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RESEARCH REPORT

The Influence of Verb-Bound Syntactic Preferences on the Processing of Syntactic Structures

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Speakers sometimes repeat syntactic structures across sentences, a phenomenon called syntactic priming. We investigated the influence of verb-bound syntactic preferences on syntactic priming effects in response choices and response latencies for German ditransitive sentences. In the response choices we found *inverse preference effects*: There were stronger syntactic priming effects for primes in the *less* preferred structure, given the syntactic preference of the prime verb. In the response latencies we found *positive preference effects*: There were stronger syntactic priming effects for primes in the *more* preferred structure, given the syntactic preference of the prime verb. These findings provide further support for the idea that syntactic processing is lexically guided.

Keywords: syntactic priming, verb bias, structure preferences

Verbs and syntactic constructions are closely connected. Both *"liefern"* [*to deliver*] and *"verkaufen"* [*to sell*] for example are ditransitive German verbs that can be used in the double object or alternatively the prepositional object dative construction. However the actual linguistic distribution of these alternative constructions varies across verbs. The verb *"liefern"* prefers the double object dative construction (*e.g., "Der Junge liefert dem Mädchen ein Paket"* [*The boy delivers the girl a package*]), while *"verkaufen"* is more common in the prepositional object dative construction (*e.g., "Die Frau verkauft die Blumen an den Mann"* [*The woman sells flowers to the man*]; Schulte im Walde, 2003).

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The close connection between verbs and syntax inspired lexicalist parsing models of syntax (e.g., Bresnan, 2001; Jackendoff, 2002; Joshi & Schabes, 1997; MacDonald, Pearlmutter, & Seidenberg, 1994), which propose that syntactic processing is strongly lexically guided. Confirming this idea, verb-bound syntactic preferences have been found to affect syntactic processing (Melinger & Dobel, 2005; Trueswell & Kim, 1998; Trueswell, Tanenhaus, & Kello, 1993). Single verbs presented in isolation changed the likelihood for the speaker to select one alternative structure instead of the other (Melinger & Dobel, 2005; Salamoura & Williams, 2006). Furthermore, while speakers often choose to repeat structures across sentences (syntactic or structural priming; Bock, 1986), not all sentences influence subsequent syntactic production choices to the same extent. The strength of syntactic priming effects on production choices is inversely related to the degree to which the structure of a prime sentence was preferred (Ferreira & Bock, 2006; Scheepers, 2003), even when the syntactic preference is conditioned by the main verb (Bernolet & Hartsuiker, 2010; Jaeger & Snider, 2007, 2008, 2013; Reitter, Keller, & Moore, 2011). This has been termed the *inverse preference effect* (Ferreira & Bock, 2006). For example, a passive (less preferred) prime structure may influence speakers more strongly to reuse the passive structure than an active (more preferred) prime structure would influence speakers to reuse the active structure. In another example, a prime sentence in the double object dative structure containing the verb *"verkaufen"* (this verb has a prepositional object dative preference) may bias speakers more to reuse the double object dative structure than a prime sentence in the double object dative structure containing the verb *"liefern"* (a verb with double object dative preference).

There are several different proposals on the mechanism driving syntactic priming. Syntactic persistence has been attributed to activation of recently processed representations in the mental lexicon (Pickering & Branigan, 1998) or error-based implicit learning (Chang, Dell, & Bock, 2006; Chang, Dell, Bock, & Griffin, 2000). The former explanation can account for short-term (the activation of the lexical item decays quickly) lexical influences on syntactic priming like the "lexical boost." This is the phenomenon in which the syntactic priming effects are amplified when not only the syntactic structure but also the lexical head of this structure is repeated (Pickering & Branigan, 1998). However an activation account cannot explain inverse preference effects. An alternative explanation in terms of error-based implicit learning (Chang et al., 2006, 2000) does account for inverse preference effects: The larger prediction error accompanying the comprehension of less preferred prime structures leads to larger changes in internal representations. Some recent error-based implicit learning frameworks include multiple mechanisms that establish verb-structure associations. In the Chang, Janciauskas, and Fitz (2012) version, a slow error-based implicit learning mechanism that updates the frequency representation after each verb-structure pairing accounts for verb bias learning, while an explicit chunk knowledge mechanism is proposed to explain the lexical boost effects.

In a hybrid account, Reitter et al. (2011) synthesized the strengths of an activation and an (unsupervised) implicit learning mechanism. In their computational model, priming emerges from two mechanisms that are based on well-established general memory retrieval mechanisms: the learning of individual syntactic representations (base-level learning) and the acquisition of links between these syntactic representations and lexical or semantic materials (spreading activation). This hybrid model can account for inverse frequency effects in response choices: Through base-level learning the frequent structures obtain an increased resting activation; an activation boost due to a more frequent prime structure thus leads to a smaller relative activation increase. In another prominent account, Jaeger and Snider (2007, 2008, 2013) proposed a computational model in which syntactic persistence is surprisal-sensitive. Prime structures accompanied by a larger surprisal lead to larger changes in response choices. The surprisal of a prime structure is defined as the inverse log-probability of the prime. This intends to capture information about how probable or expected a prime was given the context. The context includes recent experience with syntactic structures as well as knowledge on verb-bound syntactic preferences (based on life-long prior experience).

Previous work has thus demonstrated that the strength of syntactic priming effects on response choices is determined by (verb-bound) syntactic preferences and several models are able to account for the inverse preference effect (Chang et al., 2006; Jaeger & Snider, 2013; Reitter et al., 2011). But how about syntactic priming effects on response latencies?

So far only a small number of studies have investigated the effects of syntactic priming on the speed of production. These studies have demonstrated however that syntactic priming does result in faster sentence production latencies (Corley & Scheepers, 2002; Segaert, Menenti, Weber, & Hagoort, 2011; Smith & Wheeldon, 2001; Wheeldon & Smith, 2003; Wheeldon, Smith, & Apperly, 2011). In Segaert et al. (2011) we measured the effects of syntactic priming of transitives on response choices as well as latencies in two experiments. Interestingly, although syntactic priming showed an inverse preference effect on the response choices, the response latencies showed the opposite pattern. There was significant syntactic priming for the less preferred syntactic alternative (passives) in the response choices, while for the more preferred syntactic alternative (actives) there was significant priming in the response latencies (verb-bound preferences were not investigated). These findings present us with a thought-provoking dichotomy between two measures of syntactic priming in language production.

In Segaert et al. (2011, pp. 12–13) we proposed a competition account of syntactic priming aimed specifically at explaining this dichotomy. We postpone a discussion on how the Segaert et al. (2011) account relates to models that focus on explaining syntactic priming effects on response choices rather than latencies. We revisit this issue in the general discussion and focus on summarizing the Segaert et al. (2011) competition account here. In our model, syntactic encoding consists of two sequential stages: (a) *a selection stage*, during which one of the alternative syntactic constructions is selected, and (b) *a planning stage*, during which production of the selected construction is prepared. The choice of a syntactic construction is determined exclusively during the first stage: the selection stage. Production speed is determined by both stages: The selection time in stage one and the planning time in stage two contribute to the response latency as additive effects. We now explain the competition account in more detail. We start by explaining the processing mechanisms that pertain to the response choice component of syntactic priming, before moving on to the mechanism that explains the response latency component of syntactic priming.

