Plasticity of grammatical recursion in German learners of Dutch

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Abstract

We examined the multilingual comprehension and learning of cross-serial and embedded constructions in German-speaking learners of Dutch using magnetoencephalography (MEG). In several experimental sessions, learners performed a sentence-scene matching task with Dutch sentences including two different verb orders (Dutch or German verb order). The results indicated a larger evoked response for the German order relative to the Dutch order over frontal sensors after three months, but not initially. The response implies that sensitivity to violations of verb order remains plastic into adulthood.

1 Introduction

Psycholinguistic studies have examined cross-serial and embedded complement clauses in West Germanic in order to distinguish between different types of working memory models of human sentence processing (Bach, Brown, & Wilson 1986; Joshi, 1990), and this contrast has been important in applications of Tree-Adjoining Grammar (Joshi, 1985). Many language users are bilingual in German and Dutch, suggesting that they maintain knowledge akin to a synchronized grammar (Shieber and Schabes, 1990). Psycholinguistic studies of production, using syntactic priming, suggest that syntactic representations from L1 and L2 can influence each other during production (Harsuiker and Pickering, 2007). However, these effects seem to be limited to structures where word order is shared. Also, it is not yet well understood how bilingual users comprehend or acquire complement structures. For example, adult language users may have difficulty adopting the verb order preference of another language if it is not consistent with their first language. In principle, this could be the case when German-speaking learners of Dutch learn to adopt the verb order preference of Dutch in infinitival embedded clauses because German does not permit the same verb orders as Dutch (see Section 2.1).

Adult plasticity in the use of these constructions is investigated here by examining the response of German-speaking learners of Dutch using magnetoencephalography (MEG), a measurement technique that can reveal the electrophysiological response to grammatical violations. Recent work has shown that electrophysiology is sensitive to learning-related changes in adult language learners (Mueller et al 2005; Osterhout et al. 2006). The hypothesis under investigation is that the ability to adapt to different forms of recursion remains plastic in adulthood.

1.1 Linguistic and Computational Models of Grammatical Complexity

Representational work has been concerned with the distinction between crossed and nested dependencies in recursive structures from both linguistic and computational perspectives. We will first detail the descriptive and theoretical linguistic background. In Standard German complement clauses, the first verbal head has the most local NP as its dependent, as in (1) versus (2); note that the sentences are similar to the materials used in the experiment described later.

(1) *. . . dass wir das Kreuz das Dreieck*
. . . that we the cross the triangle
berühren lassen
touch let
'that we let the cross touch the triangle'

(2) **. . . dass wir das Kreuz das Dreieck lassen berühren*

The German constituent order of a complement clause, $\mathtt{NP}_1\mathtt{NP}_2\mathtt{NP}_3\mathtt{V}_2\mathtt{V}_1$. Note that in this structure, the verb cluster $\mathtt{V}_2\mathtt{V}_1$ is ordered so that the most-embedded verb, $\mathtt{V}_2$ (*berühren*), is first. The dependency between the object $\mathtt{NP}_3$ and $\mathtt{V}_2$ is therefore the shortest, while the dependency between the subject $\mathtt{NP}_1$ and $\mathtt{V}_1$ is the longest.

In contrast to German, Standard Dutch licenses a crossed dependency, as shown in (3–4), with the same interpretation as the earlier German examples. In this construction, the sequence of verbs in the complement clause is $\mathtt{V}_1\mathtt{V}_2$, e.g., (*laten raken*). The first-encountered verbal head, $\mathtt{V}_1$, is to be matched to its dependency higher in the constituent structure, $\mathtt{NP}_1$, crossing over the other dependents.

(3) **. . . dat wij het kruis de driehoek*
. . . that we the cross the triangle
raken laten
touch let
'that we let the cross touch the triangle'

(4) *. . . dat wij het kruis de driehoek laten raken*

The comparison between German and Dutch complement clauses has been influencial in the development of formal language models with higher generative capacity (Shieber, 1985; Joshi, 2004). Specifically, the crossed dependencies in Dutch and other languages in the West Germanic family cannot be modeled using context-free grammars (Evers, 1975; Shieber, 1985). The constrast between these structures has been addressed by diverse linguistic frameworks that have varying representational assumptions (Bobaljik, 2004; Kroch & Santorini, 1991; Evers, 1975). Joshi and collegues have shown that a number of linguistic frameworks can be grouped into the mildly context sensitive languages (Joshi, 1985; Joshi, Vijay-Shanker, & Weir, 1991). The capacity of LTAG to model the crossing dependency has led, in turn, to an algorithmic analysis of the time and memory requirements necessary to parse the crossing and embedded verb orders (Joshi, 1990). This analysis predicts that the Dutch crossing structure is easier to recognize because verbs can be individually linked to their dependent arguments in a queue, rather than first encoding the series of verbs into a (stack-like) working memory as in German (Joshi, 1990).

