

The processing of flexible syntax–semantics mappings: A neurophysiological investigation of split-intransitivity in German

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Abstract

Language comprehension requires a real time mapping between form and meaning. According to the Split Intransitivity Hierarchy, the interaction of telicity and agentivity creates gradient auxiliary preferences for intransitive verbs, ranging from categorical (rigid) to highly variable (flexible). This raises the question of how flexibility at the syntax–semantics interface affects language comprehension. In the present ERP study, we examined whether auxiliary selection with flexible verbs engenders quantitatively or qualitatively different neurophysiological responses to that for rigid verbs, and whether the compositional specification of telicity (via prefixation) leads to different processing signatures compared to the inherent lexical specification. Dispreferred auxiliary choices engendered a biphasic N400/late positivity pattern for rigid and prefixed verbs. The N400 for prefixed verbs had a later onset, indicating a quantitative difference between compositional and lexically specified telicity. Flexible verbs showed no effect of auxiliary choice in the average ERP. However, an additional linear mixed models analysis revealed an interaction between auxiliary selection and individual by-item / by-subject acceptability ratings. While item-based ratings proved a better predictor for N400 amplitude, subject-based ratings proved a better predictor for the late positivity amplitude. Thus, N400 amplitude is closely tied to inherent lexical properties, while the late positivity reflects individual participants' propensity to accomplish pragmatic enrichment.

1 Introduction

Successful language comprehension requires a real time mapping between form and meaning.

To this end, the language processing system can exploit correspondences between syntax and semantics. However, in some cases, the syntax–semantics interface displays considerable flexibility, thus raising the question of how multiple possible mappings affect language comprehension. For example, in the domain of split intransitivity, there are verbs that can select either BE or HAVE depending on the characteristics of the predicate (Levin & Rappaport Hovav, 1995). Under these circumstances, an auxiliary thus does not provide the language processing system with an unambiguous indication of verb meaning / semantic role of the subject. The present ERP study examined split intransitivity in German as a testing ground for flexibility at the syntax–semantics interface. Sorace (2000) has proposed that intransitive verbs are organized in a Split Intransitivity Hierarchy defined by telicity ("telic change") at the core of unaccusativity and agentivity ("atelic non motional activity") at the core of unergativity. (see Fig. 1).

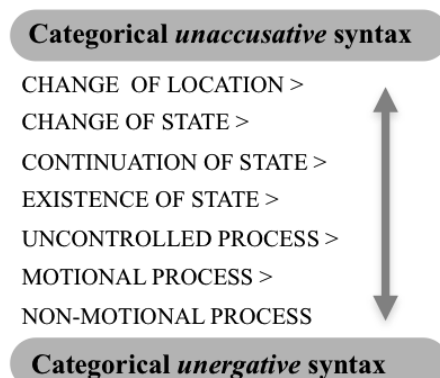


Figure 1. The Split Intransitivity Hierarchy

The interaction of these factors creates gradient auxiliary preferences, ranging from categorical

(rigid) to highly variable (flexible). The closer to the core a verb is, the more determinate its syntactic status as either unaccusative or unergative, whereas the distance of a verb from the core correlates with sensitivity to contextual or compositional factors.

2 Materials and methods

Stimulus materials (see Table 1) included core unaccusative (change of location=CH-LOC), and core unergative verbs (controlled non-motional process=CON-PROC) as well as an intermediate verb class that is not inherently specified for telicity (change of state=CH-STATE-(UN)). By presenting each of these verb classes with both BE and HAVE, we examined whether auxiliary selection with non-core (flexible) verbs engenders quantitatively or qualitatively different neurophysiological responses to that for core (rigid) verbs and to what degree these neural processing signatures correlate with acceptability judgements. We additionally included prefixed change of state verbs (CH-STATE-(PRE)) to investigate whether the compositional specification of telicity (via prefixation) leads to different processing signatures compared to the inherent lexical specification. Hence, the experiment employed 4 verb classes (à 8

different verbs). Eighty sentences were constructed per verb class (with 10 different sentence contexts per verb). All sentences had the form NP / AUXILIARY / ADVERB / PAST PARTICIPLE, half included the auxiliary SEIN and half the auxiliary HABEN, thus resulting in 320 sentences plus 80 fillers of the same form (see Table 1 for examples). All sentences were presented visually in a segmented manner (NPs/verbs for 450 ms, all other segments for 400 ms with an ISI of 100 ms), followed by an acceptability judgment and a subsequent probe detection task. Thirty-two right-handed, monolingually raised native speakers of German (17 female) between 20 - 30 years of age (mean age: 23.97) participated in the experiment. The EEG was recorded from 64 Ag/AgCl-electrodes (500 Hz sampling rate, referenced to the left mastoid, and re-referenced to linked mastoids offline). The raw EEG data were filtered offline with a 0.3-20 Hz band pass. Automatic and manual rejections were carried out to exclude periods containing movement or technical artifacts. Average ERPs were calculated per condition per participant from -200 ms to 1000 ms relative to the onset of the critical sentence-final verb, before grand-averages were computed over all participants. For the statistical analysis,