As the description of a perceived event can be encoded in alternative syntactic constructions, one alternative has to be selected first. In our model, this happens in the selection stage. Constructional alternatives are represented by competing nodes. Each node has a base-level activation which is established through a learning mechanism and is positively related with the frequency of occurrence of the syntactic alternative it represents. For example for the verb "to give," the base-level activation of the learned link between this specific verb and the prepositional object construction is higher than for the double object construction. Also, the base-level activation of a node is further updated each time a constructional alternative is processed. For an unprimed sentence, the outcome of the selection stage is largely determined by the average base-level activation of the competing nodes that are representing the alternative syntactic constructions. Noise causes random fluctuations around current activation levels. On average, for structural nodes with high base-level activation, the amount of activation that needs to be sent to activate the node is lower than the amount of activation that needs to be sent to a node with low base-level activation. For sentences following a prime sentence, residual activation will play a role (inspired by Pickering & Branigan, 1998), which, in turn, will influence the response choices. Crucially, the response choices are influenced more strongly following a less preferred than a preferred prime (i.e., an *inverse* [*negative*] effect of preference on the response choices): Given that more activation needs to be sent to activate a node with low base-level activation, there is more residual activation for the node representing the less preferred structure during subsequent target sentences. When a less preferred structure is primed, the response choices are thus more likely to be affected than when a more preferred structure is primed.

To explain the response latency component of syntactic priming, our model includes a competition mechanism in the selection stage (see also Figure 1 for an illustration). Between competing alternatives, inhibition (negative activation) is transmitted; the amount of inhibition transmitted is a positive function of the current activation level. Transmitting inhibition between competitor nodes thus enhances the difference in activation levels between these nodes. Competition in the selection stage is resolved when the difference in activation levels between competitors has reached a threshold for activation. The time

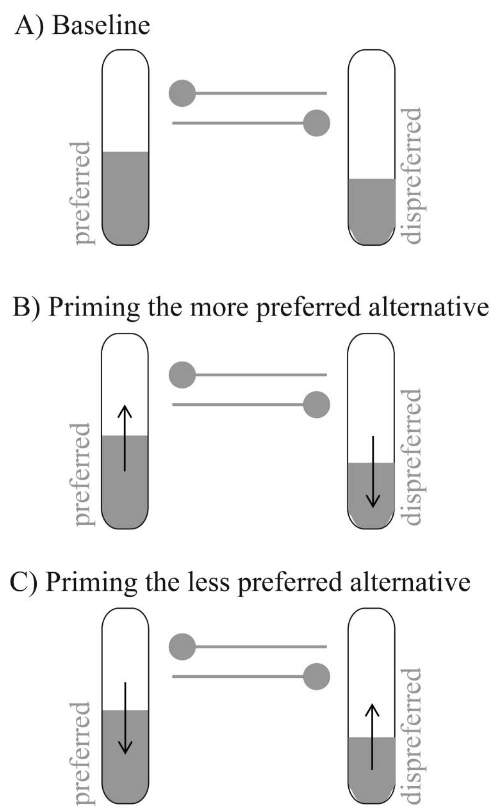

Figure 1. Schematic overview of the competition account. Displayed are the (changes in) average activation levels for the preferred (left) and dispreferred (right) constructional alternative in three situations. There is competition (inhibitory connections) between the two constructional alternatives. A. The baseline (unprimed) situation. The average base-level activation of each node is positively related to the frequency of occurrence of the corresponding constructional alternative. Nodes are competing; the amount of inhibition transmitted to a competing node is a positive function of the current activation level. As a consequence of syntactic priming, the average activation levels of the nodes changes. B. Priming the more preferred alternative results in (a) an increased difference in activation levels between the nodes, (b) a decreased selection time, and (c) a decreased planning time. C. Priming the less preferred alternative results in (a) a decreased difference in activation levels between the nodes, (b) an increased selection time, and (c) a decreased planning time. The selection time and the planning time contribute to the response latency as additive effects.

it takes to reach this threshold (the selection time) is determined by the time needed to solve competition between the competitor nodes. As mentioned before, for sentences following a prime sentence, residual activation plays a role. The selection time *de*creases with an *in*creasing difference in activation levels between competitors at the moment competition starts: the higher the current activation of a node, the more inhibition it transmits to the competitor; the lower the latter's activation, the less inhibition it can retort. Response latencies are determined not only by the selection time, but also by the planning time. In the planning stage we assume, in line with Levelt and Kelter (1982), that priming reduces the planning time as an effect of practice (which includes recent encounters with this structure on the prime).

With these processing mechanisms, the competition model assumes a *positive* effect of preference on syntactic priming effects in the response latencies. Following a prime with a more preferred structure, the difference in activation level between this structure and its competitor increases (Figure 1B). In this case, when priming increases the difference in activation levels between competitors (compared to the difference in base-level activation of the competitors), less time is needed to resolve competition and thus the selection time decreases. When a less preferred structure is primed, priming decreases the difference in activation levels between competitors compared to the base-level situation (Figure 1C), thus priming increases the competition time in the selection stage. As mentioned earlier, effects on response latencies are the result of the additive effects on the selection time and the planning time. Priming reduces planning time for more preferred as well as less preferred structures. In sum, for more preferred structures, priming decreases the selection time and decreases the planning time, which results in a production speed-up. For less preferred structures, planning time decrease, but this is canceled out by an increase in selection time, eliminating the priming benefit in the response latencies (or in some cases even resulting in an increase in the response latencies for repeated structures).

In the present article we investigate whether the dissociation in syntactic priming effects on response choices versus latencies is (a) present for syntactic constructions other than transitives (the findings on transitives were reported on in Segaert et al., 2011) and (b) determined by verb-bound syntactic preferences. This would provide further support for the underlying idea of a competition model of syntactic priming and for the need to represent nodes for corresponding syntactic alternatives per verb, allowing verb-bound preferences to determine syntactic encoding (following proposals that syntactic processing is lexically guided).

We focused on the effect of verb-bound syntactic preferences on syntactic priming of ditransitive sentences in German spoken language production. Syntactic preferences for ditransitive verbs are verb-specific and in German, verb-bound preferences have a wide-ranging distribution. We used a picture-description paradigm and simultaneously measured response choices and latencies. We manipulated the degree to which the syntactic structure of prime sentences was preferred, given the preference of the verb: prime sentences either had a double object or prepositional object dative syntactic structure, containing a verb with a preference (to a varying degree) for either the double object or the prepositional object dative. We expected to find an *inverse preference effect* of syntactic priming on response choices next to a *positive preference effect* of syntactic priming on response latencies.

Method

Participants

60 native German speakers gave informed consent prior to the experiment and were compensated for their participation. We excluded six participants who indicated in a postexperimental questionnaire to have been raised with the German dialect Hessisch, Bayerisch, Pfälzisch, or Plattdeutsch and one participant who indicated to suffer from dyslexia, thus including 53 participants (20 male/33 female, mean age of 22 years, with *SD* 2.2).

