Journal of Experimental Psychology:
Learning, Memory, and Cognition
2005, Vol. 31, No. 1, 148–158

0278-7393/05/$12.00 DOI: 10.1037/0278-7393.31.1.148

The Assembly of Phonology From Print Is Serial and Subject to Strategic Control: Evidence From Serbian

Jelena Havelka
University of Kent

Kathleen Rastle
Royal Holloway, University of London

The Serbian writing system was used to investigate whether a serial procedure is implicated in print-to-sound translation and whether components of the reading aloud system can be strategically controlled. In mixed- and pure-alphabet lists, participants read aloud phonologically bivalent words comprising bivalent letters in initial or final positions. Words with bivalent letters in initial positions were disadvantaged relative to nonbivalent controls to a greater degree than were words with bivalent letters in final positions, and the size of the effect was greater in the mixed-alphabet situations than it was in the pure-alphabet situations. A dual-route theory of bialphabetic reading aloud is proposed in which the nonlexical procedure operates serially and nonlexical spelling–sound correspondences for each script can be strategically emphasized or deemphasized.

In this article, we describe empirical data relevant to two theoretical issues of central importance to modeling the adult reading aloud system. The first issue concerns the nature of print-to-sound translation: We consider whether that translation is best characterized by procedures that operate solely in parallel (e.g., Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989; Zorzi, Houghton, & Butterworth, 1998) or whether that translation is characterized, in part, by a procedure that operates serially, from left-to-right, across the letter string (Coltheart & Rastle, 1994; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Coltheart, Woollams, Kinoshita, & Perry, 1999; Rastle & Coltheart, 1998; Rastle & Coltheart, 1999; Roberts, Rastle, Coltheart, & Besner, 2003; Weekes, 1997). The second issue concerns the control of the reading aloud system: We consider whether any of the procedures by which we translate orthography to phonology can be strategically emphasized or deemphasized (e.g., Monsell, Patterson, Graham, Hughes, & Milroy, 1992; Rastle & Coltheart, 1999; Zevin & Balota, 2000), or whether control of the reading aloud system is better characterized in terms of a time criterion operating on response output (e.g., Jared, 1997; Kinoshita & Lupker, 2002, 2003; Lupker, Brown, & Colombo, 1997; Lupker, Kinoshita, Coltheart, & Taylor, 2003; Rastle, Kinoshita, Lupker, & Coltheart, 2003). We take advantage of special properties of the Serbian writing system—namely, bialphabeticity and perfect consistency within each alphabet—to explore these issues. In doing so, we provide insight into an additional issue of growing importance: the nature of the bialphabetic or bilingual reading aloud system (see, e.g., Jared & Kroll, 2001).

Serial Processing in the Orthography-to-Phonology Computation

The past 15 years of research on the cognitive processes underlying reading aloud—in particular, how an abstract phonological representation is computed from a written stimulus—has seen the rise of two distinct classes of computational model. On one hand, there is the dual-route cascaded (DRC) model (Coltheart et al., 2001), a computational realization of the dual-route theory of reading aloud (Coltheart, 1978; Forster & Chambers, 1973). The DRC model simulates the (nonsemantic) orthography-to-phonology computation through a lexical (i.e., localist) dictionary-lookup procedure and a nonlexical rule-based procedure. Although the lexical computation of phonology is accomplished in a parallel manner, the nonlexical computation of phonology is accomplished serially, letter by letter, from left to right across the input string (see Coltheart et al., 2001; Rastle & Coltheart, 1999). On the other hand, there is the group of parallel distributed processing (PDP) models (e.g., Harm & Seidenberg, 2004; Plaut et al., 1996; Seidenberg & McClelland, 1989), which posit that the (nonsemantic) computation of phonology can be expressed as a single procedure. These models learn the statistical structure of the orthography–phonology mapping, enabling them to compute the phonology for exception words and nonwords without reference to lexicons or to rules. Commensurate with their namesake (i.e., PDP), these models are committed to distributed representation and, critically, to parallel processing.

Where "principles" provide the basis for strictly parallel processing in PDP models of reading aloud, the decision to implement a serially operating nonlexical phonological assembly system in the DRC model was made in response to empirical data (dual-route theories do not, by necessity, require serial phonological assem-

---

Jelena Havelka, Department of Psychology, University of Kent, Canterbury, United Kingdom; Kathleen Rastle, Department of Psychology, Royal Holloway, University of London, United Kingdom.

This research was supported by a Small Faculty Grant from the University of Kent. We thank Dušica Filipović (Laboratory of Experimental Psychology, University of Belgrade) for help with data collection, and Marc Brysbaert and Steve Lupker for helpful discussion. We are also grateful to Chris Kello for comments on a draft of this article.

Correspondence concerning this article should be addressed to Jelena Havelka, Department of Psychology, University of Kent, Canterbury, Kent CT2 7NP, United Kingdom. E-mail: J.Havelka@kent.ac.uk

bly). One especially important finding in this regard is the *position-of-irregularity effect* reported by Coltheart and Rastle (1994; and subsequently Rastle & Coltheart, 1999; Roberts et al., 2003). These authors demonstrated that the spelling–sound irregularity disadvantage on reading aloud latency is modulated by the position in the word at which the irregularity occurs, with the cost of irregularity decreasing monotonically and linearly over the position of irregularity (from left to right). Words comprising early irregularities thus suffer a far more considerable latency and/or accuracy disadvantage relative to matched regular controls (e.g., *CHEF* vs. *SHED*) than do words comprising later irregularities (e.g., *GLOW* vs. *GRAB*).

Rastle and Coltheart (1999) established that the DRC model—with a nonlexical phonological assembly procedure that operates serially, letter by letter, from left-to-right—provided a sufficient account of this effect. In the DRC model, incorrect nonlexical information is disadvantageous to performance to the extent to which it competes with the rise of activation for correct lexical information in the phoneme system. Nonlexical information that becomes available early in the phoneme system offers a much greater degree of competition than nonlexical information that arrives late (particularly if lexical processing has already been completed), and thus, words with early irregularities suffer a considerable performance disadvantage. Serial nonlexical processing also provides the DRC model with an account of three further empirical phenomena: the *whammy effect* (i.e., the finding that nonwords with multiletter graphemes are read aloud more slowly than nonwords with single-letter graphemes; Rastle & Coltheart, 1998), the *length-by-lexicality effect* (i.e., the finding that reading aloud latency is positively influenced by letter string length for nonwords, but not for words; Weekes, 1997), and the *position-sensitive Stroop effect* (i.e., the finding that color naming of color-unrelated words is speeded when the color and word share a sound, and that this facilitation is greatest when the shared phoneme is early in the letter string; Coltheart et al., 1999).

Although the DRC model provides an account of all four of these empirical phenomena, no model of reading aloud that operates solely in parallel provides such an account. However, this body of empirical data has not met uncritical acceptance. A particularly important challenge concerning the position-of-irregularity effect was levied by Plaut et al. (1996) and substantiated by Zorzi (2000). Plaut et al. suggested that the position-of-irregularity manipulation in Coltheart and Rastle (1994) might have been confounded with consistency—such that words with early irregularities were more inconsistent than those with later irregularities. Using the irregular words *chef* and *glow* as examples, they pointed out that the *ch*–/S/ correspondence is far more infrequent (*chaise* being the only other exemplar) than the *ow*–/o/ correspondence (which occurs in, e.g., *blow*, *flow*, and *slow*). Plaut et al. argued that such a confound may enable a strictly parallel model to capture the effect, but they were unable to substantiate this claim: Coltheart and Rastle's stimuli were disyllabic, and no English model of reading deals with such words. Rastle and Coltheart (1999) responded to this charge by demonstrating a position-of-irregularity effect on monosyllabic word reading, using stimuli controlled for five types of consistency (head, nucleus, body, coda, and antibody consistency). Despite this demonstration, however, Zorzi was able to simulate Rastle and Coltheart's findings using the strictly parallel connectionist dual-process model (Zorzi et al., 1998). Zorzi's analysis of the model revealed that Rastle and Coltheart had confounded position of irregularity with yet another type of consistency—grapheme–phoneme consistency—such that words with early irregularities were more inconsistent than words with late irregularities.

