



Available online at www.sciencedirect.com

SCIENCE @ DIRECT®

Cognition 89 (2003) 179–205

COGNITION

www.elsevier.com/locate/COGNIT

Syntactic priming of relative clause attachments: persistence of structural configuration in sentence production

Christoph Scheepers*

Department of Psychology, University of Dundee, Dundee, DD1 4HN, UK

Received 14 September 2002; accepted 10 March 2003

Abstract

Three sentence completion experiments will be reported in which participants had to generate German equivalents of “the servant of the actress who ...” (NP-of-NP-RC) constructions. Target fragments (which were unconstrained as to whether the relative pronoun permitted high or low attachment) were preceded by constrained prime fragments, which were either structurally congruent with the targets (Experiments 1 and 2) or structurally incongruent with the targets (anaphoric adverbial clauses rather than relative clauses (RCs), Experiment 3). While the first two experiments established reliable repetition of RC attachments between primes and targets, Experiment 3 failed to obtain a significant priming effect, indicating that RC attachment priming is dependent on a syntactic overlap between primes and targets. The results suggest a tendency of language producers to retain hierarchical syntactic relations over consecutive trials. Current models of syntactic priming in production do not offer an explanatory mechanism for this kind of observation as they presently stand. © 2003 Elsevier B.V. All rights reserved.

Keywords: Syntactic priming; Relative clause attachment; Sentence production

1. Introduction

When people produce sentences, they are likely to maintain aspects of syntactic structure from one sentence to the next, if possible. For example, speakers (or writers) are more likely to produce “The girl handed the paintbrush to the man” after they have just generated “The rock star sold some cocaine to an undercover agent” (both contain

* Tel.: +44-1382-344617; fax: +44-1382-229993.

E-mail address: c.scheepers@dundee.ac.uk (C. Scheepers).

prepositional object – or PO – verb phrases), whereas after having generated a double object (DO) construction like “The rock star sold an undercover agent some cocaine”, they are more likely to produce the structurally similar “The girl handed the man the paintbrush” (e.g. Bock, 1986; Branigan, Pickering, & Cleland, 2000; Corley & Scheepers, 2002; Pickering & Branigan, 1998).

Language producers are typically not aware of re-using structure in this way, a phenomenon also known as *syntactic priming*. However, the corresponding effects can be demonstrated, for example, in experiments where participants are constrained to use a particular structure in one trial (the *prime*) but are free to choose between two or more alternative structures in the following trial (the *target*). In such experiments, priming effects are usually measured categorically, by counting how many times a target utterance is structurally consistent with the previous prime. More recently, however, researchers have also focused on production latencies, showing that the tendency to repeat structure over consecutive trials is advantageous to both speakers (Smith & Wheeldon, 2001) and writers (Corley & Scheepers, 2002) in that it reduces the cognitive effort associated with generating an utterance.

The conditions under which syntactic priming occurs are regarded as providing important insights into the mechanisms of *grammatical encoding* (the process of selecting the lexical elements and assembling the syntactic framework for a message to be conveyed, cf. Bock & Levelt, 1994), not only with respect to the underlying architecture but also regarding the kinds of representations involved. Evidence for PO/DO priming to be best conceived of at the syntactic level, for example, stems from experiments showing that primes such as “Mary brought a book to study” (where the constituent starting with “to” is not a prepositional phrase (PP)) fail to elicit more PO target structures, despite the superficial similarity between the different syntactic forms; primes such as “The secretary baked a cake for her boss”, however, do increase the number of PO targets containing PPs with “to” (thus, priming is not bound to the repetition of a particular preposition); the thematic role played by the PP appears to have no relevance for syntactic priming – “The widow drove her Mercedes to the church” (where the PP denotes a location rather than a recipient) does prime a PO response like “The girl handed the paintbrush to the man” (see Bock, 1989; Bock & Loebell, 1990; Bock, Loebell, & Morey, 1992). Studies focusing on languages with variable constituent ordering (Hartsuiker & Westenberg, 2000; Scheepers & Corley, 2000) have demonstrated that linear precedence relations – another important aspect of syntactic structure – are subject to priming as well, so it is not just the presence or absence of a certain type of constituent (say, a PP) that language producers tend to retain across different sentences.

The kinds of information preserved in syntactic priming have inspired detailed models of grammar representation within the production lexicon, most explicitly so in Pickering and Branigan (1998) (henceforth P&B). Taking the network account proposed by Roelofs (1992, 1993) as a starting point, P&B differentiate between three types of information associated with a verb’s base form (or *lemma*), namely (a) a node representing its syntactic category (distinguishing it from nouns, adjectives, etc.), (b) nodes representing syntactic features such as tense, aspect, or number, and (c) nodes that represent the verb’s combinatorial properties (roughly, the syntactic environments in which the verb can occur). Category, feature, and combinatorial nodes are shared between different verb

lemmas rather than having each individual instance of a verb being specified for the relevant information. Thus if, for example, the verb lemma ⟨GIVE⟩ and both the ‘past tense’ node and the ‘perfective aspect’ node are activated, a likely articulation at a later stage would be “gave”; if the lemma ⟨RUN⟩ is activated together with the same ‘past tense’ and ‘perfective aspect’ nodes, a likely articulation would be “ran”, and so on.

Most crucial in the context of syntactic priming are the combinatorial nodes. The lemma ⟨GIVE⟩, for instance, would link to (at least) two different combinatorial nodes, representing the ‘NP_NP’ (give the dog the bone) and ‘NP_PP’ (give the bone to the dog) constructions that the verb can legally combine with. Using standard assumptions about decaying activation, P&B explain the priming of a sentence like “The girl handed the paintbrush to the man” after “The rock star sold some cocaine to an undercover agent” by suggesting that, once the ‘NP_PP’ node has been activated in the prime, it retains some residual activation and thus reaches threshold more easily when making the target utterance. Interestingly, P&B further assume that not only individual nodes, but also the links between them may retain residual activation. Hence, they predict that syntactic priming should become more pronounced when prime and target utterances employ the same verb because in this case, combined activation from the combinatorial node and the link between lemma and combinatorial node would result in a stronger pre-activation of the relevant structure than if only the combinatorial node were pre-activated.

P&B provide support for this model by adopting a sentence completion methodology (see also Branigan, Pickering, Liversedge, Stewart, & Urbach, 1995) where participants were asked to provide hand-written continuations for partial sentences. The prime fragments were constrained such that the most likely completion was of a given form (e.g. “The racing driver showed the torn overall ____” [triggering PO completions] vs. “The racing driver showed the helpful mechanic ____” [triggering DO completions]) but the target fragments always ended at the verb (e.g. “The patient showed ____”), thus permitting both PO and DO completions. A further manipulation concerned the verbs in the prime fragments, which were either the same (as in the examples above) or different (“gave” instead of “showed”) from the verb in the target. In line with P&B’s predictions, participants were more likely to produce target sentences that agreed with the primes in syntactic structure than target sentences that were of the alternative structure to the primes. Moreover, this effect was reliably stronger when the verb stayed the same between prime and target than when it differed, thus supporting the assumption that retaining the link between a lemma and a combinatorial node further enhances structural pre-activation. Additional completion experiments revealed that the priming effect is unaffected by differences between prime and target in the verb’s tense, aspect, or number, supporting the idea that feature information is separate from the representations involved in syntactic priming (i.e. lemmas and combinatorial nodes).

Having shown that participants tend to re-use combinatorial information associated with verbs, the question arises of how this information may be best characterized in linguistic terms. P&B discuss the obvious possibility that the combinatorial nodes in their model encode something similar to subcategorization frames, i.e. information about the numbers and types of arguments that a verb requires. However, certain observations, they argue, suggest that this assumption may be too specific. In particular, P&B (p. 647) refer to Bock and Loebell (1990) for a demonstration of priming between sentences that share

the same phrase structure, but differ in subcategorization: “The man is being stung by a bee” (where “by a bee” is an argument of the verb) was primed by “The 747 was landing by the airport’s tower” (where the PP “by the airport’s tower” is not an argument of the verb). P&B therefore conclude that context-free rules (e.g. ‘VP → V NP PP’ vs. ‘VP → V NP NP’) might be a more suitable candidate for the kinds of information encoded in the combinatorial nodes of their model.

Further support for this assumption stems from recent experiments showing priming of pre-nominal adjective (“the red book”) vs. post-nominal relative clause (RC) (“the book that’s red”) noun phrase (NP) structures, where the relevant structural alternatives both concern true modifier relations that cannot be expressed in terms of argument frames (Cleland & Pickering, 2001, 2003). Subcategorization might also be insufficient to explain the priming of linear precedence relations (e.g. Hartsuiker & Westenberg, 2000; Scheepers & Corley, 2000). Note that it is only the numbers and types of arguments that are encoded in a verb’s subcategorization frame – the ordering of arguments is commonly assumed to be generated by principles that are independent of individual lexical items (e.g. Chomsky, 1981; Pollard & Sag, 1987, 1994). Context-free rules, on the other hand, specify linear sequences of both argument and non-argument constituents within a phrase. Therefore, they can account for the whole range of priming phenomena discussed so far.