Materials

Our stimulus pictures depicted 16 ditransitive events such as *lending, selling, showing*. For each ditransitive verb, Table 1 lists the preference for the double object versus prepositional object dative structure based on three different measures (one rating obtained by Schulte im Walde, 2003, and two ratings obtained through our own pretest questionnaire; see note Table 1; for the English translation of each verb, see Appendix). Although the strength of the verb bias varied to a different degree for different verbs, both the double object and the prepositional object dative were judged to be grammatically correct for each verb by all three preference measures. Furthermore, the three measures converged on whether a verb categorically preferred the double object or the prepositional object dative (rightmost column of Table 1). Averaged over the eight double object preferred verbs, the preference strength toward the double object dative is .68; averaged over the eight prepositional object preferred verbs, the preference strength toward the prepositional object dative is .66 (following Schulte im Walde, 2003).

In the stimulus pictures a ditransitive event was depicted with an animate subject, one animate and one inanimate object of the action. These pictures thus elicit ditransitive sentence descriptions. Each scene was depicted with one of three couples of a male and female actor (2 × man/woman; 1 × boy/girl) and one of two inanimate objects (for a list of the inanimate objects paired with each event, see Appendix). Each of these scenes was enacted once with the male actor as subject and once with the female actor as subject. Each picture also had a version with the subject on the left and with the subject on the right. Each ditransitive picture had three versions: one grayscale version and two color-coded versions with a green, an orange and a red object or actor (which elicited either a double object or prepositional object dative; see task description). Filler pictures elicited intransitive sentences, depicting events such as *running, singing, bowing* with one actor (in grayscale, green, orange or red).

Task and Design

Participants were instructed to describe pictures with one sentence, naming first the green, then the orange, and then the red element in the picture (the colors of a traffic light served as a mnemonic to remember the order). Colored pictures thus elicited ditransitive sentences, either a double object or prepositional object dative. If the elements in the picture were not depicted in color then participants did not have to pay attention to the order of mentioning and could therefore freely choose to produce either a double object dative or a prepositional dative.

Table 1
Structure Preference Data for the Verbs Used in the Syntactic Priming Experiment

Verb	Results based on Schulte im Walde (2003)	Pretest results "How normal do you consider this sentence?"	Pretest results "Do you like this sentence?"	Preference for double object or prepositional object datives
Leihen	.98	.64	.56	double object
Verabreichen	.74	.68	.61	double object
Reichen	.68	.69	.65	double object
Liefern	.66	.55	.60	double object
Zeigen	.63	.75	.68	double object
Servieren	.60	.72	.62	double object
Vorlesen	.59	.52	.52	double object
Machen	.55	.55	.55	double object
Suchen	.45	.36	.40	prepositional object
Verkaufen	.44	.45	.49	prepositional object
Nähen	.43[a]	.44	.42	prepositional object
Reservieren	.41	.43	.46	prepositional object
Bauen	.34	.46	.54	prepositional object
Schlachten	.27	.38	.44	prepositional object
Deuten	.26	.42	.47	prepositional object
Bewachen	.13	.39	.40	prepositional object

Note. Listed in the first three columns of data is the preference for the double object dative structure according to three different measures (on a scale between 0 and 1). Listed in the rightmost column is whether a verb categorically preferred the double object or the prepositional object dative. The first measure is based on data of Schulte im Walde (2003, data obtained through personal communication) on the use of a variety of subcategorization frames for all German verbs in a 35 million word newspaper corpus. For a subset of these verbs we pulled together the subcategorization frames indicative of a double object versus a prepositional dative (a similar approach was taken by Gries and Wulff (2005) for a smaller subset of verbs). Additionally, we collected ratings through an Internet-based questionnaire in which 42 native German speakers participated. A randomized list of 36 verbs in the double object versus prepositional dative structure was rated on a 7-point scale with respect to how normal the participants judged the sentence to be *("Wie normal findest du diesen Satz?")* and how much they liked the sentence *("Magst du diesen Satz?")*. For this experiment we used the 16 verbs which were depictable and converged on the three measures in terms of which structural alternative was categorically preferred.
[a] Because nähen was not included in the corpus of Schulte im Walde, we used the average of the values obtained in our pretest questionnaire.

There were two types of trials: baseline trials and dative priming trials. On baseline trials, primes were intransitive sentences so that we could measure the baseline frequency of producing double object versus prepositional datives on subsequent targets. On dative priming trials we measured the syntactic priming effect in eight conditions, resulting from a manipulation of prime structure (double object vs. prepositional datives), fully crossed with the syntactic preference of the prime verb (double object vs. prepositional datives) fully crossed with the syntactic preference of the target verb (double object vs. prepositional datives). See Figure 2. Neither the verb nor the names of the actors/object were repeated between the prime and target sentence (adults were followed by children and vice versa).

Intransitive sentences (*"The man jumps"*) served as fillers, such that over the whole experimental list 40% of the items elicited intransitives sentences. In total, each experimental list contained 80 baseline trials and 20 trials in each of the eight dative priming conditions. We generated counterbalanced lists so that each dative target picture occurred once with a baseline prime, once with a double object dative prime and once with a prepositional dative prime across three different experimental lists. Age of actors (adults vs. children), gender of the agent (male vs. female), and position of the agent (left vs. right) is equally divided over the stimuli used in each list.

Procedure

Participants were first presented with pictures of the inanimate objects (which would be depicted during the experiment), together with their names, and then received 10 practice trials. The actual experiment lasted 70 min; Figure 3 illustrates the sequence of events on each trial. Participants' responses were recorded and a voice key measured response latencies from picture presentation. We used the following criteria to determine whether target responses were included for analysis: (a) a correct ditransitive response (either a canonical double object or canonical prepositional object dative) was used as the target sentence, (b) the correct structure was used on the prime trial, and (c) both actors and the inanimate object were named accurately and the verb was used correctly on both prime and target trial. Debriefing showed that participants were unaware of the underlying experimental manipulation.

Results

Response Choices

We excluded 30% (3,818 out of 12,720) of the responses on baseline and ditransitive priming trials (criteria described under procedure).[1] We analyzed the responses using mixed-effects logit models (Barr, Levy, Scheepers, & Tily, 2013; Jaeger, 2008; Pinheiro & Bates, 2000) in R (R Development Core Team, 2012). We started from a model including all factors and a fully specified random effect structure. We simplified this model using model comparison for the fixed effects. When a model with a fully specified random effects structure did not converge, we removed random slopes according to the following strategy: We removed the random slopes for items before removing any random slopes for subjects (since the variance for items is usually smaller in researcher-designed experiments), and we removed interaction terms before main effects, until convergence was reached. We used deviation coding (each level of a variable is compared to the grand mean). Our final model includes fixed effects for "Prime structure," "Prime verb preference,"and "Target verb preference" and allows an interaction between "Prime structure" and "Prime verb preference."[2] The random effects structure includes a random intercept for subjects and items and random slopes of "Prime structure," "Prime verb preference," "Target verb preference," and the interaction between "Prime structure" and "Prime verb preference" for subjects (this is the maximal random effect structure for which convergence is reached). For "Prime structure," "Prime verb preference," and "Target verb preference" the prepositional object dative was taken as the reference condition. Target responses were coded as 0 for double object datives and 1 for prepositional object datives.