The issue of consistency and the position-of-irregularity effect appears to have been put to rest by Roberts et al. (2003), who reported a position-of-irregularity effect using a set of stimuli that were tightly controlled on grapheme–phoneme consistency and that could be simulated only by the DRC model. However, similar challenges could be made with regard to the whammy effect (Rastle & Coltheart, 1998) and the length-by-lexicality effect (Weekes, 1997). For example, in a model that maps letters onto phonemes in a strictly parallel manner, it might be the case that multiletter graphemes (e.g., *PH*) inappropriately activate phonemes corresponding to the constituent letters (/p/, /h/) as well as the phoneme corresponding to the digraph (/f/), leading to a disadvantage for "whammied" items (see Rastle & Coltheart, 1998, for a discussion). Further, a strictly parallel model might view the Length × Lexicality interaction as a Frequency × Consistency interaction (see Perry & Ziegler, 2002; Zorzi, 2000, for a discussion). Longer words are typically more inconsistent than shorter words (Perry & Ziegler, 2002; Zorzi, 2000), and the extent to which inconsistency disadvantages performance in PDP networks is a function of frequency (Seidenberg & McClelland, 1989). Given this characterization, there may be scope within a strictly parallel model to simulate the length-by-lexicality effect. Although we emphasize that no strictly parallel model has yet simulated all four of the effects implicating left-to-right processing described earlier, the case for serial processing in reading could be strengthened further if the consistency issue could be eliminated (see also Perry & Ziegler, 2002). The empirical work described here seeks explicitly to meet this objective.

Control of Orthography-to-Phonology Translation Procedures

The empirical work described here also seeks to learn more about the extent to which orthography–phonology translation procedures are under strategic control—that is, whether the procedures by which we translate orthography to phonology can be emphasized or deemphasized relative to one another in a strategic manner (i.e., to maximize performance) through conscious or unconscious parametric variation.[1]

The notion of *route emphasis* provides a straightforward example of strategic control of reading procedures. If the architecture of the reading system comprises two processing routines, then it might be possible to vary the extent to which each is used, depending on the requirements of the reading situation. A stimulus list dominated by irregular words, for example, may result in a decreased reliance on nonlexical processing, because such processing would result in continual errors. Conversely, a stimulus list dominated by nonwords may result in a decreased reliance on lexical processing, because such processing would result in either

---

[1] Our occasional use of the agentive in this article (e.g., "Participants turned down use of the nonlexical route") should not convey a commitment to the idea that control of reading procedures is conscious.

no response or lexical capture (e.g., reading *starn* as *start*) on every trial (see, e.g., Coltheart et al., 2001; Rastle & Coltheart, 1999). Although no dual-route theory requires that processing routines be subject to strategic control, a wealth of evidence would appear to suggest that such control is possible (e.g., Baluch & Besner, 1991; Coltheart, 1978; Monsell et al., 1992; Monsell, Patterson, Tallon, & Hill, 1989; Paap & Noel, 1991; Rastle & Coltheart, 1999; Simpson & Kang, 1994; Tabossi & Laghi, 1992; Zevin & Balota, 2000). For example, Rastle and Coltheart (1999) demonstrated that nonwords and regular words are read aloud more slowly in the presence of first-position irregular fillers (e.g., *chef*) than they are in the presence of third-position irregular fillers (e.g., *glow*). They attributed this effect to strategic control of the nonlexical route: Faced with first-position exception words, participants turn down use of the nonlexical route, thus slowing the reading aloud of regular words and nonwords.

Lupker and colleagues (e.g., Chateau & Lupker, 2003; Kinoshita & Lupker, 2003; Lupker et al., 1997) have, however, provided a very persuasive challenge to the claim that orthography–phonology translation procedures are under strategic control. They contend that these apparent route emphasis effects are instead a consequence of a *time criterion* that controls postphonological response initiation. The criterion is flexible—set on the basis of the difficulty of stimuli previously encountered in the experiment—and has the effect of homogenizing reading aloud latencies. The time-criterion account readily explains the vast proportion of the route emphasis literature (but see Zevin & Balota, 2000, and the response by Kinoshita & Lupker, 2003). For example, Rastle and Coltheart's (1999) findings (i.e., nonword and regular word naming latencies are slowed in the presence of first-position irregular fillers relative to third-position irregular fillers) could be the simple result of reaction-time (RT) homogenization: First-position irregular fillers are more difficult (i.e., named more slowly) than third-position irregular fillers and slow the reading aloud of regular words and nonwords.

Lupker and colleagues have, however, gone much further than proposing a "separate but equal" account of strategic effects on reading aloud. Rather, they have demonstrated that RT homogenization effects arise in situations in which route emphasis would not be appropriate. For example, Chateau and Lupker (2003) demonstrated that Rastle and Coltheart's (1999) nonword and regular word targets could be slowed in the presence of very difficult (i.e., slow) nonword fillers relative to easier (i.e., faster) nonword fillers—a filler manipulation that should induce no route emphasis effects. It is even more striking that they demonstrated that the same target slowing could be achieved in the presence of very difficult (i.e., slow) nonword fillers relative to easier (i.e., faster) first-position irregular fillers—a result consistent with the time-criterion account, but exactly opposite that predicted by the route emphasis account.

Studies such as Rastle and Coltheart's (1999), in which performance on a set of targets was examined across different filler conditions, are not the exception: Lupker and colleagues (see, in particular, Kinoshita & Lupker, 2002, 2003) have also challenged the interpretation of studies examining modulation of the size of target-type effects such as the frequency effect (Baluch & Besner, 1991; Kang & Simpson, 2001; Simpson & Kang, 1994). These studies have typically shown that the frequency effect (a mark of lexical processing) is attenuated in conditions that would favor nonlexical processing (e.g., the inclusion of nonword fillers). However, Kinoshita and Lupker (2003) observed that in all of these studies, (a) latencies were faster overall in the condition in which the frequency effect was reduced, (b) fillers in the condition in which the frequency effect was reduced were named more quickly than fillers in the other condition, and (c) the reduced frequency effect reflected a speeding of low-frequency words with either no change or a slight speeding of high-frequency words. They asserted that these kinds of results could be explained within a time-criterion account if it were assumed that both low-frequency and high-frequency words are speeded in the context of easy (i.e., faster) fillers, but that the speeding of high-frequency words is only partial because of a floor effect. They went on to demonstrate that, relative to a condition in which fillers were low-frequency exception words, the frequency effect for regular words is reduced when fillers comprise low-frequency regular words but not when fillers comprise difficult (i.e., slow) nonwords—a result totally inconsistent with the route emphasis account.

Overall, what now seems clear is that RT homogenization effects occur in situations in which route emphasis effects would and would not be expected. What seems much less clear is whether the strength of any of the procedures by which readers translate orthography to phonology can be varied in a strategic manner.

A Dual-Route Theory of Serbian Reading Aloud

We propose that the study of the Serbian reading aloud system can contribute to the issues of serial and strategic processing that we have discussed. The Serbian language is written in two alphabets, Roman and Cyrillic, which are learned during the first two years of primary school. Adult skilled readers are fully competent in the use (i.e., reading and writing) of each alphabet. These alphabets transcribe the same language and map onto the same set of phonemes. It is critical to note that in terms of the correspondence between orthography and phonology, each alphabet within the Serbian writing system is perfectly feedforward (i.e., spelling to sound) and feedback (i.e., sound to spelling) consistent. Further, individual letters within each alphabet have a phonemic interpretation that is invariant over letter contexts, and all letters are pronounced (i.e., there are no silent letters).

In each alphabet, three types of letters can be distinguished (see Figure 1): (a) *unique letters* occur in only one of the alphabets, thus providing two graphemic interpretations for a single phoneme (one for each alphabet); (b) *common letters* are shared by the two alphabets and map onto the same phonemes in both; and (c) *bivalent letters* have the same graphemic form in both alphabets but map onto different phonemes in each alphabet.

