



This postprint was originally published by the APA as:
Ulicheva, A., Roon, K. D., Cherkasova, Z., & Mousikou, P. (2022).
**Effects of phonological features on reading-aloud latencies: A
cross-linguistic comparison.** *Journal of Experimental Psychology:
Learning, Memory, and Cognition*, 48(9), 1348-1362.
<http://dx.doi.org/10.1037/xlm0000893>

Supplementary material to this article is available. For more information see
<https://hdl.handle.net/21.11116/0000-0008-1819-2>

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The final article is available, upon publication, at:

<http://dx.doi.org/10.1037/xlm0000893>

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Effects of phonological features on reading-aloud latencies: A cross-linguistic comparison

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RUNNING HEAD: FEATURE PRIMING

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Data and code are available at <https://osf.io/w83dc/> (Ulicheva, Roon, & Mousikou, 2020).

Keywords: reading aloud, masked priming, phonological features, cross-linguistic

Abstract

Most psycholinguistic models of reading aloud and of speech production do not include linguistic representations more fine-grained than the phoneme, despite the fact that the available empirical evidence suggests that feature-level representations are activated during reading aloud and speech production. In a series of masked-priming experiments that employed the reading aloud task, we investigated effects of phonological features, such as voicing, place of articulation, and constriction location, on response latencies in English and Russian. We propose a hypothesis that predicts greater likelihood of obtaining feature-priming effects when the onsets of the prime and the target share more feature values than when they share fewer. We found that prime-target pairs whose onsets differed only in voicing (e.g., /p/-/b/) primed each other consistently in Russian, as has already been found in English. Response latencies for prime-target pairs whose onsets differed in place of articulation (e.g., /b/-/d/) patterned differently in English and Russian. Prime-target pairs whose onsets differed in constriction location only (e.g., /s/ and /ʃ/) did not yield a priming effect in Russian. We conclude that feature-priming effects are modulated not only by the phonological similarity between the onsets of primes and targets, but also by the dynamics of feature activation, and by the language-specific relationship between orthography and phonology. Our findings suggest that feature-level representations need to be included in models of reading aloud and of speech production if we are to move forward with theorizing in these research domains.

Introduction

Extant theories of reading aloud and their computational implementations have been particularly successful in explaining how printed letter strings are visually recognized and translated into spoken sounds (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Harm & Seidenberg, 1999; Perry, Ziegler, & Zorzi, 2007, 2010; Plaut, Seidenberg, McClelland, & Patterson, 1996). These theories have provided an explicit account of several empirical findings reported in the literature, thus advancing our understanding of the mental processes involved in reading aloud. One such finding is the Masked Onset Priming Effect (hereafter “MOPE”, Forster & Davis, 1991; Kinoshita, 2003). This effect refers to the finding that response latencies in reading aloud a target word or a nonword (e.g., “BAF”) are shorter when the target is preceded by a masked prime that shares the same initial letter and phoneme with the target (e.g., “biz”, that is, when the onsets match both orthographically and phonologically) compared to when the masked prime and the target start with different letters or phonemes (e.g., “suz”; Mousikou, Coltheart, & Saunders, 2010b; Schiller, 2007). Importantly, extant theories of reading aloud do not assign a role to representations more fine-grained than the phoneme. This means that such theories cannot account for experimental results where response latencies are influenced by the degree of formal similarity between different phonemes.

Reading aloud

Experimental results that pose a challenge to extant reading aloud theories have been recently reported by Mousikou, Roon, and Rastle (2015; hereafter MRR2015). Using the masked priming paradigm in a reading-aloud task, MRR2015 showed that nonword targets (e.g., “BAF”) were read aloud significantly faster when preceded by primes whose initial phoneme differed from that of the target only in voicing (e.g., “piz”), compared to when primes were unrelated (e.g., “suz”). This finding suggests that at least some feature-level

information associated with the briefly presented prime is activated prior to the execution of the target motor plan. To our knowledge, MRR2015 provides the first report of feature-level effects in reading aloud.

The empirical data obtained by MRR2015 cannot be explained within most models of reading aloud, since they lack representations of sufficient granularity. One notable exception is the model of Harm and Seidenberg (1999), who propose a connectionist computational model of reading aloud that includes representations not only for phonemes and letters, but also for phonological features. The degree to which a particular letter activates a particular feature value is determined largely by the probability of that letter associated with that feature value in the training set of the model. While this is a desirable characteristic in a model to account for the feature-level effects described above, it is unclear whether the feature representations that the model uses are also used by human readers. The phonological features that are implemented in the Harm and Seidenberg (1999) model are overly simplified, and are also inconsistent with most mainstream, current models of phonological representation. To provide but two examples, in the feature set used by Harm and Seidenberg (1999), consonants cannot be [+sonorant]. Yet, it is commonplace to define all pulmonic consonants other than stops, fricatives, and affricates (collectively, obstruents) as [+sonorant] (see, e.g., Hayes, 2009; Kenstowicz, 1994; and references therein). Another example is that the interdental fricative /θ/ is represented in their model as non-lingual, even though the tongue tip is incontrovertibly the primary oral articulator for this sound (see, e.g., Chomsky & Halle, 1968; Gick, Wilson, & Derrick, 2013; Hayes, 2009; Ladefoged & Maddieson, 1996). While these examples may seem to be unimportant details of implementation, we argue that they are not. The larger point we are arguing for is that the best models of reading aloud will be those that are maximally informed by and make most use of detailed linguistic theories of phonological representation.

Speech production

It is clear that more empirical evidence is required before further expansion of models of reading aloud can be considered, since it is unknown how and whether mismatch in phonological features (or gestures, see discussion below) other than voicing would also affect response latencies in reading aloud. Since the task of reading aloud entails speech production, with the goal in both cases being to utter a linguistic unit, it is relevant to consider evidence from speech production in the context of the present study.

Seminal evidence for the role of features in speech production comes from studies on speech errors. Such studies have documented substitutions involving a single phonetic feature difference (e.g., "glear plue sky" for "clear blue sky"; Dell, 1986; Frisch & Wright, 2002; Fromkin, 1971; Guest, 2002; Levitt & Healy, 1985; Shattuck-Hufnagel & Klatt, 1979). While slips that involve a single phonetic feature difference are relatively rare, phonemes are not randomly substituted with others: phonemes that are featurally similar with the intended target phoneme are more likely to be uttered than those that are featurally dissimilar (e.g., the speech error "reef leech" for "leaf reach" is more likely to occur than the speech error "beef reach" for "reef beech"; Goldrick, 2004; Dell, 1986; MacKay, 1970; Oppenheim & Dell, 2008; Shattuck-Hufnagel & Klatt, 1979), because the onsets /r/ and /l/ are more featurally similar than the onsets /b/ and /r/. In another study, Goldrick and Blumstein (2006) asked participants to read tongue twisters in order to elicit phonological errors (e.g., "KEFF, GEFF, KEFF, GEFF"). Voice onset times for voiceless targets (/k/) that were produced incorrectly as their voiced counterparts (/g/) were longer than for the canonical voiced consonants (i.e., they were more /k/-like). This finding suggests that characteristics of the unselected voiceless target influenced the speech plan of the uttered response.

Further, researchers have found effects on response latencies and on phonetic output based on the manipulation of feature-level representations. Gordon and Meyer (1984) found

facilitative effects of shared voicing on response latencies, though not of shared place, in a cue-response production task. Yaniv, Meyer, Gordon, Huff, and Sevald (1990) used a “primary/secondary” response-priming task (D. E. Meyer & Gordon, 1985) and found that response latencies were modulated when the vowels of primes and secondary responses shared one feature, but not when they shared two or three features. Roon and Gafos (2015) report results from a response-distractor task, in which participants learned symbol cues that required paired responses (e.g., “say /ka/ when you see ‘=’, say /ga/ when you see ‘# #.’”). An auditory distractor (e.g., /pa/ or /ba/) was played after the visual symbol cue. A significant, facilitative feature effect on response latencies was observed when responses started with a velar (e.g., /ka/) and the distractor matched in voicing but differed in place (e.g., /pa/), compared to when the responses and distractors differed in both voicing and place (e.g., /ka/-/ba/). In terms of differences in phonetic output, Whalen (1990) had participants read nonsense sequences of the form “əbVCa”, where the appearance of either the letter indicating the vowel (V) or the consonant (C) was delayed until the start of the vocal response. Participants showed anticipatory, vowel-to-vowel acoustic effects on the initial schwa (ə) when the vowel was known but not when its presentation was delayed. A similar result is reported by Krause and Kawamoto (2020), who used a word form preparation paradigm (A. S. Meyer, 1991) and found anticipatory lip rounding during the production of onset consonants when an upcoming target rounded vowel was primed, but not otherwise. While these effects involve two different aspects of production (response latencies and phonetic output) across a wide variety of experimental tasks, the relevant point is that all of the manipulations crucially depend on feature-level differences in stimuli.

There are important differences across theories of speech production with regard to how features are implemented in them. In the WEAVER++ model (and its earlier instantiations, Levelt, Roelofs, & Meyer, 1999; Roelofs, 1997, 1999, 2000), individual

features are not activated during the planning of an utterance because feature-level representations are not included in the model. On the other hand, the spreading activation model of speech production (e.g., Dell, 1986; Dell, 1988; Dell, Juliano, & Govindjee, 1993) includes feature-level representations for training distributed output representations of phonemes in a feedforward parallel distributed processing network, and can therefore account for at least some feature-level effects reviewed above (see Oppenheim & Dell, 2008; 2010, for a more prominent role assigned to features in overt speech). The empirical evidence seems to be only compatible with the latter class of theories, and also suggests that the role of features in models of speech production should be greater in scope than the one currently assigned.

Present study

In this paper, we carry out a series of reading aloud experiments using the same paradigm as MRR2015 to further elucidate the role of features in reading aloud. Accordingly, our experiments (Experiments 2 and 3) investigate whether a feature-priming effect can be obtained when prime and target onsets share manner and voicing, but differ in major place of articulation (hereafter referred to as an “all-but-place” effect), or in constriction location (Experiment 4). We included the manipulations of all-but-place and all-but-constriction-location for reasons which we expand upon below.