1.1. RC attachment

The resolution of RC attachment ambiguities as in “Don mentioned the servant of the actress who was on the balcony” (Fig. 1) has received wide attention in the psycholinguistic literature on sentence comprehension (e.g. Cuetos & Mitchell, 1988; Cuetos, Mitchell, & Corley, 1996; De Vincenzi & Job, 1995; Frazier & Clifton, 1996; Gibson, Pearlmutter, Canseco-Gonzalez & Hickok, 1996; Hemforth, Konieczny, & Scheepers, 2000). In constructions like these (which can be generated in various different languages), there are two potential attachment sites for the critical RC (“who was on the balcony”), namely (a) the so-called high attachment (HA) host (referring to the NP higher up in the syntactic tree) and (b) the low attachment (LA) host (referring to the NP lower in the tree). In the given example, attachment of the RC to the HA host would imply that “the servant ... was on the balcony” (Fig. 1a), whereas attachment of the RC to the LA host would mean that “the actress was on the balcony” (Fig. 1b).

In this paper, I will propose that constructions like these may also be quite revealing with respect to the kinds of information that are subject to priming in sentence production. Note that RCs are true modifiers, and thus they are, according to most grammar theories, not part of the argument structure of individual lexical items. Secondly, and more importantly in the context of this paper, the rules that have to be applied in order to generate either of the relevant RC attachments in a NP-of-NP-RC sequence are *identical*.

- | | | |
|-----|----|--------------|
| (1) | a. | NP → det N |
| | b. | NP → NP PP |
| | c. | NP → NP RC |
| | d. | PP → prep NP |

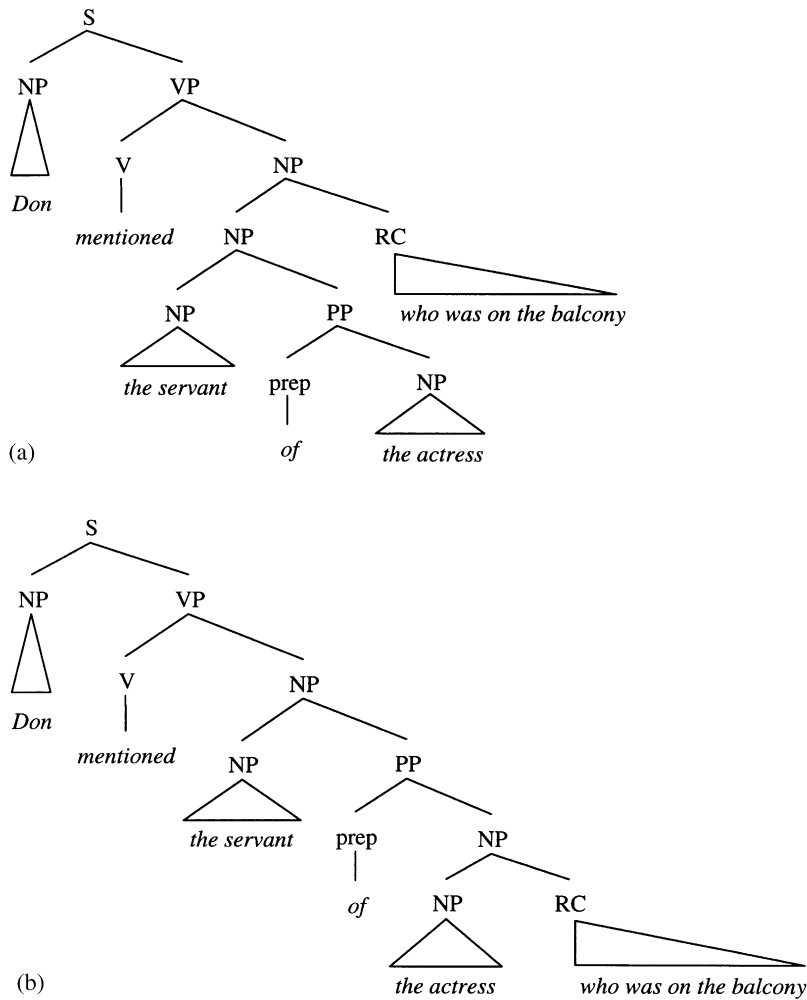


Fig. 1. (a) High attachment of the relative clause (RC). (b) Low attachment of the RC.

Assuming a simple context-free grammar (as in Pickering & Branigan, 1998), the rules in (1) are sufficient to realize either of the complex NPs shown in Fig. 1a,b. In either case, the left-recursive rule in (1c) would generate the relevant RC attachment. Hence, the difference between high vs. low RC attachment in an NP-of-NP-RC construction cannot be expressed in terms of the kinds of rules that need to be applied. Rather, it is the *hierarchical tree configuration* that characterizes the structural contrast: in the HA case, rule (1c) is used to modify the NP headed by “servant” (the NP higher up in the tree); in the LA case, (1c) is applied to modify the NP headed by “actress” (the NP lower in the tree). The following experiments were designed to test whether particular HA/LA configurations in an NP-of-NP-RC sequence are subject to priming in sentence

production. Note that the account proposed by Pickering and Branigan (1998), as well as other models (see Section 5), are completely underspecified in this respect. As discussed above, residual activation of subcategorization frames would not be applicable, and nor would the pre-activation of context-free rules account for potential priming effects because the relevant structural contrast concerns the hierarchical configuration of modifiers in the syntactic tree representation rather than the kinds of rules being applied.

The experiments used a similar procedure as in Pickering and Branigan (1998), where participants had to provide hand-written completions to partial sentences. In the first two experiments, the sentence fragments in both prime and target trials triggered the production of German equivalents of “the servant of the actress who ...” constructions (the only difference in German is that the possessive modifier is expressed by a genitive case NP rather than a PP). Unlike English, German provides overt gender marking for full NPs as well as relative pronouns, making it possible to manipulate the types of RC attachments to be generated in the prime trials. In the target trials, however, subjects were free to produce either high or low RC attachments, whose relative proportions were taken as the dependent variable.

The third experiment was designed to evaluate the syntactic nature of RC attachment priming in production. The prime fragments triggered the generation of anaphoric adverbial clauses rather than RCs, and hence were structurally incongruent with the target fragments they were paired with (which triggered the production of RCs).

In contrast to Pickering and Branigan (1998), each of the experiments in this paper included an explicit baseline condition, making it possible (a) to distinguish priming from inhibition and (b) to assess the relative effectiveness of the different types of primes in each experiment.

2. Experiment 1

2.1. Design

Twenty-four sets of materials like (2) were created. Each item consisted of a target fragment (T) that was paired with each of three types of prime fragments: a HA prime, a LA prime, and a BL (baseline) prime. HA primes, LA primes, and target fragments consisted of a subject (either a proper noun or a full NP) followed by a finite verb, the critical complex object NP (always including a genitive modifier NP), and a relative pronoun after the comma.¹ BL primes differed from HA and LA primes in that the relative pronoun was replaced by a temporal (or causal) conjunction after the comma so as to block the generation of a RC construction (hence the term

¹ There were, however, three items where prime or target fragments started with an adverbial, followed by a finite *intransitive* verb and a critical complex NP that acted as the subject rather than object.

baseline primes, as such fragments are unlikely to affect RC attachment decisions in the target trials).²

- (2) HA Die Assistentin verlas den Punktestand der Kandidatin, der ...
The assistant announced the score [masc, sing] of the candidate [fem, sing] that [masc, sing] ...
- LA Die Assistentin verlas den Punktestand der Kandidatin, die ...
The assistant announced the score [masc, sing] of the candidate [fem, sing] that [fem, sing] ...
- BL Die Assistentin verlas den Punktestand der Kandidatin, bevor ...
The assistant announced the score [masc, sing] of the candidate [fem, sing] before...
- T Der Rentner schimpfte über die Autorin der Flugblätter, die ...
The pensioner railed about the author [fem, sing] of the fliers [neut, plur] that [?] ...

The design exploited properties of the German gender and number system in order to (a) elicit the relevant RC attachments in HA and LA prime fragments and (b) help identify RC attachments made in response to the target fragments. In the primes, the critical host NPs after the verb were both singular and always differed in grammatical gender from one another (with different pairings of genders across items). In HA primes, the relative pronoun agreed in gender with the first host NP (respectively, the NP higher up in the tree), whereas in LA primes, it agreed in gender with the second host NP (the NP lower in the tree), thus constraining possible attachments in each case. The target fragments, on the other hand, were unconstrained with respect to RC attachment: the critical host NPs differed in number from each other (i.e. a feminine singular NP was always contrasted with a plural NP), but they were always followed by the relative pronoun “die” which can refer to either a feminine singular NP or to a plural NP of any gender. Half of the items contrasted a singular HA host with a plural LA host (as in example 2T), while the other half employed the reverse number assignments in the target. Contrasting number in this way was considered helpful in classifying later responses. Note that when a subject RC is produced (which was expected to be the most likely response), the relevant RC attachment can be read off the number marking at the finite verb of the RC (cf. “Der Rentner schimpfte über die Autorin der Flugblätter, die ziemlich unverschämt {war vs. waren}/The pensioner railed about the author of the fliers that {was vs. were} quite outrageous” – in German, finite verbs are always unambiguously marked for number). Primes and targets were semantically unrelated, and there was no systematic relationship concerning gender or animacy of host NPs between primes and targets. Note that the design does not plausibly permit an explanation of potential priming effects in terms of morphological feature repetition at the pronoun: whereas primes contrasted the gender of the candidate host NPs (with various gender combinations across items), targets implied a contrast in number. The full set of materials (including further information that might be useful to readers

² The issue of whether BL constructions are truly ‘neutral’ will be addressed more explicitly in the discussion of Experiment 3 (Section 4.4).

unfamiliar with German) is available at http://www.dundee.ac.uk/psychology/cscheepers/Syntactic_Priming.html.

