38). A further 10 sentences were constructed in the same way to function as practice sentences. These contained correct sentences with plain verbs and were not part of the actual experiment.

3.1.3 Procedure

The experimental procedure was identical to that in experiment A, as described in Section 2.1.3.

3.1.4 EEG recording

The EEG recoding set up was identical to the one in experiment A, as described in Section 2.1.4.

3.1.5 EEG data preprocessing and statistical analysis

The EEG data preprocessing was identical to experiment A. Videos were presented in an unsliced manner and ERP averages were calculated relative to three different trigger points: first the *sign onset*, then the moment of *nonmanual cues*, followed by the manual *mismatch onset*. Since the moment of sign onset was identical for match versus mismatch verbs and the definition of the trigger was the same as in experiment A, we only define the two other trigger positions here:

(a) *Nonmanual cues (nmc)*. Since for the mismatch condition, eye gaze and head tilt towards the location 3a was not always time aligned with the change in the manual movement path, we decided to set two different trigger positions. This nonmanual cue trigger was defined as the first frame in which eye gaze (or head tilt) towards the respective R-locus

3a was clearly identifiable. On average, this trigger occurred 374 ms (sd 272 ms) after the sign onset.

(b) *Mismatch onset (mmo)*. This trigger was placed at the first frame during the manual movement path of the verb in which the hand orientation left its lexically specified path and directed towards the R-locus 3a. On average, this trigger occurred 457 ms (sd 207 ms) after the sign onset and 82 ms (sd 173 ms) after the moment of nonmanual cues.

Note that the triggers *nonmanual cues* and *mismatch onset* were defined according to criteria that apply only to mismatching verbs, since correct plain verbs have no movement in gaze or a deviation in the movement path. In the matching verb counterparts, these triggers were time-locked to correlating moments during the path movement, where no deviation appeared. Average durations from sign onset to sign offset were 596 ms (sd 240 ms) for *matching* plain verbs and 787 ms (sd 168 ms) for *mismatching* plain verbs. The difference in sign length between conditions is based on the longer movement path for mismatching plain verbs.

The statistical analysis of the ERP data of experiment B was carried out similarly to experiment A in a hierarchical manner, using R (Team, 2012) and the ez package (Lawrence, 2012). Thus, repeated measures analysis of variance (ANOVAs) were calculated with the factor CONDITION (*match* vs. *mismatch*) and topographical region of interest (ROI). Lateral ROIs were defined as: *left-anterior* (F3, F7, FC1, FC5, C3), *right-anterior* (F4, F8, FC2, FC6, C4), *left-posterior* (CP1, CP5, P3, P7, O1), and *right-posterior* (CP2, CP6, P4, P8, O2). The midline electrodes, FZ, CZ, CPZ, PZ, and OZ were each treated as individual ROIs.

3.2 Experiment B: Results

3.2.1 Behavioural data

The statistical analyses of the behavioural data in experiment B were conducted identically to those in experiment A, described in Section 2.2.1. Empirical probabilities for the acceptability judgment in experiment B were as follows: sentences with correct plain verbs (i.e. match): 91.9% acceptability; sentences with incorrect plain verbs (i.e. mismatch): 52.3% acceptability. The estimated probability for accepting sentences in the match condition was 94.7% (with a 99% credible interval between 87.0-98.8%). The estimated probability for accepting sentences in the mismatch condition was 54.1% (with a 99% credible interval between 24.0-82.4%); Bayesian p-value: $p = 0.0015$. The estimate probabilities for the evaluation judgment in experiment B are illustrated in Table 2 (95% credible interval shown in percentage in square brackets):

Table 2. Estimate probabilities for the evaluation judgment in experiment B.