Condition		Acceptability (%)	
Verb class	Example	HABEN	SEIN
CH-LOC	Die Bergsteigerin ist/*hat vorsichtig <u>aufgestiegen</u> . <i>The mountaineer is/has carefully climbed</i> 'The mountaineer climbed carefully'	1.9 (3.0)	93.5 (6.0)
CH-STATE-(UN)	Die Dose ist/hat sofort <u>gerostet</u> . <i>The tin is/has immediately rusted</i> 'The tin rusted immediately.'	61.0 (17.0)	65.0 (19.6)
CH-STATE-(PRE)	Das Auto ist/*hat langsam <u>verrostet</u> . <i>The car is/has slowly corroded</i> 'The car corroded slowly.'	6.0 (4.4)	88.6 (8.6)
CON-PROC	Die Lehrerin *ist/hat dauernd <u>geredet</u> . <i>The teacher is/has constantly talked</i> 'The teacher talked constantly.'	94.3 (5.7)	1.2 (2.3)

Table 1. Example sentences for the critical conditions in the present study as well as mean acceptability ratings (critical word underlined). Standard deviations (by participants) are given in parentheses. Abbreviations: CH-LOC = change of location; CH-STATE-(UN) = unprefixated change of state; CH-STATE-(PRE) = prefixed change of state; CON-PROC = controlled non-motional process.

repeated measures analyses of variance (ANOVAs) were computed for mean acceptability ratings using the condition factors VERB and AUX(iliary) and the random factors participants (F_1) and items (F_2), and for average ERPs using the condition factors VERB and AUX(iliary) and the topographical factor region of interest (ROI).

3 Results

Mean acceptability ratings for the judgment task are given in Table 1. The statistical analysis revealed a significant interaction of VERB x AUX ($F_1(3,93) = 246.2, p < .001$; $F_2(3,316) = 59.23, p < .001$), which was due to a significant preference for HABEN for CON-PROC verbs, a significant preference for SEIN for CH-LOC and CH-STATE-(PRE) verbs (all F_1 s and F_2 s < 0.001) and no significant preference for one auxiliary over the other for CH-STATE-(UN) verbs.

As is apparent from Figure 2, sentences with a dispreferred auxiliary led to a biphasic N400 - late positivity response for core verbs (CH-LOC; CON-PROC), and verbs for which auxiliary choice was determined via prefixation (CH-STATE-(PRE)). Statistical analyses were conducted in two time windows: 380-530 ms for the N400 and 750-900 for the late positivity.

In the N400 time window, the statistical analysis revealed an interaction ROI x VERB x AUX ($F(15,465) = 3.81, p < .002$). Resolving the interaction by ROI showed significant interactions of VERB x AUX in all ROIs (minimal $F(3,93) = 5.09$ in the left-anterior ROI; maximal $F(3,93) = 19.60$ in the left-central and left-posterior ROIs). The simple effect of AUX was examined for each verb class in each of the ROIs showing an interaction VERB x AUX (for all effects reported, $p < 0.05$): CH-LOC verbs showed an effect of AUX in central and posterior regions; for CH-STATE-(PRE) verbs, the effect of AUX reached significance in all central and posterior regions as well as in the left-anterior ROI; CON-PROC verbs showed an effect of AUX in all regions. By contrast, CH-STATE-(UN) verbs did not show a significant effect of AUX in any region.

For the late positivity time window, the statistical analysis revealed an interaction ROI x VERB x AUX ($F(15,465) = 7.13, p < .001$). Analyses within each ROI showed significant interactions of VERB x AUX in all central and

posterior regions (minimal $F(3,93) = 3.47$ at the left-central ROI, maximal $F(3,93) = 15.78$ at the right-posterior ROI). The simple effect of AUX was examined for each verb class in each of the ROIs showing an interaction VERB x AUX (for all effects reported, $p < 0.05$): CH-LOC and CH-STATE-(PRE) verbs showed an effect of AUX in all central and posterior regions; CON-PROC verbs engendered effects of AUX in all central and posterior regions except for the left-central ROI. For CH-STATE-(UN) verbs, no region showed a significant effect of AUX.

In sum, there was no evidence for a *qualitative* distinction in the processing of rigid (core verbs) and more flexible (prefixed verbs) syntax-semantics mappings. However, an additional analysis (examination of the effect of AUX in successive 30 ms time windows) showed that the N400 for CH-STATE-(PRE) verbs had a later onset than that for the other verb types, thereby indicating a *quantitative* difference between compositional and lexically specified telicity.