Our primary goal in conducting the present study was to provide empirical results that could inform the expansion of extant models of reading aloud to include the feature-level representations. Following the insight from the model of Harm and Seidenberg (1999), we propose a hypothesis concerning the effects of orthographic and phonological (at the feature level) representations on response latencies in reading aloud. We first illustrate the predictions made by this hypothesis using the results from MRR2015. We then present results

from a series of experiments that tested this hypothesis in two different languages, English and Russian.

Hypothesis

Our hypothesis is that processing of the onset of a visually presented prime will activate feature-level representations associated with that prime's onset. Activation levels required to produce the target onset will be higher when prime and target onsets share more feature values than when they share fewer. Our hypothesis therefore predicts that priming effects will emerge when prime-target onsets are featurally similar. In contrast, priming effects will not emerge when prime-target onsets are not (as) featurally similar.

Theories of phonological representation

The precise quantification of similarity will of course depend on what theory of phonological representation is assumed. It is important to acknowledge that there are two major classes of theories of phonological representation in the linguistic literature (Clements, 1992): those based on distinctive features (Chomsky & Halle, 1968; Clements, 1985; Mielke, 2008) and those based on articulatory gestures (Browman & Goldstein, 1989, et seq.). While these types of theories differ in many regards (see below), a property common to both classes is that there is a material difference between how voicing and place are represented.

Within mainstream distinctive features theories, voicing is represented by a single distinctive feature [\pm voice], while features corresponding to "place" are more complex. Major articulator features, such as [labial], [coronal], [dorsal], specify which articulator is involved in making the constriction for a given phoneme, and correspond roughly with what is often called "place of articulation". Each of these major features has a set of unique subsidiary features, which most often indicate further detail about where and how the primary articulator makes its constriction (Clements, 1985; McCarthy, 1988). To illustrate, under any theory of distinctive features, the segments /z/ and /s/ differ in precisely one feature value

only: /z/ is [+voice], while /s/ is [-voice]. On the other hand, in terms of place of articulation, the segments /s/ and /ʃ/ are both [+coronal, -voice], but they differ in that /s/ is [+anterior] while /ʃ/ is [-anterior], indicating that while both are made with the flexible front part of the tongue, the constriction for /s/ is more anterior (i.e., closer to the teeth) than that for /ʃ/. The crucial point is that features such as [±anterior] are subsidiary to a major place feature, in this case [coronal], meaning that the feature [±anterior] is not specifiable unless a segment is [+coronal]. Thus, it is not meaningful to talk about the values of [±anterior] for /f/, because it is [-coronal] (or simply not specified for [coronal], though this distinction is immaterial to the present discussion). Similarly, it is not possible to specify the feature [±round] for segments that are not [+labial]. This has direct implications for any hypothesis that depends on differences between sounds based on place of articulation, like the present one, because such an all-but-place difference implies differences on a number of features—the major place feature and all its subsidiary features, not just one.

Within Articulatory Phonology (Browman & Goldstein, 1986, et seq.) phonological representations take the form of gestural scores, in which the constriction goals of the relevant vocal tract articulators are specified and arranged over the time course of the utterance. Even though gestural phonological representations are markedly different from distinctive features, contrasts in terms of voicing and place are also very different in nature in gestural terms as well. Two segments that differ only in voicing are contrasted by a different specification of one parameter of relative timing between the oral and glottal gestures (or alternatively the presence of a glottal abduction gesture for voiceless consonants versus the absence of such a gesture for voiced consonants), but the rest of the gestural specifications remain unchanged (full details of the specification of gestures can be found in Browman & Goldstein, 1989; Browman & Goldstein, 1990). Two segments that differ in place, however, require the specification of different sets of unrelated gestural parameters: /ta/, for example,

requires setting a constriction location (alveolar) and constriction degree (closed) for the tongue tip, while /pa/ requires setting a constriction location (bilabial) and constriction degree (closed) for the lower lip. Within a theory of gestural representations, as within a theory of distinctive features, it is therefore possible for two segments to share all properties except voicing, but not all properties except place.

Distinctive features and articulatory gestures are clearly very different formally. As a matter of expository convenience, we use the term “feature” in this study to refer generically to phonological representations at a level more fine-grained than the phoneme without necessarily privileging distinctive features over articulatory gestures. When the difference between the types of representation are material, we use the full term “distinctive features”.

Types of features and associated feature-priming effects

Given inherent differences in the composition of voicing and place features that hold across divergent types of theories of phonological representation, one might expect different patterns of feature-priming effects for prime-target pairs that differ in voicing and those that differ in place. In particular, while it is possible to find phoneme pairs that differ only in their values for voicing and match on all other features, most phonemes that differ in place of articulation mismatch on several features, since place of articulation is an aggregate construct that includes multiple subsidiary features (or different sets of gestures). Hence, the difference in voicing involves opposite values for a single feature, whereas the difference in place of articulation involves more than one feature.

As per our hypothesis, the all-but-voicing priming effect observed in MRR2015 is expected. In those experiments (the difference between their Experiments 1 and 2 was only the duration of the masked prime, which did not change the qualitative result), the primes and targets shared sufficiently many feature values, such that sufficient activation of the features of the target onset was introduced by the onset of the prime. As a result, a feature-level

priming effect was obtained. However, in the all-but-place case, prime and target onsets may involve so many different features, that the features of the target onset may not be sufficiently activated by the features of the prime onset. Our hypothesis predicts no all-but-place feature-priming effects, or at least that such effects would not be as robust as all-but-voicing feature-priming effects. By “robust” we mean that the effect should be observable in the face of lots of noise, and replicable across experiments and languages.

Unlike the major place features of labial, coronal, dorsal, etc., there are other features (like voicing) that can differentiate two phonemes without involving other features. For example, /θ/ and /s/ are both voiceless tongue-tip fricatives that differ only in constriction location (in articulatory terms), with the former being dental and the latter being alveolar. In terms of distinctive features, they both share the major place feature of [+coronal] and differ in terms of the subsidiary feature of [±distributed] (per, e.g., Hayes, 2009). According to our hypothesis, experiments that manipulate a single, subsidiary feature, all things being equal, should yield feature-priming effects, as observed in the MRR2015 all-but-voicing experiments. However, English orthography presents a problem in using phoneme pairs that differ in constriction location. This is because /θ/ is always represented by two letters in English (i.e., “th”), while /s/ is represented by a single letter (i.e., “s”, and sometimes “c”). There is evidence that a MOPE does not arise if the onset of the prime consists of multiple letters that correspond to a single phoneme (Timmer, Ganushchak, Ceusters, & Schiller, 2014). This empirical finding precludes the use of English to test our hypothesis. Importantly, our hypothesis is not dependent on language, so any language that provides a suitable contrast can be used. In Russian, the alveolar fricatives /s, z/ and retroflex /ʂ, ʐ/ are contrasted, so that /s/ vs. /ʂ/ and /z/ vs. /ʐ/ differ only in constriction location of the tongue tip in gestural terms, while each of them is represented by a single letter.

We would like to emphasize that our study was not designed to determine the nature of representations that are involved in translating phoneme representations into fully specified motor plans. Our goal was to provide additional evidence that these representations exist, and that they include feature-level information. Our results will be interpretable within any theory of phonological representation, but they cannot be used to adjudicate between existing accounts.

Summary of experiments

In Table 1 we present a summary of five experiments: the experiment from MRR2015 and the four experiments included in the present study. As mentioned above, the all-but-voicing feature-priming effect found by MRR2015 is consistent with our hypothesis, because the onsets of primes and targets mismatched in one feature value only. The feature-priming effect reported by MRR2015 was found in English, so the present Experiment 1 tested for all-but-voicing feature-priming effects in Russian. Our hypothesis is not language-dependent, and therefore such an effect should be found in languages other than English.

Table 1. Summary of previous and current experiments investigating feature-priming effects and the predictions of our hypothesis for each experiment.

| Experiment | Feature manipulation | Language | Example prime-target onsets | Predicted feature priming effect |
|----------------------|----------------------------------|-----------------|------------------------------------|---|
| MRR2015 | all-but-voicing | English | /z/-/s/ | yes |
| present Experiment 1 | all-but-voicing | Russian | /z/-/s/ | yes |
| present Experiment 2 | all-but-place | English | /f/-/s/ | no |
| present Experiment 3 | all-but-place | Russian | /f/-/s/ | no |
| present Experiment 4 | a) all-but-constriction-location | Russian | /ʃ/-/s/ | yes |
| | b) all-but-voicing (replication) | Russian | /z/-/s/ | yes |

The present Experiments 2 and 3 were designed to test for an all-but-place feature-priming effect in English and Russian, respectively. According to our hypothesis, any such effect should not be observed, or at least should not be as robust as the all-but-voicing priming effect. Experiment 4 was designed to further test the prediction that activation levels of a target onset should be activated sufficiently by a prime onset differing only in the value of a single feature, such that a facilitative feature-level effect should be found, as in the all-but-voicing manipulation. To test this, we used an all-but-constriction-location manipulation. Experiment 4 was conducted in Russian and also included the all-but-voicing manipulation

from Experiment 1. Including the latter manipulation aimed at increasing variability in the stimuli onsets, as well as at replicating Experiment 1.

All data, as well as Supplementary Materials and Appendices can be found on OSF (Ulicheva et al., 2020). All our predictions concern response latencies. We had no *a priori* hypotheses about the effects of primes on target error rates. Therefore, the statistics that concern accuracy are only reported in Supplementary Materials.

Characteristics of Russian

Since three of our four experiments (1, 3, and 4) were conducted in Russian, we first present two characteristics of the Russian language and its orthography that are not present in English. These two characteristics, namely, palatalization and position-dependent obstruent devoicing, imposed additional constraints on stimulus construction. Specifically, palatalization constrained the types of vowels that could be used in our stimuli, while devoicing influenced the calculations for across-condition matching.