	"not sure at all"	"not sure"	"sure"	"very sure"
Cond. match	29.4% [3.2, 76.8]	10.5% [2.3, 24.0]	18.2% [4.3, 34.1]	42.0% [10.1, 70.7]
Cond. mismatch	17.3% [3.1, 47.2]	19.7% [6.4, 40.0]	27.1% [2.5, 59.3]	35.9% [6.2, 69.5]

3.2.2 ERP data

In Figures 7, 8, and 9, we present grand averages for DGS sentences with agreement violation on plain verbs in comparison to correct control sentences with lexically specified plain verbs. In Figure 8, these are time-locked to the first moment of mismatch during the path movement of the critical verb indicated by an eye gaze change towards the R-locus 3a (trigger *nonmanual cues*). In contrast, in Figure 9, ERPs are time-locked to the following moment of mismatch indicated by a manual deviation in the orientation of the hand (trigger *mismatch onset*). Furthermore, Figure 7 displays grand averages for match and mismatch sentences, time-locked to the sign onset of the plain verbs.

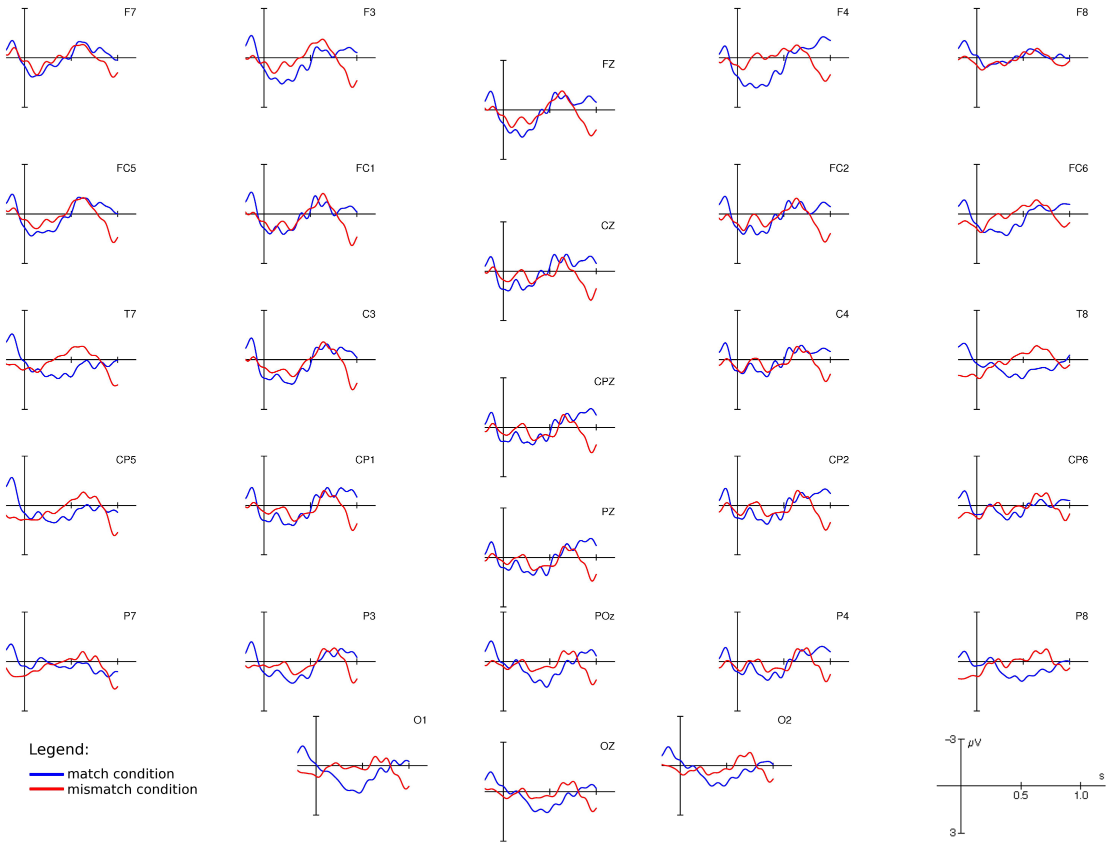

Figure 7. Grand average ERPs for matching (blue line) and mismatching (red line) plain verbs, time-locked to the trigger *sign onset*. Negativity plotted upwards.