These three letter types can be used for the formation of two types of letter strings relevant to the present study: *unique words* and *phonologically bivalent words*. Both unique Roman words (e.g., *KLAVIR* [piano]) and unique Cyrillic words (e.g., *УЧИТЕЉ* [teacher]) comprise unique and common letters. They can be read only in one alphabet, because some of the letters do not exist in the other alphabet. Phonologically bivalent words comprise common and bivalent letters and thus have two possible pronunciations, depending on the alphabet in which the letter string is read.

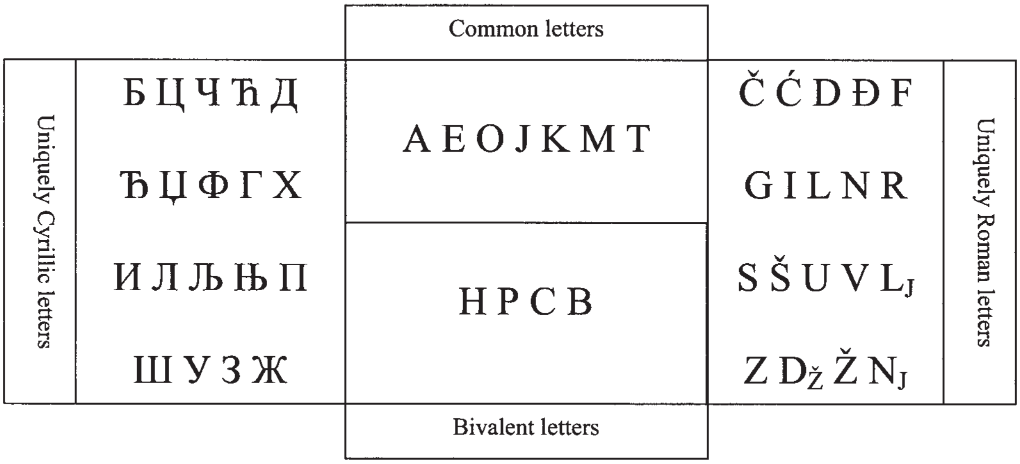

Figure 1. Letters of the Roman and Cyrillic alphabets.

However, these words are typically meaningful in only one of the alphabets and are pronounceable nonwords in the other. For example, *KOBAC* [hawk] is a word in Roman and a pronounceable nonword in Cyrillic, whereas *HOBOCT* [news] is a word in Cyrillic and a pronounceable nonword in Roman. A key finding is the *phonological bivalence effect*: Phonologically bivalent words are read aloud more slowly and with a greater degree of error than unique words (Lukatela, Lukatela, Carello, & Turvey, 1999).

One way to understand the Serbian reading aloud system is in terms of a dual-route theory, in which the pronunciation of a letter string is computed through lexical and nonlexical procedures. The lexical route would comprise five levels of representation: (a) feature units, activated in response to particular visual attributes of Roman and Cyrillic letters; (b) letter units, activated in response to Roman and Cyrillic letters; (c) orthographic units, activated in response to known orthographic forms, whether they be written in Cyrillic or Roman; (d) phonological units, activated in response to known Serbian phonological forms; and (e) phoneme units, activated in response to Serbian speech sounds. On the nonlexical side, grapheme–phoneme correspondence rules for both Cyrillic and Roman written forms would be applied to activated letter units and the output delivered to phoneme units. Because a single nonlexical route would comprise correspondences for both Cyrillic and Roman forms, two rules (resulting in different phonemic outputs) would be applied to the four bivalent letters.

Given this architecture, the locus of the phonological bivalence effect is clear. The nonlexical translation of a unique letter string (i.e., one that comprises unique and common letters) results in a single pronunciation; and because there are no spelling–sound exceptions, this pronunciation will always be identical to the lexically computed pronunciation. The nonlexical translation of a phonologically bivalent letter string (i.e., one that comprises bivalent and common letters), however, results in two pronunciations: one based upon the Cyrillic interpretation of the bivalent letters and one based upon the Roman interpretation of the bivalent letters. Only one of these pronunciations will be identical to the lexically computed pronunciation. On our dual-route account, it is this conflict within the phoneme system, generated by the application of two (conflicting) grapheme–phoneme rules, that yields the latency and accuracy cost for phonologically bivalent words.

A critical assumption of our account of Serbian reading aloud is that there is a single cognitive system for bialphabetic reading: A single orthographic lexicon comprises all known Roman and Cyrillic forms, and a single nonlexical translation procedure comprises spelling–sound rules for both Cyrillic and Roman letters (or in the case of bivalent letters, Cyrillic and Roman interpretations of letters). We believe this assumption is consistent with recent research on bilingual word recognition and reading aloud (e.g., Brysbaert, 2003; Dijkstra & Van Heuven, 2002; Jared & Kroll, 2001). From a lexical point of view, this research has demonstrated that visual lexical decisions conducted in a second language can be influenced by lexical knowledge of the dominant language (e.g., Dijkstra, Timmermans, & Schriefers, 2000; Van Heuven, Dijkstra, & Grainger, 1998) and more strikingly, that the visual recognition of words in the dominant language can be influenced by lexical knowledge of the second language (e.g., Van Hell & Dijkstra, 2002). From a nonlexical point of view, research has demonstrated that bilinguals may activate correspondences from both the native language and the second language, irrespective of the language of the task (Brysbaert, Van Dyck, & Van de Poel, 1999; Jared & Kroll, 2001; Van Wijnendaele & Brysbaert, 2002). We believe that this body of research provides independent support for the theory of bialphabetic reading aloud that we propose.

It is interesting to note that the activation of two sets of nonlexical spelling–sound correspondences in bilingual reading aloud may be subject to strategic control. Jared and Kroll (2001) demonstrated that both English–French and French–English bilinguals were influenced by French spelling–sound correspondences when reading aloud English words, but that this effect was particularly strong if participants had previously read aloud French filler words. When participants read aloud the English targets before the French filler words and were told explicitly to expect only English words, the influence of French correspondences was absent for the English–French bilinguals and was weaker for the French–English bilinguals. These results may suggest that the strength of grapheme–phoneme correspondences from each of a bilingual's languages can be emphasized or deemphasized depending on the requirements of the reading situation.

Serial and Strategic Effects in Serbian Reading: The Study

In this research, we used the special properties of the Serbian writing system to investigate serial and strategic processes in reading aloud. With regard to serial processing, we reasoned that if nonlexical phonological assembly proceeds in a serial letter-by-letter manner, then the size of the phonological bivalence effect should be modulated by the position of the bivalent letter in the word. To be specific, words with early bivalence should be read aloud more slowly and less accurately than words with late bivalence. It is important to emphasize that, unlike the position-of-irregularity effect (Coltheart & Rastle, 1994; Rastle & Coltheart, 1999), a position-of-bivalence effect could not be the result of increased inconsistency in initial-bivalent words. Although bivalent words are spelling–sound inconsistent because they map to two pronunciations (one for each alphabet), the extent to which initial- and final-bivalent words are inconsistent is perfectly controlled. The same four bivalent letters are used in initial and final positions, and these are equally inconsistent (i.e., they map consistently to a single pronunciation in Cyrillic and a single pronunciation in Roman). Furthermore, analyses of the Serbian dictionary (Kostić, 1999) reveal that bivalent letters are distributed approximately evenly across initial and final positions of words: 33.3% of words begin with a bivalent letter, and 26.2% of words contain a bivalent letter in the final or penultimate position. Given these facts, we do not believe that an argument from consistency concerning a position-of-bivalence effect could be sustained.