Russian uses the Cyrillic alphabet, which consists of 33 letters: 21 consonants, ten vowels, and two silent letters (“ъ” and “ь”, also called “signs”). Russian has an extremely productive contrast between palatalized and non-palatalized consonants that applies across manners (stops, fricatives, nasals, and liquids) for labial and coronal consonants (Avanesov, 1984; Halle, 1971; Jones & Ward, 1969; Kochetov, 2002; Padgett, 2001; Timberlake, 2004). Palatalization is achieved articulatorily by producing a tongue-body constriction near the palate (comparable to the articulation used to produce the glide /j/) concurrently with the primary articulation required for the consonant (Avanesov, 1974; Kochetov, 2002, Chapter 3; Ladefoged & Maddieson, 1996). In somewhat over-simplified terms, whether a given segment is palatalized is most often indicated not by its corresponding letter, but rather by a letter indicating the vowel (or one of the silent signs) that follows it. Letters that indicate a vowel exist in pairs, one that indicates that the preceding consonantal segment should be

palatalized, and another one that indicates that the preceding consonantal segment should not be palatalized (e.g., “люк” /lʲuk/ vs. “лук” /luk/, ‘hatch’ vs. ‘onion’). Hence, the vowel letter indicates a difference in the place of articulation of the preceding consonant by adding a second, dorsal constriction near the palate to the primary oral articulation (labial or coronal).

Another relevant fact about Russian is that voiced obstruents (i.e., stops and fricatives) are devoiced word-finally, e.g., /kod/ and /glaz/ (‘code’ and ‘eye’, respectively) are pronounced [kot] and [glas] in the Nominative singular, but as [koda] and [glaza] in the Genitive singular. It is commonly held that the last segment of the “underlying representation” (UR) of the lexical item in these cases is the voiced obstruent, which surfaces as voiceless in specific environments (Halle, 1971), because of the existence of words like /kot/ ‘cat’, which is [kot] in the Nominative singular and [kota] in the genitive singular. This difference in voicing of the underlying segment is represented in Russian orthography and does not change based on the surface form (SF), as shown in Table 2.

Table 2. Underlying (UR) and surface (SF) forms in Russian showing final obstruent devoicing.

| | Underlyingly voiceless | | | Underlyingly voiced | | |
|---------------------|------------------------|-----------|----------------|---------------------|-----------|----------------|
| | <u>UR</u> | <u>SF</u> | <u>Russian</u> | <u>UR</u> | <u>SF</u> | <u>Russian</u> |
| Nominative Singular | /kot/ | [kot] | кот | /kod/ | [kot] | код |
| Genitive Singular | /kota/ | [kʌ'ta] | кота | /koda/ | ['kodə] | кода |

Experiment 1: Russian all-but-voicing

Experiment 1 was designed to replicate in Russian the all-but-voicing result reported by Mousikou et al. (2015, experiment 2) in English. Just like in the English study, the onsets of prime-target pairs mismatch only on the value of a single feature; hence, we expected that

target response latencies in the all-but-voicing feature-priming condition would be shorter than in the unrelated condition.

Method

Participants. Twenty-four undergraduate and postgraduate students at the Higher School of Economics in Moscow, Russia, participated in Experiment 1. All participants were native monolingual speakers of Russian with no history of reading, spelling, or learning difficulties. Students provided written consent prior to participating in the study. Participation was voluntary.

Materials. Targets and primes in Experiment 1 consisted of orthographically licit three-letter combinations that corresponded to nonwords. Stimuli were constructed using the Russian Google N-gram corpus (<http://books.google.com/ngrams>; retrieved in March 2015) that contained 1,054,210 words and their frequencies. All duplicate word entries and strings including non-Cyrillic characters were first removed. Then, only words with over 50 instances-per-million were considered in order to minimize the number of misspelled and archaic words, as well as infrequent abbreviations. Inflected words of different grammatical categories were present in the corpus. To use the examples from Table 2, /kod/ and /koda/ were counted as two separate entries, even though they are two declensions of the same word (the calculations reported in Appendix A are based on this corpus).

To construct the nonwords, all possible consonant-vowel-consonant combinations in Russian were first generated using 21 consonant letters excluding "auxiliary" letters that do not correspond to any phoneme (the two signs, and the five palatalizing vowel letters). These were excluded because there is empirical evidence showing that some skilled readers can process the second letter of masked primes (Mousikou, Coltheart, Finkbeiner, & Saunders, 2010a). To avoid instances of consonant palatalization (as described in the Introduction), only non-palatalising orthographic vowels ("a", "o", "y", "ы", "э", corresponding to the vowels /a,

o, u, i, ε/, respectively) were used. This procedure yielded 2,205 legal CVC combinations, of which 532 corresponded to existing words, which were excluded. Further, letter strings that are traditionally considered orthographically illegal in school textbooks, such as **“шш”* and **“чч”* (Klimanova & Makeeva, 2011), were removed (182 items), and so were 221 pseudo-homophones (e.g., *“люг”* /lʲug/ is pronounced [lʲuk], which is the same as *“люк”* /lʲuk/, ‘onion’). The Russian Dual Route Cascading model (Ulicheva, Coltheart, Saunders, & Perry, 2016) was used to check automatically the generated pronunciations. Nonwords containing the rhotic trill, /r/, were filtered out (101 items) due to its unique articulatory requirements (Proctor, 2011). The resulting set of nonwords consisted of 1,169 items.

Seventy-five nonword targets with three corresponding primes were selected (300 items in total). Primes were of three types: onset related, feature related, and unrelated. Onset related primes shared the initial letter and phoneme with the target, but had no other letters or phonemes in common (e.g., /bof/-/bim/, *“боф”*-*“БИМ”*). Feature related primes and their corresponding targets had no letters or phonemes in common, but critically, their first phoneme shared all features except voicing (e.g., /pɛf/-/bim/, *“пэф”*-*“БИМ”*). Unrelated primes and their corresponding targets shared no letters or phonemes, while their first phoneme also mismatched in manner and place (e.g., /suf/-/bim/, *“суф”*-*“БИМ”*). To keep the three types of primes in a given trio as similar as possible to each other, their final letters and phonemes were kept identical (as in MRR2015). Targets always began with one of ten consonants, either voiced, /b, v, d, z, g/ (*“б”, “в”, “д”, “з”, “г”*), or their voiceless counterparts, /p, f, t, s, k/ (*“п”, “ф”, “т”, “с”, “к”*). Six practice prime-target pairs were selected using the same procedure. There were no item repetitions in the stimuli set. Upon inspection, four pseudo-homophones, which failed to be filtered using the automatic check, were identified among the primes and replaced with new ones.

The three prime sets were designed to be as similar to each other as possible. For this reason, they were matched on 24 psycholinguistic variables (see Appendix A for a description of the variables, details on their calculation, and matching statistics). MRR2015 took several psycholinguistic variables into account when matching the experimental stimuli across conditions. We calculated some additional ones due to the specific characteristics of Russian. More specifically, we distinguished between words that began with the same letter (head neighbors) and words that began with the same phoneme (onset neighbors) due to the influence of vowels on consonant palatalization. We also accounted for phonotactic dependency (Ulicheva et al., 2016), and several measures of bigram frequency (see Appendix A for details). There were no significant differences between the three types of primes on any variable, except for position-specific token bigram frequency (feature related primes had higher values on this measure than the other two types of primes). Importantly though, the stimuli were matched on a total of seven measures of bigram frequency and four measures of trigram frequency.

Following the procedure of MRR2015, we quantified the degree of phonological similarity between the three types of primes and their targets. This procedure was adapted to the Russian language (see Appendix B for details). The calculations were performed twice, once for underlying phonemic transcriptions and once for surface transcriptions (see Table 2). Both types of transcription yielded similar results. Analogous to MRR2015, the three types of primes were phonologically similar in all phoneme positions but the first, which forms the experimental manipulation of interest in our experiment ($p < .001$, for first position, and $p > .05$, for second and third positions, see Appendix B for details). The three types of primes and their corresponding targets are listed in Appendix C.

Design. The design of this experiment was identical to that of MRR2015 (Experiment 2). In particular, there were 75 prime-target pairs in each experimental condition, yielding a

total of 225 trials per participant in a fully counterbalanced design. As such, each participant saw each of the 75 targets three times, each time preceded by a different prime type. The 225 trials were divided into three blocks, so that the same target appeared only once within the same block. A short break was administered between the blocks. We ensured that at least 50 trials intervened before the same target reappeared. Three lists were constructed to counterbalance the order of block presentation, so if a given prime-target pair appeared in the first block of the first list, it would then appear in the second block of the second list and in the third block of the third list. Eight participants were assigned to each list.

Apparatus and procedure. The same procedure as in Experiment 2 of MRR2015 was used in Russian. Primes were presented for 50 ms, as this is the most common prime duration used in masked priming experiments (Forster & Davis, 1984; Forster, Davis, Schoknecht, & Carter, 1987; Kinoshita, 2003). As per MRR2015, participants were tested individually, seated approximately 40 cm in front of a CRT monitor in a dimly lit room. Stimulus presentation and data recording were controlled by DMDX software (Forster & Forster, 2003). Verbal responses were recorded by a head-worn microphone. Participants were told that they would see a series of hashtags followed by nonwords presented in uppercase letters and that they had to read the nonwords out loud as quickly as possible. The presence of primes was not mentioned to the participants. Each trial started with the presentation of a forward mask (###) that remained on the screen for 500 ms. The prime was then presented in lowercase letters for 50 ms (three ticks based on the monitor's refresh rate of 16.67 ms) followed by the target, which was presented in uppercase letters and acted as a backward mask to the prime. The stimuli appeared in white on a black background (12-point Courier New font) and remained on the screen for 2,000 ms or until participants responded, whichever happened first. The order of trial presentation within blocks and lists was randomized across participants. Six practice trials preceded the experimental trials.

Analyses

Response latencies in this and all subsequent experiments were determined by the acoustic onsets of participants' responses. These were hand-marked using CheckVocal (Protopapas, 2007), following the criteria specified by Rastle, Croot, Harrington, and Coltheart (2005). Responses that contained hesitations, mispronounced phonemes, as well as phoneme omissions or additions were labelled as incorrect. More generally, only pronunciations of nonwords that native speakers of the corresponding language considered illegitimate were marked as incorrect.

The statistical analyses were performed using linear mixed-effects models (Baayen, Davidson, & Bates, 2008) as implemented in the *lme4* package (version 1.1-14, Bates, Maechler, Bolker, & Walker, 2015) in the statistical software R (Version 3.6.1, 2019-07-05, "Action of the Toes", R Development Core Team, 2018). The BoxCox procedure indicated that inverse response latency (multiplicative inverse of the response latency) was the best transformation to normalize residuals. The significance of the fixed effects was determined with type III model comparisons using the *Anova* function in the *car* package (Version 3.0-4; Fox & Weisberg, 2011). Post-hoc comparisons were carried out using cell means coding and single *df* contrasts with the *glht* function of the *multcomp* package (Version 1.4-10; Hothorn, Bretz, & Westfall, 2008) using the normal distribution to evaluate significance.

