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Research Article

Grammatical and Phonological Influences on Word Order

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ABSTRACT—*During the grammatical encoding of spoken multiword utterances, various kinds of information must be used to determine the order of words. For example, whereas in adjective-noun utterances like "red car," word order can be determined on the basis of the word's grammatical class information, in noun-noun utterances like ". . . by car, bus, or . . .," word order cannot be determined on the basis of a word's grammatical class information. We investigated whether a word's phonological properties play a role in grammatical encoding. In four experiments, participants produced multiword utterances in which the words' onset phonology was manipulated. Phonological-onset relatedness yielded inhibitory effects in noun-noun utterances, no effects in noun-adjective utterances, and facilitatory effects in adjective-noun, noun-verb, and adjective-adjective-noun utterances. These results cannot be explained by differences in the stimulus displays used to elicit the utterances and suggest that grammatical encoding is sensitive to the phonological properties of words.*

A fundamental distinction in current models of language production is between models that assume that processes are only sensitive to information of a single type and those that assume that multiple types of information converge at a particular processing level. Consider, for example, the following three different hypotheses about the processing of a word's grammatical and phonological information. One hypothesis assumes that these two properties of words are processed at two strictly sequential processing levels (Bock & Levelt, 1994; Garrett, 1980; Levelt, 1989). The second hypothesis assumes that they are processed at two sequential but interactive processing levels (Dell, Oppenheim, & Kittredge, 2008; Stemberger, 1985). The third hypothesis assumes that they are processed within a single processing level (Alario & Caramazza, 2002). These hypotheses make different predictions about the influence of phonological properties on grammatical encoding. The first hypothesis predicts that grammatical encoding should not be sensitive to the phonological properties of words, whereas the latter two hypotheses predict that grammatical encoding should be sensitive to phonological properties, albeit in different ways and for different reasons. We tested these predictions by investigating whether the phonological properties of words influence grammatical encoding.

Classic evidence for the hypothesis that grammatical and phonological properties of words are processed at two strictly sequential levels comes from the analyses of speech errors by Garrett (1975, 1980). Garrett focused on word-exchange errors in which two words erroneously switch positions in an utterance (e.g., "that *log* could use another *fire*"). Garrett reported that these errors had two important characteristics. First, the exchanged words came almost invariably from the same grammatical class, and second, there was no evidence for a phonological relationship between the exchanged words. These data have been interpreted in terms of a level of grammatical encoding at which words are ordered into a linear-order structure (e.g., Ferreira & Humphreys, 2001). Furthermore, this grammatical encoding process takes place independently from the process of phonological encoding.

However, the results reported by Garrett have not gone unchallenged. Dell and Reich (1981) reported that, in their corpus of speech errors, in 25% of cases in which exchanged words shared grammatical class, the exchanged words also shared the same onset consonant (e.g., "he does *yogurt* and eats *yoga*"), a percentage that clearly differed from their estimated chance level of 6%. On the basis of these results, Dell and Reich argued in favor of the hypothesis that grammatical encoding is influenced both by the grammatical properties and by the phonological properties of words.

Further evidence for this hypothesis comes from a study by Alario and Caramazza (2002), who investigated the influence of phonological information on the grammatical encoding of French noun phrases (NPs; see Miozzo & Caramazza, 1999, for

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related results with Italian NPs). In French NPs, the form of a determiner depends on the grammatical gender of the controlling noun and on the phonology of the immediately following word. In the experiment, participants named pictures with possessive determiner-adjective-noun NPs. The onsets of the adjective and the noun in the NPs were either compatible with only one determiner form (as in "ma nouvelle table" [my new table], where the onsets of *table* and *nouvelle* both require selection of the feminine *ma*), or were compatible with two different determiner forms (as in "mon ancienne table" [my old table], where *table* on its own would take the form *ma*, but is overridden by the onset of *ancienne*, which requires the form *mon*). NP production latencies were affected by this phonological manipulation, indicating that grammatical and phonological properties of words jointly influence the grammatical encoding of NPs.