On the face of it, the difference between Dutch and German embedded constructions with respect to formal language properties might lead one to expect a relatively high threshold for acquiring these constructions in a second language or borrowing them in language contact settings. However, this assumption is not supported by the considerable synchronic and diachronic variability among the West Germanic languages and/or dialects (Barbiers et al. in press; Pauwels, 1953; Wurmbrand, 2004). For example, the embedded clause construction is found in Frisian and the cross-serial construction is found in Swiss German. Also note that both Dutch and German allowed either order earlier in their language histories. During the 14th century, Early New High German permitted either the nested or crossed verb orders but Modern German does not (Sapp, 2006). The substantial dialectal and diachronic variation in the use of these structures would suggest that the subordinate clause verb order is relatively susceptible to change.

1.2 Working Memory Processing Models

Within psycholinguistics, processing models of complexity (Gibson, 1998; Lewis, 1996; Gordon et al., 2002) have addressed why some structures appear to be more difficult to parse or interpret than others in comprehension. They also address why, in some extreme cases, certain types of grammatical sentences seem to be impossible to process, even when the constructions are unambiguous and involve only two or three clauses. In most cases, these theories employ a complexity metric as a linking assumption. This complexity metric associates strings and hypothesized grammatical representations with processing difficulty and breakdown.

Dependency locality theory (DLT; Gibson, 1989) proposes that the processing cost of a linguistic construction depends on how the construction consumes working memory storage or computational resources. The DLT proposal is that the processing cost of a construction increases proportional to the number of incomplete syntactic dependencies that must be held in working memory before they are resolved. This type of resource cost is strongly influenced by the locality of the head and a dependent, such that longer-distance dependencies between a head and a dependent incur a greater resource cost. A second type of cost is incurred when new discourse entities must be set up in a discourse model. Other models of linguistic processing complexity emphasize interference in working memory as a potential source of processing difficulty (Lewis, 1996; Gordon et al. 2002). In these accounts, the number of open dependencies of the same type (e.g., the same grammatical case) will determine processing difficulty, other factors held constant.

The contrast between crossed versus embedded dependencies has been used to support these models. Bach et al. (1986) had separate groups of Dutch and German native speakers rate the comprehensibility, as well as answer paraphrase questions, concerning sentences similar to those in (1-2), but with an increasing number of verbs. They observed equivalent question answering performance for both Dutch and German participants for the constructions using two verbs, but differences between the two language groups for higher levels of embedding and more verbs. With three or more verbs, Dutch participants made fewer errors with the Dutch cross-serial construction than the German participants made with the German embedded construction. Also, the Dutch subjects rated the (three-verb) cross-serial construction easier to process than the Germans rated the German (three-verb) embedded construction. These differences have been taken as evidence first, that the cross-serial construction is easier to process than the embedded construction, and second, that human parsing does not employ a stack-based working memory for linguistic material, but rather a queue-like working memory, because a stack-like architecture would not have predicted the advantage for Dutch. Joshi (1990) has argued that the performance differences observed by Bach *et al.* (1986) could be accounted for by representational assumptions as well.

The DLT account (Gibson, 1998) of these findings assumes that syntactic categories that are predicted first will accrue a greater memory cost because they must be maintained in working memory. In Dutch, this cost is initially higher because the first verb of a three-verb cluster closes a longer-distance dependency than the corresponding German version of the sentence. However, because this dependency is closed, the other verbs can be processed with less cost. In the German version, the first verb of the cluster closes a short-distance dependency, but the other dependencies must be kept active in working memory. Later in the German verb cluster the longer distance dependency is resolved with a higher cost. Thus, in the DLT account the linear order of the verbs allows Dutch to distribute integration costs over the verb cluster more equally than in the German version, which concentrates the higher–cost dependencies near the end of the verb cluster.

The difference between fewer versus more embeddings was also investigated by Kaan and Vasić (2004), who investigated reading times of Dutch subjects presented with two- and three-verb versions of the Dutch cross-serial dependency. They showed that average reading times increased at the first verb of the three-verb constructions relative to the two-verb constructions, and in addition, that the type of NP presented in the pre-verbal string affected integration at the verb. They concluded that a storage component like that proposed in Gibson (1998) along with a role for interference proposed by Gordon et al. (2001) would best account for the reading time data.