With regard to strategic processing, we reasoned that if the strength of any of the procedures by which readers translate orthography to phonology can be strategically varied, then the size of the bivalence effect might be influenced by the context in which the stimuli are presented. To be specific, we asked whether the bivalence effect would be attenuated if words were presented in pure blocks of Cyrillic or Roman, relative to presentation in mixed-alphabet blocks. On our dual-route theory of Serbian reading aloud, the attenuation of the bivalence effect in pure-alphabet blocks could be interpreted as evidence that the strength of particular nonlexical rules can be emphasized or deemphasized (relative to one another) in response to the requirements of the reading situation (i.e., *rule emphasis*). Such a finding would be similar to that reported by Jared and Kroll (2001) regarding bilingual reading aloud. However, we will argue that it is not clear how one could use a time-criterion mechanism (e.g., Kinoshita & Lupker, 2003; Lupker et al., 1997; Taylor & Lupker, 2001) to explain such an effect.

Method

Participants. As part of a course requirement, 64 students from the University of Belgrade (Belgrade, Serbia) participated in the experiment. Half of these participants were assigned to the mixed-alphabet condition, and half were assigned to the pure-alphabet condition. All participants had normal or corrected-to-normal vision, were native speakers of Serbian, and were very familiar with both alphabets.

Design. Four factors were varied in the experiment: block type (pure alphabet vs. mixed alphabet), alphabet (Roman vs. Cyrillic), word type (bivalent vs. unique), and position of bivalence (initial vs. final). All of these factors except block type were varied within subjects.

Those participants assigned to the mixed-alphabet condition received both levels of the word-type and alphabet variables (i.e., Roman bivalent, Cyrillic bivalent, Roman unique, and Cyrillic unique) in a single trial block. Those participants assigned to the pure-alphabet condition received the Roman bivalent and Roman unique words in one block, and the Cyrillic bivalent and Cyrillic unique words in another block. For those participants assigned to the pure-alphabet condition, the order of alphabets presented was counterbalanced.

Materials and apparatus. We selected 40 bivalent Serbian words. These words consisted of common letters and a single bivalent letter (i.e., there were no letters within these targets that were unique to a script). Twenty of the bivalent targets could be read aloud as words in Roman and as pronounceable nonwords (with a different pronunciation of the bivalent letter) in Cyrillic (hereafter called Roman bivalent targets). Similarly, 20 of the bivalent targets could be read aloud as words in Cyrillic and as pronounceable nonwords (with a different pronunciation of the bivalent letter) in Roman (hereafter called Cyrillic bivalent targets). For each of these sets of bivalent targets, half began with the bivalent letter (e.g., Roman: *BAKA*; Cyrillic: *COKO*), and half comprised a bivalent letter in either the final or the penultimate position (e.g., Roman: *JEMAC*; Cyrillic: *METAH*). All targets were nouns presented in their base form, nominative singular (the base case to which inflections can be added). Bivalent letters were never part of an inflection.

For each of the bivalent targets, we selected a unique control word. Controls for the Roman bivalent words were written in Cyrillic, and controls for the Cyrillic bivalent words were written in Roman. Bivalent targets needed unique controls to be written in the other alphabet so that pairwise matching on initial phoneme could be achieved. Controls matched on initial phoneme and written in the same alphabet as the initial bivalent targets would have, by definition, included the critical bivalent letter. Each unique control had exactly the same number of letters as its corresponding bivalent target. Further, controls were matched to bivalent targets as closely as possible on frequency (initial: $t(19) = 1.05$, *ns*; final: $t(19) = 0.95$, *ns*) and neighborhood size (initial: $t(19) = 0.08$, *ns*; final: $t(19) = 0.08$, *ns*). Frequencies and neighborhood size values were computed from the *Frequency Dictionary of Contemporary Serbian Language* (Kostić, 1999) and the *Corpus of Serbian Language* (Kostić, 2001). All stimuli are shown in the Appendix.

Stimulus presentation and data recording were controlled by the DMDX software (Forster & Forster, 2003) running on a Pentium II PC. Reading aloud responses were recorded directly to the hard drive of the PC at a sampling rate of 22 kHz with a Labtec Clearvoice microphone (Model No. LVA-7330, Labtec, United Kingdom) mounted on a headset intended to keep the microphone a constant distance from the mouth. Recording began on presentation of each target and continued for 2 s.

Procedure. Participants were tested individually in a quiet room. They were seated approximately 60 cm from the computer monitor and told that they would be seeing a series of words on the monitor that they were to read aloud as quickly and as accurately as possible. Each trial began with a 500-ms presentation of a fixation point in the center of the screen; this was followed immediately by the presentation of the target word, which stayed onscreen for 2,000 ms. Participants were given 12 practice trials before the experiment began, and each received a different random order of the stimuli.

Data preparation. There is now substantial evidence to suggest that electronic voice keys not only introduce significant error into measures of naming latency (e.g., Pechmann, Reetz, & Zerbst, 1989) but also contribute error that affects some stimulus types more than others, leading to systematic experimental bias (Rastle & Davis, 2002). For this reason, reading aloud latency measurements were accomplished manually for each recorded utterance via a visual inspection of the speech waveform or sound spectrogram using the Cool Edit speech-signal-processing package (Cool Edit, Syntrillium Software). The onset of acoustic energy (excluding lip pops and other nonspeech sounds) was denoted by a clear increase in amplitude on the speech waveform following a period of silence. For items beginning with the stop consonants /b d g p t k/ and the affricates /tS dZ/, the onset of acoustic energy corresponded to the burst–release phase of production, following a period of silence during which the vocal tract is occluded completely. These measurements were carried out by a research assistant naive to the purposes of the experiment.

Results

RT and error data from the mixed- and pure-alphabet conditions were collected and cleaned in three ways. First, 2 outlying participants were excluded (both from the mixed-alphabet condition) because of unusually slow and/or error-prone responding: One participant had an error rate of more than 20% and one participant had an average RT of more than 900 ms. Second, data from four items producing more than 30% errors in either the mixed- or pure-alphabet conditions were removed, along with their matched controls. Finally, five outlying data points over 1,450 ms were removed. Complete item data are presented in the Appendix.

RT and error data were analyzed by subjects and by items in mixed-design analyses of variance (ANOVAs) in which bivalence (bivalent vs. control), position of bivalence (initial vs. final), block type (mixed alphabet vs. pure alphabet), and alphabet (Roman vs. Cyrillic) were considered as factors. In the by-subjects analysis, all factors except block type were treated as repeated; in the by-items analysis, bivalence and block type were treated as repeated factors, and position and alphabet were treated as unrepeated factors. Effects were considered statistically significant if they reached the $p < .05$ level. Mean data from the by-subjects analysis are presented in Table 1.

Of primary interest to us were the bivalence effect and its interaction with position, block type, and alphabet, and so we restrict our statistical report to these tests. Analyses of the RT data showed a significant effect of phonological bivalence, in which bivalent words were read aloud more slowly than control words (632 ms vs. 587 ms), $F_1(1, 60) = 117.36$, *MSE* = 2,114.24; $F_2(1, 32) = 18.87$, *MSE* = 3,918.59. The effect of bivalence was modulated, however, by position, block type, and alphabet. Words with initial bivalence were read aloud more slowly relative to their controls (bivalent: 643 ms; controls: 564 ms) than were words with final bivalence (bivalent: 621 ms; controls: 611 ms), $F_1(1, 60) = 130.37$, *MSE* = 1,106.40; $F_2(1, 32) = 11.35$, *MSE* = 3,918.59. Further, the effect of bivalence was larger in the mixed-alphabet situation (bivalent: 671 ms; controls: 597 ms) than in the pure-alphabet situation (bivalent: 593 ms; controls: 578 ms), $F_1(1, 60) = 52.10$, *MSE* = 2,114.24; $F_2(1, 32) = 36.55$, *MSE* = 945.16. Finally, the effect of Cyrillic bivalence (i.e., when the bivalent letter string corresponded to a word in Cyrillic) was larger (bivalent: 640 ms; controls: 570 ms) than the effect of Roman bivalence (i.e., when the bivalent letter string corresponded to a word in Roman; bivalent: 623 ms; controls: 604 ms), $F_1(1, 60) = 27.86$, *MSE* = 2,957.89; $F_2(1, 32) = 6.80$, *MSE* = 3,918.59. None of the three-way or four-way interactions among bivalence, position, alphabet, and block type reached significance both by participants and by items.