Incorrect responses were removed (10.8% of the data), and so were trials whose previous trial corresponded to an error (14.0% of the remaining data). Trials with a response latency below 200 or above 1500 ms (0.1% of the data) were considered as extreme values and were also removed. Outliers were removed following the procedure outlined by Baayen and Milin (2010). A base model, which included only participants and items as random intercepts, was fitted to the data and data points with residuals exceeding 2.5 SDs were removed (2.1% of the data). One of the participants had very fast response latencies

compared to the rest and was identified as an outlier (the corresponding random intercept was 2 SDs smaller than the mean intercept, based on the output of the *ranef* function applied to the statistical model reported below). Therefore, data from this participant were removed (3.2%), leaving a total of 23 participants to be included in the analyses. The final dataset included 3920 data points (81.4% of all trials with a correct response). The LME model included the effect-coded fixed effect of Prime Type (onset related vs. feature related vs. unrelated), as well as previous trial response latency and trial order (both standardized) as covariates. Random intercepts and random slopes for the effect of Prime Type were used for both subjects and items.

Results

Results indicated a significant main effect of Prime Type ($\chi^2 = 87.010, p < .001$). Target reading-aloud latencies in the feature related condition ($M = 481$ ms, $SE = 7$) were significantly faster ($\Delta = 9$ ms, $z = -3.313, p < .001$) than in the unrelated condition ($M = 489$ ms, $SE = 6$), indicating a feature-priming effect. Also, the onset related condition ($M = 458$ ms, $SE = 7$) yielded significantly faster target reading-aloud latencies ($\Delta = 31$ ms, $z = -8.435, p < .001$) than the unrelated condition, indicating a MOPE. Previous-trial response latency and trial order were also significant. The results from the mixed-effects analyses for all experiments are provided in Table 3, while the corresponding mean model latencies are displayed in Figure 1.

Discussion

The results from Experiment 1 replicate the all-but-voicing feature-priming effect observed in English by MRR2015. Our results also replicate the MOPE in Russian, which has been first reported by Timmer, Ganushchak, Mitlina, and Schiller (2014) and Jouravlev, Lupker, and Jared (2014). Importantly, the presence of a feature-priming effect is consistent

with our hypothesis, which posits that feature-priming effects should arise regardless of language when onsets of prime-target pairs differ by a single feature value.

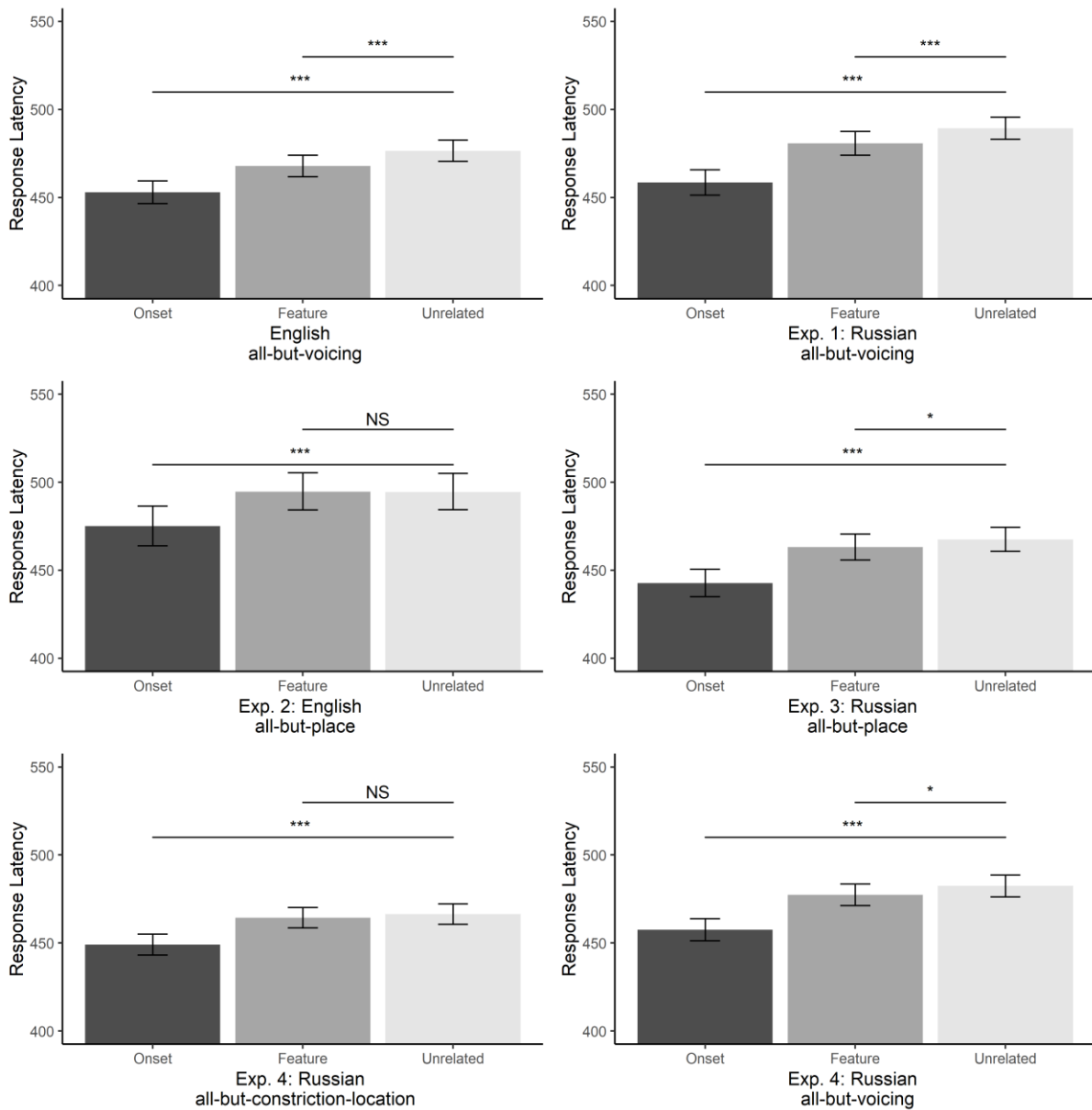


Figure 1. Priming effects on response latencies in Mousikou et al. (2015, top left panel, "English all-but-voicing") and Experiments 1-4 of the present study. NS stands for "non-significant". Back-transformed estimated response latencies (in milliseconds) with corresponding Standard Errors are displayed. Asterisks indicate significant differences between the conditions.

Table 3. Summary of Linear Mixed-Effects Analyses for response latencies in Experiments 1, 2, 3, and 4.

| Experiment | Fixed effects (df) | χ^2 | <i>p</i> |
|--|---------------------------------------|----------|----------|
| Experiment 1 Russian all-but-voicing | Intercept (1) | 5250.793 | <.001 |
| | Prime Type (2) | 87.010 | <.001 |
| | Order (1) | 18.806 | <.001 |
| | Previous Response Latency (1) | 170.836 | <.001 |
| Experiment 2 English all-but-place | Intercept (1) | 2097.385 | <.001 |
| | Prime Type (2) | 53.712 | <.001 |
| | Order (1) | 90.408 | <.001 |
| | Previous Response Latency (1) | 168.882 | <.001 |
| Experiment 3 Russian all-but-place | Intercept (1) | 3965.344 | <.001 |
| | Prime Type (2) | 88.582 | <.001 |
| | Order (1) | 51.093 | <.001 |
| | Previous Response Latency (1) | 185.094 | <.001 |
| Experiment 4 Russian all-but-constriction- location/all-but-voicing | Intercept (1) | 7326.084 | <.001 |
| | Prime Type (2) | 179.775 | <.001 |
| | Feature Manipulation (1) | 7.337 | <.010 |
| | Prime Type x Feature Manipulation (2) | 7.805 | <.050 |
| | Order (1) | 62.291 | <.001 |
| | Previous Response Latency (1) | 529.548 | <.001 |

Experiment 2: English all-but-place

In this experiment, we manipulated the major place of articulation of the initial consonants of primes and targets in English while keeping manner and voicing constant (all-but-place manipulation, e.g., “biz”-“DEG”). As discussed in the Introduction, two phonemes that differ in place of articulation mismatch on several features, not just one. Therefore, they are sufficiently different from each other, so as to yield no feature-priming effects.

Method

Participants. Twenty-four undergraduate students from Royal Holloway, University of London, participated in Experiment 2. All participants were monolingual native speakers of southern British English and reported no visual, reading, or language difficulties. They received £5 for their participation.

Materials. Seventy-eight nonwords with a consonant-vowel-consonant (CVC) graphemic and phonological structure served as target items. Another 234 nonwords with the same characteristics served as onset related, feature related, and unrelated primes. All items were extracted from the ARC Nonword Database (Rastle, Harrington, & Coltheart, 2002) and consisted of three letters/phonemes each. The three types of primes were matched on a number of psycholinguistic variables (see Appendix A).

Three groups of 78 prime-target pairs were formed, with each group corresponding to a different experimental condition: onset related, feature related, and unrelated. In the onset related condition, primes and targets shared only their first letter/phoneme (e.g., “dav”-“DEG”). In the feature related condition, primes and targets had no letters in common, but the initial phonemes shared voicing and manner and differed in place of articulation (e.g., “gav”-“DEG”). In the unrelated condition, the initial phonemes of primes and targets always differed in voicing, manner, and place of articulation, while primes and targets never shared any letters/phonemes in the second or third position (e.g., “fiv”-“DEG”). As per MRR2015, the three types of primes that were paired with the same target shared their last letter/phoneme (e.g., “dav”/“gav”/“fiv”-“DEG”). The average similarity scores between the first phonemes of the primes are reported in Appendix B. These indicated that primes across the three conditions were phonologically similar in all phoneme positions but the first ($p < .001$, for first position, and $p > .05$, for the second and third positions). In addition to the 234 prime-target pairs that formed the experimental stimuli, six pairs of primes and targets that matched the experimental stimuli on the same criteria were selected as practice items.