Figure 4 summarizes the relative proportion of prepositional object dative responses. The fixed effects of the best model fit are summarized in Table 2. The negative estimate for the intercept indicates that in the baseline condition double object datives were more frequent than prepositional object datives. Following double object dative primes, more double object dative targets are produced compared to baseline ($p < .001$). Following prepositional object dative primes, more prepositional object dative targets are produced compared to baseline ($p < .001$). The absolute value of the estimated effect of double object dative primes ($\beta = -0.23$) is smaller than the estimated effect of prepositional object dative primes ($\beta = 0.39$).

Next we turn to an investigation of the effect of prime verb preferences. The strength of prepositional object dative priming did not depend on the prime verb preference ($p > .2$), but the strength of double object dative priming did ($p < .05$). The positive estimate of this effect indicates that more double object dative targets are produced following a double object dative prime of which the verb has a preference for the prepositional object dative, than following a double object dative prime of which the verb has a preference for the double object dative. In other words, there is a stronger effect on the response choices of double object dative primes for which this structure was dispreferred than for which this structure was preferred.

Target verb preference also affected the response choices ($p < .001$): The negative estimate indicates that more prepositional object dative response targets are produced for target verbs with a prepositional object dative preference than for target verbs with a double object dative preference. Allowing target verb preference to interact with the effect of prime structure did not improve the model fit ($\chi^2 = 1.63$, $p > .44$).

We also estimated three models including continuous information about verb preference (one model for each available continuous measure of prime verb preference listed in Table 1) instead of cate-

[1] Five percent of all responses (635 out of 12,720) was excluded because the target picture was described as a noncanonical double object (NP[nominative]<NP[accusative]<NP[dative], 1.5%, 188 out of 12,720) or noncanonical prepositional object dative (NP[nominative]<PP < NP[accusative], 3.5%, 477 out of 12,720).

[2] Possible prime structures are intransitive baseline primes, double object dative primes, and prepositional object dative primes. In order to compute the interaction between the effect of double object and prepositional dative priming (vs. baseline) and the effect of prime verb preference, we needed to insert random prime verb preference data for the intransitive primes in the baseline condition. Since each target occurred in three counterbalanced lists (once with a baseline prime, once with a dative prime in double object prime structure, and once with a dative prime in prepositional object prime structure—see Procedure), we assigned each item in the baseline condition the same prime verb preference value as the corresponding dative prime verb (like Bernolet & Hartsuiker, 2010).

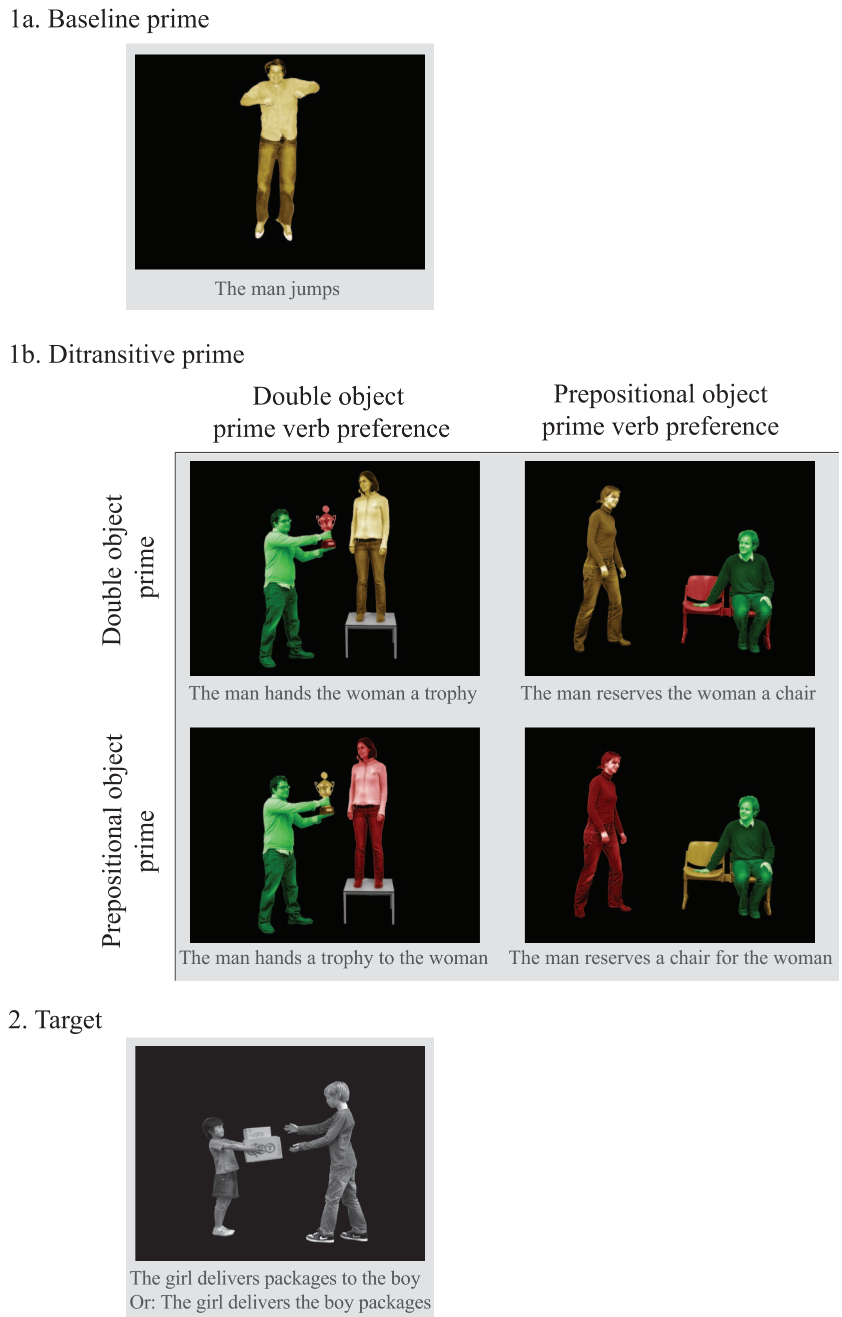

Figure 2. Design. Each trial consisted of a prime followed by a target. Primes were pictures in which elements were color-coded for the order of precedence in the sentence, allowing us to manipulate the syntactic structure participants would produce. A grayscale target eliciting a ditransitive sentence immediately followed the prime. We measured which structure participants used to describe target pictures: the double object versus prepositional object dative (e.g., *Das Mädchen liefert dem Jungen ein Paket,* vs. *Das Mädchen liefert ein Paket an den Jungen*; in this case the target verb *liefern* has a preference for the double object structure). Additionally, we measured participants' response latencies on the target pictures. On baseline trials, primes were intransitives, so that we could measure the baseline frequency of using double object versus prepositional datives. On dative priming trials, we measured the syntactic priming effects of datives in eight conditions. Dative primes were produced in the double object or prepositional dative structure, and the prime verb had a preference for the double object or for the prepositional object dative. Additionally (but not depicted in the figure), the target verb had a preference for the double object or for the prepositional object dative. The English translation of the sentences participants produced is inserted for clarity. Individuals whose faces appear here gave consent for the use of their likenesses. See the online article for the color version of this figure.