In the experiments reported here, we found that grammatical encoding is sensitive to the phonology of words. Specifically, we found that the phonological properties of words in an utterance are visible to the processes that order words for production. In four experiments, participants produced pairs or triplets of words that varied in grammatical class (e.g., noun-noun vs. adjective-noun), canonical order (adjective-noun vs. noun-adjective), and whether the phonological onset of the first two words was related (e.g., *ring rake*) or unrelated (e.g., *glass rake*). The experimental question we addressed is whether phonological-onset relatedness modulates the speed of utterance production as a function of the grammatical category and order of the words that compose them.

Previous studies have reported inhibitory effects of phonological-onset relatedness in the production of consecutive nouns (Miozzo, 2000; O'Seaghdha & Marin, 2000; Sevald & Dell, 1994; Sevald, Dell, & Cole, 1995; Sullivan & Riffel, 1999; Shattuck-Hufnagel, 1987; Wheeldon, 2003; Wilshire, 1998). However, a recent study by Damian and Dumay (2007) reported facilitatory effects of onset relatedness in the production of adjective-noun utterances. Although caution should be exercised in the interpretation of this modulation of the phonological effect by utterance type, because the studies relied on different stimulus displays to elicit the different utterance types, the reported contrast suggests an interaction of grammatical category by phonology in multiword production tasks. In Experiment 1a, we confirmed the interaction of grammatical category by phonological relatedness (noun-noun vs. adjective-noun); in Experiment 1b, we found that this effect generalizes to noun-verb utterances; in Experiment 2a, we found that the effect is not simply due to the production of words of different grammatical categories but to the grammatical encoding processes involved in ordering words for production (adjective-noun vs. noun-adjective); and in Experiment 2b, we found that the effect generalizes beyond grammatical category to those semantic properties of words involved in ordering words (adjective-adjective-noun).

EXPERIMENT 1A: NOUN-NOUN VERSUS ADJECTIVE-NOUN UTTERANCES

Participants

Participants ($N = 20$) were native English speakers and students at Harvard University. Half took part in the noun-noun condition, and half took part in the adjective-noun condition. They were paid $5 for their participation.

Materials and Design

The factor type of utterance (noun-noun vs. adjective-noun) was crossed with the factor phonological-onset relatedness (related vs. unrelated). Noun-noun utterances were elicited by a pictured object with a superimposed word, and adjective-noun utterances were elicited by a word in a certain ink color. The names of the objects and colors in these two naming conditions were selected to have similar properties. The pictured objects were ring, gun, ball, and pipe, and the colors were red, green, blue, and pink. The object and color names thus shared initial onset consonants, and were matched on their lexical frequency as much as possible (object names: mean = 167, range = 31–434; color names: mean = 126, range = 48–434).

For each object and color, we selected 10 words that shared at least the onset consonant (e.g., the words *rocket* and *rope* were used with the object ring and the color red; for the full list of items, see Appendix in the Supporting Information available online; see p. 1268). All of these words were listed as nouns in the CELEX lexical database (Baayen, Piepenbrock, & van Rijn, 1995) and were names of pictured items in the Cycowicz et al. (1997) picture database. (For an overview of the lexical properties of the words in the experiments reported here, see Table 1.) These object-word and color-word pairs were used in the *related* condition. The stimuli for the *unrelated* condition were created by pairing each word with color and object names with a different onset, so that there was no phonological overlap. In total, there were 80 experimental items for each utterance type. An additional set of 80 filler items was created for each utterance type, by pairing each of the 40 nouns selected from the CELEX database with two object or color names such that there was no phonological overlap; filler trials formed a separate condition that was

TABLE 1

Mean Lexical Frequency per Million and Word Length for the Utterance Types Used in Experiments 1 and 2

Utterance type	Word frequency	Word length (letters)
Noun-noun (Experiment 1a)	43.6	4.9
Adjective-noun (Experiments 1a and 2a)	54.1	4.8
Noun-verb (Experiment 1b)	26.2	5.0
Adjective-adjective-noun (Experiment 2b)	32.8	5.9

Note. Frequency values were obtained from the CELEX lexical database (Baayen, Piepenbrock, & van Rijn, 1995).

not analyzed. Overall, for each utterance type, there were 40 related items that shared onset phonology and 40 unrelated and 80 filler items that did not share onset phonology. Finally, 20 practice items were created by pairing 5 words that did not appear as filler or experimental items with the objects and colors.