As is apparent from Figure 7, ERP waves relative to the sign onset do not differ in the time window of about 0-700 ms. Since the mismatch between conditions started approximately 374 ms (trigger nonmanual cues) and, respectively, 457 ms (trigger mismatch onset) into the sign, the ERP effect undergoes a latency shift and is thus correlated to trigger *nmc* or *mmo* instead of to the sign onset. Hence, at both triggers – nonmanual cues and mismatch onset – appears a broadly distributed positive deflection for mismatching plain verbs compared to matching plain verbs. At the trigger *nmc*, the positivity occurs in the time window 470-820 ms, while it occurs in the time window 420-730 ms for trigger *mmo*.

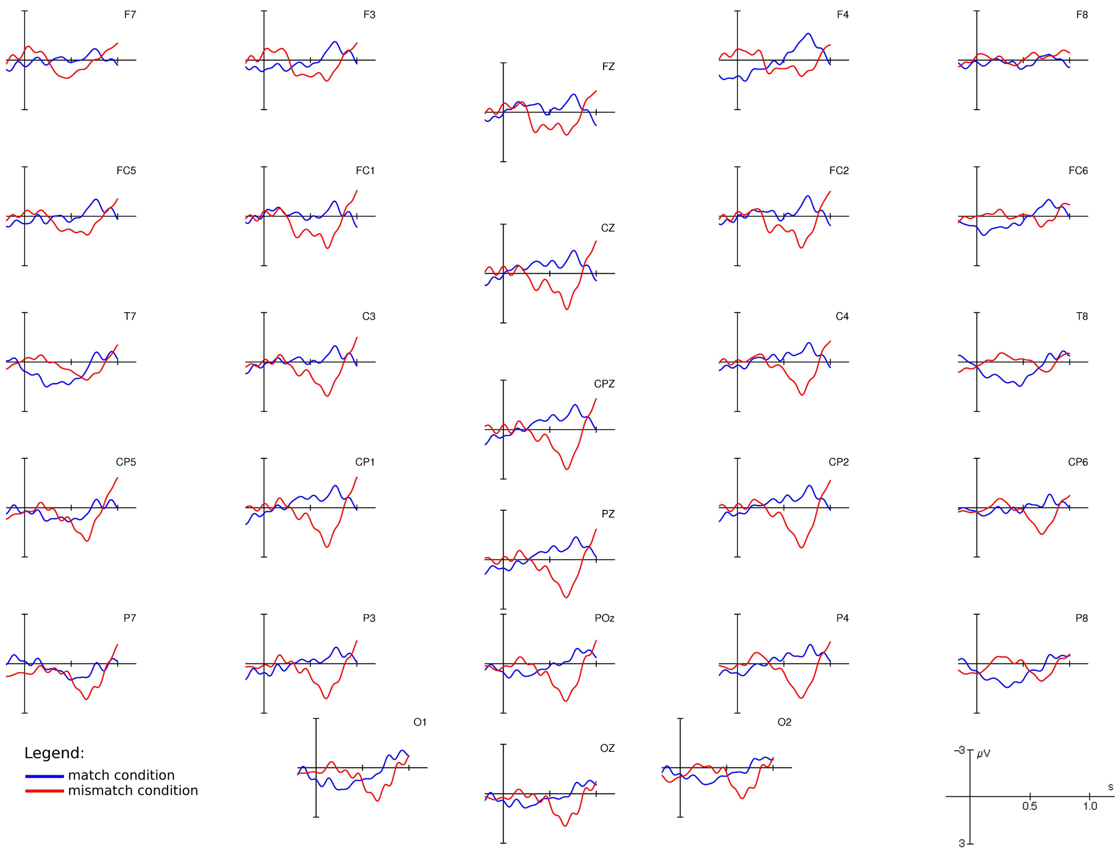

Figure 8. Grand average ERPs for matching (blue line) and mismatching (red linie) plain verbs, time-locked to the trigger *eye gaze onset*. Negativity plotted upwards.