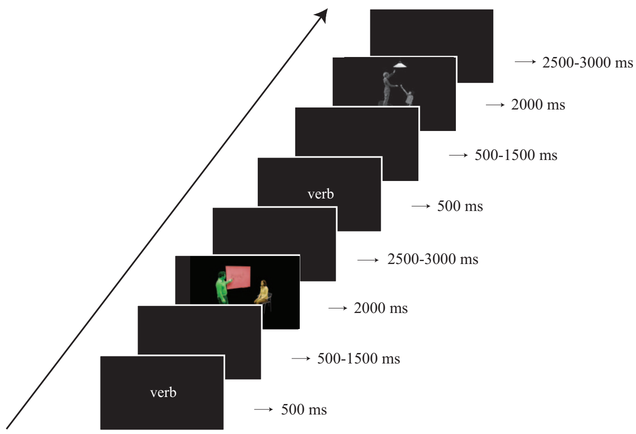

Figure 3. Procedure. Each trial consisted of the following events: A verb was presented in its infinitive form and after a jittered interval the prime picture was presented. After a next jittered interval a verb was again presented, followed by the next jittered interval and a target picture. After another jittered interval the next trial started. Individuals whose faces appear here gave consent for the use of their likenesses. See the online article for the color version of this figure.

Table 2
Summary of Fixed Effects in the Mixed Logit Model for the Response Choices

Predictor	Coefficient	*SE*	Wald *Z*	*p*
Intercept (baseline)	−0.50	0.22	−2.32	$<.05^{*}$
Prime structure: double object	−0.23	0.06	−3.61	$<.001^{***}$
Prime structure: prepositional object	0.39	0.07	5.72	$<.001^{***}$
Prime verb preference	0.02	0.03	0.46	$>.6$
Target verb preference	−1.80	0.15	−12.08	$<.001^{***}$
Prime structure: double object by Prime verb preference	0.11	0.05	2.24	$<.05^{*}$
Prime structure: prepositional object by Prime verb preference	−0.05	0.05	−1.07	$>.2$

Note. $N = 8{,}902$; log-likelihood = −3,544.
$^{*}\ p < .05$. $^{***}\ p < .001$.

gorical information. Continuous measures of "prime verb preference" are centered to their mean. The random effects structure for these models includes a random intercept for subjects and items and random slopes of "Prime structure," "Prime verb preference," and "Target verb preference" for subjects (this is the maximal random effect structure for which convergence is reached). These models did not yield significant interactions between "Prime structure" and "Prime verb preference": Prime verb preference as measured by Schulte im Walde (2003) did not interact with the effect of the double object prime (β = 0.28, $p > .25$) or the prepositional object prime (β = –.08, $p > .75$); prime verb preference as measured by our pretest data ("How normal do you consider this sentence") did not interact with the effect of the double object prime (β = 0.54, $p > .14$) or the prepositional object prime (β = −0.20, $p > .60$); prime verb preference as measured by our pretest data ("Do you like this sentence") did not interact with the effect of the double object prime (β = 0.86, $p > .13$) or the prepositional object prime (β = −0.27, $p > .62$).

Response Latencies

For the analyses of the response latencies we created a post hoc variable "Syntactic repetition" with the levels No syntactic repetition and Syntactic repetition. This variable captures the relationship between the prime structure and the structure of the participant's target response. In other words, when this variable shows to be a significant predictor of the latencies, it demonstrates that there is a relation (although not necessarily of a causal nature since the variable is created post hoc) between the syntactic priming effect in the response choices and the latencies.

Of the correct responses on the ditransitive priming trials, we excluded 5.4% (290 out of 5,415) because they contained sounds triggering the voice key before speech onset or because they were two

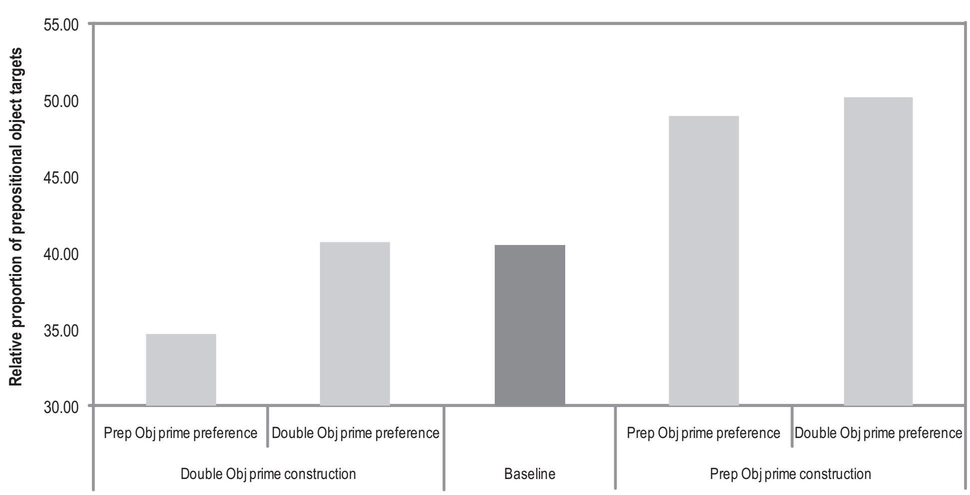

Figure 4. Response choice results. The relative proportion of prepositional object datives is illustrated for each condition. The strength of prepositional object dative priming does not seem to depend on the preference of the prime verb, but the strength of double object dative priming is shown to depend on the prime verb preference.

standard deviations below or above the mean calculated per subject and per condition. Response latencies were analyzed using mixed-effects linear models (Baayen, Davidson, & Bates, 2008; Barr et al., 2013; Pinheiro & Bates, 2000) in R. We started from a model including all factors and a fully specified random effect structure. We simplified this model using model comparison for the fixed effects. When models with a fully specified random effects structure did not converge, we removed the random slopes for items before removing any random slopes for subjects, and we removed interactions before main effects. We used deviation coding (each level of a variable is compared to the grand mean). Our final model includes fixed effects for "Prime verb preference," "Target structure," and "Syntactic repetition" and allows a three-way interaction between these factors. The random effects structure consists of a random intercept for subjects and items and random slopes of "Prime verb preference" and "Target structure" for subjects (this is the maximal random effect structure for which convergence is reached). As reference conditions we used: prepositional object prime verb preference, prepositional object target structure, and syntactic repetition.

