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Bi-alphabetism: A window on phonological processing

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In Serbian, lexical decision latencies to words composed of letters that exist in both the Roman and Cyrillic alphabets (some of which have different phonemic interpretations in each) are slower than for the unique alphabet transcription of those same words. In this study, we use the effect of phonological ambiguity to explore the time course of semantic facilitation. Targets are either the phonologically ambiguous forms (e.g., PETAK meaning "Friday" when pronounced as a Roman string /petak/ but without meaning when pronounced in Cyrillic as /retak/) or the unique alphabet transcription of the same word (ПЕТАК). We manipulate alphabet match and semantic relatedness of prime to target. In addition to replicating slowing due to phonological ambiguity, we show 1) greater alphabet switch cost for bivalent then for unambiguous targets as well as for unrelated then for related prime-target pairs and 2) greater semantic facilitation as the number of shared common letters between prime and target increases. Results reveal the interaction of phonological and semantic processes in Serbian. The findings are discussed in terms of a triangle model of language processing, which hypothesizes a division of labor between an orthography-to-semantics, and an orthography-to-phonology-to-semantics route and their simultaneous contribution to activation of meaning.

Key words: *bi-alphabetism, phonological ambiguity, semantics, visual lexical decision, Serbian, word recognition; cross-languages comparisons.*

INTRODUCTION

Phonological processes are critical to skilled word recognition and to its acquisition. Word recognition studies based on manipulations of letters from the two alphabets in use in the former Yugoslavia (Cyrillic and Roman) have played a central role in the understanding of those processes. By now, there is a vast literature (e.g., Feldman & Turvey, 1983) showing that Serbian words composed only of letters that exist in both the Roman and Cyrillic alphabets, some of which have different phonemic interpretations in each (e.g., C, P, H, B), are slower in a lexical decision task than are the unique alphabet transcriptions of those same words where some phonemes are transcribed by letters that are unique to one alphabet. For example, decision latencies are slower and less accurate to phonologically ambiguous targets (e.g., PETAK meaning "Friday" when pronounced as a Roman string /petak/ but without meaning when pronounced in Cyrillic as /retak/) than to the unique alphabet transcription of the same word ПЕТАК (see Table 1). By contrast alphabetically ambiguous words like MAMA that retain the same phonology when read as Roman or as Cyrillic are no slower to recognize than other words that contain letters that are unique to one alphabet. Therefore, phonological ambiguity rather than alphabetic ambiguity is key. The PETAK – ПЕТАК comparison is particularly compelling evidence of phonological processes because it contrasts two alphabetic transcriptions of the same word. Crucially, all of its lexical properties (e.g., frequency, letter length, meaning, family size and entropies, and number of associates) are identical when the same word is transcribed into two different alphabets. Similar effects have been reported when different words appear as phonologically ambiguous and as unambiguous targets (Lukatela, Popadić, Ognjenović, & Turvey, 1980; Lukatela, Savić, Gligorijević, & Turvey, 1978) as when comparisons entail ambiguous and unambiguous versions of the same targets as in the PETAK – ПЕТАК contrast above. Finally, effects of phonological ambiguity on decision latencies persist across skill levels. Results have been replicated when critical materials are presented either to university students (Feldman, Kostić, Lukatela, & Turvey, 1983; Feldman & Turvey, 1983) or to elementary school children (Ognjenović, Lukatela, Feldman, & Turvey, 1983).

When effects of phonological ambiguity on word recognition were first documented (Lukatela et al., 1980; Lukatela et al., 1978), the emphasis was on demonstrating robust effects of phonology with words in skilled readers. One novel claim from the work in Serbian was that phonological processing characterized not only meaningless pronounceable letter strings but words as well. More importantly, it demonstrated that phonological processing of words was characteristic not only of beginning but also of skilled readers.

These claims arrived against a theoretical backdrop emphasizing the utilization of phonological knowledge as one of two options or routes for visual word recognition (e.g., Coltheart, Besner, Jonasson, & Davelaar, 1979; Coltheart, Davelaar, Jonasson, & Besner, 1977; McCusker, Hillinger, & Bias, 1981). The underlying assumption of the dual route models, that were popular at the time, was that phonological processes were a default option to be relied upon only when orthographic and semantic knowledge about a word was inadequate. Conditions could be met either because a letter string's meaning was not known so that a mapping between orthographic form and semantics was not possible, or because it was only rarely encountered so that the mapping was very weak (see review by Frost, 1998). In essence, theories of word recognition at the time were described as "stubbornly nonphonological" (Carello, Turvey, & Lukatela, 1992). Collectively, the work in Serbian from the Laboratory of Experimental Psychology at the Faculty of Philosophy at the University of Belgrade posed a challenge to views that granted primacy in word recognition to orthography but not phonology, in that results consistently showed slowed and less accurate recognition of words that were phonologically ambiguous, than of the unique alphabet transcription of those same words. Phonological ambiguity was nonselective in that it impaired recognition not only in an experimental context where the lexical reading of phonologically ambiguous strings could be in Roman or in Cyrillic, but also when the lexical reading of ambiguous strings required the Roman mapping between letter and phoneme exclusively (see Feldman, 1983). By contrast, there was no slowing when mappings were bivalent so as to activate two orthographies when letters were not phonologically ambiguous (e.g., MAMA). In essence, the bi-alphabetic studies conducted in Serbian demonstrated that phonological processing was not optional because readers could not suppress mappings between letters and phonemes for one of the alphabets. Moreover, it was nonselective in that even skilled readers could not selectively activate a single network of mappings. In essence, the presentation of P always activated both the /r/ and the /p/ reading regardless of skill, of experimental context and of which alphabet mapping formed a word. Although incompatible with dual-route models, this pattern fits well with parallel-distributed models of word recognition, such as triangular model of Harm and Seidenberg (2004). In that framework, slower recognition of phonologically ambiguous words (such as PETAK) is a consequence of two phonological mappings from single orthographic units. Fundamentally, phonological ambiguity was captured in terms of competition at a phonological level.