2.2. Procedure

The 24 (items) \times 3 (conditions) prime–target pairs were allotted to three master files containing different versions of materials such that (a) each item appeared exactly once per file (in one of the three conditions), (b) each file contained eight items per condition, and (c) each file contained an equal number (four) of items whose target fragment contrasted a singular HA host with a plural LA host, and vice versa, per condition. Additionally, 51 filler fragments were included in each file. The fillers were structurally unrelated to the items of interest, i.e. they never permitted the production of a RC construction. Ten different questionnaire booklets were generated from each file. Each booklet comprised a different quasi-random order of items, subject to the constraint that there were five fillers at the beginning, and that each prime–target pair was preceded by at least two fillers. Each sentence fragment was printed in a single line, followed by two carriage returns and a solid line that marked the area where a hand-written sentence completion had to be provided. Participants were free in choosing their responses, except that the resulting sentences should be “grammatically correct and reasonably plausible”. Further instructions emphasized that participants should rely on first impressions rather than trying to create witty or original completions, and that they should work through the booklet at a reasonable pace.

2.3. Participants

The booklets were randomly distributed among 30 native German participants from the Saarland University community. Subjects were paid 5 euro each for participation, and they were unaware of the purpose of this study until debriefing at the close of the experiment. Participants were tested one at a time at the Psycholinguistics Lab in Saarbrücken. A typical session took about 30 minutes to complete.

2.4. Response annotation

Along with participant and item IDs, the relevant priming condition, and the serial number of the trial, target responses were coded for (a) correctness of the preceding prime completion, (b) internal structure of the target RC, and (c) attachment of the target RC.

2.4.1. Correctness of prime completion

A prime completion was coded as either ‘correct’ (i.e. the prime was completed as intended by experimental manipulation) or ‘incorrect’ (the prime was not completed as intended by experimental manipulation). Instances of the latter sort included occasional ungrammaticalities (e.g. “Franziska erinnerte sich an den Bruder der Freundin, als (Kind in den Brunnen gefallen war)/Franziska remembered the brother of the friend when (child

had fallen into the well”)³ as well as responses that implied an unintended case or gender marking of the relative pronoun (e.g. “Der Patient konsultierte den Chefarzt der Klinik, der (er vertrauen konnte)/The patient consulted the head physician of the clinic that [‘fem, dat’ instead of ‘masc, nom’] (he could trust in)”). The latter implied that only subject RCs were effectively treated as ‘correct’ in the primes.

2.4.2. *Internal structure of target RC*

A target completion fell into the category ‘subject-RC’ if the relative pronoun unequivocally acted as the subject of the resulting RC; it fell into the category ‘object-RC’ if the relative pronoun unequivocally acted as the/an object of the resulting RC (e.g. “Der Pensionär schimpfte über die Verfasserin der Flugblätter, die (er ausgesprochen unverschämt fand)/The pensioner railed about the author of the fliers that (he found downright outrageous)”). All remaining completions fell into the category ‘other’. These included (a) responses that did not imply a RC (e.g. “Franziska sammelte alle Werke der Schriftstellerin, die (guten wie die schlechten)/Franziska collected all works of the writer, the (good ones as well as the bad ones)”) or (b) responses that were ambiguous between a subject-RC and an object-RC reading (e.g. “Franziska sammelte alle Werke der Schriftstellerin, die (sie persönlich kannte)/Franziska collected all works of the writer that (‘she personally knew’ or ‘knew her personally’)”).

2.4.3. *Attachment of target RC*

The most relevant annotation concerned the attachment of the target RC. Obviously, in cases where target completions resulted in a subject-RC (which was by far the most frequent response, see Section 2.5), attachment to either the ‘high’ or the ‘low’ attachment host NP could simply be determined by means of number agreement between the host NP and the verb of the target RC (a subject-RC must attach to the host that agrees in number with its verb). However, in case of object-RCs or target completions that were ambiguous between a subject-RC and an object-RC reading, number marking at the verb of the target RC could not be used to identify the relevant attachment. Instead of excluding such completions straight away, annotations of the relevant target attachments were based on plausibility criteria if possible. For instance, “Der Pensionär schimpfte über die Verfasserin der Flugblätter, die (er in seinem Briefkasten gefunden hatte)/The pensioner railed about the author of the fliers that (he had found in his letter box)” was coded as ‘low attachment’ because it seemed rather unlikely that a reading was intended where “the author was found in the letter box”. All remaining responses (where no RC was produced or where neither number agreement nor plausibility could unequivocally determine a target RC’s attachment) were coded as ‘unclassifiable’. These also included a small number of contradictory responses such as “Der Hausmeister reparierte die Türklingel der Mieter, die (nicht laut genug waren)/The janitor repaired the doorbell of the tenants that (were not loud enough)” where number agreement and plausibility favour different attachments (potential instances of erroneous number agreement).

³ Example completions ((...)) were taken from actual responses.

2.5. Results

2.5.1. General findings

All trials where the prime completion was classified as ‘incorrect’ were excluded from further analysis. This resulted in 234 (98%) valid trials for the HA prime condition, 229 (95%) valid trials for the LA prime condition, and 231 (96%) valid trials for the BL prime condition. In an overwhelming majority of these trials (ca. 91%), target fragments were completed as subject-RCs. There were only 7% object-RCs and less than 2% other (ambiguous or invalid) target completions. A more detailed inspection of the relationship between the internal structures of target completions (subject- vs. object-RCs) and their relevant attachments (high vs. low vs. unclassifiable (UC)) revealed that the relative proportion of UC target attachments was very low (2%) for subject-RCs, but relatively high (44%) for the small number of object-RCs produced. This was expected because HA vs. LA of an object-RC could only be determined on the basis of rather ‘soft’ plausibility criteria. Apart from that, there was no systematic relationship (neither globally, nor by prime condition) between the internal structure of a target-RC and its attachment to either of the relevant host NPs.

With respect to RC attachment, target completions were distributed as follows: 36% of all target-RCs were attached high, 59% were attached low and 6% were UC regarding HA vs. LA. The present sentence completion study thus revealed a bias towards LA completions, which appears to deviate from the HA preference typically found in comprehension studies on RC attachment in German (e.g. Hemforth et al., 2000). Although it is possible that syntactic preferences in production differ from those in comprehension, a closer inspection of the items suggested that this finding is actually due to pragmatic biases in the target fragments rather than a differential effect of processing mode (see Section 2.6 for a more detailed discussion).

2.5.2. Priming effects

Table 1 lists the observed proportions of HA, LA, and UC target completions for each level of prime type. Descriptively, there were more HA target completions after HA primes than after LA primes or BL primes. Furthermore, the relative proportion of LA target completions was slightly higher after LA primes than after BL primes.

Inferential analyses were based on *hierarchical log-linear models* (see Howell, 2002, for an introduction). Informally speaking, log-linear models combine features of a standard cross-tabulation chi-square test (determining the fit between observed and expected cell counts) with those of ANOVA (simultaneous testing of main effects

Table 1
Numbers of HA, LA, and UC target completions (columns) by levels of prime type (rows) for Experiment 1

	HA target	LA target	UC target
HA prime	104 (44%)	116 (50%)	14 (6%)
LA prime	66 (29%)	149 (65%)	14 (6%)
BL prime	75 (33%)	142 (62%)	14 (6%)

Relative frequencies per prime condition are listed in parentheses.

and interactions within a complex multi-factorial design). Unlike ANOVA (but very much like a standard cross-tabulation test), log-linear models are optimized for the analysis of categorical frequencies: they neither rely on parametric assumptions concerning the dependent variable (such as normality, homogeneity of variance, etc.), nor do they require factor levels to be linearly independent of one another (the response variable is always treated as a factor in log-linear analysis).

In order to assess the generality of effects across individuals and materials, log-linear models were tested in which observed cell counts were adjusted to factor combinations of prime type (HA vs. LA vs. BL), target completion (HA vs. LA vs. UC), and either participants ($N = 30$) or items ($N = 24$).⁴ Effects in the context of participants will be reported as *LRCS1*, and effects in the context of items as *LRCS2* (where *LRCS* abbreviates *Likelihood Ratio Chi-Square*). For each effect, both partial as well as marginal association *LRCSs* were computed: partial associations refer to tests in which expected frequencies are calculated from all effects that *compete* with the effect of interest at the same level of the effect hierarchy; marginal associations refer to tests in which expected frequencies are calculated from all effects that *constitute* the effect of interest at a more general level of the effect hierarchy. (Thus, log-linear models allow for evaluating the robustness of an effect within different effect contexts.) In case partial and marginal associations differ for a given effect, I will report the more conservative figure (i.e. the worst case scenario in terms of significance), referred to as ‘min. *LRCS*’.

Overall, there was a significant two-way interaction between prime type and target completion (min. *LRCS1* = 12.012, $df = 4$,⁵ $P < 0.02$; min. *LRCS2* = 12.347, $df = 4$, $P < 0.02$). Since proportions of classifiable vs. unclassifiable target completions were nearly identical across prime conditions (min. *LRCSs* < 0.02, $df = 2$, $P_s > 0.99$), pairwise comparisons by prime type considered only the complementary proportions of HA to LA target completions. These tests confirmed a reliably higher proportion of HA target completions after HA primes than after LA primes or BL primes (HA vs. LA primes: min. *LRCS1* = 10.913, $df = 1$, $P < 0.001$; min. *LRCS2* = 11.216, $df = 1$, $P < 0.001$; HA vs. BL primes: min. *LRCS1* = 6.369, $df = 1$, $P < 0.02$; min. *LRCS2* = 6.539, $df = 1$, $P = 0.01$). The contrast between the LA prime condition and the BL prime condition – though descriptively present – did not approach significance (min. *LRCSs* < 0.7, $df = 1$, $P_s > 0.40$).