Design. The design of the experiment was identical to that used in MRR2015 and in Experiment 1 of the present study, except that in Experiment 2 there were 78 prime-target pairs in each experimental condition for a total of 234 trials per participant. As for Experiment 1, we ensured that at least 52 trials intervened before the same target reappeared.

Apparatus and Procedure. The apparatus and procedure were identical to those used in Experiment 1.

Analyses

The analyses were performed in the same way as in Experiment 1. Incorrect responses were removed (3.0% of the data), and so were trials following an incorrect trial (3.8% of the data). There were no extreme values in the dataset (i.e., no latencies below 200 or above 1500 ms). However, outliers (2.2% of the data) were removed following the same procedure as in Experiment 1. One of the participants had very slow response latencies compared to the rest and was identified as an outlier (as indicated by the *ranef* function of the *lme4* package). Therefore, data from this participant were removed (4.5%), leaving a total of 23 participants to be included in the analyses. Our statistical model was identical to that of Experiment 1. It was based on 4892 observations (89.8% of all correct trials).

Results

Results indicated a significant main effect of Prime Type ($\chi^2 = 53.712, p < .001$). Target reading-aloud latencies in the feature related condition ($M = 495$ ms, $SE = 11$) did not differ significantly ($\Delta = 0$ ms, $z = .032, p = .974$) from those in the unrelated condition ($M = 495$ ms, $SE = 11$). The onset related condition ($M = 475$ ms, $SE = 12$) yielded significantly faster target reading-aloud latencies ($\Delta = 20$ ms, $z = -6.175, p < .001$) than the unrelated condition, indicating a MOPE. Previous-trial response latency and trial order were also significant.

Discussion

No feature-priming effect was detected in English when initial phonemes of primes and targets shared voicing and manner of articulation but differed in place of articulation. Given that the difference between two phonemes that mismatch on major place of articulation

involves several features, we predicted no priming effects in the all-but-place condition. Hence, our findings were consistent with the predictions derived from our hypothesis.

Experiment 3: Russian all-but-place

Experiment 3 was conducted to test whether an all-but-place priming effect would be observed in Russian. On the basis of our own predictions and the results from Experiment 2, we did not expect to find such an effect.

Method

Participants. Twenty-four undergraduate and postgraduate students at the Higher School of Economics in Moscow, Russia, participated in the study. Recruitment criteria were the same as those in Experiments 1 and 2. None of the participants who took part in Experiment 3 had participated in Experiment 1.

Materials. The stimuli selection procedure was similar to that used in Experiments 1 and 2. As in Experiment 2, the initial phonemes of feature related primes shared manner and voicing with the initial phonemes of their targets, yet they differed in place of articulation (e.g., /pɛb/-/toʃ/). The stimuli used in Experiment 3 are shown in Appendix C. Onset, feature, and unrelated primes were matched on the same psycholinguistic variables as the primes in the other experiments (see Appendix A). As per MRR2015 and Experiments 1 and 2 of the present study, the three types of primes were phonologically similar in all phoneme positions but the first, which forms the experimental manipulation of interest in our experiment ($p < .001$, for first position, and $p > .05$, for second and third positions; see Appendix B for details).

Design, Apparatus, and Procedure. These were identical to those of Experiment 1.

Analyses

The analyses were performed as in Experiments 1 and 2. Incorrect responses were first removed (5.4% of the data), as well as trials whose previous trial corresponded to an

error (9.3% of the data). Latencies below 200 or above 1500 ms (one observation) were considered extreme values and were also removed. Outliers (2.1% of the data) were removed in the same way as for Experiments 1 and 2. Data from 24 participants (4536 observations that represent 88.8% of the original dataset with correct responses) were included in the analyses.

Results

Results indicated a significant main effect of Prime Type ($\chi^2 = 88.582, p < .001$). Target reading-aloud latencies in the feature related condition ($M = 463$ ms, $SE = 8$) were faster than in the unrelated condition ($M = 467$ ms, $SE = 7$). This difference reached significance ($\Delta = 4$ ms, $z = -2.030, p = .042$), thus denoting a feature-priming effect. Also, the onset related condition ($M = 443$ ms, $SE = 8$) yielded significantly faster target reading-aloud latencies ($\Delta = 25$ ms, $z = -8.920, p < .001$) than the unrelated condition, indicating a MOPE. Previous-trial response latency and trial order were also significant.

Discussion

The results from Experiment 3 revealed a significant 4-millisecond feature-priming effect in Russian. In this experiment, the initial segments of the prime-target pairs were matched on voicing and manner but differed in place of articulation. While our hypothesis does not preclude an all-but-place priming effect, such an effect was not expected in Russian, because it was also not found in English (Experiment 2). We address this point in the General Discussion.

Experiment 4: Russian all-but-voicing/all-but-constriction-location

Experiment 4 involved two manipulations that tested feature-priming effects in Russian. First, we investigated whether a feature-priming effect would be observed when the initial phonemes of primes and targets differ only in constriction location (e.g., /zit/-/zok/). According to our hypothesis, a significant all-but-constriction-location priming effect should

be observed in this experiment, because initial segments of primes and targets in this condition differ on one feature value only, and thus are relatively close to each other in representational terms. This is analogous to the all-but-voicing manipulation in Experiment 1. We also included the all-but-voicing manipulation in Experiment 4, so that target onsets in this experiment would vary as much as target onsets in the other experiments. Including the all-but-voicing manipulation further allowed us to seek to replicate the results from Experiment 1.

Method

Participants. Forty-nine undergraduate and postgraduate students at the Higher School of Economics in Moscow, Russia, participated in Experiment 4. Recruitment criteria were similar to those in Experiments 1 and 3. Given the restrictions that we had for the construction of the stimuli in this experiment due to the specific experimental manipulation, fewer prime-target pairs could be selected (see Materials section below). We therefore doubled the number of participants in this experiment compared to the other three in order to compensate for the loss of power and make all four experiments as comparable as possible. None of the participants had taken part in Experiments 1 or 3.

Materials. The selection of stimuli for the constriction-location manipulation in Experiment 4 was similar to the one used in Experiments 1 and 3. The only difference concerned feature related primes, whose first phonemes shared all features except constriction location with the first phonemes of their corresponding targets (e.g., /zit/-/zok/). Targets and their onset related primes always began with one of the four consonants /s, ʃ, z, z/. Their feature related counterparts began with /ʃ, s, z, z/, respectively. Their unrelated counterparts were /g/, /g/, /k/ or /p/, and /k/ or /p/, respectively. Due to the specific constraints that we adopted for the construction of the stimuli in Experiments 1, 2, and 3, the stimuli that could be selected for Experiment 4 following the same principles ended up being fewer than

in the former experiments (51 targets; 204 nonwords in total). A voicing-feature manipulation (as in Experiment 1) was additionally included to match the number of different target onsets to those in the former experiments. For both the constriction-location condition and the voicing condition, 51 targets along with their three corresponding primes were selected. To make the nonwords in the voicing condition maximally distinct from the ones in the constriction-location condition, we avoided nonwords starting with /ʒ, s, z, z/. Otherwise, selection criteria were identical to those adopted in the other experiments.

Primes in all three conditions were matched on the same psycholinguistic variables as in the other experiments. Matching statistics for the two feature-type conditions in this experiment, as well as phonological similarity values between primes and targets are reported in Appendices A and B, respectively. Note that the same similarity matrix as in our previous experiments was used in Experiment 4. Given that in the constriction-location condition the onsets of the feature related primes and those of their corresponding targets differed only by a single feature value, we expected their phonological similarity to be maximal. Calculations on the basis of our matrix revealed indeed that this was the case (the three types of primes were phonologically similar in all phoneme positions, $p > .05$, but the first, $p < .001$). The stimuli are listed in Appendix C.

Design, Apparatus and Procedure. Each experimental condition consisted of 51 prime-target pairs for a total of 306 trials per participant in a fully counterbalanced design. Sixteen participants were tested on list A, 16 on list B, and 17 on list C. Apparatus and procedure details were otherwise identical to those in the other experiments.

Analysis

Incorrect responses (6.6% of the data) and trials whose previous trial corresponded to an error (9.3% of the data) were removed. The latency of one trial was below 200, and so it was removed from the dataset. Outliers (2.0% of the data) were removed following the same

procedure as for all other experiments. One of the participants yielded extremely fast response latencies compared to the rest and was identified as an outlier (as indicated by the *ranef* function of the *lme4* package). Therefore, data from this participant were removed (0.9%), leaving a total of 48 participants to be included in the analyses. The final dataset included 12337 observations (88.1% of all correct trials). In the following section, we will present the results within each experimental manipulation first, mirroring the presentation of experiments 1–3, and then conclude with the direct comparison of the two Manipulation conditions.

Manipulation 1: All-but-constriction-location

Results indicated a significant main effect of Prime Type ($\chi^2 = 111.895, p < .001$). Target reading-aloud latencies in the feature related condition ($M = 464$ ms, $SE = 6$) were faster than in the unrelated condition ($M = 466$ ms, $SE = 6$). This difference was not statistically significant ($\Delta = 2$ ms, $z = -1.084, p = .278$), denoting no feature-priming effect. Also, the onset related condition ($M = 449$ ms, $SE = 6$) yielded significantly faster target reading-aloud latencies ($\Delta = 17$ ms, $z = -8.026, p < .001$) than the unrelated condition, indicating a MOPE. Previous-trial response latency and trial order were also significant.

Manipulation 2: All-but-voicing

The effect of Prime Type was significant ($\chi^2 = 166.03, p < .001$). Targets were read aloud faster in the feature related condition ($M = 478$ ms, $SE = 6$) than in the unrelated condition ($M = 483$ ms, $SE = 6$). This difference was significant ($\Delta = 5$ ms, $z = -2.387, p < .05$). Further, a MOPE was observed: targets were read aloud significantly faster in the onset related condition ($M = 458$ ms, $SE = 6$) than in the unrelated condition ($\Delta = 25$ ms, $z = -12.17, p < .001$). Previous-trial response latency and trial order were significant.