Table 1. Serbian word structure based on alphabet overlap.

Composition		Alphabet	Phonemic interpretation	Meaning
Bivalent and Common				
	BETAP	Roman	/betap/	meaningless
		Cyrillic	/vetar/	wind
	PETAK	Roman	/petak/	Friday
		Cyrillic	/retak/	meaningless
	POTOP	Roman	/potop/	flood
		Cyrillic	/rotor/	motor
Common				
	MAMA	Roman	/mama/	mother
		Cyrillic	/mama/	mother
Unique and Common				
	VETAR	Roman	/vetar/	wind
	ПЕТАК	Cyrillic	/petak/	Friday

Subsequent studies investigated the implications of phonological ambiguity when number of bivalent letters and thus degree of phonological complexity varied. For example, the difference between phonologically bivalent forms like

PETAK and their unique alphabet transcription such as ПЕТАК was smaller when only one letter was bivalent (viz., P) than when several letters were, as in CAMOBAP (SAMOVAR) where there were three (viz., C, B and P) bivalent letters (Feldman & Turvey, 1983).

Other studies focused on words formed from several morphemes (morphologically complex). For morphologically complex word forms with phonologically ambigous stems such as BEH in BEHA (/vena/ means vein; other inflected forms such as BEHИ retain the stem /ven/ but include a different affix), effects of stem ambiguity persisted with an alphabetically ambiguous but phonologically unequivocal inflectional affix, such as the nominative feminine inflection "A" that appears in either alpahbet. However, the effect was substantially weakened or even eliminated by adding a different, alphabetically and phonologically unequivocal inflectional affix, such as dative feminine inflection "I" or "И". Thus, decision latencies for BEHA differered significantly from VENA (304 ms) whereas the difference (12 ms) between BEHИ and VENI was not significant (Feldman et al., 1983b). In BEHA-VENA type pairs, the full first word included a phonologically ambiguous stem (BEH) and an alphabetically ambiguous affix (A) resulting in a word that is phonologically ambiguous word. In BEHИ-VENI type pairs, the last letter "И" or "I" specified alphabet. Word form differences were robust for word pairs with "A", but not for word pairs with "И" or "I". Both include a cross alphabet comparison and both match inflectional case. Although equivalent with respect to an "orthgraphic" manipulation, pairs differed crucially in that only the first member of the first pair (viz., BEHA) is fully phonologically ambiguous. Results failed to prove evidence for slowing based on mappings in two alphabets because only the phonologically ambiguous whole word forms impaired recognition. Thus, any orthographic recognition system, with independent orthographic options for each alphabet, even when options work in parallel, could not account for the outcome. In essence, results demonstrated that orthographic (alphabet) and phonological codes worked concurrently.

In Serbian, the mapping between letter and phoneme is simple, therefore non Serbian researchers first tended to dismiss phonological effects among skilled readers in Serbian as an idiosyncracy of the shallow mapping between orthography and phonology. Many studies of phonology in English were based on homophones such as ROSE and ROWS, words that sound the same but are spelled differently. Poorer performance for homophones than for orthographically equivalent words showed that two spelling patterns, mapping onto the same phonology, can impair performance (Van Orden, 1987; Van Orden, Johnson, & Hale, 1988; Van Orden, Pennington, & Stone, 1990). It was this effect of homophony on visual word recognition in English, where the mapping between letter and sound is more complex, that made relevant the interaction of phonology with orthography for theories of word recognition more universally. Phonological effects in English as well as in Serbian suggested similarities across languages and therefore work against the claim that reading processes differ in fundamental ways across languages with different structures and different writing systems (for an overview see Seidenberg, 1992).