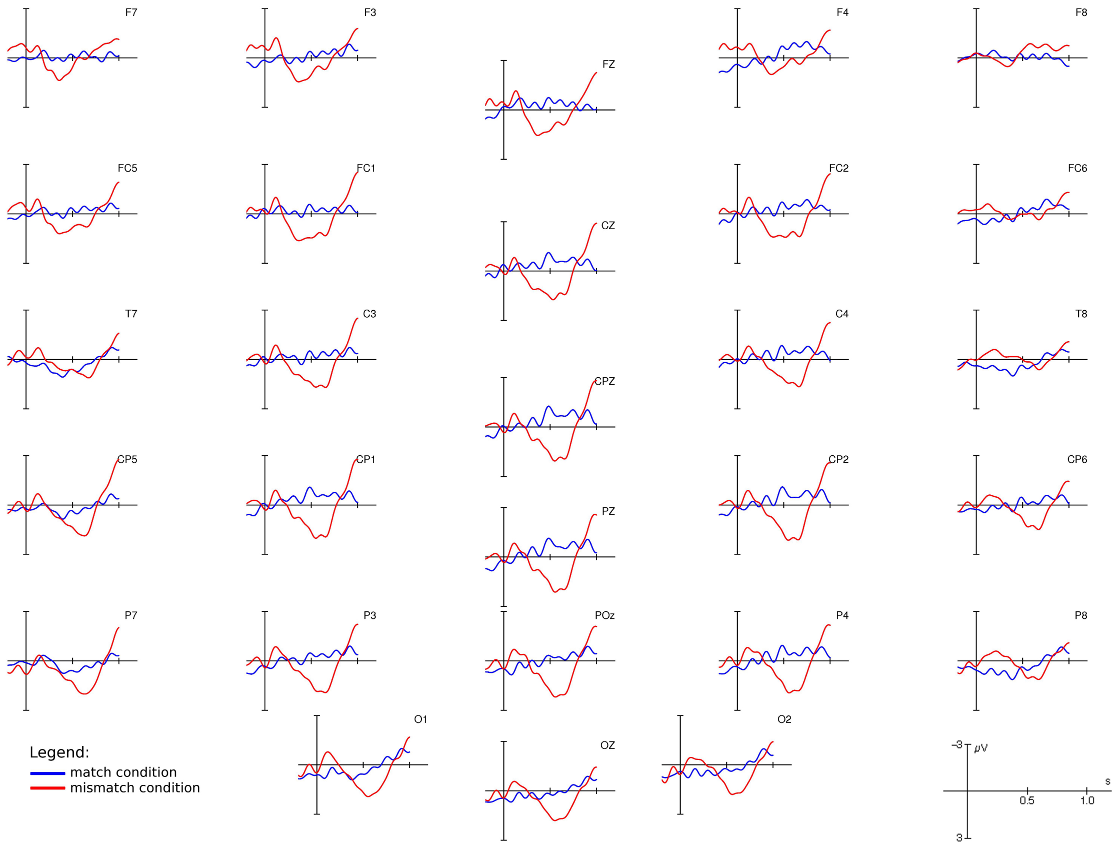

Figure 9. Grand average ERPs for matching (blue line) and mismatching (red linie) plain verbs, time-locked to the trigger *mismatch onset*. Negativity plotted upwards.