Figure 5 summarizes the response latency data. The fixed effects of the best model fit are summarized in Table 3. The two-way interaction between syntactic repetition and target structure approached significance ($p < .06$), suggesting that syntactic repetition speeds up response latencies more strongly for double object than prepositional object targets. Furthermore, there was a three-way interaction between syntactic repetition, target structure and prime verb preference ($p < .001$), indicating that the syntactic repetition effect on response latencies depends on the relationship between the target structure and prime verb preference (see Figure 5A). Including target verb preference as predictor in the model did not improve the model fit ($\chi^2_1 = 1.49$, $p > .22$). To investigate the three-way interaction further, we split the data according the target structure produced. We estimated two separate models, one predicting response latencies for prepositional object dative targets and one for double object dative targets. Each model included fixed effects for "Prime verb preference," "Syntactic repetition," and their interaction, a random intercept for subjects and items and a random slope of "Prime verb preference" (maximal random effect structure for which convergence is reached). For the response latencies of prepositional object dative targets the interaction between syntactic repetition and prime verb preference approached significance ($\beta = -12.85$, $p < .06$), suggesting that there is a stronger syntactic repetition effect for sentences containing prime verbs with a preference for the prepositional object dative. For the response latencies of double object dative targets there was a significant effect of syntactic repetition ($\beta = 14.05$, $p < .02$) and a significant interaction between syntactic repetition and prime verb preference ($\beta = 15.56$, $p < .01$). This indicates that there is a stronger syntactic repetition effect for sentences containing prime verbs with a preference for the double object dative.

We also estimated models including continuous instead of categorical information about verb preference. One model is estimated for each available continuous measure of prime verb preference listed in Table 1. We report the model using prime verb preference information as measured by Schulte im Walde (2003) as Model A, the model using prime verb preference information as measured by our pretest data with the question "How normal do you consider this sentence" as Model B, and the model using prime verb preference information as measured by our pretest data with the question "Do you like this sentence" as Model C. These continuous measures of "prime verb preference" are centered to their mean. Each model included fixed effects for "Prime verb preference," "Target structure," and "Syntactic repetition", a three-way interaction between these factors, a random intercept for subjects and items and a random slope of "Target structure" for subjects (this is the maximal random effect structure for which convergence is reached).[3] Each of these models yielded the same results as the model including categorical information. In all three models, there was a significant two-way interaction between syntactic repetition and target structure (Model A $\beta = -31.34$, $p < .015$; Model B $\beta = -49.64$, $p < .012$; Model C $\beta = -70.16$, $p < .015$), indicating that there is a stronger speed-up for syntactically repeated double object datives than prepositional object datives. Also, in all three models there was a significant three-way interaction between syntactic repetition, target structure and prime verb preference (Model A $\beta = 76.47$, $p < .001$; Model B $\beta = 110.81$, $p < .002$; Model C $\beta = 149.28$, $p < .005$). Figure 5B illustrates this three-way interaction: the syntactic repetition effect in the response latencies (no syntactic repetition minus syntactic repetition) for a particular target structure is positively correlated with the degree to which this structure was preferred for the prime verb.[4]

[3] Also for a different model, but with the same level of complexity in the random effect structure, convergence is reached. This is a model with a random intercept for subjects and items and a random slope of "Prime verb preference" for subjects. For this model, model comparison reveals that there is no improvement in the log-likelihood in comparison with a model with a random intercept for subjects and items and no random slope. However, for a model with a random intercept for subjects and items and a random slope of "Target structure" for subjects, there is an improvement in the log-likelihood in comparison with a model without this random slope ($p < .007$). Therefore, we choose to report a model with a random intercept for subjects and items and a random slope of "Target structure" for subjects.

[4] One could be concerned that in our stimulus set some of the verbs that prefer the prepositional object dative construction are benefactive verbs. Strictly speaking, "verkaufen," "deuten," and "reservieren" take a recipient argument, while "suchen," "naehen," "bauen," "schlachten," and "bewachen" take a beneficiary adjunct. In German, the verbs that take a beneficiary adjunct and the verbs that take a recipient argument have in common that they describe a ditransitive relational constellation with three participants. Both subgroups of verbs can be used in sentences with a subject and two noun phrases as well as in sentences with a subject, a noun phrase, and a prepositional phrase. We performed additional analyses on our data, for which we separated the targets containing verbs with a beneficiary adjunct from the ones with a recipient argument. Our findings remain the same. The results of these analyses therefore suggest that a strict linguistic distinction between those two subgroups of verbs is not reflected in a distinction in psycholinguistic behavior, at least not in terms of the effects of syntactic priming.

When we only include target verbs that take a recipient adjunct, the *response choice results* are as follows: There was a main effect of double object dative primes on the response choices compared to baseline ($p < .001$) and an effect of prepositional object dative primes compared to baseline ($p < .001$). The strength of prepositional object dative priming did not depend on prime verb preference ($p > .06$), but the strength of double object dative priming did ($p < .01$): Double object dative primes for which this structure was dispreferred had a stronger effect on response choices than double object dative primes for which this structure was preferred. Target verb preference also affected the response choices ($p < .001$).

When we only include target verbs that take a recipient adjunct, the *response latency results* are as follows: When using categorical information about verb prime verb preference, there is a three-way interaction between syntactic repetition, target structure and prime verb preference ($p < .005$). When using continuous information the results for the three-way interaction are as follows: using prime verb preference information as measured by Schulte im Walde (2003; $p < .001$), using prime verb preference information as measured by our pretest data with the question "How normal do you consider this sentence" ($p < .03$), using prime verb preference information as measured by our pretest data with the question "Do you like this sentence" ($p < .06$).