Table 1
Reaction Time (ms) and Error Data (Percentage) From the By-Subjects Analysis of the Experiment

	Block type			
	Mixed		Pure	
Position and alphabet	*RT*	% error	*RT*	% error
Initial				
Cyrillic bivalent	709	10.00	619	2.78
Roman control	551	0.00	526	0.69
Roman bivalent	680	1.00	574	0.00
Cyrillic control	603	0.00	576	0.31
Final				
Cyrillic bivalent	654	5.33	594	0.00
Roman control	612	0.67	592	0.94
Roman bivalent	654	3.81	585	0.00
Cyrillic control	622	1.43	603	0.45

Analyses of the error data largely paralleled the RT data. Phonologically bivalent words were read aloud less accurately than were unique control words (bivalent: 2.87% error; controls: 0.54% error), $F_1(1, 60) = 48.04$, *MSE* = 0.0013; $F_2(1, 32) = 12.19$, *MSE* = 0.0015. The majority of these errors (44%) were alphabet errors, in which participants read the bivalent target as a nonword in the wrong alphabet, and omission errors (32%), in which participants failed to produce a response in the time allowed. Words with initial bivalence were read aloud less accurately relative to their controls (bivalent: 3.41% error; controls: 0.25% error) than were words with final bivalence (bivalent: 2.10% error; controls: 0.83% error), but this Bivalence × Position interaction was reliable only in the by-subjects analysis, $F_1(1, 60) = 7.77$, *MSE* = 0.0013; $F_2(1, 32) = 1.81$, *ns*. Further, the bivalence effect was larger in the mixed-alphabet situation (bivalent: 4.9% error; controls: 0.49% error) than it was in the pure-alphabet situation (bivalent: 0.69% error; controls: 0.59% error), $F_1(1, 60) = 43.82$, *MSE* = 0.0013; $F_2(1, 32) = 17.61$, *MSE* = 0.00097. Finally, the effect of Cyrillic bivalence on error rate (bivalent: 4.5% error; controls: 0.57% error) was greater than that of Roman bivalence (bivalent: 1.1% error; controls: 0.51% error), $F_1(1, 60) = 15.22$, *MSE* = 0.0023; $F_2(1, 32) = 6.24$, *MSE* = 0.0099. There were no further interactions among these factors that reached significance both by participants and by items.

General Discussion

In this research, we investigated two issues of central importance to modeling the reading aloud system: (a) Is there evidence that a serially operating phonological assembly system plays a role in the orthography–phonology translation?; and (b) Is there evidence that readers exercise strategic control over the procedures by which they translate orthography to phonology? In order to answer these questions, we examined the phonological bivalence effect on Serbian (bialphabetic) reading (Lukatela et al., 1999), in which words that contain a phonologically bivalent letter (i.e., one that has a different pronunciation in Cyrillic and Roman alphabets) are read aloud more slowly than words that do not. To be specific, we asked whether the position of the bivalent letter would influence the size of the bivalence effect, and whether the bivalence effect could be attenuated if participants were given stimuli in pure-alphabet blocks. Results were clear. Words with initial bivalence were read aloud more slowly relative to their unique (i.e., nonbivalent) controls than were words with final bivalence. Further, the bivalence effect was much larger when participants received Cyrillic and Roman words in the same block of trials than when presented with pure-alphabet blocks. Finally, there was evidence that the effect of Cyrillic bivalence was greater than that of Roman bivalence.

The Position-of-Bivalence Effect and Serial Processing

The position-of-bivalence effect that we have uncovered strengthens the case for a serial process in reading aloud. It provides an analogous finding to the position-of-irregularity effect (Coltheart & Rastle, 1994; Rastle & Coltheart, 1999) but is immune to the argument lodged by Zorzi (2000; but see Roberts et al., 2003)—namely, that the position-of-irregularity manipulation was confounded with grapheme–phoneme consistency. In the experiment presented here, the bivalent letters are inconsistent (i.e., they can be pronounced in more than one way). However, there are only four of them, and they are equally inconsistent: Each letter is always pronounced one way in Cyrillic and another way in Roman. Therefore, there is no sense in which words with final bivalence could be more grapheme–phoneme consistent relative to their controls than words with initial bivalence. These data thus make an important contribution to the body of literature that implicates a serial process in the translation from orthography to phonology—a body of literature that includes the position-of-irregularity effect (Coltheart & Rastle, 1994; Rastle & Coltheart, 1999; Roberts et al., 2003), the whammy effect (Rastle & Coltheart, 1998), the length-by-lexicality effect (Weekes, 1997), and the position-sensitive Stroop effect (Coltheart et al., 1999). The DRC model (Coltheart et al., 2001), with its serial nonlexical phonological assembly procedure, provides a clear account of all of these effects. The models that operate solely in parallel (Harm & Seidenberg, 2004; Plaut et al., 1996; Zorzi et al., 1998), however, offer no coherent account of these effects: This is a set of phenomena that these models handle inappropriately.

Are There Alternative Explanations for Serial Effects?

Theorists from a connectionist perspective have sometimes asserted that serial effects like the position-of-bivalence effect reflect not serial processing in the orthography–phonology computation but left-to-right processing in aspects of reading that precede (e.g., eye fixations) or follow (e.g., articulation) this computation: For example, "The . . . effects of length are a reminder that there are aspects of word recognition and pronunciation that are beyond the scope of implemented models" (Seidenberg & Plaut, 1998, p. 235). It is important that these types of claims be accompanied, of course, by a specific PDP theory incorporating eye fixations or articulation that provides an explanation for the serial effects otherwise attributed to the orthography–phonology translation. In this section, we consider our findings in light of the few such theories that have been proposed. If any of these theories provides a plausible explanation for our findings, then our strong claims concerning PDP models may be unjustified.

Serial effects and eye fixations: Plaut (1999). Plaut (1999) recognized that the existing PDP models (e.g., Plaut et al., 1996) do not provide an adequate account of sequential processes in reading (in particular, length effects), and so sought to explore how these models might be extended to capture such phenomena. He developed a three-layer refixation network comprising 10 position-specific letter slots, 100 hidden units, and 36 phoneme units. The network also comprises a fourth group of 10 position units with connections both to and from the hidden units. These position units establish a point of fixation (Position Slot 0) and allow the network to keep track of which grapheme–phoneme correspondence in the letter string it is currently attempting.

When a letter string is presented to the network, its first letter is aligned with the point of fixation. On the first time step, the network must activate the phoneme corresponding to the first grapheme and activate the position unit for the next grapheme. On the second time step, the network must activate the phoneme corresponding to the second grapheme and activate the position unit for the next grapheme. This process continues like this, the network outputting one phoneme at a time, until the network reaches a blank letter unit. If the network encounters difficulty with a particular grapheme–phoneme mapping, it refixates the input: It makes the equivalent of a rightward saccade (by shifting the letter input to the left) so that it can fixate the problematic grapheme directly (at Position Slot 0). In doing so, the network is able to use its more extensive experience at fixation to resolve the grapheme–phoneme mapping. The trained network simulated the benchmark Consistency × Frequency interaction when number of fixations was used as a dependent variable (it is not clear how one would derive RTs from this network).

Crucially, network also revealed the Length × Lexicality interaction on number of fixations. The network is successful in producing the length effect because longer stimuli require more processing in the periphery (i.e., away from the point of fixation), where the network has less experience resolving the grapheme–phoneme mapping. As is typically the case with these networks (e.g., Seidenberg & McClelland, 1989), any difficulties in resolving the grapheme–phoneme mapping are particularly exacerbated for low-frequency words or for nonwords—hence, the Length × Lexicality interaction. We believe that this network would fail to produce the position-of-bivalence effect for the very reason that it succeeds at simulating the Length × Lexicality interaction. All other things being equal (critically, the degree of inconsistency of the grapheme–phoneme mapping across position), this network predicts a greater disadvantage for final bivalent words (in which the difficulty lies in the periphery) than for initial bivalent words (in which the difficulty lies at fixation), exactly opposite the pattern that we observed.