In the TAG-based processing model of the Bach et al. data, an embedded pushdown automaton and a complexity metric are proposed. Joshi (1990) proposed a complexity metric to express the amount of memory (or time) required to recognize sentences with the automaton, similar to the complexity metric(s) proposed by Gibson (1998). The distinguishing feature of the model is that multiple memory stores ("stacks of stacks") are used to store intermediate parse results during the recognition of multiple-clause embeddings, rather than a single (pushdown) store. The automaton is able to use the patterns of symbols in the multiple stores to recognize certain types of extended projections. These projections are able to capture the crossing dependencies found in Dutch in such a way that clause relationships are recognized at each verb in Dutch, but crucially, only at the end of the verb sequence in German. Thus, the Joshi (1990) account formalizes the explanation for the processing differences between Dutch and German, and provides a linking hypothesis between the linguistic representation and the complexity metrics.

The above models, while offering a detailed account of performance parameters observed in controlled experimental settings, nevertheless abstract away from the fact that linguistic function is implemented in networks of neurons arranged in the cerebral cortex that is subject to experience-dependent change. Some work within psycholinguistics has addressed learning linguistic complexity. In artificial neural network approaches, grammatical knowledge is modeled with a network for string sequences, termed a simple recurrent network (SRN), rather than a symbolic grammar. Christiansen and Chater (1999) addressed the cross-serial versus embedded contrast with this approach, and have also argued that approaches like the SRN have important properties such as experience-dependent plasticity and robustness to non-ideal input. However, Grüning (2006) has recently argued that models of sequences consistent with embedded constructions are arguably *simpler* than systems that model sequences consistent with cross-serial dependencies, which is not completely consistent with the behavioral data reviewed above. However there are few experimental data on human learning of these types of structures, so it is not yet clear which human learning patterns these networks (or symbolic approaches) would be expected to model.

In the population-based approach of Niyogi (2006) a learner hears a grammar selected from a *population* of individuals (who may speak somewhat different languages). One major distinction between this approach and that of the SRN is that it models the population of speakers as a dynamical system rather than an individual. This approach is relevant for the present experiment because the approach assumes a model of grammatical plasticity in which (hypothesized) grammars become stable (Niyogi, 2006, pp. 187-189). It is not yet clear whether aspects of grammar such as verb order constraints should be viewed as either stable or plastic in such a model.

While artificial neural network models of linguistic processing offer an account of how linguistic complexity might arise in networks of threshold-based processing units, they nonetheless abstract away from realistic details of electrophysiological responses usually modeled within psychophysiology and neuroscience, and more importantly, how those electrophysiological responses change with experience. SRN models emphasize the role of experience-dependent change in response to statistics of the input, but there have been few attempts to link these hypotheses to physical neural systems.

2 Method

The present experiment attempts to make this link by examining the electrophysiological response of learners over time (see Davidson & Indefrey, submitted). In three experimental sessions spanning their initial acquisition of Dutch in an intensive Dutch course, German learners performed a sentence-scene matching task with Dutch sentences including two different verb constituent orders (Dutch verb order, German verb order). In addition they rated the grammaticality of similar constructions in a separate rating task. The sessions took place over a period of three months (at the start of the course, at two weeks, and at three months after the start of the course).

2.1 Participants and Materials

The participants (n = 13) were all over 18 years old. The materials consisted of sentences that described a simple scene involving geometric objects. Half of the sentences contained a verb order consistent with Dutch (crossing dependencies, 5) and half consistent with German (embedded dependencies, 6).

(5) *Je zal zien dat wij het rode kruis*
You will see that we the red cross
de blauwe driehoek laten raken
the blue triangle let touch
'You will see that we let the red cross touch the blue triangle'

(6) *Je zal zien dat wij het rode kruis de blauwe driehoek raken laten*

In addition to the MEG task, the learners also rated the acceptability of sentences with a similar structure as the examples, but different words.

A control group (n = 25) of native Dutch speakers also rated the same sentences, but were not scanned with the MEG.