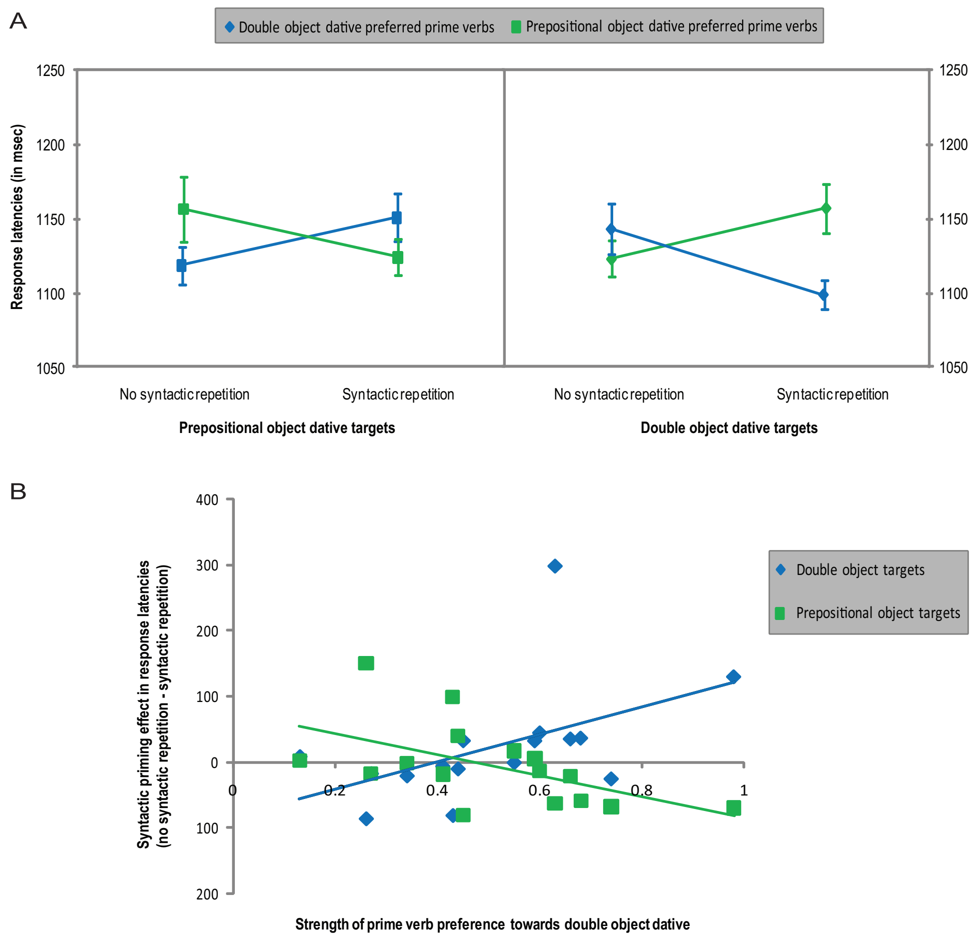

Figure 5. Response latency results. A. Depicted are the mean response latencies and standard errors when there is no syntactic repetition versus when there is syntactic repetition, for prime verbs with a double object preference and for prime verbs with a prepositional object preference, separated for prepositional object targets (left panel) and double object targets (right panel). Response latencies are facilitated for syntactically repeated compared to not-repeated prepositional object target structures if the prime verb had a prepositional object preference. Response latencies are also facilitated for syntactically repeated compared to not-repeated double object target structures if the prime verb had a double object preference. B. Depicted is the response latency priming effect (no syntactic repetition minus syntactic repetition) for double object and prepositional object targets in function of the strength of the prime verb preference toward the double object dative structure as measured by Schulte im Walde (2003). The syntactic repetition effect in response latencies for double object targets is stronger for prime verbs with a stronger preference toward the double object structure. Furthermore, the syntactic repetition effect in response latencies for prepositional object targets is stronger for prime verbs with a stronger preference toward the prepositional object structure. See the online article for the color version of this figure.

Discussion

In the present article we aimed to further investigate the dichotomy between syntactic priming effects in response choices and syntactic priming effects in response latencies. As we hypothesized at the outset of this study, we found *inverse preference effects* of syntactic priming on response choices as well as *positive preference effects* of syntactic priming on response latencies. The predictions on this dichotomy were derived from a competition account of syntactic priming proposed in Segaert et al. (2011). Furthermore, we found that verb-bound syntactic preferences determine syntactic priming effects. This is in line with proposals that syntactic processing is lexically guided that not merely overall syntactic preferences but also syntactic preferences bound to the prime verb should determine syntactic priming effects.

We focused on the effect of verb-bound syntactic preferences of German ditransitives. We used a picture-description paradigm and simultaneously measured response choices and latencies. First, in line with previous findings, the response choices showed an *inverse preference effect.* There was a stronger effect of primes in the prepositional object dative structure (which is overall less preferred in German; Loebell & Bock, 2003; Melinger & Dobel, 2005) than of primes in the double object dative structure. Fur-

Table 3
Summary of Fixed Effects in the Mixed Linear Model for the Response Latencies

Predictor	Coefficient	*SE*	*df*	t	$Pr(>\|t\|)$
Intercept	1,133.92	24.68	3,956	45.94	$<.001^{***}$
Target structure	−2.73	6.27	897	−0.44	>.66
Syntactic repetition	5.12	4.54	897	1.13	>.25
Prime verb preference	−1.42	5.48	897	−0.26	>.79
Syntactic repetition by Target structure	8.59	4.57	897	1.88	<.06
Target structure by Prime verb preference	−4.56	4.55	897	−1.00	>.31
Syntactic repetition by Prime verb preference	1.92	4.49	897	0.43	>.66
Syntactic repetition by Target structure by Prime verb preference	14.56	4.51	897	3.23	$<.001^{***}$

Note. $N = 4{,}913$; log-likelihood $= -34{,}977$. Listed are *p*-values base on the *t*-distribution (with upper bound degrees of freedom). There are good arguments in favor of calculating the mean estimate across Markov chain Monte Carlo (MCMC) samples for the coefficients and the *p*-values based on the posterior distribution instead (Baayen et al., 2008), but MCMC sampling has not yet been implemented for models with random slopes.
*** $p < .001$.

thermore, the strength of double object dative priming in the response choices was sensitive to the syntactic preference of the verb used in the prime sentence: there was a stronger effect for double object dative primes containing a verb with prepositional object dative preference than a verb with double object dative preference. So, when the double object prime structure was less preferred (i.e., for verbs with prepositional object dative preference), there was a stronger effect on the response choices. Second, in line with our predictions, the response latencies showed an overall and verb-bound *positive preference effect*. Such a finding has not been reported until now. There was a stronger speed-up for syntactically repeated double object datives (which are overall more preferred in German) than for syntactically repeated prepositional object datives. Furthermore, the strength of double object dative as well as prepositional object dative priming in the response latencies was positively correlated with the degree to which the syntactic structure was preferred for the verb used in the prime sentence. The more a prime structure is preferred (given the syntactic preference of the specific verb), the stronger the speed-up when the structure is repeated.

These findings place key constraints on processing models of syntax. A comparison between languages shows that verb-bound syntactic preferences are not an inherent aspect of the semantics of a verb. For instance, the verb *"to show"* in Dutch [*"tonen"*] has a preference for the prepositional object dative (Bernolet & Hartsuiker, 2010), while in German [*"zeigen"*] it has a preference for the double object dative (Schulte im Walde, 2003). Evidence for a link between specific verbs and structure-preferences thus provides strong support for lexicalist parsing models of syntax (e.g., Jackendoff, 2002; Joshi & Schabes, 1997; MacDonald et al., 1994), proposing that syntactic processing is driven by constraints at the lexical level.

Our findings also have important implications for theories on the mechanism driving syntactic priming. Several well-established and computationally explicit syntactic priming theories can account for the inverse preference effect on response choices (Chang et al., 2006; Jaeger & Snider, 2013; Reitter et al., 2011). As discussed earlier, Chang et al. proposed an error-based implicit learning mechanism in a recurrent network. This model was recently applied to the German dative alternation, and it predicts a verb position effect in structural priming. The magnitude of priming in the model is related to prediction error, and hence it might also explain inverse preference effects of syntactic priming in structure choices like the ones observed in our study (Chang, Baumann, Pappert, & Fitz, in press). In the current implementation of this model (and similar connectionist architectures), however, there is no standard way of deriving timing predictions. Also the model proposed by Jaeger and Snider (2013) currently does not incorporate a link function which would allow predictions about response latencies. These frameworks (Chang, et al., 2006; Jaeger & Snider, 2013) are therefore compatible with the response choice findings presented in this article, but they do not predict our full set of findings. We do not believe however that our findings are a basis to reject these theories since in their current form they are not intended to specify predictions about syntactic priming effects in response latencies.