The pattern of results stayed the same when only subject-RC target completions were considered (Table 2). The three-way interactions ‘participants (or items) \times prime type \times target completion’ were not significant ($P_s > 0.99$), confirming that the interaction between prime type and target completion can be generalized across individuals and materials. Likewise, there was no substantial influence of the type of number contrast in

⁴ The inclusion of participants (respectively items) implied that expected frequencies for the effects of interest (e.g. the prime type \times target completion interaction) were adjusted for inter-individual variation. This is analogous to *partiallying out* effects of participants or items within the context of repeated-measures ANOVAs (except that interactions with either of the two variables can still be tested in log-linear models).

⁵ Degrees of freedom are calculated as $(k - 1) * (m - 1)$, where k refers to the number of prime type levels and m to the number of target completion levels, i.e. $(3 - 1) * (3 - 1) = 4$. No *error term df* is computed because log-linear models deal with cell counts rather than cell means (hence, there is no within-cell variance to be accounted for).

Table 2
Data for Experiment 1, considering subject-RC target completions only

	HA target	LA target	UC target
HA prime	98 (47%)	108 (51%)	4 (2%)
LA prime	63 (30%)	143 (68%)	4 (2%)
BL prime	74 (35%)	137 (64%)	3 (1%)

The prime type \times target completion interaction remained significant: min. $LRCs1 = 11.726$, $df = 4$, $P < 0.02$; min. $LRCs2 = 12.063$, $df = 4$, $P < 0.02$.

the target (singular HA host vs. plural LA host, and vice versa) on the priming effects reported ($P_s > 0.45$).

2.6. Discussion

Experiment 1 provided clear evidence for priming of RC attachments in sentence production. As was discussed earlier, models that draw upon residual activation of subcategorization frames or individual syntactic rules (cf. Pickering & Branigan, 1998) would find this result difficult to explain without further assumptions. However, this experiment also revealed a rather prominent asymmetry in priming of high vs. low RC attachments (relative to the baseline) that may, at present, be characterized in two different ways. On the one hand, it could indeed reflect a baseline-dependent asymmetry in the sense that priming is less pronounced for globally preferred structures (LA in this case) than for non-preferred structures (HA). On the other hand, the observed asymmetry could be baseline-independent in the sense that priming is more pronounced for HAs than for LAs, regardless of whether there is a HA or LA preference in the baseline. The latter would suggest some kind of general – and yet to be explained – restriction on the priming of RC attachments.

The intention behind Experiment 2 was therefore to increase the baseline proportion of HA target responses in comparison to Experiment 1. If the magnitude of priming is inversely proportional to the strength of the baseline preference (as the first hypothesis suggests) then, given a higher frequency of HAs, LA priming should become stronger whereas HA priming should become weaker than in Experiment 1. A baseline-independent asymmetry, on the other hand, should manifest itself in no substantial changes from the priming pattern observed in Experiment 1; that is, a reliable repetition effect (relative to the baseline) should only be observed in the HA prime condition but not, or only marginally so, in the LA prime condition, even though the baseline proportion of HA targets may be higher.

In fact, it appeared that some of the target fragments used in Experiment 1 were biased in the sense that the LA option was pragmatically more accessible than the HA option. To give an example, the target fragment “Kurt überprüfte die Papiere der Bewerberin, die ____/Kurt checked the documents of the applicant that ____” (Item 09) was associated with a 96% bias (across all conditions) towards LA completions. The reason for this might be that, among other things, human attachment hosts (applicant) have a certain advantage over non-human ones (documents), as it appears relatively easy to come up with

something that modifies a human (e.g. “wears contact lenses”, “lives in Ouagadougou”, “drives a Rolls Royce”, “supports Glasgow Rangers”, etc.), whereas modification of a non-human entity such as a set of application documents may require more specific knowledge about the relevant properties that can be modified (e.g. “are printed on watermarked sheets”, “appear to be faked”, etc.). A different example is “Der Astronom errechnete die genaue Lebensdauer der Sterne, die ____/The astronomer calculated the exact life span of the stars that ____” (Item 16), which was completed with a LA continuation in 93% of the cases. Here, the reason for the LA bias might be that there is simply not much to say about the particular HA host (the exact life span) that would inspire further modification within a RC (except that it “was relatively long”, as was graciously attested by a single participant).

As these two examples illustrate, there were a number of potential pragmatic reasons for the overall LA bias in Experiment 1. They appeared to vary from target fragment to target fragment, but all happened to work in the same direction across items. Instead of trying to resolve the issue towards an all-embracing pragmatic explanation of the LA bias (which was not a primary aim of this paper), the purpose of Experiment 2 was to increase the overall proportion of HA responses in order to investigate potential changes in the priming magnitudes associated with HA vs. LA primes (as discussed earlier). To achieve this, target fragments with a notable LA bias (70% or more LA completions) were substantially edited for Experiment 2, making the HA option intuitively at least as accessible as the LA option. For instance, the *astronomer* target fragment quoted above (Item 16) was replaced with a completely new one (“Der Ausschuß verwies auf die Herkunft der Spenden, die ____/The commission referred to the source of the donations that ____”). The modifications also resulted in a syntactically more homogenous set of target fragments, such that the critical complex host NPs now always acted as objects (never as subjects). Some prime fragments were slightly changed so as to avoid lexical repetition (some of the new targets contained words that have also been used in the original primes). The full set of items for Experiment 2 is available at http://www.dundee.ac.uk/psychology/cscheepers/Syntactic_Priming.html.

3. Experiment 2

3.1. Method

Design, procedures, filler materials, annotation criteria, and data analysis techniques were the same as in Experiment 1.

3.2. Participants

Thirty new subjects (native German speakers) from the Saarland University community were paid for participation. They were unaware of the purpose of this study until debriefing at the close of the experiment. As before, participants were tested one at a time at the Psycholinguistics Lab in Saarbrücken. A typical session lasted for about 30 minutes. One participant had to be excluded from further analysis because, in an obvious attempt to

be funny, he or she completed almost every fragment using the same verb. The relevant questionnaire booklet was re-run with a new participant.

3.3. Results

3.3.1. General findings

Trials with ‘incorrect’ prime completions were discarded. This resulted in 238 (99%) valid trials for the HA prime condition, 233 (97%) valid trials for the LA prime condition, and 237 (99%) valid trials for the BL prime condition. Again, most of the target fragments (94%) were completed as subject-RCs. Object-RCs accounted for about 6%, and other responses for less than 1% of the target completions. The relative proportion of UC target attachments was higher for object-RCs (32%) than for subject-RCs (1%), and there was no further relationship (neither globally, nor by prime condition) between the internal structure of a target-RC and its attachment to either of the relevant host NPs. Overall, about 48% of all target-RCs were attached high, 48% were attached low, and 3% were UC regarding HA vs. LA. Hence, as intended, the new set of items (with modified target fragments) elicited a higher proportion of HA target completions than the earlier materials (Experiment 1).

3.3.2. Priming effects

Table 3 lists the observed proportions of HA, LA, and UC target completions for each level of prime type. Descriptively, there were more LA target completions after LA primes than after HA primes or BL primes. Moreover, the relative proportion of HA target completions was somewhat higher after HA primes than after LA primes or BL primes. Also note that the BL prime condition showed a slight (non-significant) advantage for HA over LA target completions in this experiment, contrasting with Experiment 1.

Log-linear analyses established a significant overall prime type \times target completion interaction (min. $LRCS1 = 18.132$, $df = 4$, $P < 0.002$; min. $LRCS2 = 18.619$, $df = 4$, $P < 0.001$). Relative proportions of classifiable vs. unclassifiable target completions were not substantially affected by prime type (min. $LRCSs < 0.54$, $df = 2$, $P_s > 0.76$). However, pair-wise comparisons considering only the proportions of HA to LA target completions confirmed that there were reliably more LA target completions after LA primes than after HA or BL primes (LA vs. HA primes: min. $LRCS1 = 16.522$, $df = 1$, $P < 0.001$; min. $LRCS2 = 16.921$, $df = 1$, $P < 0.001$; LA vs. BL primes: min. $LRCS1 = 8.889$, $df = 1$, $P < 0.003$; min. $LRCS2 = 9.107$, $df = 1$, $P < 0.003$).

Table 3

Numbers of HA, LA, and UC target completions (columns) by levels of prime type (rows) for Experiment 2

	HA target	LA target	UC target
HA prime	136 (57%)	97 (41%)	5 (2%)
LA prime	86 (37%)	139 (60%)	8 (3%)
BL prime	121 (51%)	107 (45%)	9 (4%)

Relative frequencies per prime condition are listed in parentheses.

Table 4
Data for Experiment 2, considering subject-RC target completions only

	HA target	LA target	UC target
HA prime	126 (57%)	95 (43%)	2 (1%)
LA prime	84 (38%)	136 (61%)	3 (1%)
BL prime	111 (51%)	106 (49%)	1 (0%)

The prime type \times target completion interaction remained significant: min. $LRCs1 = 14.583$, $df = 4$, $P < 0.01$; min. $LRCs2 = 14.968$, $df = 4$, $P < 0.01$.

The contrast between the HA and the BL prime condition was not reliable (min. $LRCs < 1.2$, $df = 1$, $Ps > 0.27$).

As in Experiment 1, the overall pattern of results did not change when only subject-RC completions were considered (Table 4). The three-way interactions between participants (respectively items), prime type, and target completion were not significant ($Ps > 0.91$), and there was no substantial influence of the type of number contrast in the target (singular HA host vs. plural LA host, and vice versa) on the priming effects reported ($Ps > 0.33$).