Effects of homophony were eventually captured in terms of a triangle model. Harm and Seidenberg's (2004) version of the triangle model incorporated both computations from orthography to semantics (O→S) and from orthography to phonology to semantics (O→P→S). It differed from theories with a dual route structure that assumed that one or the other of the independent routes would dominate processing and that choice depended on factors that include but are not limited to reading skill level, type of orthography (deep, shallow) and type of word (regular, irregular) within a deep orthography. In the Harm and Seidenberg model, by contrast, partial activation of distributed representations of meaning from both routes occur simultaneously. Crucially, the routes do not function independently. Rather, there is a division of labor between routes or pathways. Effects of frequency on phonological processes as well as effects of orthographic depth across languages were described in terms of the division of labor between the (O→P→S) and (O →S) routes. With respect to Serbian, differences among unique, ambiguous and common letters can be characterized in terms of consistency or competition in the (O→P) mapping. Consequently many differences among words reflect the relative contributions of the (O→P→S) route as well as the (O →S) route. Note that it is the (O→P→S) route that captures mapping differences between letters that are phonologically ambiguous (one to two) across alphabets and letters whose orthography to phonology mappings are common to both alphabets (one to one).

PROBLEM

The interaction of phonological with orthographic knowledge remains relatively well investigated whereas the way in which phonological knowledge interacts with semantic knowledge receives less attention in ongoing research. In the present study, we look at the interaction of phonological with semantic as well as with orthographic knowledge. We ask how phonological ambiguity in Serbian words is modulated by semantic relatedness and by alphabetic match or consistency of a prime context. Our focus is within-word comparisons of phonologically ambiguous and unique forms of the same word, as in PETAK-ПЕТАК pairs. Borrowing from the work on code switching at the level of language (Costa, Miozzo & Caramazza, 1999; Gollan & Ferreira, 2009; Meuter & Allport, 1999), we ask whether switching alphabet between prime and target disproportionally impairs recognition for phonologically ambiguous relative to phonologically unambiguous targets. The critical comparison is between decision latencies when alphabet changes between prime and target (alphabet incongruity) and when it does not (alphabet congruity). Further, we also ask whether the influence of alphabet switch is greater for phonologically ambiguous than for phonologically unambiguous targets. This question extends some earlier work in single word recognition where we asked whether ambiguity effects also arise when the experimental context consistently invites activation of the letter-sound mappings of only a single alphabet (Feldman, 1983; Lukatela et al., 1978). More novel is that after we ask whether the detriment of switching alphabet between prime and target is greater when targets are phonologically ambiguous than when they are unambiguous, we ask whether alphabet switching is more damaging for semantically unrelated than for semantically related prime-target pairs. We ask this semantic question for phonologically ambiguous and then for unambiguous forms of those same targets. This question extends predictions of triangle model (Harm & Seidenberg, 2004) to the influence of prior context on O→P→S mapping. In addition, we ask whether frequency effects are comparable for both ambiguous and unambiguous words. In previous work, we have failed to see an effect of target frequency on phonological ambiguity. In those analyses, we used decision latency to the unambiguous form as an index of frequency and asked whether the difference between ambiguous and unambiguous transcriptions was greater for words that were slow than for words that were fast to recognize. Here we examine frequency more directly.

A second particularly novel and previously unexamined question concerns the effect of letters common to both alphabets with preserved phonology that were shared by prime and target. We predict greater priming for pairs that share more than for those that share fewer common letters (e.g. *platno* – *otac* share three common letters whereas *barut-pamet share two* and *limar – hokej share none*). Although never tested in the bi-alphabetism work in Serbian, this prediction derives from the triangle model of Harm and Seidenberg (2004). Firstly, this model predicts that processing, that is computation of meaning would be more efficient when the O→S and O→P→S route operate together. When applied to a priming paradigm, we predict that facilitation will be greater when orthographic and phonological priming co-occur. One implication is that only the activation of common letters in prime and target will contribute to facilitatory priming within both routes. In the case of unique letters (SLUGA /sluga/ - MACA /masa/), facilitatory priming can occur only in the O→P→S route because there is no match for them at the level of orthography, that is in the O→S route. In other words phonological but not orthographic priming is possible for unique letters (moreover, due to P→O feedback conections, there could even be some competition between the two orthographic letter forms to which a single phonemic is mapped). In the case of bivalent letters (OTAC /otats/ - MACA /masa/), there will be facilitatory priming in the O→S route but, at the same time, competing O→P mappings will inhibit priming in the O→P→S route. In contrast, common letters share both orthography and phonology, and should produce facilitation in both routes not only because the O→P mappings do not compete but also because the same mapping is reinforced in both alphabets. One implication is that the predicted effect of number of common letters shared by prime and target will be larger for semantically related prime-target pairs. This reflects feedback activation from the semantic level of computation to the orthographic level when performing a lexical decision.

EXPERIMENTS 1 AND 2

Method

Participants. Eighty undergraduate students from the Department of Psychology, Faculty of Philosophy, University of Belgrade participated in the first experiment, and 58 undergraduate students from the Department of Psychology, Faculty of Philosophy, University of Novi Sad participated in the second experiment. All participants were right-handed native speakers of Serbian and had normal hearing and normal or corrected-to-normal vision. None participated in both of the two experiments. Within each experiment, participants were randomly assigned to one of the four counterbalanced lists.

Materials and design. In experiment 1 we presented phonologically ambiguous targets, whereas phonologically unambiguous targets were presented in experiment 2. In each experiment target nouns were presented in either Cyrillic, or Roman alphabet. The targets were preceded by noun primes that were either semantically related, or semantically unrelated to the target noun and were presented either in the same, or in the different alphabet (Table 2).