Two other aspects of this PDP simulation invite comment. First, the model produced an average of 1.32 fixations per word, ranging from an average single fixation for high-frequency words to an average 2.38 fixations for six-letter nonwords. Although the eye movement literature demonstrates that single-word refixations do occur in skilled adult readers, it also demonstrates that they occur only infrequently for stimuli of this length (Rayner, Sereno, & Raney, 1996). Any future attempt to account for serial effects in terms of eye movements will need to bear this literature in mind. Second, we find it somewhat telling that this initial attempt to capture serial phenomena in a PDP model involved the implementation of a network that resolves one grapheme–phoneme correspondence at a time, from left to right across the input string. It is exactly our point that effects like the Length × Lexicality interaction cannot be captured in a strictly parallel simulation of the orthography–phonology mapping.

Serial effects and articulation: Kawamoto, Kello, and their colleagues. A standard assumption of speech production research, which we also make here, is that articulation is initiated only once an abstract representation for the complete phonological word has been computed (Levelt, 1989). In recent years, however, this assumption has been challenged by an idea that has been termed *cascaded articulation* (Kello, Plaut, & MacWhinney, 2000), the general proposal that the computation of a phonological code and the articulation of that code may overlap. Kawamoto, Kello, Jones, and Bame (1998) proposed a specific formulation of cascaded articulation that provided a means for reconciling the position-of-irregularity effect with PDP models of reading aloud. They argued that articulation begins in speeded reading aloud as soon as the initial phoneme is computed, irrespective of whether subsequent phonemes have been computed. If this were the case, they argued, then no cost of irregularity would be apparent for words with late irregularities (e.g., *grow*): Articulation (and the emission of acoustic energy) would have begun before the irregular phoneme had been computed. Words with early irregularities (e.g., *chef*), however, would suffer an irregularity cost, because the initial phoneme would have to be computed before articulation could begin. Kawamoto et al.'s idea was that noninitial phonemes could be computed during the articulation of previous phonemes. This argument could not apply to the whammy effect, the length-by-lexicality effect, or the position-sensitive Stroop effect; however, it would apply to our position-of-bivalence effect—so it is important to consider the argument carefully.

A fundamental aspect of speech production, recognized for over 100 years, is coarticulation: The individual speech sounds that build an utterance overlap each other in time (see Rastle, Harrington, Coltheart, & Palethorpe, 2000, for a review). Kawamoto et al. (1998) acknowledged that coarticulatory effects of an anticipatory nature (i.e., later sounds overlapping earlier sounds) could not occur if spoken responses were initiated solely on the basis of knowledge of the initial phoneme. They therefore proposed to reconcile their theory with anticipatory coarticulation by predicting that effects of anticipatory coarticulation would not be found in speeded reading aloud: "Although we agree that coarticulatory effects in typical speech production experiments should be found, we do not believe that this argument applies to speeded word naming" (p. 878). Rastle et al. (2000) disconfirmed this prediction. In a speeded reading aloud experiment (that revealed a benchmark effect, the regularity effect), they used speech physiological techniques to characterize articulation at initial points in the initial phoneme of each utterance (e.g., for words beginning with plosive phonemes, the measurements were taken at the onset of maximum articulatory closure). They observed highly significant influences of subsequent phonemes on the articulation of initial phonemes. These observations falsified Kawamoto et al.'s version of cascaded articulation: The criterion for responding in speeded reading aloud is not knowledge of the initial phoneme.

No PDP theorist has since argued that serial effects can be interpreted within the rubric of cascaded articulation. Kello and colleagues (Kello, in press; Kello & Plaut, 2003; Kello et al., 2000) have worked toward developing another formulation of cascaded articulation, but it is not clear how this formulation could be applied to the types of serial effects discussed here. For one, Kello et al. (2000) have emphasized that the relationship between articulation and the computation of phonology is flexible, such that articulation can become cascaded as a function of task demands—in particular, extreme pressure for speed. They found evidence for cascaded articulation in a Stroop interference task only when a deadline was imposed on naming responses; there was no evidence for cascaded articulation in the nondeadlined version of this task, which they argued reflected staged articulation (see also Kello, 2004, for similar data using a type of deadlined reading aloud task). It is therefore not clear whether or how this version of cascaded articulation would apply to the nondeadlined situations (e.g., reading aloud, Stroop color naming) in which serial effects emerge. Equally important, Kello and colleagues do not appear to posit an initial phoneme criterion for the initiation of articulation, even when articulation does become cascaded (although exactly what criterion they do posit is not stated explicitly):

> . . . one can posit a version of cascaded articulation in which, unlike the initial phoneme criterion, a response is initiated when all components of the entire syllable are activated to some degree . . . (Kello et al., 2000, p. 343).

> . . . a response may be fully specified at the time of response initiation, but processing may continue into response execution. For example, a response may be initiated on the basis of a complete, but "quick and dirty," representation of the response (Kello, 2004, p. 952).

> . . . each segment of a response may be partially, but not fully, specified at the time of response initiation (Kello, 2004, p. 952).

If the grapheme–phoneme mapping is resolved in parallel, and if the criterion for articulation is the achievement of some (albeit reduced) critical level of activation for all segments of the response, then it is unclear where serial effects on naming latency would come from. Why, for example, would irregularities or bivalences in final positions be so inexpensive? And what of the other serial effects, such as the position-sensitive Stroop effect (Coltheart et al., 1999)? It is clear that any future attempt to apply this formulation of cascaded articulation to serial effects would need to be accompanied by increased theoretical specificity in these areas.

The Bivalence Effect and Strategic Processing

Our finding that the phonological bivalence effect was attenuated in pure-alphabet conditions relative to mixed-alphabet conditions provides evidence that the procedures by which readers translate orthography to phonology are under strategic control. This effect can be interpreted within the dual-route theory of Serbian reading aloud that we have proposed not as route shifting but as evidence that readers selectively deemphasize some of their nonlexical rules (relative to their other nonlexical rules) when those rules are not required. Like in Jared and Kroll's (2001) study of bilingual readers, the alternative correspondences for the bivalent words in our study (i.e., those that generated incorrect pronunciations) exerted maximal influence in the experimental situation in which they needed to be used: the mixed-alphabet blocks. When participants experienced words from only one alphabet, these alternative correspondences had a lesser effect. This effect suggests that letter–sound correspondences for bialphabetic or bilingual readers are represented in a single nonlexical route (at least in cases in which both languages are alphabetic), but that the strength of each set of rules may be tuned—and strategically emphasized or deemphasized—independently of the other.

Differential weighting on the strength of correspondences from each alphabet or language also provides a means to capture language or alphabetic dominance (see Jared & Kroll, 2001) in our dual-route model. As described, the effect of Cyrillic bivalence was greater than the effect of Roman bivalence in both pure and mixed blocks. We are not aware of any simple distributional characteristics that could explain this result: Bivalent letters occur with approximately equal frequency in initial positions of Cyrillic and Roman words, bivalent letters occur with approximately equal frequency in final positions of Cyrillic and Roman words, and words with no unique letters (like our bivalent stimuli) are actually slightly more common in Cyrillic than in Roman. We believe instead that this finding indicates that participants in our study may have been slightly "Roman dominant."[2] If, in our dual-route model, Roman spelling–sound correspondences were weighted more strongly than Cyrillic spelling–sound correspondences, then we would predict a greater disadvantage for Cyrillic bivalent words than for Roman bivalent words—exactly as we observed. This Alphabet × Bivalence interaction would, of course, have been magnified in our study because of the use of cross-script unique controls. Roman dominance would have exaggerated the effect of Cyrillic bivalence (by producing relatively fast latencies for Roman unique controls) and underestimated the effect of Roman bivalence (by again producing relatively fast latencies for Roman bivalent words).