3.4. Discussion

Compared to Experiment 1, the second experiment obtained a *reverse* pattern of results: first, there was a numerical baseline bias towards HA completions; second, there was a clear LA priming effect (reliably more LA target completions after LA primes rather than BL primes), whereas the HA priming effect became much weaker than in Experiment 1 (the contrast between the HA and the BL prime condition was descriptively present, but not reliable). Apart from strengthening the evidence for priming of RC attachments in production, these findings support the hypothesis that the magnitude of RC attachment priming is inversely proportional to the given baseline preference; they do not support the alternative assumption that priming is confined to one particular RC attachment option. Thus, it can be concluded that both HAs and LAs are susceptible to priming. However, the strength of the priming effect for either of the two attachment options depends on the baseline bias (which, in turn, appears to be influenced by pragmatic factors favouring one or the other attachment option in different target fragments): in case of a baseline preference for LA, HA priming is more pronounced (Experiment 1); in case of a baseline trend towards HA, LA priming is more pronounced (Experiment 2). While a specific explanation of this would go beyond the scope of this paper (but see Scheepers, 2003), it is worth pointing out that similar observations have been made elsewhere, on rather different kinds of structural contrasts (e.g. Hartsuiker & Westenberg, 2000) and in different processing modalities (e.g. Scheepers & Crocker, in press).

An important question that still remains to be answered is at which level of representation the RC attachment priming effect actually emerges. It could be argued that the present experiments do not address the issue of syntactic priming properly because, in contrast to earlier studies where the structures of interest were mostly syntactic

alternations of roughly the same meanings, different RC attachments would, of necessity, also imply differences in the relevant discourse structures. For example, a RC links to either of the two candidate host NPs not only by virtue of syntactic attachment but also through anaphoric binding (co-indexing at the discourse level between the relative pronoun and the host-NP entity it refers to, cf. Hemforth et al., 2000). Equally, it may be possible that the observed priming effects reflect a propensity of the language producer to repeat a particular focus structure from one trial to the next: referring back to a matrix clause NP from a subordinate clause (such as a RC) is likely to put extra focus on that NP; thus, if language producers are driven by a tendency to preserve focus structure over consecutive trials, they should be likely to maintain RC attachments from primes to targets because such a strategy would ensure that the targets place the same NPs into focus as the preceding primes.

Although it seems unlikely that RC attachment priming is solely due to such non-syntactic factors (after all, earlier research has shown that structural priming occurs even if non-syntactic factors are controlled), the following experiment will examine these alternative explanations more explicitly. In particular, Experiment 3 will employ primes that differ in syntactic structure from the targets (the latter will be the same as in Experiment 2) while still enforcing anaphoric bindings that put either the first ('high') or the second ('low') candidate host NP into focus. If RC attachment priming is due to maintaining non-syntactic aspects such as focus structure or anaphoric binding, the new primes should be as effective as the earlier ones. A substantial reduction in the magnitude of priming would, however, suggest that RC attachment priming is dependent on a syntactic overlap between primes and targets. Hence, the latter would support the view that the results from Experiments 1 and 2 reflect true syntactic priming of RC attachments in sentence production.

4. Experiment 3

4.1. Design and materials

The materials for Experiment 3 were based on those from Experiment 2,⁶ except that the non-baseline primes (now labelled HR for *high referent* and LR for *low referent*) were modified by replacing the relative pronoun with a temporal (or causal) conjunction after the comma, followed by a demonstrative pronoun of the appropriate gender (matching the gender of the 'high' or 'low' matrix host NP, respectively). Baseline primes (BL), as well as target fragments (T), were the same as in Experiment 2. An example is given in (3).

⁶ Recall that the targets from Experiment 2 were not as strongly biased as those from Experiment 1. Moreover, Experiment 2 revealed slightly stronger priming effects overall than Experiment 1 (presumably because of the smaller bias and/or because of more homogeneous structures in the targets). Hence, I assumed that the new primes would stand a higher chance of being effective if they were combined with the targets from Experiment 2 rather than 1.

- (3) HR Die Assistentin verlas den Punkttestand der Kandidatin, als dieser ...
The assistant announced the score [masc, sing] of the candidate [fem, sing] when this [masc, sing] ...
- LR Die Assistentin verlas den Punkttestand der Kandidatin, als diese ...
The assistant announced the score [masc, sing] of the candidate [fem, sing] when this [fem, sing] ...
- BL Die Assistentin verlas den Punkttestand der Kandidatin, bevor ...
The assistant announced the score [masc, sing] of the candidate [fem, sing] before ...
- T Der Rentner schimpfte über die Autorin der Flugblätter, die ...
The pensioner railed about the author [fem, sing] of the fliers [neut, plur] that [?] ...

The crucial difference between Experiment 3 and the earlier experiments is that the non-baseline primes (HR and LR) now enforced the production of adverbial clauses due to the insertion of a conjunction after the comma. However, unlike BL primes, which triggered adverbial clauses as well, the new non-baseline primes also contained pronouns that unambiguously referred to either of the critical host NPs in the matrix clause. In other words, HR and LR primes triggered the same anaphoric bindings and/or focus structures as the HA and LA primes of the earlier experiments, yet in contrast to the latter, they were syntactically very different from the targets they were paired with: unlike RCs, adverbial clauses do not attach to an NP in the matrix clause; rather, they attach to VP or S, as illustrated in Fig. 2. The main function of an adverbial clause is to modify the event or action described in the matrix clause (typically, as a specification of *why*, *how*, or *when* the event or action took place); elements within the adverbial clause may refer back to an NP in the matrix clause, but crucially, this does not involve syntactic attachment of the adverbial clause to the relevant NP.⁷ From this, it follows that any repetition effects elicited by the primes in the current experiment must be due to non-syntactic factors such as focus structure or anaphoric binding. The use of demonstrative pronouns in the primes (instead of personal pronouns) had the advantage of blocking reference to the non-critical subject NP in the matrix clause (referring back to the matrix subject NP with a demonstrative pronoun would sound pragmatically odd). The full set of materials is available at http://www.dundee.ac.uk/psychology/cscheepers/Syntactic_Priming.html.

4.2. Participants and procedures

Thirty new subjects (native German speakers) from the Saarland University community were paid for participation. They were unaware of the purpose of this study until debriefing at the close of the experiment. Participants were tested in individual sessions,

⁷ This can be demonstrated by means of a simple linguistic test: while RCs (ii) may appear within the NP slot of a NP-V sentence, adverbial clauses may not (iii).

(i) NP slept.

(ii) *The servant of the actress who was on the balcony* slept.

(iii) **The servant of the actress when she was on the balcony* slept.

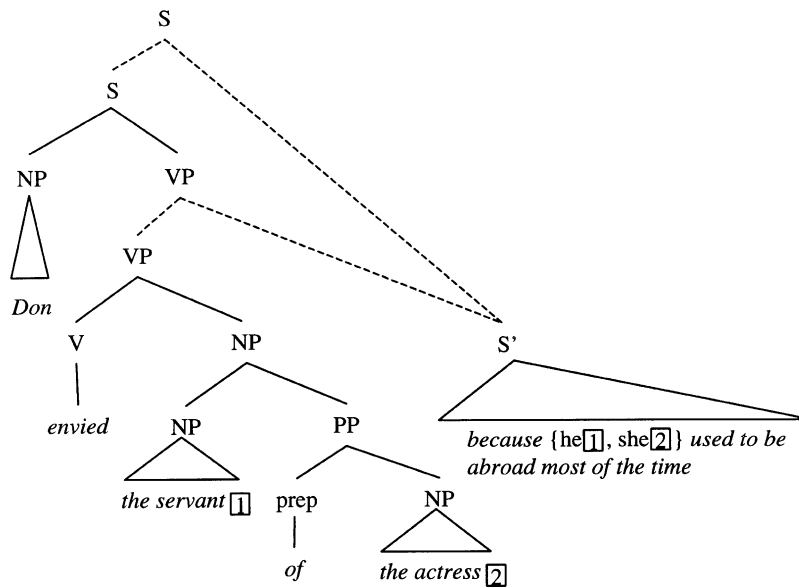


Fig. 2. Attachment of an adverbial clause. The indices [1] and [2] are meant to indicate co-reference between pronouns and antecedents at the discourse level.

each of which took about 30 minutes to complete. Procedures, filler materials, annotation criteria, and data analysis were the same as before. There were three instances (out of 480) where participants had used the demonstrative pronoun of a HR or LR prime to refer back to the matrix subject NP; these were treated as ‘incorrect’ prime completions.

4.3. Results

4.3.1. General findings

Trials with ‘incorrect’ prime completions were eliminated, resulting in 237 (99%) valid trials for the HR prime condition, 232 (97%) valid trials for the LR prime condition, and 239 (99%) valid trials for the BL prime condition. As before, most of the target fragments (94%) were completed as subject-RCs. Object-RCs accounted for about 5%, and other responses for ca. 1% of the target completions. The relative proportion of UC target attachments was higher for object-RCs (38%) than for subject-RCs (less than 1%), and there was no further relationship (neither globally, nor by prime condition) between the internal structure of a target-RC and its attachment to either of the relevant host NPs. Overall, about 46% of all target-RCs were attached high, 51% were attached low, and 3% were UC regarding HA vs. LA. The mean proportion of HAs was about 2% lower than in Experiment 2, and about 10% higher than in Experiment 1.