Comparison of manipulations

Results indicated a significant main effect of Prime Type ($\chi^2 = 179.775, p < .001$) as well as a significant main effect of experimental Manipulation, that is, all-but-constriction vs. all-but-voicing ($\chi^2 = 7.337, p = .007$). Also, the interaction between Prime Type and Manipulation was significant ($\chi^2 = 7.805, p = .020$). Previous response latency and trial order were also significant.

Post-hoc contrasts for the effect of Prime Type revealed that target reading-aloud latencies in the feature related condition ($M = 471$ ms, $SE = 6$) were significantly faster ($\Delta = 4$ ms, $z = -2.327, p = .020$) than in the unrelated condition ($M = 474$ ms, $SE = 5$), indicating a feature-priming effect. Also, the onset related condition ($M = 453$ ms, $SE = 6$) yielded significantly faster target reading-aloud latencies ($\Delta = 21$ ms, $z = -11.680, p < .001$) than the unrelated condition, indicating a MOPE. Target reading-aloud latencies in the all-but-constriction-location manipulation ($M = 460$ ms, $SE = 6$) were significantly faster ($\Delta = 12$ ms, $z = -2.709, p = .007$) than in the all-but-voicing manipulation ($M = 472$ ms, $SE = 6$). Both the MOPE and the feature-priming effect were significantly bigger ($\chi^2 = 142.930, p < .001$, and $\chi^2 = 6.246, p = .044$, respectively) in the all-but-voicing manipulation than in the all-but-constriction-location manipulation, thus yielding a significant Prime Type by Manipulation interaction. The feature-priming effect was significant in the all-but-voicing manipulation ($z = -2.304, p = .021$), whereas it was not significant in the all-but-constriction-location manipulation ($z = -1.034, p = .301$).

Discussion

In Experiment 4, we replicated the all-but-voicing effect in Russian. However, we observed no feature-priming effects when prime and target onsets differed only in the feature value that specifies constriction location. According to our hypothesis, a feature-priming effect should have been observed in both feature-type manipulations. We address this disparity below.

Cross-experiment comparisons

In order to establish whether the significant differences that we observed within experiments were meaningful across experiments, we ran cross-experiment pairwise comparisons including data from all four of the present experiments as well as the data from MRR2015. The details of the models and the results are presented in Appendix D. In summary, our experiments validated in Russian the presence of the all-but-voicing feature effect reported by MRR2015 in English. While our analyses convincingly showed that the all-but-voicing effect is robust, our data were inconclusive with regard to the presence or absence of the all-but-place effect in Russian: it was not as robust as the all-but-voicing effect in Russian, but clearly more prominent than the all-but-place effect in English; yet, not statistically different from either of them. These comparisons also supported the conclusion that the all-but-place effect in Russian is more prominent than the all-but-constriction-location effect.

General Discussion

The goal of the present study was to collect further experimental data to inform how theories of reading aloud and their computational implementations should be expanded to include representations at the level of phonological features, as well as to explain how these representations might interact with orthographic representations. In a masked-priming experiment, MRR2015 found that skilled readers produced faster naming latencies when the onsets of the prime-target pairs differed only in voicing than when they mismatched on voicing, place, and manner, thus showing that response latencies in reading aloud can be indeed modulated by feature-level representations. Based on this finding, we proposed a hypothesis, namely, that the processing of the onset of a masked prime will activate feature-level representations associated with that prime's onset. Accordingly, feature-priming effects should be expected when the onsets of a prime and a target are featurally similar. In

particular, if the onset of the prime shares many feature values with the onset of the target, then the activation levels of features required to produce the target will be elevated by the time the target is presented, and the response will start sooner. The experiment by MRR2015 manipulated only one feature (voicing) in one language (English). In the present study, we manipulated different numbers and types of features using two languages, English and Russian.

In order to test our hypothesis, it was necessary to take into consideration that most theories of phonological representation involve hierarchies of features, with some features being independently specifiable and others being specifiable in sets. For example, while it is reasonably straightforward to have two phonemes that differ in voicing only, it is not possible to change place alone in a similar fashion. Major place features indicate which articulator is involved in producing a phoneme, but there are also dependent features that further specify how and where that articulator needs to constrict the vocal tract. This difference between place and voicing is reflected in the two major classes of theories of phonological representation (recall that the predictions derived from our hypothesis are summarized in Table 1). The results from the present experiments are presented alongside those from MRR2015 in Figure 1 for ease of comparison.

Priming with identical and all-but-voicing onsets

Our first result is a replication of the basic masked onset priming effect (MOPE) across all four experiments using English and Russian materials. Our results are in line with other studies reporting a MOPE in a language with a Cyrillic alphabet (Jouravlev et al., 2014; Timmer, Ganushchak, Mitlina, et al., 2014).

Further, our Experiments 1 and 4 provide a solid replication of the all-but-voicing feature-priming effect (“piz”-“BAF”) in Russian. Note that this effect has been previously reported only in English (MRR2015), and that Russian has a very different phonological

system than English. These results are consistent with our hypothesis, according to which feature-priming effects are expected when two phonemes mismatch only on the value of one feature (e.g., as it is the case with the voicing feature). As we mentioned earlier, two phonemes that share all features but voicing have representations that are sufficiently similar so as to yield a priming effect. Our study demonstrates that this representational similarity holds true in at least two languages that make use of voicing as a contrastive feature. This suggests that features, not just phonemes, are linked with orthographic representations in skilled readers, at least in languages with an alphabetic orthography.

Priming with onsets that differ in place of articulation

In Experiment 2, we did not find an all-but-place feature-priming effect in English: targets were responded to with the same speed regardless of whether they were preceded by a feature related or an unrelated prime. This result was consistent with our hypothesis, according to which, two phonemes that differ in place mismatch on several features, and therefore are not primeable to the same extent as two phonemes that mismatch on voicing.

The pattern of results in the analogous all-but-place Russian experiment was different, in that a significant all-but-place feature-priming effect was found in that experiment (Experiment 3; see Figure 1, row 2). Note that this effect in Russian did not differ significantly from the all-but-voicing feature-priming effect in Russian (see cross-experiment comparisons reported in Appendix D). However, the all-but-place feature-priming effect in Russian also did not differ significantly from the non-observed all-but-place feature-priming effect in English (see Appendix D). This lack of significant differences in the across-experiment comparisons limits our ability to draw strong conclusions with regard to this effect.

The results of the all-but-constriction-location experiment in Russian (Experiment 4) were unexpected. On the basis of our hypothesis, we expected that this effect would be

present, because the initial phonemes of the prime and the target differed by only one feature value, as in the all-but-voicing manipulation. Our results, however, indicated no evidence for an all-but-constriction-location effect in Experiment 4, where the same participants also showed reliable feature-priming effects in the all-but-voicing manipulation. We offer below some speculations as to why we think there was no all-but-constriction-location effect.

First potential explanation: Even though the majority of participants are not consciously aware of the presence of masked primes, their responses to the targets can become tuned to regularities in the prime context. In a series of experiments, Bodner and Masson (2001) manipulated the relative proportion of repetition and unrelated primes. When the vast majority of the primes were repetition (i.e., identity) primes, the priming effect was greater than when similar proportions of repetition and unrelated primes were used. In other words, when the vast majority of the primes were valid (i.e., facilitated the identification of the target), participants showed greater priming effects. This finding by Bodner and Masson (2001) suggests that readers may be more sensitive to masked primes when most of them facilitate the processing of the targets. In our study, including multiple feature manipulations in a single experiment might have reduced the “validity” of the feature related primes (i.e., in Experiment 1, there were 33.3% of all-but-voicing feature related primes, yet in Experiment 4, 16.7% were feature related involving the all-but-voicing manipulation, and 16.7% were feature related involving the all-but-constriction-location manipulation. In other words, the "validity" of the feature primes that could facilitate target reading aloud was reduced in Experiment 4 in both feature type conditions.

Second potential explanation: Another factor that may modulate the strength with which feature values are activated from print is the predictability of this feature value in a given language (as proposed by Harm & Seidenberg, 1999; and similar to the learned weighted links between representations used in the DIVA model of speech motor control,

Tourville & Guenther, 2011). Taken together, the degree of featural overlap between phonemes and the probability with which these features can be predicted from orthography may have contributed to the wide variety of experimental findings reported here. Following Harm and Seidenberg (1999), we propose that subphonemic information may be activated more or less strongly from print, depending on the strength of connections between letters and specific features in a given language. For example, the letter “v” in English monosyllables always corresponds to a voiced labiodental fricative, thus making this letter-feature connection consistent and reliable. In contrast, the letter “g” in English may correspond to a voiced velar stop in “gear” [giə], a voiced postalveolar affricate in “gym” [dʒɪm], or a coronal nasal in “gnome” [noʊm], thus making letter-feature connections relatively weaker. These differences in the predictability of subphonemic characteristics in a given orthography may influence reading aloud processes. In particular, it would not be surprising if skilled readers were sensitive to the letter-feature regularities of their orthography. Such sensitivity might be reflected in tasks that involve mapping print to sound, such as reading aloud. When we consider the initial letters used in the all-but-constriction-location manipulation of Experiment 4 (/s/-/ʃ/ “с”-“ш”; /z/-/ʒ/ “з”-“ж”) and all their possible phonological realisations in Russian, it turns out that phonological features that are associated with each possible phoneme are varied. For example, the letter “с” can correspond to several values of constriction location and/or place and either value for voicing: it can indicate a voiceless alveolar in “сок” /sok/ ‘juice’, a voiced alveolar in “сдать” /zdati/ ‘give’, a voiceless postalveolar in “сшить” /ʃ:iti/ ‘sew’, a voiced postalveolar in “сжать” /zati/ ‘compress’, or a voiceless palatal in “счет” /ɕ:ot/ ‘bill’. Conversely, initial letters in the other Russian experiments can be associated with their corresponding features more reliably (“б” is always a bilabial: /b/ +voiced or /p/ -voiced). In other words, due to the specific relationship between Russian orthography and phonology, the short-lived influence of the masked feature

related prime on the target may have resulted in non-sufficient activation of the target onset's place feature value(s) in the all-but-constriction-location manipulation. In a similar vein, predictability could explain why we obtained some, albeit limited, evidence in favour of the all-but-place effect in Russian. The place of articulation of the consonants in our stimuli was highly predictable from print in Russian (i.e., each letter is reliably associated with a unique place of articulation). This stands in contrast to English, where the value for place of articulation for a given letter can be idiosyncratic (cf. “g” is a velar in “gear” [giə] vs. postalveolar in “gym” [dʒɪm]; “c” is coronal alveolar in “cell” [sɜl] vs. velar in “call” [kɔl], “p” is bilabial in “poll” [pɔl] vs. labiodental in “phrase” [freɪz], etc.).