Table 2. Schema of the design for experiments 1 and 2.

Phonological ambiguity	**Prime-target alphabet match**	**Semantic relatedness**	**Target alphabet**
Phonologically ambiguous (Experiment 1)	Same alphabet	Semantically related	Cyrillic
			Roman
		Semantically unrelated	Cyrillic
			Roman
	Different alphabet	Semantically related	Cyrillic
			Roman
		Semantically unrelated	Cyrillic
			Roman
Phonologically unambiguous (Experiment 2)	Same alphabet	Semantically related	Cyrillic
			Roman
		Semantically unrelated	Cyrillic
			Roman
	Different alphabet	Semantically related	Cyrillic
			Roman
		Semantically unrelated	Cyrillic
			Roman

Experimental materials within a list consisted of 40 Serbian prime-target noun pairs (in nominative singular). In addition, each list included 40 noun primes paired with pseudonoun targets as well as 16 filler pairs.

Half of the targets were presented in Cyrillic alphabet, and half were presented in Roman alphabet. In the first experiment, the forty critical targets were composed of common and bivalent graphemes, and were selected to be phonologically ambiguous in the alphabet in which they appeared. For example, the noun *korak* (*step*), was presented in the Cyrillic alphabet (*"KOPAK"*), and could be pronounced as /korak/ according to letter-sound mappings in the Cyrillic alphabet, in which case it denotes the word "step", or as /kopak/ following the letter-sound mappings in Roman alphabet, in which case it is meaningless. Analogously, the noun *baba (grandmother)*, when presented in the Roman alphabet (*"BABA"*), could be pronounced as /baba/ in accordance to the letter-sound mappings of the Roman alphabet, in which case it denotes a word. According to the letter-sound mappings of Cyrillic, by contrast, it is pronounced as /vava/ and has no meaning. In each experiment, each target noun was preceded either by a semantically related or a semantically unrelated prime, half of which were presented in the same, and half of which were presented in different alphabet. This alphabet match or mismatch was randomized across trials. Regardless of alphabet, prime nouns contained at least one unique letter. Consequently, targets but never primes were ambiguous.

Pairs of filler nouns contained all types of letters, and they fully mirrored the principal design – half of the targets were presented in Roman, and half in Cyrillic alphabet; half of the pairs had matching alphabet readings (Cyrillic-Cyrillic or Roman-Roman and half had alternating alphabet); half of the pairs were semantically related, and half were semantically unrelated. Following the construction principle for noun targets in experiment 1, pseudonoun targets also contained common and bivalent letters. Consequently, all of the pseudonouns were phonologically ambiguous. However, unlike noun targets, pseudonoun targets were meaningless in both phonological interpretations. Analogous to word targets, half had noun primes in Roman, and half in Cyrillic alphabet.

In the second experiment, we applied the same principle of stimulus construction and the same design as in the first experiment. The only difference was that the alphabet of each target was switched (letter strings that were previously presented in the Cyrillic alphabet, were now presented in the Roman alphabet, and those that were previously presented in Roman were now presented in Cyrillic). One consequence of this manipulation was that none of the targets presented in Experiment 2 were phonologically ambiguous (Table 3).

To summarize, our critical prime-target pairs followed a 2x2x2x2 factorial design. The first factor was phonological ambiguity of the target (phonologically ambiguous [experiment 1], phonologically unambiguous [experiment 2]). The second factor was alphabet of the target (Cyrillic, Roman). In experiments 1 and 2, alphabet was manipulated within participants but between items; across experiments 1 and 2, ambiguity and alphabet were manipulated between participants but within items. The third factor, semantic relatedness of the prime (semantically related, semantically unrelated) was manipulated within participants and items. The fourth factor, prime-target alphabet match (same alphabet, different alphabet), was manipulated within participants and items. For each of the two experiments we counterbalanced the items by following a Latin square design, thus creating four lists of stimuli pairs per experiment. While target nouns were identical in the four lists within an experiment, their primes differed with respect to semantic relatedness and alphabet match. Therefore alphabet match or mismatch did not signal lexicality of the target. Across experiments, alphabet of target nouns and primes switched.

The data were analyzed for the effects of several continuous predictors (Baayen et al., 2011; Baayen & Milin, 2010). Those were trial number of each prime-target pair where order was randomized for each participant, reaction time elicited by the preceding target, and lemma frequency of the target noun. Finally, one additional factor was included as a control variable – number of common letters shared by prime and target. This variable had three levels – none (prime and target share no common letters, e.g. *limar-hokej*), one (prime and target share one, or two common letters, e.g. *limun-meso*), and two or more (prime and target share two, or more common letters, e.g. *platno-otac*). Dependent variables were reaction time measured from target onset in milliseconds and error probability.