This descriptive impression was confirmed by the statistical analysis. For the 470-820 ms time window at trigger nonmanual cues, lateral electrodes show an over-all main effect for CONDITION: $F(1,13) = 17.00$, $p < 0.01$; while midline electrodes show a CONDTION to ROI interaction ($F(1,13) = 4.19$, $p < 0.05$), with the following significance for the electrodes Fz: $F(1,13) = 8.04$, $p < 0.05$; Cz: $F(1,13) = 36.32$, $p < 0.0001$; CPz: $F(1,13) = 53.97$, $p < 0.00001$; Pz: $F(1,13) = 56.77$, $p < 0.00001$; POz: $F(1,13) = 12.70$, $p < 0.01$; and Oz: $F(1,13) = 8.56$, $p < 0.05$. For the 420-730 ms time window at trigger mismatch onset, lateral electrodes also show an over-all main effect for CONDITION: $F(1,13) = 24.65$, $p < 0.001$. Additionally, midline electrodes show a CONDTION to ROI interaction

($F(1,13) = 4.79$, $p < 0.05$), with the following significance for the electrodes Fz: $F(1,13) = 9.48$, $p < 0.01$; Cz: $F(1,13) = 32.65$, $p < 0.0001$; CPz: $F(1,13) = 47.16$, $p < 0.0001$; Pz: $F(1,13) = 42.63$, $p < 0.0001$; POz: $F(1,13) = 21.82$, $p < 0.001$; and Oz: $F(1,13) = 14.68$, $p < 0.01$. According to visual inspection of the trigger mismatch onset, there is an early negativity effect in the time window 40-190 ms post trigger onset, which was not significant ($F(1,13) = 3.24$, $p > 0.09$).

3.3 Experiment B: Discussion

In contrast to the results of experiment A, artificial agreement violation with plain verbs elicited a broadly distributed positivity effect in the time window of approximately 470-820 ms after the trigger nonmanual cues, i.e. the first cue of the nonmanual mismatch. The effect also appeared relative to the manual mismatch, 420-730 ms post trigger mismatch onset. Interestingly, artificially manipulated plain verbs did not elicit an N400 effect and thus were not interpreted as semantically incongruent. We therefore conclude that participants understood the semantics of the mismatch plain verbs. In addition, this type of violation did not elicit a classic biphasic pattern of LAN and P600, as no left anterior negativity was engendered. However, the elicited broadly distributed late positivity can be an instance of a P600. Parallel to the interpretation of the effects described in experiment A, the results of experiment B can be interpreted in the framework of different theoretical approaches. The late positivity elicited by incorrect plain verbs may indicate either a violation of well-formedness in the sense of the *extended Argument Dependency Model* (eADM) by Bornkessel & Schlesewsky (2006) or it could reflect additional costs in the sense of context updating as proposed by work from Schumacher (e.g., Baumann & Schumacher, 2011), both approaches already discussed in Section 2.3.1.

In light of the eADM, the late positivity effect could be explained as caused by an evaluation process during the third phase of constituent comprehension. Note that we instructed our informants to sign the verb with a lengthened path movement directing towards the locus 3a in the signing space. Thus, we did not violate the HMH syllable structure of plain verbs. The modified path movement could be interpreted as an inaccurate or infelicitous production of the sign. Mismatching plain verbs would hence not be interpreted as morpho-syntactically incorrect but rather as less acceptable and not well-formed, i.e. a violation of the verb's phonological specification. In a different explanation in the sense of Baumann & Schumacher (2011) and Huang & Schumacher (2012, 2014), the positivity effect could also reflect the need to update the situation model. Similarly to agreement verbs, which can assign R-loci to new referents prior to their explicit introduction, the ending of the plain verbs at the locus 3a could indicate that the sentence is not completed and a further proposition needs to follow. This would require enhanced processing costs for updating the context. After evaluating the ERP data, we conducted an informal post-experimental behavioural feedback task to get further insight into the possible functional interpretations of the effect. We asked nine deaf and two hard of hearing members of the Deaf community around Göttingen (5 female, 6 male) about their intuition on the stimulus sentences with incorrect plain verbs (e.g., I GRANDMA WAIT_{3a} or I LAPTOP BUY_{3a}). If their first intuitive feedback was in the sense of "what is coming next?" or "what is happening then?", this would indicate that the sentences were not completed and that participants would expect a further proposition to fulfil the sentence. This kind of response would emphasize the explanation that context updating caused the late positivity effect. In contrast, if the first feedback of signers was in the sense of "this is strange" or "this is wrong", it would support the idea that signers interpreted the sentences as not felicitous and not well-formed. Furthermore, if signers' first feedback was in the sense of "I wait for grandma" or "I buy the laptop there", it would highly indicate that the extended path movement of the plain verbs towards the locus 3a in fact refers to the object of the sentence. As a result, the signers general first reaction was that these sentences are strange and do not exist in DGS. None of the signers asked how the sentences proceed. The behavioural feedback in this informal post-test suggests that the extended movement path in agreeing plain verbs is rather a violation of well-formedness than an indication for further context information. Hence, incorrect plain verbs as presented here were not judged as possible agreeing verbs.[6] This observation could also explain the behavioural results of the acceptability judgment, which participants performed during the experiment. Although an estimate probability of 54.1% for accepting mismatch sentences is near chance level, we can exclude that participants were uncertain about their assignment, because the acceptance rate for sentences with correct plain verbs was 94.7%. Hence, we assume a similar explanation as already discussed for experiment A in Section 2.3. Note that it is uncertain with what type of spoken language phenomenon the "inflected" plain verbs in experiment B can be compared to. Apart from this first study, agreement violation with plain verbs has not yet been investigated with online measuring methods. It is necessary to conduct further experiments on this topic, in order to shed enough light on the correlation between the underlying linguistic principle and the perhaps modality-specific ERP components. Thus, a definitive interpretation of the results is not possible at this stage.