Third potential explanation: The formulation of our hypothesis makes the simplifying assumption that interactions among features involve activation only. However, it is also possible that when the feature values associated with a prime are activated, mismatching feature values may be inhibited. Dynamical models virtually always require inhibitory dynamics as well as excitatory dynamics: see, for example, Mousikou et al. (2010a), who showed that the MOPE is both facilitatory and inhibitory in nature, and how the Dual Route Cascaded model of reading aloud (Coltheart et al., 2001) had to be modified to simulate this empirical finding. To use the example of the all-but-voicing condition from MRR2015, the mismatch of voicing between the onsets of the prime and the target may have induced inhibition of the voicing value required for the target, but not sufficiently so to offset the priming effect attributable to the activation of the shared features. This might not have been the case in the constriction-location manipulation, where the mismatch of constriction location between the onsets of the prime and the target may have induced inhibition of the relevant feature value(s) required for the target, thus wiping out a potential priming effect attributable to the activation of the shared feature values. It is important to note that our

hypothesis is formulated such that it does not depend on or stipulate how mismatching features interact, though ultimately, this is an important question to be answered.

While it is the case that our all-but-voicing and all-but-constriction-location conditions each involved manipulating one feature value, it is an open empirical and theoretical question as to how and whether features activate and/or inhibit each other. It may be the case that the dynamical interactions between voicing and other features may not be the same as those between constriction location and other features (see, e.g., Roon & Gafos, 2016, for an example of a model that incorporates such feature-dependent differences in the dynamics of phonological planning). For instance, it may be possible that activation spreads to major features, such as voicing, faster or slower than it spreads to subsidiary features, such as constriction location, possibly due to activation of the latter only being possible via activation of the former. This would lead to subsidiary and major features not being primeable to the same extent¹. This question about the specifics of the dynamic forces involved is separate from the two other considerations mentioned above. Further research is needed in order to fully understand how representational similarity, predictability, and excitatory/inhibitory dynamics may interplay in reading aloud.

Theoretical implications

The combined results from the present experiments, as well as those from MRR2015, have implications for the enrichment and expansion of models of reading aloud. The clearest implication is that feature-level representations need to be included in these models, since all-but-voicing feature-priming effects have now been reliably found in a number of experiments in both English and Russian, and an all-but-place feature-priming effect was found in Russian. We also argue that detailed linguistic theories of phonological representation are

¹ We thank an anonymous reviewer for pointing this out.

important for guiding future research with regard to how feature-level representations might be incorporated into these models.

The present results support the view that orthographic representations are linked to and can activate feature-level representations in a gradient fashion. We have speculated here that the gradient nature of the activation of feature-level representations may be based at least in part on the predictability of a given feature for a given letter. In addition to the masked-priming results reported here and elsewhere, and the results from other experimental tasks that point to such a link, evidence for this association has also been observed in beginning readers. Rack, Hulme, Snowling, and Wightman (1994) taught 5-year-old children with very limited reading skills to associate printed cues with spoken words. Children were more successful in learning pairings when the first letter of the orthographic cue (e.g., “dbl”) represented a phoneme that differed from the first phoneme of the spoken word only in voicing (e.g., “table”), compared to when the two differed in more than one feature (e.g., “kbl”). The empirical case is strong for the expansion of models of reading aloud to incorporate phonological representations more fine-grained than phonemes, and take into account the relationship of these representations with orthographic representations. However, more experimental, modeling, and theoretical work is required to understand more fully how these features interact.

Our findings are also relevant to theories of speech production, given that like reading aloud, speech production results in the production of the vocal response. These processes involve overlapping as well as unique mechanisms. Based on our results, we can speculate that the impact of featural information on speech may depend on factors like task characteristics (e.g., presentation of written materials) and the participants’ native language. We believe that masked priming is a promising tool for providing further empirical bases for how best to incorporate features in models of reading aloud.

Conclusion

The fundamental goal of the present study was to test further the conclusion made by Mousikou et al. (2015), namely, that feature-level representations are required in models of reading aloud. The results of the present study make a strong case supporting that conclusion. At the same time, the present results also show that the successful expansion of these models to include feature-level representations, as well as the interaction of those representations with orthographic representations, requires embracing the details of theoretical accounts of phonological representation, as well as language- and orthography-specific considerations that influence the dynamics of the interactions of all of these representations. The complex interactions among all of these factors suggested by the present results provide a strong motivation for the expansion of these models as the next priority in the field, as these expanded models would be uniquely useful in making further explicit, testable predictions. This iteration between model development and experimentation should ultimately lead to a more satisfactory understanding of the processes by which written language is converted into speech.

Acknowledgements

This work was funded by the ESRC Future Research Leader Fellowship and the Marie Skłodowska-Curie Individual Fellowship (IF-EF, European Union's Horizon 2020 Research and Innovation Programme) awarded to A.U. (grant numbers ES/N016440/1; Grant Agreement 747987). K.R. gratefully acknowledges support from NIH Grant DC-002717 to Haskins Laboratories and the City University of New York. Z.C. was funded through the Russian Academic Excellence Project '5-100'. P.M. was supported by a British Academy Postdoctoral Fellowship. We thank the Head of the Neurolinguistics Laboratory at the Higher School of Economics, Dr Olga Dragoy, as well as other members of this laboratory, for facilitating data collection and providing us with space and access to laboratory equipment and participants. We are indebted to Prof Kathy Rastle for her feedback on an earlier draft of this manuscript.

References

- Avanesov, R. I. (1974). *Russkaja literaturnaja i dialektnaja fonetika [Russian literary and dialectal phonetics]*. Moscow: Prosveshchenije.
- Avanesov, R. I. (1984). *Ruskoje literaturnoje proiznoshenije [Russian literary pronunciation]*. Moscow: Prosveshchenije.
- Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language, 59*, 390–412. doi:10.1016/j.jml.2007.12.005
- Baayen, R. H., & Milin, P. (2010). Analyzing reaction times. *International Journal of Psychological Research, 3*(2), 12–28. doi:10.21500/20112084.807
- Bates, D. M., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects models using lme4. *Journal of Statistical Software, 67*(1), 1–48. doi:10.18637/jss.v067.i01
- Bodner, G. E., & Masson, M. E. J. (2001). Prime validity affects masked repetition priming: Evidence for an episodic resource account of priming. *Journal of Memory and Language, 45*(4), 616–647. doi:10.1006/jmla.2001.2791
- Browman, C. P., & Goldstein, L. M. (1986). Towards an articulatory phonology. *Phonology Yearbook, 3*, 219–252. doi:http://www.jstor.org/stable/4615400
- Browman, C. P., & Goldstein, L. M. (1989). Articulatory gestures as phonological units. *Phonology, 6*(2), 201–251. doi:10.1017/S0952675700001019
- Browman, C. P., & Goldstein, L. M. (1990). Gestural specification using dynamically-defined articulatory structures. *Journal of Phonetics, 18*, 299–320. doi:10.1016/s0095-4470(19)30376-6
- Chomsky, N., & Halle, M. (1968). *The sound pattern of English*. New York: Harper & Row.

- Clements, G. N. (1985). The geometry of phonological features. *Phonology*, 2(1), 225–252.
doi:10.1017/S0952675700000440
- Clements, G. N. (1992). Phonological primes: Features or gestures? *Phonetica*, 49(3–4), 181–193. doi:10.1159/000261914
- Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review*, 108(1), 204–256. doi:10.1037/0033-295x.108.1.204
- Dell, G. S. (1986). A spreading-activation theory of retrieval in sentence production. *Psychological Review*, 93(3), 283–321. doi:10.1037/0033-295X.93.3.283
- Dell, G. S. (1988). The retrieval of phonological forms in production: tests of predictions from a connectionist model. *Journal of Memory and Language*, 27(2), 124–142.
doi:10.1016/0749-596X(88)90070-8
- Dell, G. S., Juliano, C., & Govindjee, A. (1993). Structure and content in language production: A theory of frame constraints in phonological speech errors. *Cognitive Science*, 17, 149–195. doi:10.1207/s15516709cog1702_1
- Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 10(4), 680–698. doi:10.1037/0278-7393.10.4.680
- Forster, K. I., & Davis, C. (1991). The density constraint on form-priming in the naming task: Interference effects from a masked prime. *Journal of Memory and Language*, 30, 1–25. doi:10.1016/0749-596X(91)90008-8
- Forster, K. I., Davis, C., Schoknecht, C., & Carter, R. G. (1987). Masked priming with graphemically related forms: Repetition or partial activation? *Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology*, 39(2), 211–251. doi:10.1080/14640748708401785

- Forster, K. I., & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, & Computers*, 35(1), 116–124.
doi:10.3758/BF03195503
- Fox, J., & Weisberg, S. (2011). *An R companion to applied regression (2nd ed.)* CA: Thousand Oaks.
- Frisch, S. A., & Wright, R. (2002). The phonetics of phonological speech errors: An acoustic analysis of slips of the tongue. *Journal of Phonetics*, 30(2), 139–162.
doi:10.1006/jpho.2002.0176
- Fromkin, V. A. (1971). The non-anomalous nature of anomalous utterances. *Language*, 47(1), 27–52. doi:10.2307/412187
- Gick, B., Wilson, I., & Derrick, D. (2013). *Articulatory Phonetics*. Chichester: Wiley-Blackwell.
- Goldrick, M. (2004). Phonological features and phonotactic constraints in speech production. *Journal of Memory & Language*, 51, 586–603. doi:10.1016/j.jml.2004.07.004
- Goldrick, M., & Blumstein, S. E. (2006). Cascading activation from phonological planning to articulatory processes: Evidence from tongue twisters. *Language and Cognitive Processes*, 21(6), 649–683. doi:10.1080/01690960500181332
- Gordon, P. C., & Meyer, D. E. (1984). Perceptual-motor processing of phonetic features in speech. *Journal of Experimental Psychology: Human Perception and Performance*, 10(2), 153–178. doi:10.1037/0096-1523.10.2.153
- Guest, D. J. (2002). *Phonetic Features in Language Production: An Experimental Examination of Phonetic Feature Errors*. (Ph.D.), University of Illinois at Urbana-Champaign, Urbana-Champaign, IL.
- Halle, M. (1971). *The Sound Pattern of Russian*. The Hague/Paris: Mouton.