We have claimed that our data are consistent with a rule emphasis account, in which the strength of a particular set of correspondence rules can be strategically emphasized or deemphasized. However, it is important to consider whether our findings could instead reflect the operation of a simple time criterion (Lupker et al., 1997; Taylor & Lupker, 2001). The time-criterion account predicts that when sets of items are mixed in a single block, their latencies become more homogeneous relative to presentation in pure blocks. Lupker and colleagues have typically presented fast (e.g., regular words, high-frequency words) and slow (e.g., irregular words, low-frequency words) stimuli in pure and mixed blocks (e.g., Lupker et al., 1997) and observed an RT homogenization in the mixed blocks. Although our manipulation is somewhat different (with pure blocks of Roman and Cyrillic words comprising fast and slow items), Lupker and colleagues' principles still apply: There should be a homogenization of latencies in mixed blocks relative to pure blocks.

Our data do not reflect this pattern. Pure-block performance showed slightly faster average latencies for Roman words (569 ms) than for Cyrillic words (598 ms). According to the RT homogenization account of Lupker and colleagues, mixed-block performance should have revealed very slightly slowed latencies for Roman words and very slightly speeded latencies for Cyrillic words (e.g., Kinoshita & Lupker, 2002, 2003; Lupker et al., 1997). Instead, we observed an across-the-board mixing cost on the order of 52 ms that was particularly evident for bivalent words (81 ms) relative to unique words (23 ms) and for first-position bivalent words (98 ms) relative to final-position bivalent words (65 ms). We do not, therefore, consider that the time-criterion account of Lupker and colleagues (Kinoshita & Lupker, 2002, 2003; Lupker et al., 1997; Rastle et al., 2003; Taylor & Lupker, 2001) provides an alternative explanation for the pattern of findings that we have observed in this study.

In summary, we have demonstrated that the bivalence effect on Serbian reading aloud is modulated by the position of the bivalent letter in a word: Initial bivalence is far more costly than final bivalence. These data strengthen the claim that the assembly of phonology from print proceeds in a serial, left-to-right manner (Coltheart & Rastle, 1994; Rastle & Coltheart, 1999) and provide yet more evidence against a fundamental principle of PDP models of reading aloud (e.g., Plaut et al., 1996). We have further demonstrated that the bivalence effect can be reduced in pure-alphabet situations—indicating that participants can selectively emphasize or deemphasize sets of nonlexical rules as needed. Taken together, these data support a dual-route theory of bialphabetic reading in which (a) the nonlexical procedure operates serially and (b) the nonlexical spelling–sound correspondences for each script are weighted independently of one another and can be strategically emphasized or deemphasized.

References

Baluch, B., & Besner, D. (1991). Visual word recognition: Evidence for strategic control of lexical and nonlexical routines in oral reading. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 17,* 644–652.

Brysbaert, M. (2003). Bilingual visual word recognition: Evidence from masked phonological priming. In S. Kinoshita & S. J. Lupker (Eds.), *Masked priming: The state of the art* (pp. 323–343). New York: Psychology Press.

Brysbaert, M., Van Dyck, G., & Van de Poel, M. (1999). Visual word recognition in bilinguals: Evidence from masked phonological priming. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 137–148.

Chateau, D., & Lupker, S. J. (2003). Strategic effects in word naming: Examining the route-emphasis versus time-criterion accounts. *Journal of Experimental Psychology: Human Perception and Performance, 29,* 139–151.

Coltheart, M. (1978). Lexical access in simple reading tasks. In G. Underwood (Ed.), *Strategies of information processing* (pp. 151–216). London: Academic Press.

Coltheart, M., & Rastle, K. (1994). Serial processing in reading aloud: Evidence for dual-route models of reading. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1197–1211.

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,* 204–256.

Coltheart, M., Woollams, A., Kinoshita, S., & Perry, C. (1999). A position-sensitive Stroop effect: Further evidence for a left-to-right component in print-to-speech conversion. *Psychonomic Bulletin & Review, 6,* 456–463.

Dijkstra, T., Timmermans, M., & Schriefers, H. (2000). On being blinded by your other language: Effects of task demands on interlingual homograph recognition. *Journal of Memory and Language, 42,* 445–464.

---

[2] The claim of Roman dominance is backed up by a marginal three-way Alphabet × Bivalence × Order interaction in the pure blocks, $F(1, 30) = 3.76$, $p = .06$, with the effect of Cyrillic bivalence being larger when presented in the second pure block (66 ms) than when presented in the first pure block (32 ms). The size of the Roman bivalence effect was unaffected by pure-block order.

Dijkstra, T., & Van Heuven, W. J. B. (2002). The architecture of the bilingual word recognition system: From identification to decision. *Bilingualism: Language and Cognition, 5,* 175–197.

Forster, K. I., & Chambers, S. M. (1973). Lexical access and naming time. *Journal of Verbal Learning and Verbal Behavior, 12,* 627–635.

Forster, K. I., & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, & Computers, 35,* 116–124.

Harm, M., & Seidenberg, M. S. (2004). Computing the meanings of words in reading: Cooperative division of labor between visual and phonological processes. *Psychological Review, 111,* 662–720.

Jared, D. (1997). Evidence that strategy effects in word naming reflect changes in output timing rather than changes in processing route. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23,* 1424–1438.

Jared, D., & Kroll, J. F. (2001). Do bilinguals activate phonological representations in one or both of their languages when naming words? *Journal of Memory and Language, 44,* 2–31.

Kang, H., & Simpson, G. B. (2001). Local strategic control of information in visual word recognition. *Memory & Cognition, 29,* 648–655.

Kawamoto, A. H., Kello, C., Jones, R., & Bame, K. (1998). Initial phoneme versus whole word criterion to initiate pronunciation: Evidence based on response latency and initial phoneme duration. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 362–381.

Kello, C. T. (2004). Control over the time course of cognition in the tempo-naming task. *Journal of Experimental Psychology: Human Perception and Performance, 30,* 942–955.

Kello, C. T., & Plaut, D. C. (2003). Strategic control over rate of processing in word reading: A computational investigation. *Journal of Memory and Language, 48,* 207–232.

Kello, C. T., Plaut, D. C., & MacWhinney, B. (2000). The task dependence of staged versus cascaded processing: An empirical and computational study of Stroop interference in speech production. *Journal of Experimental Psychology: General, 129,* 340–360.

Kinoshita, S., & Lupker, S. J. (2002). Effects of filler type in naming: Change in time criterion or attentional control of pathways? *Memory & Cognition, 30,* 1277–1287.

Kinoshita, S., & Lupker, S. J. (2003). Priming and attentional control of lexical and sublexical pathways in naming: A reevaluation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 405–415.

Kostić, Đ. (1999). *Frequency dictionary of contemporary Serbian language*. Belgrade, Serbia: Institute for Experimental Phonetics and Speech Pathology and Laboratory for Experimental Psychology, University of Belgrade.

Kostić, Đ. (2001). *Quantitative description of Serbian language structure—Corpus of Serbian language*. Belgrade, Serbia: Institute for Experimental Phonetics and Speech Pathology and Laboratory for Experimental Psychology, University of Belgrade.

Levelt, W. J. M. (1989). *Speaking: From intention to articulation*. Cambridge, MA: MIT Press.

Lukatela, G., Lukatela, K., Carello, C., & Turvey, M. T. (1999). Effects of frequency and phonological ambiguity on naming Serbo-Croatian words. *European Journal Of Cognitive Psychology, 11,* 1–16.

Lupker, S. J., Brown, P., & Colombo, L. (1997). Strategic control in a naming task: Changing routes or changing deadlines? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23,* 570–590.

Lupker, S. J., Kinoshita, S., Coltheart, M., & Taylor, T. E. (2003). Mixing costs and mixing benefits in naming words, pictures, and sums. *Journal of Memory and Language, 49,* 556–575.

Monsell, S., Patterson, K. E., Graham, A., Hughes, C. H., & Milroy, R. (1992). Lexical and sublexical translation of spelling to sound: Strategic anticipation of lexical status. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 452–467.

Monsell, S., Patterson, K. E., Tallon, J., & Hill, J. (1989, January). *Voluntary surface dyslexia: A new argument for two processes in oral reading?* Paper presented at the meeting of the Experimental Psychology Society, London.