[6] This stands in contrast to deaf children learning a sign language as native language, who overgeneralize the agreement principle and produce plain verbs in agreeing forms (Bellugi, Poizner, & Klima, 1993; Newport & Meier, 1985; Hänel, 2005); or in contrast to plain verbs going through a grammaticalization process and becoming agreeing verbs (Meir 2016). We thank an anonymous reviewer for pointing out this difference.

4. General discussion and conclusion

In the two experiments, we investigated incorrect forms of agreement verbs and plain verbs in sentential contexts of natural signing. In contrast to morpho-syntactic agreement violation studies in spoken languages (cf. Molinaro et al., 2011) and in contrast to previous agreement violation studies in sign languages (Capek et al., 2009, Hänel-Faulhaber et al., 2014), incorrect agreement verbs and incorrect plain verbs in the present studies did not elicit a biphasic pattern of LAN and P600. Instead, in experiment A, unspecified agreement verbs elicited two rather independent effects: first, a right posterior effect, followed by a left anterior effect, which seem to reflect separate cognitive processes. In experiment B, artificially inflected plain verbs elicited a broadly distributed positive deflection. One of the main differences between incorrect agreement verbs and incorrect plain verbs is that incorrect agreement verbs involve a contextually inappropriate or unexpected path movement and/or hand orientation, which can be appropriate in a different context. In contrast, the path movement as well as the initial- and final-hold of plain verbs is lexically specified, so the incorrect form – as constructed in the present experiment – is not appropriate in any context.

Comparing the results of experiment A and experiment B with the two previous studies on agreement violation in sign languages (i.e., Capek et al., 2009, Hänel-Faulhaber et al., 2014), we can observe different forms of agreement violation. In Table 3, we list the different types of agreement violation with agreement verbs and with plain verbs, allocated to the studies they appeared in and the ERP effects they elicited. The "setting" provides information about the referents of the sentences (abbreviated with "R") and the respective loci they were associated with. Further, we contrast the correct verb form with the incorrect verb form that was used.

Table 3. List of different types of agreement violations, (R = referent; L = locus; *nmc* = trigger *nonmanual cues*; *so* = trigger *sign onset*).