4.3.2. Priming effects

Table 5 lists the observed proportions of HA, LA, and UC target completions for each level of prime type. Descriptively, there was a slight advantage for LA over HA target

Table 5
Numbers of HA, LA, and UC target completions (columns) by levels of prime type (rows) for Experiment 3

	HA target	LA target	UC target
HR prime	115 (49%)	115 (49%)	7 (3%)
LR prime	104 (45%)	121 (52%)	7 (3%)
BL prime	105 (44%)	124 (52%)	10 (4%)

Relative frequencies per prime condition are listed in parentheses.

completions in the baseline condition (comparable to – but considerably weaker than – the bias found in Experiment 1); differences between individual prime conditions (especially between HR and the other conditions) were pointing in the expected directions, but overall, priming magnitudes appeared much smaller than in the previous experiments.

In fact, the two-way prime type \times target completion interaction did not approach significance in this experiment (min. $LRC\text{S}1 = 1.072$, $df = 4$, $P > 0.89$; min. $LRC\text{S}2 = 1.130$, $df = 4$, $P > 0.88$). Pair-wise comparisons across prime conditions (considering only proportions of HA to LA target completions) could not establish a reliable effect either (all P s > 0.39). The picture stayed the same when only subject-RC target completions were considered (Table 6), and there were no significant three-way interactions involving participants, items, or type of number contrast (all P s > 0.50). Hence, it can be concluded that Experiment 3 failed to obtain any reliable priming effects.

4.4. Discussion

Given that Experiment 3 had about the same statistical power (in terms of numbers of observations) as the earlier two experiments, the fact that it could not establish a significant effect of prime type is both meaningful and important. It suggests that the results from the earlier two experiments are not due to priming of anaphoric bindings or of focus structure, but rather relate to syntactic persistence in sentence production. That is, reliable RC attachment priming seems to occur only if the prime triggers a syntactic configuration that can be replicated in the target; if, on the other hand, the prime just triggers a certain anaphoric binding (or focus structure) without agreeing in syntactic structure with the target, then priming effects are reduced to insignificance.

Table 6
Data for Experiment 3, considering subject-RC target completions only

	HA target	LA target	UC target
HR prime	108 (49%)	110 (50%)	2 (1%)
LR prime	98 (45%)	119 (55%)	0 (0%)
BL prime	101 (45%)	121 (54%)	3 (1%)

The prime type \times target completion interaction remained unreliable: min. $LRC\text{S}1 = 1.423$, $df = 4$, $P > 0.83$; min. $LRC\text{S}2 = 1.535$, $df = 4$, $P > 0.81$.

A perhaps more compelling demonstration of this finding is achieved if we compare the experiments directly with one another, focusing only on the non-baseline conditions and considering only the proportions of classifiable (HA and LA) target completions: for Experiment 1, there was, on average, about 15% priming between the HA and LA prime conditions, for Experiment 2, the effect amounted to about 20%, and for Experiment 3, the effect between HR and LR was reduced to a mere 4% average difference. The corresponding log-linear analyses (treating all factors as between-subjects/items variables) revealed a reliable experiment \times prime type \times target completion interaction between Experiments 1 and 3 (min. *LRC*S = 4.058, *df* = 1, $P < 0.05$), and between Experiments 2 and 3 (min. *LRC*S = 6.188, *df* = 1, $P < 0.02$), but not between Experiments 1 and 2 (min. *LRC*S = 0.168, *df* = 1, $P = 0.68$). This confirms a substantial reduction in the magnitude of priming for Experiment 3, where primes and targets were structurally incongruent.

In fact, these results have yet another important implication. It could be argued that the BL primes employed in each of the reported experiments were not exactly ‘neutral’, since they were triggering adverbial clauses comparable to the HR/LR primes in Experiment 3: on a considerable number of BL trials, participants could have inserted a pronoun that refers back to one of the critical attachment hosts, which might, in turn, have influenced their attachment decision in the corresponding target trial.⁸ The results from Experiment 3 (specifically, the non-significant contrast between HR and LR primes) suggest, however, that referring back to a critical matrix host NP from an adverbial clause (in the prime) does not substantially affect the RC attachment decision in the target trial. Hence, there is little reason to believe in a biasing influence of the BL primes.

5. General discussion

The experiments presented in this paper demonstrated reliable priming for the generation of NP-of-NP-RC sequences regarding the attachment of the critical RC. If prime fragments triggered RC attachment to the HA host, then this type of attachment was also more likely to be generated in the targets. By contrast, if prime fragments triggered RC attachment to the LA host, then LAs rather than HAs were more likely to be generated in the targets.

A comparison between Experiments 1 and 2 further suggested a rather interesting influence of the baseline bias: for generally preferred attachments, priming effects turned out to be weaker than for non-preferred attachments (the baseline preferences themselves appeared to be influenced by what I have called *pragmatic accessibility*, cf. Section 2.6). The issue of why preferred structures are associated with weaker priming effects is certainly worth further investigation,⁹ especially given that similar observations have been made elsewhere (e.g. Hartsuiker & Westenberg, 2000; Scheepers & Crocker, in press).

Importantly, RC attachment priming cannot convincingly be attributed to non-syntactic mechanisms such as repetition of anaphoric bindings or of focus structure: when

⁸ An informal inspection of the BL prime completions suggested, however, that participants were more likely to refer back to the (non-critical) matrix subject NP in case they inserted a pronoun.

⁹ For example, it could be due to the *informativity* of the prime in relation to the baseline bias (Scheepers, 2003): a prime that corresponds with a structure which is preferred *anyway* is less informative (and thus helpful in guiding target attachment decisions) than a prime that corresponds with a non-preferred structure.

RC-targets were preceded by primes that triggered anaphoric adverbial clauses (Experiment 3), there was no sign of a reliable priming effect. This supports the view that repetition of RC attachments (as observed in Experiments 1 and 2) falls into the domain of syntactic priming in sentence production.

5.1. A potential explanation

In Section 1, I have argued that the model proposed by Pickering and Branigan (1998) cannot account for RC attachment priming because, in its present form, it focuses solely on the *building blocks* of syntactic representation (subcategorization frames or context-free rules) that may be retained from one utterance to the next. RC attachments, however, add a further dimension to this because they concern the issue of hierarchical syntactic configuration, which cannot be expressed in terms of the underlying syntactic rules themselves. This is because different RC attachments always employ the same syntactic rules (or modifier-adjoining principles; cf. Chomsky, 1981; Pollard & Sag, 1987, 1994).

Hence, in order to explain syntactic priming of RC attachments in production, I suggest the following extension of Pickering and Branigan's model. In addition to combinatorial nodes (encoding context-free rules), there needs to be a mental record of the *sequence* of syntactic rule applications (or combinatorial node activations) during sentence generation. For example, under the assumption of a top-down generator (cf. Yngve, 1960), the rule sequence $\langle \text{NP} \rightarrow \text{NP RC} \rangle \langle \text{NP} \rightarrow \text{NP PP} \rangle \langle \text{PP} \rightarrow \text{prep NP} \rangle$ would result in an NP-of-NP-RC string with high attachment of the RC, whereas the sequence $\langle \text{NP} \rightarrow \text{NP PP} \rangle \langle \text{PP} \rightarrow \text{prep NP} \rangle \langle \text{NP} \rightarrow \text{NP RC} \rangle$ would yield low attachment of the RC (Fig. 3).¹⁰ Other algorithms (e.g. bottom-up generation) may assume different rule sequences for the relevant attachments, but crucially, a 'high attachment sequence' will always differ from a 'low attachment sequence'.

Now, if we further assume that such a sequence of generative rule applications is easier to reproduce (e.g. via residual activation) after having been instantiated in a given trial, we can predict that after generating a certain type of RC attachment in a prime trial, the producer should be likely to maintain this type of attachment in the following target trial. Moreover, we can predict that after having produced an adverbial clause in the prime trial, RC attachment in the target trial will not be substantially affected (the rules that need to be applied, as well as their relative sequencing, will differ between adverbial clauses and RCs). Hence, under the assumption that not only individual syntactic rules may retain residual activation (cf. Pickering & Branigan, 1998), but also the order in which they are being applied during structure assembly, the results from Experiments 1–3 can be explained.

The proposed account appears to emphasize procedural aspects of sentence generation (cf. Bock & Loebell, 1990) more than declarative aspects (cf. Branigan et al., 1995, 2000). However, in my opinion the distinction between 'syntactic procedures' on the one hand and 'syntactic representations' on the other is somewhat arbitrary anyway, given that such

¹⁰ Interestingly, such a top-down approach predicts low RC attachments to be easier to generate than high RC attachments because the numbers of right-branching commitments that need to be kept in memory before being expanded are greater for HAs than for LAs. Although the experiments reported in this paper seem to support this (on average, they obtained 53% LA target attachments as opposed to 43% HA target attachments), one has to bear in mind that part of this overall preference is due to potential pragmatic biases in the materials (see Section 2.6).