Items were pseudorandomly organized into two sets of trials. Objects and colors appeared an equal number of times in each set, and a given word appeared only once per set. Consecutive trials never shared the same object or color; the same onset phonology of object, color, or word; or the same semantic category of object, color, or word. The order of sets was counterbalanced across participants.

Procedure

Participants sat in front of a computer screen and microphone and performed either the noun-noun or the adjective-noun task. The experimental software was DMDX (Forster & Forster, 2003).

For both tasks, participants were first familiarized with the 85 words that would appear in the experiment. On each trial, a fixation point appeared on screen for 700 ms, after which the word appeared (for 1,500 ms, or until a vocal response). Participants in the noun-noun task were told that they would see a pictured object with a superimposed word and that they should first name the object and then the word. They were told the object names in advance. Participants in the adjective-noun task were told that they would see a colored word and that they should first name the color followed by the word. They were told the color names in advance. After familiarization, participants completed the practice and experimental phases. The trial structure in both phases was identical. In each trial, a fixation point appeared for 700 ms, followed by the stimulus (i.e., object and word or colored word) for 1,500 ms, followed by a blank screen (for 2,000 ms).

The experiment lasted about 25 min.

Analyses

The same analyses were performed for all experiments. Only the experimental trials were analyzed. Trials on which the participant produced an incorrect response or hesitated between the first and the second response were discarded. Trials on which the reaction time (RT) was less than 300 ms or those on which the RT was bigger than the participant's mean RT plus three standard deviations were considered outliers and discarded. Out of a total of 800 trials, 21 trials (2.6%) were discarded from the noun-noun condition and 24 trials (3.0%) were discarded from the adjective-noun condition.

For the subject (F_1) analyses, the type of utterance was a between-subjects variable, and the phonological-onset relatedness was a within-subjects variable. For the item (F_2) analyses, both type of utterance and phonological-onset relatedness were between-items variables.

Results and Discussion

An overview of the mean RTs and error percentages is presented in Table 2.

In the RT analysis, there was no main effect of type of utterance (both Fs < 1) or phonological-onset relatedness, $F_1(1, 18) = 2.1$, $p = .2, p_{rep} = .82$; $F_2(1, 156) = 1.2, p = .3, p_{rep} = .77$. There was a significant interaction between these factors, $F_1(1, 18) = 32.8$, $p < .001$, $p_{rep} = .99$; $F_2(1, 156) = 18.0$, $p < .001$, $p_{rep} = .99$. Further pairwise comparisons revealed an effect of phonological-onset relatedness in noun-noun utterances, $t_1(9) = 4.01, p < .003, p_{rep} = .98$; $t_2(78) = 1.97, p < .05, p_{rep} = .92$, and, in the opposite direction, in adjective-noun utterances, $t_1(9) = 4.9$, $p < .001, p_{rep} = .99$; $t_2(78) = 4.6, p < .001, p_{rep} = .99$. The error

TABLE 2

Mean Reaction Times and Error Percentages in Experiments 1 and 2

Experiment and utterance type	Display type	Mean reaction time (ms)		Reaction time difference (ms)
		Related condition	Unrelated condition	
Experiment 1a				
Noun-noun	Picture-word	735 (5)	709 (1)	−26
Adjective-noun	Colored word	698 (3)	742 (6)	44
Experiment 1b				
Noun-verb	Picture-word	623 (3)	644 (9)	21
Experiment 2a				
Adjective-noun	Colored picture	802 (12)	847 (12)	46
Noun-adjective	Colored picture	861 (9)	867 (10)	6
Experiment 2b				
Adjective-adjective-noun	Picture-word	856 (9)	880 (8)	24

Note. Paired words in the related condition shared at least their onset consonant (e.g., *ring*, *rake*). Paired words in the unrelated condition did not share onset consonants (e.g., *glass*, *rake*). Reaction time difference was calculated by subtracting the mean reaction time in the related condition from the mean reaction time in the unrelated condition. Standard errors are given in parentheses.

analysis revealed an effect of phonological-onset relatedness in noun-noun utterances, $t_1(9) = 3.31, p < .01, p_{rep} = .97; t_2(78) = 3.43, p < .01, p_{rep} = .97$, but not in adjective-noun utterances, $t_1(9) = 1.50, p = .17, p_{rep} = .83; t_2(78) = 1.55, p = .13, p_{rep} = .86$.