Viol.	**used in…**	**setting**	**corr.**	**incorr.**	**ERP effect**
(1)	• Capek et al. (unspecified agr.) • Experiment A	R1 = signer (L.1), R2 = 3rd person (L.3a)	$_{1}$VERB$_{3a}$	**$_{1}$VERB$_{3b}$**	• Capek: early anterior negativity (200-360 ms, right hemispheric), late positivity (425-1200 ms); • Experiment A: a preceding right posterior positivity (220-570 ms, *nmc*), a following left anterior effect (300-600ms, *so*), probably unrelated to each other.
(2)	• Capek et al. (reverse agr.)	R1 = signer (L.1), R2 = 3rd person (L.3a)	$_{1}$VERB$_{3a}$	**$_{3a}$VERB$_{1}$**	early anterior negativity (140-200 ms, left hemispheric), late positivity (475-1200 ms);
(3)	• Capek et al. (reverse agr.)	R1 = 3rd person (L.3a), R2 = 3rd person (L.3b)	$_{3a}$VERB$_{3b}$	**$_{3b}$VERB$_{3a}$**	not analysed separately but together with (2)
(4)	• Capek et al. (unspecified agr.)	R1 = 3rd person (L.3a), R2 = 3rd person (L.3b)	$_{3a}$VERB$_{3b}$	**$_{3b}$VERB$_{N}$** (neut.)	not analysed separately but together with (1)
(5)	• Hänel-Faulhaber et al.	R1 = 3rd person (L.3a), R2 = 3rd person (L.3b)	$_{3a}$VERB$_{3b}$	**$_{N}$VERB$_{1}$**	left anterior negativity (400-600 ms) late posterior positivity (1000-1300 ms)
(6)	• Experiment B	R1 = 3rd person (default L.3a)	VERB (no agr.)	**VERB$_{3a}$**	broadly distributed positivity (420-730 ms, *nmc*)

As can be seen in Table 3, verb agreement – expressed by the path movement of the verb from subject location to object location – can be violated in structurally different ways: by means of a reverse path movement (violation 2 and 3), by a movement from correct subject location to an unspecified object location (violation 1), by a movement from the object location towards an unspecified neutral location (violation 4), or by a movement from an unspecified location towards the location of the signer who was neither the subject nor the object of the sentence (violation 5). Each type of agreement violation entails a possibly different alternative interpretation. We want to exemplify this on an original example from Capek et al. (2009) in example (4).[7]

(4) BOY IX_{3a}, GIRL IX_{3b} TWO-OF-THEM PLAY++ (ASL)

BOY __________ GIRL IX_{3b}, WRONG IX_{3b} $FALL_{3b}$

'There was a boy and a girl and they were playing. The boy chased the girl, but oops, she fell.'

Correct: ${}_{3a}CHASE_{3b}$

Reversed: $*{}_{3b}CHASE_{3a}$

Unspecified: $*{}_{3a}CHASE_{1}$

The referent BOY is associated with the R-locus 3a on the right (ipsilateral) side of the signer, while the referent GIRL is associated with the locus 3b on the left (contralateral) side of the signer. In the correct sentence, the verb CHASE moves from 3a to 3b, meaning that the boy chases the girl. Since in ASL the verb is articulated preceding the object, the sentence BOY ${}_{3b}CHASE_{3a}$ GIRL … with a reversed verb movement might also be interpreted as a topic

[7] In the original example, locations were identified with letters "e" and "c", and index signs were indicated by PRO. For reasons of uniformity, we replaced the letters with subscript "3a" and "3b" and changed PRO into IX. "++" marks a reduplication of the verb.