Importantly, auxiliary choice did not show any modulation of the grand average ERP response for lexically indeterminate verbs (CH-STATE-(UN)). Two scenarios appear to be possible: (a) the syntax-semantics mapping is underspecified such that both HAVE and BE fulfill the processing system's expectations for this particular verb class; or (b) the absence of an effect in the grand averages is a result of the averaging procedure.¹ For a more fine-grained analysis of the ERP data for this verb class we, thus used linear mixed models (Baayen et al. 2008) including the fixed factors AUX and ROI and the crossed random factors participants and items. By-participant acceptability (i.e. individual participants' acceptability ratings for each auxiliary type) and by-item acceptability ratings (i.e. acceptability ratings per auxiliary type for individual items) were included as covariates (in separate models). Mean ERP amplitudes for the N400 and late positivity time windows constituted the dependent variable. For both time windows, the inclusion of acceptability ratings led to an improvement of model fits over a base model without acceptability, as revealed by a likelihood ratio test (all p 's < 0.001). In the earlier time window, the item-based acceptabilities led to a slightly better fitting

¹ I.e. a product of averaging over gradient responses which differ on a trial-to-trial basis.

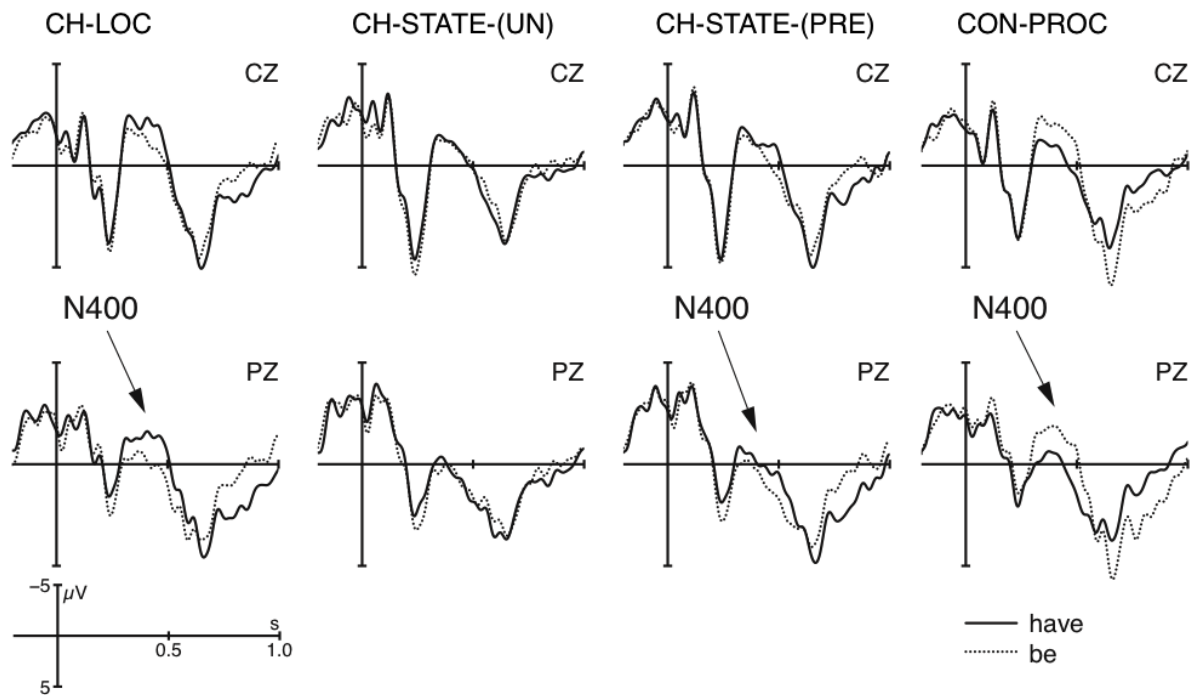


Figure 2. Grand average ERPs at the position of the past participle (onset at the vertical bar) for: (CH-LOC) change of locations verbs, (CH-STATE-(UN)) change of state verbs, (CH-STATE-(PRE)) prefixed change of state verbs, and (CON-PROC) verbs of controlled non-motional process. Negativity is plotted upwards.

model than the subject-based acceptabilities ($\chi^2 = 2.27, p < 0.001$). In the later time window, by contrast, subject-based acceptabilities led to a substantial improvement of the model fit in comparison to item-based acceptabilities ($\chi^2 = 76.49, p < 0.001$).