The results of Experiment 1a confirm the interaction of grammatical category by phonological-onset relatedness in the production of two-word utterances that could be gleaned from the literature. In Experiment 1b, we tested the generalizability of this phenomenon by having participants produce noun-verb utterances in response to picture-word displays.

EXPERIMENT 1B: NOUN-VERB UTTERANCES

Participants

Participants ($N = 15$) were drawn from the same population as in Experiment 1a. None had participated in Experiment 1a. They were paid $5.

Materials and Design

The picture-word displays were similar to those used in Experiment 1a. The picture corresponded to the noun response, and the word corresponded to the verb response. Four pictures denoting actors were selected (i.e., man, woman, boy, and girl). Related and unrelated conditions were created as in Experiment 1a. All verbs were presented in the third-person singular form (e.g., *makes*, *meets*).

Procedure

The procedure was identical to that of Experiment 1a.

Results and Discussion

From a total of 1,200 trials, 73 (6.1%) were discarded. The RT analysis revealed a facilitatory main effect of phonological-onset relatedness, $t_1(14) = 2.6, p < .03, p_{rep} = .94; t_2(78) = 2.7, p < .009, p_{rep} = .97$, which was mirrored in the error analysis, $t_1(14) = 5.0, p < .001, p_{rep} = .99; t_2(78) = 4.0, p < .001, p_{rep} = .99$.

The results of this experiment, together with those from Experiment 1a, confirm that phonological-onset relatedness has a facilitatory effect on the production of two-word utterances of different grammatical categories but an inhibitory effect on utterances composed of words of the same grammatical category.

Do these results reflect the selection of words from different grammatical categories, or do they reflect processes related to the ordering of these words? These alternatives can be distinguished by considering the production of adjective-noun versus noun-adjective utterances. In both types of utterances, words from different grammatical classes must be selected, but they differ in whether they are produced in a canonical or noncanonical order. If the observed Grammatical Category × Phonology interaction is due to word-selection processes, we should obtain the same results for the two types of utterances. However, if the interaction reflects word-ordering processes, the two utterance types should produce different results. Specifically, the facilitatory effect of phonological onset should not be found for noun-adjective utterances.

EXPERIMENT 2A: ADJECTIVE-NOUN VERSUS NOUN-ADJECTIVE UTTERANCES

Participants

Participants ($N = 30$) were drawn from the same population as in Experiments 1a and 1b. Half of the participants took part in the adjective-noun condition, and half of the participants took part in the noun-adjective condition. None had participated in the previous experiments. They were paid $5.

Materials and Design

Participants named colored objects. The colors and objects corresponded to the colors and words used in the adjective-noun condition in Experiment 1a. Pictures of objects were black-and-white line drawings chosen from the Cycowicz et al. (1997) database, and each object's outline was colored accordingly (see Damian & Dumay, 2007). Four pictures were replaced due to low name agreement. All other aspects of the design were kept the same.

Procedure

Participants were first familiarized with the pictures. On each trial, a fixation cross was shown for 700 ms, followed by the picture for 1,000 ms, and finally the picture with its name for 1,000 ms; in this final stage, the participants named the picture aloud. In the practice phase, participants were told to name the color followed by the picture or the picture followed by the color, depending on the naming condition. Other aspects of the procedure were kept the same.