Procedure. Letter strings were presented visually, on the screen for a lexical decision judgment, using *SuperLab Pro 2.0* (Cedrus, 2001). Each trial was preceded with a fixation point in duration of 1000 ms. Primes were presented for 250 ms and were immediately followed by target. Targets appeared on the screen until participants responded with a maximum duration of 1500 ms. Targets were presented below the position of their previously presented prime such that primes were 60 pixels above the vertical center of the screen and targets were 40 pixels above the vertical center. Participants indicated their judgment as to the lexical status of the letter string by button-press (using MS serial mouse, as recommended by the software manufacturer), affirmative response being mapped to the index finger, and negative response being mapped to the middle finger of the dominant hand. Reaction times were measured from the presentation of the stimulus until the button press. Prior to presentation of the experimental materials, there were 20 practice trials. In order to motivate participants to pay attention both to primes and targets, each participant was asked to repeat the most recently presented pair at four points during the practice session and at four points during experiment session, at random intervals. This protocol replicates that in earlier studies (e.g. Lukatela, Turvey, Feldman, Carello, & Katz, 1989).

Table 3. Schema of the materials-to-design mapping for experiments 1 and 2.

	Prime				Target	Target alphabet
	Semantically related		Semantically unrelated			
	Same alphabet	Different alphabet	Same alphabet	Different alphabet		
Experiment 1	ХОД	HOD	КАНАЛ	KANAL	КОРАК	Cyrillic
	walk	walk	channel	channel	step	
	DEDA	ДЕДА	TRUBA	ТРУБА	BABA	Roman
	grandfather	grandfather	trumpet	trumpet	grandmother	
Experiment 2	HOD	ХОД	KANAL	КАНАЛ	KORAK	Roman
	walk	walk	channel	channel	step	
	ДЕДА	DEDA	ТРУБА	TRUBA	БАБА	Cyrillic
	grandfather	grandfather	trumpet	trumpet	grandmother	

Results and discussion

Prior to analyzing the data, we excluded those participants and items that exceeded a 25% error threshold. This led to the exclusion of 31 participants and 10 items from Experiment 1 (where targets were phonologically ambiguous), and to the exclusion of 9 participants and 4 items from Experiment 2 (where the same targets were phonologically unambiguous). We consider the difference in exclusion rate between Experiments 1 and 2 to reflect the influence of phonological ambiguity on word recognition. In other respects, including the experimental conditions and the experimental materials as well as the population from which samples were drawn, experiments were identical.

Reaction time and error data were analyzed in a mixed-effect regression with participant and target as random-effect factors (Baayen, 2008; Baayen, Davidson, & Bates, 2008) using the lme4 package (Bates, 2008) in R statistical software (http://www.r-project.org/). In order to approximate normality, response latencies were transformed into negative reciprocal values (-1000/rt; Baayen & Milin, 2010), and lemma frequencies (a control variable) were transformed to a logarithmic scale. Further, the continuous predictors (trial number, preceding trial rt, and target (log) lemma frequency) were standardized (z-scored) to be more comparable in range, both to each other and to discrete predictors (as suggested by Gelman & Hill, 2007). We tested throughout for possible interactions of fixed and random effects, as well as for possible nonlinearities in fixed effects. Finally, we performed analyses of predicted value residuals. Subsequently, each model was refitted by excluding outliers. Their removal did not affect the pattern of results that we report.

Latencies. An analysis of negative reciprocals on response latencies revealed effects of several fixed-effect predictors, as well as interactions between them (Table 4 and Figure 1) in addition to random intercepts for both participants and items. There was a significant facilitatory effect of trial order (Figure 1, upper left panel), indicating that participants were becoming faster during the course of experiment. Additionally, there was a significant trial order by participant interaction, indicating that there were differences among participants with respect to the extent of the change in response speed throughout the experimental session. There also was a significant effect of previous reaction time, which indicated that, in parallel, a participant's response was influenced by the speed of her/his previous response. In addition there was a significant effect of (log) lemma frequency of the target.

With respect to the factors of primary interest in the study, there was a significant effect of target alphabet (Figure 1, middle left panel), indicating that targets printed in the Roman alphabet generally elicited longer response latencies than targets printed in the Cyrillic alphabet. The alphabet effect may reflect our participants' greater exposure to languages transcribed with Roman (English, German) than with Cyrillic (e.g., Russian, Greek) graphemes, and we will return to this in the discussion. In addition to an effect of prime-target alphabet match, there was a significant interaction of phonological ambiguity of the target with prime-target alphabet match. This interaction revealed that the advantage of presenting prime and target in the same alphabet (or the disadvantage of switching alphabet between prime and target) was larger for phonologically ambiguous than for unambiguous targets (Figure 1, middle central panel). In essence, mismatching alphabet of the prime further augmented the slowing due to phonological ambiguity. Not surprisingly, targets preceded by a semantically related prime were faster than those after an unrelated prime. Additionally, there was a marginally significant interaction between semantic relatedness and alphabet match of prime and target (Figure 1, middle right panel). This interaction suggested that the facilitatory effect of matching alphabet was stronger for semantically unrelated than for related prime-target pairs (stated alternatively, that the inhibitory effect of mismatching alphabet was more damaging for semantically unrelated than for related prime-target pairs). Finally, there was a significant interaction between prime-target semantic relatedness and number of common letters that they shared (Figure 1, lower left panel). For semantically related prime-target pairs, there was a strong facilitatory effect of number of shared common letters, whereas for semantically unrelated prime-target pairs there was no such effect. Subsequent analyses revealed that the effect of number common letters shared by prime and target was stronger than the effect of number of ambiguous letters. Further analyses revealed that neither could be attributed to target length.