2.2 Procedure, Recordings, and Analysis

MEG signals were recorded in a magnetically-shielded room using a CTF system equipped with 151 axial gradiometers (VSM Tech Ltd., CTF Systems, Coquitlam, B. C., Canada), at a sampling rate of 1 kHz, low-pass filtered at 150 Hz during acquisition. The MEG provides a measure of magnetic field fluctuations due to electrical activity of synchronized post-synaptic potentials (Hämäläinen et al., 1993), analogous to EEG. The planar gradient of the sensor activity was derived to increase the spatial sensitivity of the measure. The data were analyzed with a clustering algorithm and tested for significance using randomization tests (Maris and Oostenveld, 2007). The analysis tested the null hypothesis of no differential violation response to the verb orders in each of the sessions. The behavioural data were analyzed using a mixed effect model (Baayen et al., 1986). For contrasts, posterior density intervals (HPD_d) were computed to assess whether the distribution of the parameter of interest is likely to include zero.

3 Results

3.1 Behavioural Classification

Figure 1 shows that the Dutch control participants rated the Dutch verb order as acceptable, and the German verb order as unacceptable, as expected. The German learners initially rated the sentences that were incompatible with German grammar as unacceptable, but over time rated the sentences as acceptable as the Dutch-speaking control group. Similarly, they rated the sentences compatible with German grammar more acceptable at the start of acquisition but less so later in acquisition, again approximating the Dutch control group's rating.

A direct comparison of the ratings for the German versus the Dutch order showed that the learners rated the Dutch order worse at the first session (d = 1.15, HPD_d = 0.25,2.02), equal in the second session (d = -0.90, HPD_d = -2.18,0.36, includes zero), and the German order worse in the last (d = -2.54, HPD_d = -3.79,-1.30).

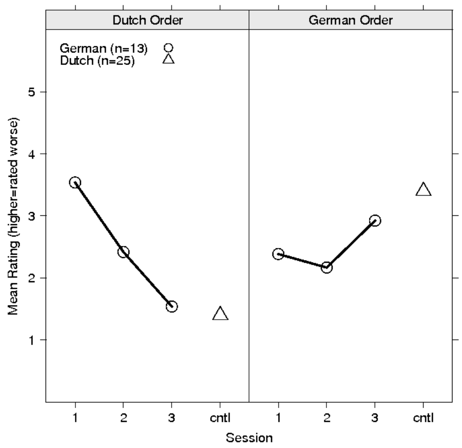

Figure 1: Average of median ratings of sentences following the German and Dutch verb orders.

3.2 Event-Related Fields

The average planar gradient of the evoked field to the initial verb within the cluster revealed a larger evoked response for the German order relative to the Dutch order over frontal sensors after two weeks, but not initially. At the second and third test sessions there was a significantly larger amplitude response for the German order compared to the Dutch order; session 2: $sumT$ = 32.72, p = 0.0073, 12 sensors; session 3: $sumT$ = 72.88, p = 0.0006, 25 sensors. Figures 2 and 3 show the topography of the response at sessions one and three for a time window of 0.2 to 0.4 s after the onset of the initial verb.

4 Discussion

The experiment reported here presented Dutch complement clause constructions to beginning German learners of Dutch over several sessions. This was done to examine how learners respond to different verb cluster orders of Dutch sentences as knowledge and proficiency of Dutch is acquired. The sentences were arranged to contrast two verb orders. One construction was a violation of Dutch grammar, which required a cross-serial dependency between verbs and their dependents. The other construction was a violation of German grammmar (were it applied to the Dutch sentences), which does not permit cross-serial dependencies, but instead requires the strict embed-

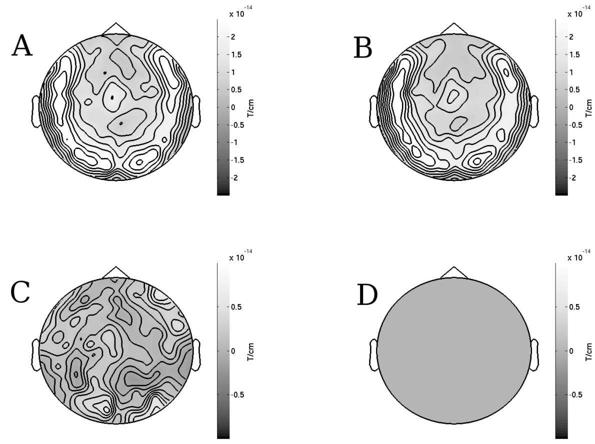

Figure 2: Topography of the average planar gradient of the event-related fields (0.2 to 0.4 s) for the German and Dutch verb orders in initial session. A. German order, B. Dutch order, C. German-Dutch contrast, D. statistically significant difference (none present).