Paap, K. R., & Noel, R. W. (1991). Dual-route models of print to sound: Still a good horse race. *Psychological Research, 53,* 13–24.

Pechmann, T., Reetz, H., & Zerbst, D. (1989). *Kritik einer Me-Smethode: Zur Ungenauigkeit von voice-key Messungen* [The unreliability of voice-key measurements]. *Sprache and Kognition, 8,* 65–71.

Perry, C., & Ziegler, J. C. (2002). Cross-language computational investigation of the length effect in reading aloud. *Journal of Experimental Psychology: Human Perception and Performance, 28,* 990–1001.

Plaut, D. C. (1999). A connectionist approach to word reading and acquired dyslexia: Extension to sequential processing. *Cognitive Science, 23,* 543–568.

Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103,* 56–115.

Rastle, K., & Coltheart, M. (1998). Whammies and double whammies: The effect of length on nonword reading. *Psychonomic Bulletin & Review, 5,* 277–282.

Rastle, K., & Coltheart, M. (1999). Serial and strategic effects in reading aloud. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 482–503.

Rastle, K., & Davis, M. H. (2002). On the complexities of measuring naming. *Journal of Experimental Psychology: Human Perception and Performance, 28,* 307–314.

Rastle, K., Harrington, J., Coltheart, M., & Palethorpe, S. (2000). Reading aloud begins when the computation of phonology is complete. *Journal of Experimental Psychology: Human Perception and Performance, 26,* 1178–1191.

Rastle, K., Kinoshita, S., Lupker, S., & Coltheart, M. (2003). Cross-task strategic effects. *Memory & Cognition, 31,* 867–876.

Rayner, K., Sereno, S. C., & Raney, G. E. (1996). Eye movement control in reading: A comparison of two types of models. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 1188–1200.

Roberts, M., Rastle, K., Coltheart, M., & Besner, D. (2003). When parallel processing in visual word recognition is not enough: New evidence from naming. *Psychonomic Bulletin & Review, 10,* 405–414.

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96,* 523–568.

Seidenberg, M. S., & Plaut, D. C. (1998). Evaluating word reading models at the item level: Matching the grain of theory and data. *Psychological Science, 9,* 234–237.

Simpson, G. B., & Kang, H. W. (1994). The flexible use of phonological information in word recognition in Korean. *Journal of Memory and Language, 33,* 319–331.

Tabossi, P., & Laghi, L. (1992). Semantic priming in the pronunciation of words in two writing systems: Italian and English. *Memory & Cognition, 20,* 303–313.

Taylor, T. E., & Lupker, S. J. (2001). Sequential effects in naming: A time-criterion account. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27,* 117–138.

Van Hell, J. G., & Dijkstra, T. (2002). Foreign language knowledge can influence native language performance in exclusively native contexts. *Psychonomic Bulletin & Review, 9,* 780–789.

Van Heuven, W. J. B., Dijkstra, T., & Grainger, J. (1998). Orthographic neighborhood effects in bilingual word recognition. *Journal of Memory and Language, 39,* 458–483.

Van Wijnendaele, I., & Brysbaert, M. (2002). Visual word recognition in bilinguals: Phonological priming from the second to the first language. *Journal of Experimental Psychology: Human Perception and Performance, 28,* 616–627.

Weekes, B. S. (1997). Differential effects of number of letters on word and nonword naming latency. *Quarterly Journal of Experimental Psychology, 50A,* 439–456.

Zevin, J. D., & Balota, D. A. (2000). Priming and attentional control of lexical and sublexical pathways during naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 121–135.

Zorzi, M. (2000). Serial processing in reading aloud: No challenge for a parallel model. *Journal of Experimental Psychology: Human Perception and Performance, 26,* 847–856.

Zorzi, M., Houghton, G., & Butterworth, B. (1998). Two routes or one in reading aloud? A connectionist dual-process model. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 1131–1161.

Appendix

Items Used in the Experiment With Their Reaction Times (ms) and Error Data (Proportion)

Alphabet and position	Bivalent stimulus	Control stimulus	Bivalent mixed RT	Control mixed RT	Bivalent pure RT	Control pure RT	Bivalent mixed error	Control mixed error	Bivalent pure error	Control pure error
Roman										
Begin	PAKT	ПАША	845	667	621	603	0.03	0.00	0.00	0.03
Begin	BAKA	БАЗА	678	538	529	532	0.00	0.00	0.00	0.00
Begin	BOEM	БОЗА	583	627	545	543	0.00	0.00	0.00	0.00
Begin	BATAK	БАХАТ	668	626	582	593	0.00	0.00	0.00	0.00
Begin	HAJKA	ХОТЕЛ	590	509	523	505	0.00	0.00	0.00	0.00
Begin	PATKA	ПАЛАЦ	726	614	581	581	0.03	0.00	0.00	0.00
Begin	PAMET	ПАЛМА	738	624	619	581	0.00	0.00	0.00	0.00
Begin	PETAO	ПЕЧАТ	672	589	570	591	0.00	0.00	0.00	0.00
Begin	POEMA	ПОХОД	619	610	587	598	0.00	0.00	0.00	0.00
Begin	BOJKOT	БОМБАШ	678	622	580	632	0.03	0.00	0.00	0.00
End	KAMP	КАБЛ	662	646	560	629	0.00	0.03	0.00	0.00
End	TAOC	ТАФТ								
End	OTAC	ОГАЊ	607	573	528	591	0.03	0.00	0.00	0.00
End	JEMAC	ЈЕЛЕК								
End	MAMAC	МАЧАК	608	557	551	552	0.00	0.00	0.00	0.00
End	TAJAC	ТАЛОГ	650	614	588	624	0.17	0.00	0.00	0.00
End	AMEBA	АТАШЕ	578	703	561	673	0.00	0.07	0.00	0.03
End	ETAPA	ЕТИДА								
End	TEMPO	ТЕТКА	696	634	596	623	0.00	0.00	0.00	0.00
End	TAKMAC	ТАЈФУН	780	626	710	640	0.07	0.00	0.00	0.00
Cyrillic										
Begin	СЕТА	SENO	795	509	605	493	0.20	0.00	0.03	0.00
Begin	СМАК	SMUK	801	537	605	495	0.17	0.00	0.00	0.00
Begin	СОКО	SOVA	592	490	501	456	0.00	0.00	0.00	0.00
Begin	РАКА	RALO	943	647	684	569	0.13	0.00	0.00	0.03
Begin	СТАЈА	STAZA	611	510	574	478	0.03	0.00	0.00	0.00
Begin	НОКАТ	NORMA	711	589	645	566	0.17	0.00	0.00	0.00
Begin	НАЈАМ	NAVOD								
Begin	РЕКЕТ	RIVAL	822	563	727	550	0.20	0.00	0.13	0.00
Begin	СОМОТ	SOKAK	574	566	550	514	0.00	0.00	0.03	0.00
Begin	СТОМАК	STOČIĆ	531	549	676	612	0.00	0.00	0.06	0.03
End	АТАР	ALAS	759	653	644	580	0.10	0.00	0.00	0.00
End	КЕКС	KLAN	708	613	599	560	0.03	0.00	0.00	0.00
End	ОКОВ	OKNO	716	562	603	571	0.10	0.00	0.00	0.00
End	МЕТАН	MERAČ	684	600	622	593	0.17	0.00	0.00	0.00
End	МОТОР	MOTIV	555	510	512	503	0.00	0.00	0.00	0.00
End	ОКЕАН	OKRUG	601	627	570	620	0.00	0.00	0.00	0.00
End	МЕТАР	MINUT	599	563	587	542	0.07	0.00	0.00	0.00
End	КОКОС	KOLOS	693	678	623	636	0.03	0.00	0.00	0.00
End	АКТЕР	ARHIV	602	599	577	601	0.00	0.00	0.00	0.00
End	АМАТЕР	AMANET	621	718	600	715	0.03	0.07	0.00	0.09

Note. RT = reaction time.

Received March 23, 2004
Revision received July 14, 2004
Accepted July 26, 2004 ■