Table 4. Partial effects of the predictors
in the mixed-effect regression analysis of reaction latencies.

Random Effects				
	Std.Dev.	**MCMCmean**	**HPD95lower**	**HPD95upper**
Participant: Intercept adj.	0.1581	0.1322	0.1125	0.1506
Participant: Trial number slope adj.	0.0478	0.0446	0.0315	0.0585
Item: Intercept adj.	0.0815	0.0778	0.0579	0.0981
Residual	0.2615	0.264	0.2571	0.2707

Fixed Effects				
	Estimate	**HPD95lower**	**HPD95upper**	**pMCMC**
Intercept	-1.4160	-1.4766	-1.3663	0.001
Trial number	-0.0169	-0.0309	-0.0040	0.018
Previous trial RT	0.0374	0.0292	0.0511	0.001
Target (log) lemma frequency	-0.0827	-0.1065	-0.0576	0.001
Alphabet of the target (Roman)	0.0409	0.0221	0.0608	0.001
Phonological ambiguity of the target (unambiguous)	-0.0537	-0.1137	0.0066	0.074
Prime target alphabet match (same alphabet)	-0.1444	-0.1768	-0.1044	0.001
Prime target semantic relatedness (unrelated)	0.0503	-0.0026	0.1032	0.064
Number of shared common letters (one)	-0.0443	-0.0882	-0.0049	0.028
Number of shared common letters (two or more)	-0.0623	-0.1267	-0.0070	0.036
Phonological ambiguity of the target (unambiguous) x Prime target alphabet match (same alphabet)	0.0691	0.0310	0.1117	0.001
Prime target alphabet match (same alphabet) x Prime target semantic relatedness (unrelated)	-0.0366	-0.0745	0.0047	0.078
Prime target semantic relatedness (unrelated) x Number of shared common letters (one)	0.0928	0.0319	0.1600	0.004
Prime target semantic relatedness (unrelated) x Number of shared common letters (two or more)	0.1019	0.0294	0.1744	0.010

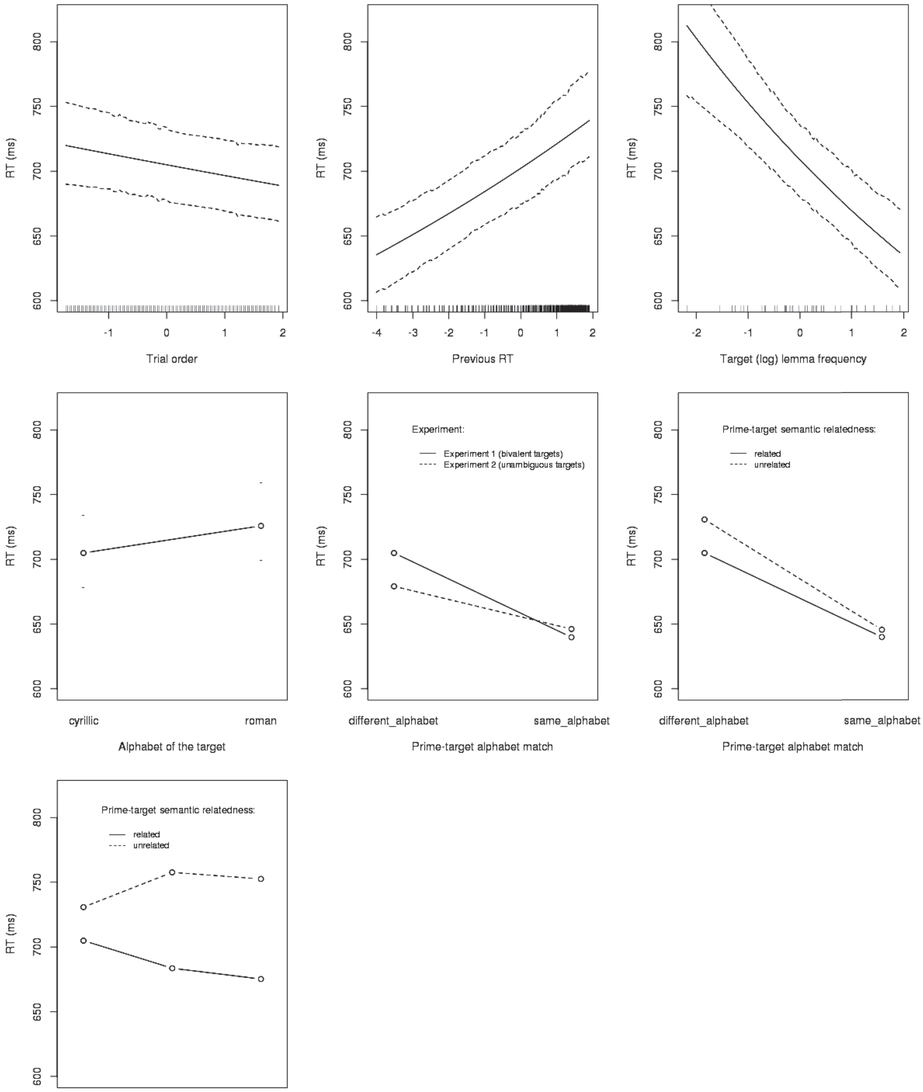

Figure 1. Partial effects of the predictors in the linear mixed-efffect regression analysis of reaction latencies.