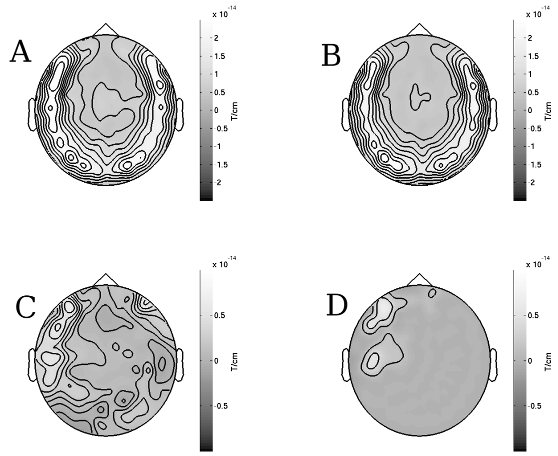

Figure 3: Topography of the average planar gradient of the event-related fields (0.2 to 0.4 s) for the German and Dutch verb orders after three months. A. German order, B. Dutch order, C. German-Dutch contrast, D. statistically significant differences.

ding of verbs and their dependents.

The behavioural and electrophysiological results suggest that cortical responses to verb order preferences in complement clauses can change within three months after the onset of adult language learning, implying that this aspect of grammatical processing remains plastic into adulthood. The primary implication of this result is that the preference for crossed versus the embedded order is relatively flexible. This is in contrast to the assumptions of some theoretical models of language change (Labov, 2007), which assume that adult acquisition is relatively slow and error-prone. However, it must be stressed that Dutch and German are similar in many other respects, so it is likely that the learners in the present study acquired proficiency at a faster rate than learners with a different L1.

The results reported here have several implications for representational and processing models. Work on formal grammar has highlighted the distinction between crossed versus nested dependencies because of the implications that these structures have for different families of mathematical grammars. The existence of crossed dependencies like those in Dutch imply that grammars that are more expressive than context free grammars are necessary in order to successfully model linguistic grammatical patterns. Although this property is fundamental for frameworks which attempt to find a proper structural description of human languages using a constrained formal system, the formal distinction between context free and context sensitive grammars does not, in itself, imply that crossed dependencies are more complex to process, or more complex to learn. The work on processing reviewed in the Introduction in fact suggests that crossed dependencies are in fact easier for comprehenders to parse than nested dependencies. The results presented here add to this literature by showing that crossing dependencies can be acquired in a relatively short period of time by adult learners, at least when other aspects of the L1 are similar (e.g., Germanic).

Our findings of fast L2 verb order acquisition suggest a need for a bilingual model of crossed and nested dependencies. A formal framework for modeling the correspondences between different grammatical systems has been proposed by Shieber (Shieber & Schabes, 1990). In this *Synchronous* Tree-Adjoining Grammar (STAG), a transfer lexicon is used to map pairs of elementary trees to one another in two separate TAGs. One advantage of such a framework is that the same modeling advantages found in TAG can be used in modeling correspondences between grammatical systems. In TAG, lexical items are associated with elementary trees to model local dependencies (factoring dependencies and recursion; Joshi, 1990). In the case of German and Dutch, pairs of elementary trees with inverted verb orders would be associated with each other in the transfer lexicon. Learning the Dutch verb order when the L1 is German would consist of learning that a subset of Dutch verbs (non-finite verbs, causative verbs, perception verbs) requires an inverted order in a complement clause. The links in the STAG transfer lexicon would model the fact that bilingual or learning speakers know that the meaning of the Dutch version of the sentence is the same as the German version, with a different verb order. A model of this type may account for the relative speed at which the learners acquired the Dutch order.

The present study, along with several other recent findings in the EEG literature (Osterhout et al. 2006; Mueller et al. 2005), offers evidence that the representational capacity of adult language users can change quickly during adult language learning. However, resource-based psycholinguistic models of processing complexity like those reviewed in the introduction have not yet addressed how the grammatical or representational resources used to parse complex sentences can change with language experience. Future modeling efforts could be directed at jointly modeling how grammatical representations are learned under resource limitations. An interesting modeling issue concerns how a network model (e.g., Christiansen & Chater, 1999) could learn to be sensitive to both the German and Dutch verb orders in the same speaker. Note that Dutch permits both verb orders, depending on finiteness of the verbs involved, so it appears to be necessary to address this issue in order to model single languages as well. Also, the work reported here has not explored the extent to which learning the Dutch verb order impacts processing of German sentences, or how long the sensitivity to verb order differences remains in the absence of direct experience with Dutch. Future empirical work could address these issues by examining behavioral or electrophysiological indices of parsing complexity in proficient German-Dutch bilinguals, as well as learners who are no longer active users of Dutch.

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