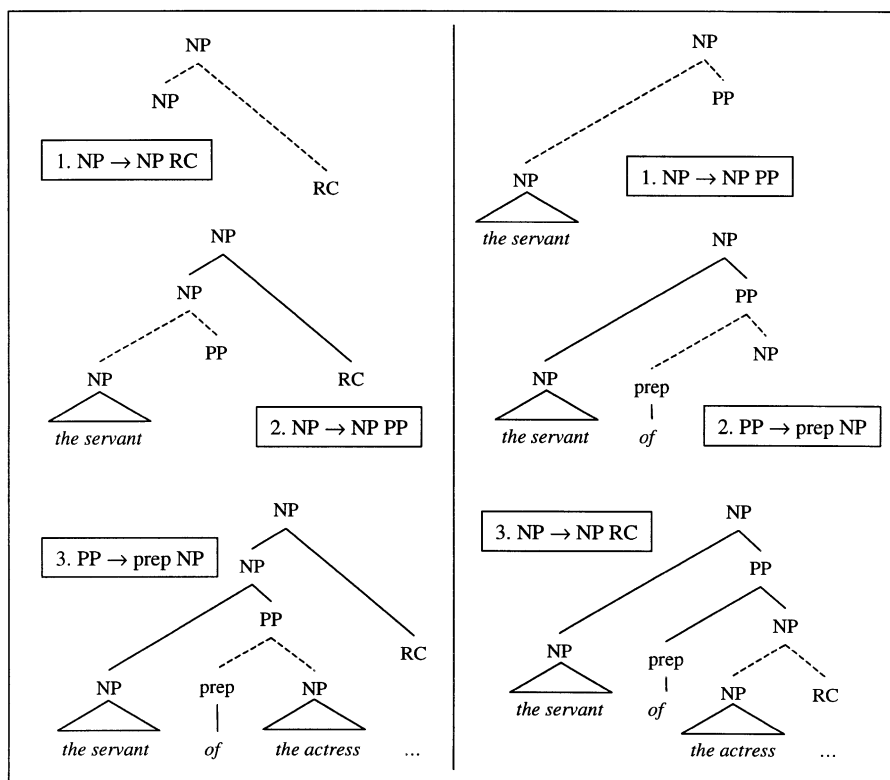


Fig. 3. Top-down generation sequence for high attachment (left hand panel) and low attachment (right hand panel) of a RC. For the sake of brevity, the NPs *the servant* and *the actress* are treated as terminal symbols.

a distinction largely depends on the grammatical framework and notational format chosen; for example, using a *tree description* framework (e.g. Marcus, Hindle, & Fleck, 1983) rather than context-free rules it is possible to formalize the critical high vs. low RC attachment contrast in representational rather than procedural terms. Unless there is agreement about the exact format of grammatical representation in language production, there is little point in taking up one or the other side of the *procedural vs. declarative* debate. In conclusion, while I proposed a procedural account of RC attachment priming in production, I do not categorically deny the possibility of alternative, non-procedural explanations. Importantly, however, any such alternative would have to take the notion of hierarchical syntactic configuration into account.

5.2. Further questions

Given that this paper is the first to have shown syntactic priming beyond individual syntactic rules (or local frames), there are still many open questions concerning the approach I have just outlined. For example, does it generalize to three-site RC attachments (“Don mentioned the servant of the mother of the actress who ...”) or to

commitments at even more global levels of syntactic representation (e.g. between a RC and an adverbial clause continuation in a fragment like “Don mentioned the servant of the actress ...”)? Experiments that address these questions in detail are currently underway.

5.2.1. Long-term priming

Another issue is whether structure assembly sequences (resulting in different syntactic attachment configurations) possess permanent traces in long-term memory or whether they are just temporarily activated each time a given structure is generated. The former has been claimed to be the case in sentence comprehension. The so-called *tuning hypothesis*, for example, states that sentence comprehenders prefer syntactic configurations (such as HAs vs. LAs in NP-of-NP-RC sequences) that they have encountered most frequently in the past (e.g. Mitchell & Cuetos, 1991; Mitchell, Cuetos, Corley, & Brysbaert, 1995; but see, e.g. Carreiras & Clifton, 1999; Desmet, Brysbaert, & De Baecke, 2002, for some challenging evidence). Crucially, such a proposal implies that these configurations (or the underlying structure assembly sequences) must be represented in long-term memory in some way.

Whether such a claim can also be made for sentence production is difficult to say on the basis of the present data. However, one could argue that if such long-term representations exist for production, it should be possible to show some evidence for *long-term priming*, i.e. general shifts in the relative proportions of target completions over the course of an experiment (see, e.g. Hartsuiker & Westenberg, 2000, who observed such an effect in a written completion experiment on word order priming). In particular, one might predict for Experiment 1, where a baseline bias towards LAs was observed, that participants should have produced more HAs towards the end of the experiment than at the beginning of the experiment (repeated encounters with HA primes [and targets] over time should have increased participants’ readiness to adopt this usually dispreferred response option). Likewise, for Experiment 2, where a (weak) baseline bias towards HAs was observed, one would predict more LAs towards the end rather than at the beginning of the experiment.

However, additional log-linear analyses comparing the first half of trials (Block1) with the second half of trials (Block2) in each of the two experiments could not establish any reliable long-term priming effects: for Experiment 1, there were 35% HA (vs. 59% LA) target completions in Block1, and 35% HA (vs. 58% LA) target completions in Block2; for Experiment 2, the relevant proportions were 50% LA (vs. 47% HA) target completions in Block1 and 47% LA (vs. 49% HA) target completions in Block2 ($P_s > 0.98$ for the experimental block \times target completion interactions). Detailed analyses by prime condition also failed to detect a significant influence of experimental block (all $P_s > 0.20$).¹¹ The absence of a substantial long-term priming effect could imply that RC attachment priming in production is a rather transient phenomenon, and that structure assembly sequences do not necessarily have to be represented in long-term memory.

5.2.2. Level of processing

A final, more theoretical issue concerns the level of processing at which structure assembly sequences are being activated. Bock and Levelt (1994) distinguish between two

¹¹ There were also no long-term priming effects in Experiment 3, which is, however, less surprising because this experiment failed to obtain reliable short-term priming effects either.

distinct steps of grammatical encoding: the so-called *functional* level and the *positional* level. While the former is assumed to be responsible for lexical access and grammatical function assignment (on the basis of conceptual level information), the latter is reserved for the linear sequencing and hierarchical structuring of representations generated at the functional level. Given that the HA vs. LA contrast investigated in this paper concerns a difference in hierarchical structuring rather than a difference in wording or grammatical function assignment, it seems most natural to view repetition of RC attachments as an instance of priming at the positional level of grammatical encoding (cf. Hartsuiker & Westenberg, 2000; Scheepers & Corley, 2000).

Note that the account by Pickering and Branigan (1998) is underspecified with respect to whether combinatorial nodes (viz. context-free rules) are to be represented at the functional or the positional level; all they claim is that combinatorial nodes *link to* lemma nodes at the functional level (not only for verbs, but also for nouns; see Cleland & Pickering, 2001, 2003). The proposed extension of the model (in terms of rule sequencing at the positional level) is therefore not at odds with the original model architecture. An interesting question in this respect is whether structure assembly sequences would link to lemma nodes in the same way as individual syntactic rules do in Pickering and Branigan's model. If so, one might observe stronger RC attachment priming effects if head nouns of host-NPs were shared (or at least semantically related) between primes and targets than if they were different (as in the present experiments). For the moment, I leave this as an empirical issue for future research.

5.3. Other models

Having outlined a possible explanation of RC attachment priming in production, the question arises whether there are models of grammatical encoding that might find the present results difficult to accommodate. I believe that there is at least one instance of such a model, which is described in detail in Dell, Chang, and Griffin (1999) and in Chang, Dell, Bock, and Griffin (2000). This connectionist type of model, which can be viewed as an alternative to the rule-based accounts discussed so far, combines a production network whose task is to generate word sequences from content with a variant of a simple recurrent network (SRN; cf. Elman, 1990; Jordan, 1986) that is trained to associate word sequences with sequences of (roughly) thematic representations. The model assumes a close relationship between comprehension and production in that the SRN that maps word sequences onto messages (thus, carrying out comprehension) interacts with the behaviour of the production system via linking its context units to the hidden units of the production network. Sentence-level priming in production is an emergent feature of this architecture: the same mechanism through which the system actually learns to produce sentences also causes priming in subsequent productions. Priming is therefore treated as a form of implicit learning without postulating the activation of explicit syntactic representations in short-term memory. Using this model, Chang et al. (2000) are able to simulate a variety of syntactic priming results from the literature, including, for example, priming of active vs. passive sentences or of PO vs. DO constructions in English.

Although the model is certainly interesting (effectively, it suggests that certain sentence-level priming effects do not necessarily have to be syntactic in nature, as they can

be modelled via implicit learning of mappings between word and message sequences), I doubt that such a model can successfully accommodate the evidence provided in this paper. Recall that an account of RC attachment priming in production must be able to represent hierarchical syntactic relations, for otherwise there is no way of expressing the relevant structural contrast that the system must adapt to (crucially, different RC attachment configurations do not imply different word orders). However, while SRNs are unquestionably able to capture sequential probabilistic contingencies within a language (comparable to classical Markov Models), they remain entirely unspecific as to the kinds of syntactic representations they are able to acquire. Specifically, it is not clear whether they can at all be trained to represent true hierarchical syntactic relations rather than some weak finite-state approximation to such relations (cf. Steedman, 1999). Thus, SRNs may not provide an appropriate architecture for modelling the present results. This is, of course, by no means equivalent with saying that connectionist models *per se* would fail to provide a suitable framework. In particular, hybrid architectures that combine symbolic grammars with recursive neural networks (Costa, Frasconi, Lombardo, & Soda, *in press*; Sturt, Costa, Lombardo, & Frasconi, 2003) appear to be a promising new development towards dealing with attachment preferences in NP-of-NP-RC constructions.

Finally, recall from the previous sections that the present studies could not establish any long-term priming effects in the relative proportions of RC attachments produced. However, long-term priming is one of the core predictions of accounts based on implicit learning. This is because such models do not distinguish between long-term vs. short-term adaptation in language production (both follow from essentially the same mechanism); thus, whenever there is evidence for ‘short-term priming’ there should also be evidence for ‘long-term priming’, according to an implicit learning approach.