Results and Discussion

From a total of 2,400 trials, 258 (11%) were discarded, 144 in the adjective-noun condition, and 114 in the noun-adjective condition. The main effect of type of utterance was significant in the RT analysis by items, $F_2(1, 156) = 12.7, p < .001, p_{rep} = .99$, but not in the analysis by participants, $F_1(1, 28) = 1.2, p = .28, p_{rep} = .78$. Phonological-onset relatedness had a significant effect in the by-participant and by-item analyses, $F_1(1, 28) = 16.9, p < .001, p_{rep} = .99; F_2(1, 156) = 6.7, p < .02, p_{rep} = .95$; the interaction between type of utterance and onset relatedness was significant in the analysis by participants and marginal in the analysis by items, $F_1(1, 28) = 9.7, p < .005, p_{rep} = .98; F_2(1, 156) = 3.5, p < .06, p_{rep} = .91$. Pair-wise comparisons revealed an effect of phonological-onset relatedness in the adjective-noun condition, $t_1(14) = 4.57, p < .001, p_{rep} = .99; t_2(78) = 3.85, p < .001, p_{rep} = .99$, but not in the noun-adjective condition (both ts < 1).

Type of utterance, $F_1(1, 28) = 2.1$, $p = .15$, $p_{rep} = .85$; $F_2(1, 156) = 2.3$, $p = .13$, $p_{rep} = .86$; phonological-onset relatedness (both Fs < 1); and their interaction (both Fs < 1) were not significant in the error analyses.

The results of this experiment suggest that the observed Grammatical Category × Phonology interaction is driven principally by grammatical encoding and not by word-selection processes. Does this effect reflect only the role of grammatical category in word-ordering processes, or is it a more general effect that also applies to the semantic properties that contribute to word-ordering processes? In Experiment 2b, participants produced adjective-adjective-noun utterances in their canonical order. Given that adjective ordering is semantically driven (e.g., Martin, 1969), a facilitatory effect of onset relatedness for adjective-adjective-noun utterances would generalize the effect to utterances in which semantic properties determine word order.

EXPERIMENT 2B: ADJECTIVE-ADJECTIVE-NOUN UTTERANCES

Participants

Participants ($N = 15$) were drawn from the same population as in Experiment 1. They were paid $5.

Materials and Design

The picture-word displays were identical to those used in Experiment 1a. The picture corresponded to the first adjective, the word corresponded to the second adjective, and the final noun always corresponded to the word "boy." Four pictures that denoted evaluative adjectives (*nice*, *poor*, *kind*, and *mean*) were selected as the first adjective (Bache, 1973). These pictures were cartoon faces of a boy. Related and unrelated conditions were created as in Experiment 1. All words were nonevaluative adjectives (e.g., *native*, *needy*).

To ensure the preferred order of these adjectives, 20 English speakers rated all experimental pairs in their assigned and reversed order. These English speakers preferred the assigned order of adjective pairs over their reversed order, $t_1(19) = 20$, $p < .001$, $p_{rep} = .99$; $t_2(78) = 20$, $p < .001$, $p_{rep} = .99$. In addition, English speakers did not prefer the order of pairs in the related condition over the unrelated condition, $t_1(19) = 2.1$, $p > .06$, $p_{rep} = .91$; $t_2 < 1$.

Procedure

The procedure was similar to that used in Experiment 1. Participants first practiced naming the evaluative adjectives denoted by the cartoon face. On each trial a fixation point appeared on screen for 700 ms, followed by the picture for 1,500 ms. In the practice phase, participants were told to name first the evaluative adjective denoted by the face, followed by the superimposed word, and finally followed by the word "boy." Other aspects of the procedure were identical to that used in Experiment 1.

Results and Discussion

From a total of 1,200 trials, 106 trials were discarded (8.8%). One item ("calm") was omitted from the analysis because of a high error rate (23%). The RT analysis revealed a main effect for phonological-onset relatedness, $t_1(14) = 3.79$, $p < .003$, $p_{rep} = .98$; $t_2(78) = 1.82$, $p = .07$, $p_{rep} = .90$. Phonological-onset relatedness was not significant in the error analyses (both ts < 1).

The facilitatory effect of phonological relatedness obtained with adjective-adjective pairs suggests that this effect occurs during word ordering, independently of the syntactic or semantic properties that guide this process.

GENERAL DISCUSSION

Phonological-onset relatedness yielded inhibitory effects in noun-noun utterances, no effect in noun-adjective utterances, and facilitatory effects in those utterances where a word's order-relevant properties (syntactic or semantic) are produced in a canonical order: adjective-noun, noun-verb, and adjective-adjective-noun utterances.[1] These results cannot be explained in terms of differences between the stimulus displays used to elicit the utterance types.