A competition model of syntactic priming (Segaert et al., 2011) is able to account for the findings observed in the present study (the account was explained in detail in the introduction section of this article). Our account is a conceptual model however which has not been computationally implemented. The results presented in this article nonetheless provide further support for this account and for the idea that the account should be of a lexical nature. On the assumption of a lexicalized grammar, we hypothesize an activation-and-competition network with competing nodes for syntactic alternatives for each verb separately, allowing verb-bound preferences to determine syntactic encoding. The competition model then assumes an *inverse (negative*) effect of verb-bound preferences on syntactic priming effects in response choices. The crucial processing mechanisms accounting for the response choice component of syntactic priming are base-level activation established through learning and residual activation. Given that more activation needs to be sent to activate a node with low base-level activation, there is more residual activation for the node representing the less preferred structure and response choices during subsequent target sentences are influenced more strongly. The competition model also predicts a *positive* effect of verb-bound preferences on syntactic priming effects in the response latencies. The crucial processing mechanism incorporated in our model to account for the response latency component of syntactic priming is competition. When a more preferred (given the preference of the verb) structure is primed, priming increases the difference in activation levels between competitors and less time is needed to resolve competition, thus the selection time decreases. When a less preferred (given the preference of the verb) structure is primed, priming decreases the difference in activation levels between competitors and the selection time increases. Priming effects on response latencies are the result of the additive effects on the selection time and the planning time; priming always reduces planning time as an effect of practice. Priming of the preferred alternative thus results in a response latency benefit, but for priming of the less preferred alternative this benefit is eliminated. The processing mechanisms proposed in our model are plausible accounts to explain the response choice and response latency components of syntactic priming. However, it is not straightforward how to these mechanisms should be combined and computationally implemented.

The competition account we explored is related to the hybrid account proposed by Reitter et al. (2011) in a sense that it also incorporates a spreading activation as well as a learning mechanism. The Reitter et al. account is based on a well-specified ACT-R architecture, which could predict timing aspects based on activation levels. The Reitter et al. model could thus be run in order to derive predictions about production latencies, but given the technical complexity of this matter this would be the subject of a separate study. Moreover, a mechanism that is able to explain the dichotomy between syntactic priming in response choices and latencies—a competition mechanism or another mechanism with the same explanatory power—could in principle be incorporated in a revised version of other established and computationally implemented accounts of syntactic priming (Chang, et al., in press; Jaeger & Snider, 2013) for which only in their current implementation there is no standard way of generating predictions about response latencies. In sum, we emphasize that although our competition model is able to account for our present findings it is by no means the complete picture. Any further models that preferably are computationally implemented and that make similar predictions would provide us with further insight. In any case, our findings clearly point toward the need to not focus exclusively on syntactic priming effects in response choices but also investigate effects in response latencies, in empirical and theoretical work.

In previous empirical work exploring the influence of verb-bound syntactic preferences on priming effects in response choices, Bernolet and Hartsuiker (2010) found verb-bound inverse preference effects of double object dative priming but not prepositional dative priming. At first glance, this strongly resembles the present findings; however, the overall relative preference for double object and prepositional object datives in German and Dutch is different. Consequently, while we found an effect of syntactic preferences for the preferred alternative, Bernolet and Hartsuiker (2010) and Jaeger and Snider (2013) found verb-bound syntactic preferences effects for the dispreferred dative construction (double object in Dutch and prepositional object in English). These issues will need to be explored further in future research.

One of the factors that could play a role in determining whether a priming effect is observed in response choices is the specific verbs that are used in a particular experiment (see also Jaeger & Snider, 2013; Weatherholz, Campbell-Kibler, & Jaeger, 2012). The specific verbs used could perhaps also play a role in determining whether the influence of verb-bound syntactic preference effect on priming is observed. For comparison between the present findings and Bernolet and Hartsuiker (2010) it should be noted that there is a different distribution of verb-bound syntactic preferences of German versus Dutch ditransitives. This makes it harder to compare the effects of verb-bound syntactic preferences between the experiments. In Dutch, most ditransitive verbs have a preference for the prepositional object dative, and this is reflected in the materials of Bernolet and Hartsuiker (2010) (except for two prime verbs, prime and target verbs had a preference for the prepositional object dative). So, within their experiment, there was a relatively uniform representation of verb-specific preferences, and this kept the overall preference in place for prepositional object datives in the Dutch language (76% of datives in the baseline are prepositional object datives). In German, there is a more diverse representation of verb-specific syntactic preferences, and this is reflected in the materials of our experiment (both for prime and target verbs, there were as many verbs with a preference for the double object dative, as there were with a preference for the prepositional object dative). With a large range of variation in the verb-specific preferences, there is a relatively weak overall bias (41% of datives in the baseline are prepositional object datives). We believe these issues deserve further attention in future research.

In sum, the present article reports on the first investigation of the influence of verb-bound syntactic preferences on the relationship between syntactic priming effects on response choices and effects on response latencies. We found that verb-bound preferences indeed influence syntactic processing: there was an *inverse preference effect* of syntactic priming effects in response choices and a *positive preference effect* of syntactic priming effects in response latencies. This support the idea that syntactic processing is lexically guided (lexicalist parsing models of syntax; e.g., Jackendoff, 2002; Joshi & Schabes, 1997; MacDonald et al., 1994).

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(*Appendix follows*)

Appendix

List of the Ditransitive Verbs Paired With Inanimate Objects Depicted in the Stimuli

German words		English translations	
Ditransitive verb	Object	Ditransitive verb	Object
leihen	Fahrrad	to lend	bike
	Handy		mobile
verabreichen	Tablette	to administer	tablets
	Medizin		medication
reichen	Glühbirne	to hand	light bulb
	Pokal		trophy
liefern	Paket	to deliver	package
	Briefe		letters
zeigen	Bild	to show	painting
	Buch		book
servieren	Wein	to serve	wine
	Pizza		pizza
vorlesen	Buch	to read aloud	book
	Menü		menu
machen	Cocktail	to prepare	cocktail drink
	Pizza		pizza
suchen	Hut	to search	hat
	Schuh		shoe
verkaufen	Wein	to sell	wine
	Blumen		flowers
nähen	Socke	to sow	sock
	Kleidung		clothing
reservieren	Theaterkarten	to reserve	theater tickets
	Stuhl		chair
bauen	Bahnstrecke	to build	railway track
	Sandburg		sandcastle
schlachten	Hase	to slaughter	hare
	Schwein		pig
deuten	Formel	to interpret	formula
	Bibel		bible
bewachen	Schatzkiste	to guard	treasure chest
	Geld		money

Note. The two leftmost columns list the verbs in the German infinitive form as they were presented before the picture and the two inanimate objects with which each verb was paired. The two rightmost columns list their English translations.

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