Taken together, it seems hard to imagine that the present results on RC attachment priming (including the lack of a priming effect in Experiment 3) can be easily accounted for by an architecture such as the one proposed by Chang et al. (2000).

6. Conclusion

Experiments 1 and 2 in this paper provided evidence for a tendency of language producers to maintain the hierarchical structuring of NP-of-NP-RC constructions over consecutive trials in a sentence completion paradigm. Explanations on the basis of discourse structure repetition, semantic overlap between primes and targets, or repetition of agreement features at relative pronouns (gender, number, etc.) fail to account for the data: (a) there was no reliable indication of discourse structure priming in Experiment 3; (b) primes and targets were always semantically unrelated; and (c) there was no systematic overlap regarding the agreement features of relative pronouns between primes and targets. The results from Experiments 1 and 2 must therefore relate to structural priming in sentence production. In contrast to earlier studies, the priming effects in this paper show that *global* aspects of syntactic structure (hierarchical attachment configurations) are subject to priming just as *local* aspects are (subcategorization frames or individual phrase structure rules). This may pose a challenge to models of grammatical encoding which do not include an explicit representation of hierarchical syntactic relations.

It seems likely that the above conclusions generalize to examples other than NP-of-NP-RC constructions. The present findings may therefore be seen as an inspiration for further research on the persistence of structural configuration in sentence production.

Acknowledgements

Part of this work was conducted within the project seminar *Psycholinguistische Forschungspraxis*, held at the Computational Linguistics Department in Saarbrücken in Winter 2000/01. I wish to acknowledge Garance Paris, Ruth Kusterer, and Stefan Legien for assisting me in the preparation and realization of Experiment 1. Claudia Thiel and Kerstin Klöckner assisted me in running Experiments 2 and 3. This paper has greatly benefited from discussions with Matt Crocker, Barbara Hemforth, Frank Keller, and Martin Pickering, as well as from comments by three anonymous reviewers. Financial support came from the Computational Linguistics Department at Saarland University and from Deutsche Forschungsgemeinschaft SFB 378 (Project EM-7 Alpha).

References

- Bock, J. K. (1986). Syntactic persistence in language production. *Cognitive Psychology*, 18, 355–387.
- Bock, J. K. (1989). Closed class immanence in sentence production. *Cognition*, 31, 163–186.
- Bock, J. K., & Levelt, W. J. (1994). Language production: grammatical encoding. In M. A. Gernsbacher (Ed.), *Handbook of psycholinguistics* (pp. 945–984). San Diego, CA: Academic Press.
- Bock, J. K., & Loebell, H. (1990). Framing sentences. *Cognition*, 35, 1–39.
- Bock, J. K., Loebell, H., & Morey, R. (1992). From conceptual roles to structural relations: bridging the syntactic cleft. *Psychological Review*, 99, 150–171.
- Branigan, H. P., Pickering, M. J., & Cleland, A. A. (2000). Syntactic co-ordination in dialogue. *Cognition*, 75, B13–B25.
- Branigan, H. P., Pickering, M. J., Livsedge, S. P., Steward, A. J., & Urbach, T. P. (1995). Syntactic priming: investigating the mental representation of language. *Journal of Psycholinguistic Research*, 24, 489–506.
- Carreiras, M., & Clifton, C. (1999). Another word on parsing relative clauses: eye-tracking evidence from Spanish and English. *Memory and Cognition*, 27, 826–833.
- Chang, F., Dell, G. S., Bock, J. K., & Griffin, Z. M. (2000). Structural priming as implicit learning: a comparison of models of sentence production. *Journal of Psycholinguistic Research*, 29, 217–229.
- Chomsky, N. (1981). *Lectures on government and binding*. Dordrecht: Foris.
- Cleland, A. A., & Pickering, M. J. (2001). *Priming of noun phrase structure*. Paper presented at the 7th Annual Conference on Architectures and Mechanisms for Language Processing (AMLaP), Saarbrücken, Germany, 2001.
- Cleland, A. A., & Pickering, M. J. (2003). The use of lexical and syntactic information in language production: evidence from the priming of noun-phrase structure. *Journal of Memory and Language*, 49(2), 214–230.
- Corley, M. M. B., & Scheepers, C. (2002). Syntactic priming in English sentence production: categorical and latency evidence from an internet-based study. *Psychonomic Bulletin and Review*, 9(1), 126–131.
- Costa, F., Frascioni, P., Lombardo, V., & Soda, G. (in press). Towards incremental parsing of natural language using recursive neural networks. *Applied Intelligence*.
- Cuetos, F., & Mitchell, D. C. (1988). Cross-linguistic differences in parsing: restrictions on the issue of the late closure strategy in Spanish. *Cognition*, 30, 73–105.
- Cuetos, F., Mitchell, D. C., & Corley, M. M. B. (1996). Parsing in different languages. In M. Carreiras, J. Garcia-Albea, & N. Sebastian-Galles (Eds.), *Language processing in Spanish* (pp. 145–187). Hillsdale, NJ: Erlbaum.

- Dell, G. S., Chang, F., & Griffin, Z. M. (1999). Connectionist models of language production: lexical access and grammatical encoding. *Cognitive Science*, 23(4), 517–542.
- Desmet, T., Brysbaert, M., & De Baecke, C. (2002). The correspondence between sentence production and corpus frequencies in modifier attachment. *Quarterly Journal of Experimental Psychology*, 55A(3), 879–896.
- De Vincenzi, M., & Job, R. (1995). An investigation of late closure: the role of syntax, thematic structure, and pragmatics in initial and final interpretation. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 21(5), 1303–1321.
- Elman, J. L. (1990). Finding structure in time. *Cognitive Science*, 14, 213–252.
- Frazier, L., & Clifton, C., Jr. (1996). *Construal*. Cambridge, MA: MIT Press.
- Gibson, E., Pearlmutter, N., Canseco-Gonzalez, E., & Hickok, G. (1996). Recency preference in the human sentence processing mechanism. *Cognition*, 59, 23–59.
- Hartsuiker, R. J., & Westenberg, C. (2000). Word order priming in written and spoken sentence production. *Cognition*, 75, B27–B39.
- Hemforth, B., Konieczny, L., & Scheepers, C. (2000). Syntactic attachment and anaphor resolution: the two sides of relative clause attachment. In M. Crocker, M. Pickering, & C. Clifton, Jr. (Eds.), *Architectures and mechanisms for language processing* (pp. 259–281). Cambridge: Cambridge University Press.
- Howell, D. C. (2002). *Statistical methods for psychology* (5th ed.). Pacific Grove, CA: Duxbury.
- Jordan, M. I. (1986). *Serial order: a parallel distributed processing account* (ICS Tech. Rep. No. 8604). La Jolla, CA: University of California at San Diego.
- Marcus, M., Hindle, D., & Fleck, M. (1983). D-Theory: talking about talking about trees. *Association for Computational Linguistics*, 21, 129–136.
- Mitchell, D. C., & Cuetos, F. (1991). The origins of parsing strategies. In C. Smith (Ed.), *Current issues in natural language processing*. Austin, TX: Center for Cognitive Science, University of Texas.
- Mitchell, D. C., Cuetos, F., Corley, M. M. B., & Brysbaert, M. (1995). Exposure-based models of human parsing: evidence for the use of course-grained (non-lexical) statistical records. *Journal of Psycholinguistic Research*, 24, 469–488.
- Pickering, M. J., & Branigan, H. P. (1998). The representation of verbs: evidence from syntactic priming in language production. *Journal of Memory and Language*, 39, 633–651.
- Pollard, C., & Sag, I. A. (1987) (1). *Information-based syntax and semantics*. Stanford, CA: CLSI.
- Pollard, C., & Sag, I. A. (1994). *Head-driven phrase structure grammar*. Stanford, CA & Chicago, IL: CLSI & University of Chicago Press.
- Roelofs, A. (1992). A spreading-activation theory of lemma retrieval in speaking. *Cognition*, 42, 107–142.
- Roelofs, A. (1993). Testing a non-decompositional theory of lemma retrieval in speaking: retrieval of verbs. *Cognition*, 47, 59–87.
- Scheepers, C. (2003). *A rational analysis of syntactic priming*. Unpublished manuscript, University of Dundee. Manuscript in preparation.
- Scheepers, C., & Corley, M. M. B. (2000). Syntactic priming in German sentence production. In L. R. Gleitman, & A. K. Joshi (Eds.), (pp. 435–440). *Proceedings of the twenty-second meeting of the Cognitive Science Society*, Mahwah, NJ: Lawrence Erlbaum Associates.
- Scheepers, C., & Crocker, M. W. (in press). Constituent order priming from reading to listening: a visual-world study. In M. Carreiras, & C. Clifton (Eds.), *The on-line study of sentence comprehension: eye-tracking, ERP, and beyond*. Hove: Psychology Press.
- Smith, M., & Wheeldon, L. (2001). Syntactic priming in spoken sentence production – an online study. *Cognition*, 78, 123–164.
- Steedman, M. (1999). Connectionist sentence processing in perspective. *Cognitive Science*, 23(4), 615–634.
- Sturt, P., Costa, F., Lombardo, V., & Frasconi, P. (2003). Learning first-pass structural attachment preferences with dynamic grammars and recursive neural networks. *Cognition*, 88, 133–169.
- Yngve, V. H. (1960). A model and a hypothesis for language structure. *Proceedings of the American Philosophical Society*, 104, 444–466.