Errors. A logistic mixed-effect regression analysis of errors revealed random effects of participants and items, as well as effects of several fixed-effect predictors and interactions between them (Table 5 and Figure 2). There was a significant three-way interaction among trial order, phonological ambiguity of the target, and prime-target semantic relatedness (Figure 2, upper left and right panels). Whether participants were getting faster, or slower during the course of the experiment depended on whether targets were phonologically ambiguous and on the semantic relatedness between prime and target. Over trials in the first experiment where targets were phonologically ambiguous, participants became less accurate for semantically unrelated prime-target pairs, and became more accurate for semantically related prime-target pairs (Figure 2, upper left panel). In the second experiment where targets were phonologically unambiguous, the effect attenuated significantly and reversed: participants became more accurate for semantically unrelated prime-target pairs, whereas performance did not change with trial number for semantically related prime-target pairs (Figure 2, upper right panel). There was also a significant target (log) lemma frequency by phonological ambiguity of the target interaction. Although higher frequency significantly reduced the probability of an error in both experiments, this effect was stronger for phonologically ambiguous than for unambiguous targets (Figure 2, lower left panel). Additionally, there was an interaction between the fixed effect of frequency, and the random effect of participants, indicating that the slope of frequency effect varied across participants (see Table 5, Random Effects).

Table 5. Partial effects of the predictors in mixed-efffect regression analysis of errors.

Random Effects		
	Variance	**Std.Dev.**
Participant: Intercept adj.	0.87515	0.9355
Participant: target frequency slope adj.	0.48257	0.69467
Item: Intercept adj.	3.54709	1.88337

Fixed Effects				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
Intercept	-2.7325	0.4031	-6.779	<0.0001
Trial order	-0.3831	0.1968	-1.947	0.0516
Target (log) lemma frequency	-0.9896	0.3405	-2.906	0.0037
Phonological ambiguity of the target (unambiguous)	-4.0358	0.5317	-7.59	<0.0001
Prime target alphabet match (same alphabet)	-5.7515	0.6582	-8.739	<0.0001
Prime target semantic relatedness (unrelated)	1.4491	0.3067	4.724	<0.0001
Prime target semantic relatedness (unrelated) x Trial order	0.7242	0.2657	2.726	0.0064
Phonological ambiguity of the target (unambiguous) x Target (log) lemma frequency	-0.9466	0.285	-3.321	0.0009
Phonological ambiguity of the target (unambiguous) x Prime target alphabet match (same alphabet)	4.104	0.8432	4.867	<0.0001
Phonological ambiguity of the target (unambiguous) x Prime target semantic relatedness (unrelated)	0.291	0.526	0.553	0.5801
Phonological ambiguity of the target (unambiguous) x Trial order	0.1487	0.4184	0.355	0.7222
Phonological ambiguity of the target (unambiguous) x Prime target semantic relatedness (unrelated) x Trial order	-1.2982	0.5083	-2.554	0.0106

Overall, participants were more accurate for phonologically unambiguous targets, as well as for prime-target pairs of matching alphabet. Additionally, there was a significant interaction of these two predictors indicating that the advantage of prime-target alphabet match (or cost of prime-target alphabet switch) was larger for phonologically ambiguous targets. Finally, participants were generally more accurate for semantically related, than for semantically unrelated prime-target pairs.

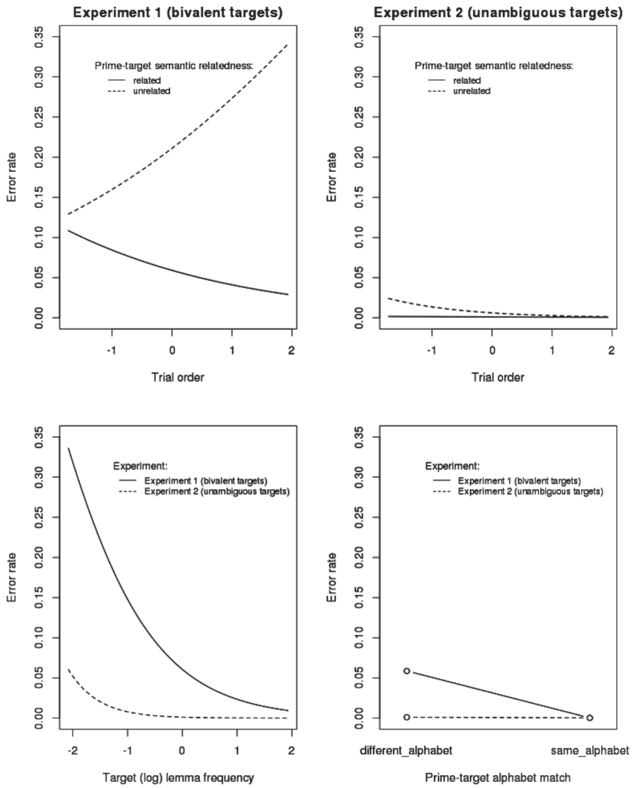

Figure 2. Partial effects of the predictors
in linear mixed-efffect regression analysis of errors.