The results are difficult to reconcile with the hypothesis that the grammatical and phonological properties of words are processed at two strictly sequential processing levels (Bock & Levelt, 1994; Garrett, 1980; Levelt, 1989). This hypothesis assumes that grammatical encoding takes place independently from phonological encoding, and predicts that phonological-onset relatedness would yield comparable effects across all utterance types. Contrary to this expectation, the effect of onset relatedness was modulated by the utterance type.

Our results are consistent with the hypothesis that grammatical encoding is influenced by the grammatical and phonological properties of words. This hypothesis can be accounted for in two ways. First, one could assume that the grammatical and phonological properties of words are processed at two sequential and interactive processing levels where activated phonological representations feed back activation to lexical (grammatical) representations (Dell, 1986; Stemberger, 1985). In this model, the activation levels of lexical representations increase and are more equal to each other when they share a common phonological representation. A recently proposed version of this model also assumes that lexical selection is competitive and grammatically constrained (Dell et al., 2008). This model predicts that lexical selection will be relatively fast in phonologically

[1]Note that noun-noun and noun-adjective utterances are not ungrammatical (e.g., ". . . by car, bus, or . . .," "he painted the car red"), and that, therefore, our results cannot be explained by an interaction between grammaticality and phonological relatedness.

related adjective-noun utterances and relatively slow in phonologically related noun-noun utterances; therefore, this model provides an accurate account of the facilitatory and inhibitory effect in adjective-noun and noun-noun utterances, respectively.

However, problems with this account are highlighted by the data collected here and in previously conducted studies. Specifically, the model does not have a ready explanation for the difference in the phonological effect between adjective-noun and noun-adjective pairs, and would incorrectly predict an inhibitory effect of onset phonology for adjective-adjective-noun utterances. Also, this explanation would incorrectly predict inhibitory effects of rhyme repetition in noun-noun utterances when facilitatory effects have been found (e.g., Miozzo, 2000; Sevald & Dell, 1994), and is undermined by recent studies that challenge the assumption of competitive lexical selection on experimental grounds (e.g., Janssen, Schirm, Mahon, & Caramazza, 2008; Mahon, Costa, Peterson, Vargas, & Caramazza, 2007).

It is also possible to explain the data by extending the model of Alario and Caramazza (2002). This model relies on the assumptions that the semantic, grammatical, and phonological properties of words become available in a cascaded fashion (e.g., Janssen, Alario, & Caramazza, 2008), and that these properties converge on the grammatical encoding process. As in Garrett (1980), MacKay (1982), and Dell et al. (2008), grammatical encoding is construed as a decision process that assigns words to their position in a linear order structure. However, contrary to these earlier proposals, this decision process operates on the basis of a word's semantic, grammatical, and phonological properties. The different properties of words have different weights in this decision process. When target words are produced in a canonical order, their order-relevant syntactic or semantic properties determine the assignments of words and the impact of phonological properties on the assignment process is minimal. When target words are not produced in their canonical order, the assignment of the words cannot occur on the basis of their order-relevant properties, and their phonological onset similarity further hampers the assignment process.[2] If it is furthermore assumed that the repetition of phonology leads to faster lexical selection (Schriefers, Meyer, & Levelt, 1990), and that the delay in assigning phonologically similar nouns overrides this facilitatory effect, one can explain the results reported here.

To conclude, our results suggest that the phonological properties of words influence the grammatical encoding process. These results converge with previous reports that have found that phonological properties influence the decision to produce a particular syntactic structure (e.g., Bock, 1987; Lee & Gibbons, 2007; but see Cleland & Pickering, 2003), influence subject-verb agreement processes (Hartsuiker, Schriefers, Bock, & Kikstra, 2003; Haskell & MacDonald, 2003; but see Bock & Eberhard, 1993), and interact with grammatical properties in tip-of-the-tongue resolution (e.g., Abrams & Rodriguez, 2005). These results are best explained by a model that assumes that decisions that take place during grammatical encoding are influenced by multiple kinds of information that have differential weights in this decision process.

[2]A special role of word onsets in the assignment process (Shattuck-Hufnagel, 1987) could explain the contrasting effects of onset and rhyme similarity.

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