Discussion

For sentences including a dispreferred auxiliary, we observed a biphasic N400 - late positivity pattern. This pattern was engendered by core unergative verbs (verbs of controlled non-motional process) and core unaccusative verbs (verbs of change of location), i.e. verbs with an inherent lexical specification of the key semantic feature of telicity, and for lexically indeterminate verbs for which the choice of auxiliary was determined by the addition of a telicity-inducing prefix (prefixed change of state verbs). Importantly, there was no evidence for a *qualitative* distinction in the processing of flexible vs. rigid syntax-semantic mappings. The data did, however, provide evidence for a *quantitative* distinction between the processing of these different verb types in the form of an

N400 latency shift. Compositional as opposed to lexically specified telicity led to a longer N400 onset latency, which could be taken as an indication of the additional computational effort required by the composition process. These results are consistent with the SIH and allow a more fine-grained understanding of the neurophysiological bases for the gradient behavioural differences among verbs belonging to the same continuum.

All in all, we interpret the N400 effects observed here as correlates of the mismatch between the processing system's expectation for a particular lexical aspect (as induced by the auxiliary) and the properties of the verb that is actually encountered. When the mismatch is compositional (i.e. induced via the combination of a verb and a telicity-inducing prefix), its detection is computationally more complex than in the case of a direct lexical encoding of telicity, thereby leading to a longer N400 latency. By contrast, we assume that the late positivity reflects a categorisation process by means of which the sentences with a dispreferred auxiliary are classified as ill-formed (Bornkessel & Schleewsky, 2006; Kretschmar, 2010).

Perhaps the most interesting finding of the present study was that sentences with lexically indeterminate verbs (unprefixed change of state verbs, CH-STATE-(UN)) did not show any differences between BE and HAVE in grand average ERPs, and also led to gradient acceptability ratings. An additional analysis of the ERP data for this verb class using linear mixed models revealed an interaction between auxiliary selection and acceptability ratings. Whereas, in the N400 time window, individual item-based acceptability per condition provided a slightly better-fitting model, individual subject-based acceptability per condition proved to be a better predictor for the late positivity time window. This finding suggests that the absence of an effect was likely due to the averaging procedure rather than resulting from the processing system's general indifference to auxiliary selection with this particular class of verbs.

Crucially, these results support the interpretation advanced above that the N400 effects in the present study index a mismatch between an auxiliary-induced expectation and the actual aspectual properties of the verb. In the N400 time window, the interaction between auxiliary type and item-based acceptability was, in part, due to more negative-going ERPs for the HAVE sentences with decreasing item-based acceptabilities. Considering that a change of state implies telicity at some level, these verbs are clearly close to the "BE end" of the split intransitivity hierarchy (see Figure 1). Thus, it appears plausible that these verbs should show an (albeit weak) mismatch when encountered with HAVE.² Strikingly, the late positivity time window showed an inverse pattern with regard to the relationship between ERP effects and acceptability ratings. ERPs tended to be more positive for those individual subjects who showed a higher acceptability for the CH-STATE-(UN) verbs with HAVE.³ We suggest that this positivity response reflects processes of pragmatic enrichment (see Burkhardt, 2006; Burkhardt & Roehm, 2007; Schumacher, to appear). When used with HAVE, verbs of this

² Moreover, the current findings suggest that some of the change of state verbs employed in the present study are more strongly specified for telicity than others.

³ This indicates that, in this case, the positivity response is not simply the reflection of a mismatch between an expected and actually encountered verb type (in which case amplitudes should have been more positive for *lower* acceptabilities).

type call for an enrichment process in order for the change of state to be interpreted as a process rather than as a telic change. If this process of enrichment is successful, the acceptability of CH-STATE-(UN) verbs with HAVE is higher. The correlation with individual participants' acceptability ratings indicates that some participants may have a propensity for aspectual enrichment processes, thus leading them to consider these verbs more acceptable with HAVE in comparison to participants with a lower tendency to enrich.

Conclusion

The present study demonstrated that indeterminacy at the syntax-semantics interface is, in part, processed in a qualitatively similar manner to consistent (rigid) form-to-meaning mappings, while also providing evidence for some degrees of quantitative and qualitative variation. N400 amplitudes were shown to correlate consistently with item-based aspectual preferences. On a trial-by-trial basis, this even appears to be the case for verbs that are lexically not specified for telicity. In addition, N400 latency was modulated by the compositional complexity of the aspectual information: the N400 onset was delayed for verbs in which the preference for BE was brought about compositionally rather than via lexical specification for telicity. Finally, qualitatively different effects for indeterminacy vs. consistency were observed in the late positivity time window. Whereas violations of consistent (rigid) form-to-meaning mappings engendered a late positivity for unacceptable auxiliary selections, the amplitude of the late positivity for indeterminate verbs correlated positively with individual participants' acceptability ratings. We suggest that this distinction reflects a well-formedness categorisation for consistent mappings on the one hand and processes of pragmatic enrichment for flexible (indeterminate) mappings on the other. The latter appear to vary across individual speakers. These findings, on the whole, allow us to gain a better understanding of the gradient effects obtained in previous studies on the SIH and, more generally, of the cognitive bases of gradient variation in language.

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