- Harm, M. W., & Seidenberg, M. S. (1999). Phonology, reading acquisition, and dyslexia: Insights from connectionist models. *Psychological Review*, *106*(3), 491–528.
doi:10.1037/0033-295x.106.3.491
- Hayes, B. (2009). *Introductory Phonology*. Malden, MA: Wiley-Blackwell.
- Hothorn, T., Bretz, F., & Westfall, P. (2008). Simultaneous inference in general parametric models. *Biomedical Journal*, *50*(3), 346–363. doi:10.1002/bimj.200810425
- Jones, D., & Ward, D. (1969). *The Phonetics of Russian*. Cambridge: Cambridge University Press.
- Jouravlev, O., Lupker, S. J., & Jared, D. (2014). Cross-language phonological activation: Evidence from masked onset priming and ERPs. *Brain and Language*, *134*, 11–22.
doi:10.1016/j.bandl.2014.04.003
- Kenstowicz, M. (1994). *Phonology in generative grammar*. Malden, MA: Blackwell Publishing.
- Kinoshita, S. (2003). The nature of masked onset priming effects in naming: A review. In S. Kinoshita & S. J. Lupker (Eds.), *Masked priming. The state of the art* (pp. 223–238). New York/Hove, England: Psychology Press.
- Klimanova, L. F., & Makeeva, S. G. (2011). *Russkij jazyk. 1 klass. [The Russian Language. Grade 1]*. Moscow: Prosveshcheniye.
- Kochetov, A. (2002). *Production, perception, and emergent phonotactic patterns: A case of contrastive palatalization*. New York, London: Routledge.
- Krause, P. A., & Kawamoto, A. H. (2020). Nuclear vowel priming and anticipatory oral postures: Evidence for parallel phonological planning? *Language, Cognition and Neuroscience*, *35*(1), 106–123. doi:10.1080/23273798.2019.1636104

- Ladefoged, P., & Maddieson, I. (1996). *The Sounds of the World's Languages*. Malden, MA: Blackwell Publishing.
- Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, 22(1), 1–38.
doi:10.1017/S0140525X99001776
- Levitt, A. G., & Healy, A. F. (1985). The roles of phoneme frequency, similarity, and availability in the experimental elicitation of speech errors. *Journal of Memory and Language*, 24(6), 717–733. doi:10.1016/0749-596X(85)90055-5
- MacKay, D. G. (1970). Spoonerisms: The structure of errors in the serial order of speech. *Neuropsychologia*, 8, 323-350. doi:10.1016/0028-3932(70)90078-3
- McCarthy, J. J. (1988). Feature geometry and dependency: A review. *Phonetica*, 45(2–4), 84–108. doi:10.1159/000261820
- Meyer, A. S. (1991). The time course of phonological encoding in language production: Phonological encoding inside a syllable. *Journal of Memory and Language*, 30, 69–89. doi:10.1016/0749-596X(91)90011-8
- Meyer, D. E., & Gordon, P. C. (1985). Speech production: Motor programming of phonetic features. *Journal of Memory and Language*, 24, 3–26. doi:10.1016/0749-596X(85)90013-0
- Mielke, J. (2008). *The emergence of distinctive features*. Oxford: Oxford University Press.
- Mousikou, P., Coltheart, M., Finkbeiner, M., & Saunders, S. (2010a). Can the dual-route cascaded computational model of reading offer a valid account of the masked onset priming effect? *Quarterly Journal of Experimental Psychology*, 63, 984–1003.
doi:10.1080/17470210903156586

- Mousikou, P., Coltheart, M., & Saunders, S. (2010b). Computational modelling of the masked onset priming effect in reading aloud. *European Journal of Cognitive Psychology*, 22(5), 725–763. doi:10.1080/09541440903052798
- Mousikou, P., Roon, K. D., & Rastle, K. (2015). Masked primes activate feature representations in reading aloud. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 41(3), 636–649. doi:10.1037/xlm0000072
- Oppenheim, G. M., & Dell, G. S. (2008). Inner speech slips exhibit lexical bias, but not the phonemic similarity effect. *Cognition*, 106(1), 528–537.
doi:10.1016/j.cognition.2007.02.006
- Oppenheim, G. M., & Dell, G. S. (2010). Motor movement matters: The flexible abstractness of inner speech. *Memory & Cognition*, 38(8), 1147–1160. doi:10.3758/MC.38.8.1147
- Padgett, J. (2001). Contrast dispersion and Russian palatalization. In E. V. Hume & K. Johnson (Eds.), *The Role of Speech Perception in Phonology* (pp. 187–218). San Diego, CA: Academic Press.
- Perry, C., Ziegler, J. C., & Zorzi, M. (2007). Nested incremental modeling in the development of computational theories: the CDP+ model of reading aloud. *Psychological Review*, 114, 273–315. doi:10.1037/0033-295X.114.2.273
- Perry, C., Ziegler, J. C., & Zorzi, M. (2010). Beyond single syllables: Large-scale modeling of reading aloud with the Connectionist Dual Process (CDP++) model. *Cognitive Psychology*, 61(2), 106–151. doi:10.1016/j.cogpsych.2010.04.001
- Plaut, D. C., Seidenberg, M. S., McClelland, J. L., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review*, 103, 56–115. doi:10.1037/0033-295x.103.1.56
- Proctor, M. (2011). Towards a gestural characterization of liquids: Evidence from Spanish and Russian. *Laboratory Phonology*, 2(2), 451–485. doi:10.1515/labphon.2011.017

- Protopapas, A. (2007). CheckVocal: A program to facilitate checking the accuracy and response time of vocal responses from DMDX. *Behavior Research Methods*, *39*, 859–862. doi:10.3758/BF03192979
- R Development Core Team. (2018). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from <http://www.R-project.org>
- Rack, J. P., Hulme, C., Snowling, M., & Wightman, J. (1994). The role of phonology in young children learning to read words: The direct-mapping hypothesis. *Journal of Experimental Child Psychology*, *57*(1), 42–71. doi:10.1006/jecp.1994.1003
- Rastle, K., Croot, K. P., Harrington, J. M., & Coltheart, M. (2005). Characterizing the motor execution stage of speech production: Consonantal effects on delayed naming latency and onset duration. *Journal of Experimental Psychology: Human Perception and Performance*, *31*(5), 1083–1095. doi:10.1037/0096-1523.31.5.1083
- Rastle, K., Harrington, J., & Coltheart, M. (2002). 358,534 nonwords: The ARC Nonword Database. *Quarterly Journal of Experimental Psychology*, *55*, 1339–1362. doi:10.1080/02724980244000099
- Roelofs, A. (1997). The WEAVER model of word-form encoding in speech production. *Cognition*, *64*, 249–284. doi:10.1016/s0010-0277(97)00027-9
- Roelofs, A. (1999). Phonological segments and features as planning units in speech production. *Language and Cognitive Processes*, *14*(2), 173–200. doi:10.1080/016909699386338
- Roelofs, A. (2000). WEAVER++ and other computational models of lemma retrieval and word-form encoding. In L. R. Wheeldon (Ed.), *Aspects of Language Production* (pp. 71–114). Philadelphia: Psychology Press.

- Roon, K. D., & Gafos, A. I. (2015). Perceptuo-motor effects of response-distractor compatibility in speech: beyond phonemic identity. *Psychonomic Bulletin & Review*, 22(1), 242–250. doi:10.3758/s13423-014-0666-6
- Roon, K. D., & Gafos, A. I. (2016). Perceiving while producing: Modeling the dynamics of phonological planning. *Journal of Memory and Language*, 89, 222–243. doi:10.1016/j.jml.2016.01.005
- Shattuck-Hufnagel, S., & Klatt, D. H. (1979). The limited use of distinctive features and markedness in speech production: Evidence from speech error data. *Journal of Memory and Language*, 18(1), 41–55. doi:10.1016/s0022-5371(79)90554-1
- Schiller, N. O. (2007). Phonology and orthography in reading aloud. *Psychonomic Bulletin & Review*, 14(3), 460–465. doi:10.3758/BF03194089
- Timberlake, A. (2004). *A Reference Grammar of Russian*. Cambridge/New York: Cambridge University Press.
- Timmer, K., Ganushchak, L. Y., Ceusters, I., & Schiller, N. O. (2014). Second language phonology influences first language word naming. *Brain & Language*, 133, 14–25. doi:10.1016/j.bandl.2014.03.004
- Timmer, K., Ganushchak, L. Y., Mitlina, Y., & Schiller, N. O. (2014). Trial by trial: Selecting first or second language phonology of a visually masked word. *Language, Cognition and Neuroscience*, 29(9), 1059–1069. doi:10.1080/01690965.2013.824994
- Tourville, J. A., & Guenther, F. H. (2011). The DIVA model: A neural theory of speech acquisition and production. *Language and Cognitive Processes*, 26(7), 952–981. doi:10.1080/01690960903498424
- Ulicheva, A., Coltheart, M., Saunders, S., & Perry, C. (2016). Phonotactic constraints: Implications for models of oral reading in Russian. *Journal of Experimental*

Psychology: Learning, Memory, and Cognition, 42(4), 636–656.

doi:10.1037/xlm0000203

Ulicheva, A., Roon, K. D., & Mousikou, P. (2020). Feature priming in English and Russian.

Open Science Framework. <https://osf.io/w83dc/>

Whalen, D. H. (1990). Coarticulation is largely planned. *Journal of Phonetics*, 18(1), 3–35.

doi:10.1016/S0095-4470(19)30356-0

Yaniv, I., Meyer, D. E., Gordon, P. C., Huff, C. A., & Sevald, C. A. (1990). Vowel similarity, connectionist models, and syllable structure in motor programming of speech. *Journal of Memory and Language*, 29(1), 1–26. doi:10.1016/0749-596x(90)90007-M