DISCUSSION

Results of the present study replicate and extend previous work on bi-alphabetism and what it reveals about word recogntion. Although it was not the main focus of this study, we generally replicated earlier findings of a processing advantage for Cyrillic variants of the words, compared to their Roman variants

(Feldman, Lukatela, & Turvey, 1985). From a discriminative learning perspective (c.f., Baayen et al., 2011), this advantage could be interpreted as a consequence of the fact that more languages are written with Roman than with Cyrllic graphemes. If Roman graphemes serve as a cue to more languages than Cyrillic graphemes, then words containing Cyrillic letters may be easier to disciminate than those containing Roman letters. Obviouly, this interpretation holds only for speakers exposed to multiple languages, and should be further investigated.

A comparison of two alphabetic transcriptions of the same word replicated slower decisions latencies and a higher incidence of errors for forms that were phonologically ambiguous. In addition, the magnitude of the ambiguity effect varied with alphabet of the prime such that phonologically ambiguous targets were affected more by the alphabet of the prime than were unambiguous targets. In essence effects of alphabet code switching were not uniform. Alphabet switching between prime and target impacted word recognition when targets were phonologically ambiguous more than when they were unambiguous.

Described in terms of Seidenberg's triangle model (Harm & Seidenberg, 2004), it appears that a target's O→P→S mapping can be influenced by the alphabet of the preceding prime. Further, semantic relatedness and alphabet match of prime and target interacted such that the inhibitory effect of mismatching alphabet was more damaging for semantically unrelated than for related prime-target pairs. Here, the absence of feedback due to semantic similarity exaggerated the effect of having both the Cyrillic and Roman O→P mappings active for one prime-target pair as arises when alphabet is mismatched.

Most novel was the finding that number of common letters shared by prime and target influenced target recognition and that we could detect no association with word length or with number of shared ambiguous letters. Furthermore, as depicted in Figure 1, on the lower left panel, the number of common letters played a significant role only for semantically related prime-target pairs. The distinction between common and ambiguous letters centers on the one to one mapping between orthography and phonology for common letters, as opposed to the one to two mapping for ambiguous letters. With respect to a prime-target pair, common letters that recur are associated with shared phonology whereas ambiguous letters that recur are not. Therefore in the presence of semantically similar primes with several common letters, target recognition benefits from the degree of shared phonology between prime and target. Admittedly, different targets appear at each level of shared phonology yet it is unlikely that some unidentified lexical property accounts for the effect of number of common letters. One argument is that reaction times to targets after unrelated primes failed to vary with number of common letters. This is depicted in Figure 1, lower left panel. Only slightly more probable is that all the primes with many common letters were semantically more highly related to their targets than were those primes with fewer common letters.

In keeping with the triangle model (Harm & Seidenberg, 2004), an alternative account stresses the joint effect of shared meaning and shared form. Because similarity that derives from semantics can interact with similarity that derives from form, primes that share both form and meaning benefit target recognition more than primes that have equal similarity along one dimension but less along the second. Although materials in the present study were not constructed to investigate why targets after semantically related primes benefit more when primes share many as compared with few common letters, relevant data exist in English. Pastizzo and Feldman (2009) reported that at an SOA comparable to that in the present experiment (viz., 250 ms), decision latenceis were significanlty faster (23 ms) to targets after primes that shared form and meaning (e.g., BOAT-FLOAT) than to those same target after primes that shared only meaning (e.g., SWIM-FLOAT). The design of that study was particulary rigorous in that all targets appeared with all prime types; pair types were matched on degree of semantic relatedness and primes did not differ on a variety of relevant properties (word length, frequency). Conjoint influences of similarity from form and meaning as anticipated by the triangle model are not limited to the present study (see e.g., Bergen, 2004; Gonnerman, Seidenberg, & Andersen, 2007).

The work on bi-alphabetism in Serbian has contributed much to our understanding of word recognition more generally. When phonological effects were first reported in Serbian they were dismissed as an idiosyncrasy of a language with a shallow orthography and an unusually systematic mapping between letter and sound. Reactions did not change until after homophony effects were published in English (Van Orden et al., 1987; 1990). A common assumption at the time was that reading processes differ in fundamental ways across languages with different structures and different writing systems (see Frost, 2012). Those working on Serbian argued that superficial differences between languages provide a tool with which one can investigate and come to appreciate the more abstract similarities, often captured in terms of complex trade-offs between orthography, phonology and semantics, which has advanced our understanding of the processes that underlie reading and word recognition.

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