construction with a subordinate clause, meaning 'the boy, the girl chases him, …'. Note that topic constructions in ASL are typically produced with raised eyebrows (Aarons, 1994; Wilbur, 2012) and we assume this was not the case in the present example. However, we would like to claim that this could be a possible interpretation at the moment of processing the verb $_{3b}$CHASE$_{3a}$. A notable incongruence, indicated by a missing verb of the matrix clause would appear only afterwards. Furthermore, in the incorrect sentence BOY $_{3a}$CHASE$_{1}$ GIRL … used by Capek et al. (2009) for unspecified verb agreement, the verb ends at the location of the signer, which may lead to the relative clause interpretation 'the boy, (who) he-chases-me, …'. This example shows that different forms of "incorrect" verb agreement can lead to different possible (but in this context not salient) reinterpretations. Accordingly, the ERP responses that were found in each study could be caused by different cognitive processes and should thus not be interpreted as the result of a single morpho-syntactic agreement violation. We therefore question, whether participants actually interpret these agreement violations as syntactic anomalies, as proposed by Capek et al. (2009: p. 8787): „The distribution of the P600 effects for processing ASL syntactic violations is similar to that reported in studies of written and spoken language processing." Within their design, Capek and colleagues combined different kinds of agreement violation under one category (e.g., unspecified agreement violation) and further used different types of verbs: typical agreement verbs like CHASE, verbs that do not necessarily take two animate arguments (and are thus not agreement verbs according to Rathman & Marthurs' 2002 definition) like WASH in CAR… I MUST $_{1}$WASH$_{3a}$, and backwards verbs like COPY. Thus, these different types of verbs and the corresponding different types of incorrect forms could have evoked different neurophysiological responses. Capek et al. (2009) themselves discuss that verbs in reverse agreement form can also be semantically incongruent: The sentence CAR CL$_{3a}$… I MUST **$_{3a}$WASH$_{1}$** with reverse verb agreement can mean 'I must car-washes-me.' which describes also a semantic violation. However, they claim that participants interpreted this as a syntactic anomaly, because the neurophysiologic response to reverse agreement violation was a P600 instead of an N400 effect. In our sense, this conclusion seems to be drawn too quickly, regarding that the one-to-one mapping of language related ERPs and linguistic domains is questionable. As discussed in Bornkessel-Schlesewsky & Schlesewsky (2008), an increasing number of studies report "semantic P600" effects. We therefore doubt that the late positivity effects found for sign language agreement violation (with agreement verbs) merely result from a syntactic violation.

The study by Hänel-Faulhaber et al. (2014) investigates a completely different type of agreement violation. In a first sentence, two 3rd person referents were associated on the ipsi- and contralateral side of the signer (i.e. locus 3a and 3b). However, incorrect agreement verbs moved from a neutral location opposite the signer (locus 3c) towards the location of the signer (locus 1). Thereby, the incorrect verb form marked an unspecified referent as the subject (at the neutral location) and the signer as the object, two contextually unassociated or less accessible loci. Although the neutral location opposite the signer could be interpreted as marking the addressee (and thereby the participant of the experiment), the incorrect verb form, e.g. $_{3c}$NEEDLE$_{1}$, can hardly be reinterpreted with the two previously introduced referents: BOY POINT$_{3a}$ GIRL POINT$_{3b}$ $_{3c}$NEEDLE$_{1}$ […] (Hänel-Faulhaber et al., 2014: p. 7). Since DGS is an SOV language, the incongruence between subject and object position and the incorrect agreement verb at the end of the sentence is more difficult to reinterpret compared to the agreement violations presented in Capek et al. (2009) or in our current experiment A. Although this type of agreement violation comes closer to a morpho-syntactic agreement violation in a spoken language, the referential loci in signing space cannot be disentangled from a semantic and pragmatic component.

The status of sign language agreement is evidently distinct from agreement in spoken languages. That is to say, the agreement system in one spoken language compared to that of another spoken language shares more core principles than the agreement systems of a spoken language and a sign language. In addition to the obvious modality-specific aspects of agreement in sign languages – the gestural origin, the use of the signing space, and the fact that only a subset of verbs can agree in sign languages –, neurophysiological correlates to agreement violation in sign languages also emphasize the modality-specific status of the phenomenon. The two present ERP studies on agreement violation in DGS show that verb agreement in sign languages is diverse and some of the agreement patterns cannot be equated with morpho-syntactic verb agreement in spoken languages. Agreement violation of agreement verbs can be realized in several different forms that imply different alternative interpretations. In contrast, agreement violation with plain verbs is a violation of the verbs lexical specification. Different kinds of agreement violation seem to evoke different ERP responses due to processing costs of either updating the situation context or evaluating the processed item as not well-formed.

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