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Seriality of phonological encoding in naming objects and reading their names

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There is a remarkable lack of research bringing together the literatures on oral reading and speaking. As concerns phonological encoding, both models of reading and speaking assume a process of segmental spellout for words, which is followed by serial prosodification in models of speaking (e.g., Levelt, Roelofs, & Meyer, 1999). Thus, a natural place to merge models of reading and speaking would be at the level of segmental spellout. This view predicts similar seriality effects in reading and object naming. Experiment 1 showed that the seriality of encoding inside a syllable revealed in previous studies of speaking is observed for both naming objects and reading their names. Experiment 2 showed that both object naming and reading exhibit the seriality of the encoding of successive syllables previously observed for speaking. Experiment 3 showed that the seriality is also observed when object naming and reading trials are mixed rather than tested separately, as in the first two experiments. These results suggest that a serial phonological encoding mechanism is shared between naming objects and reading their names.

The speaking of words (e.g., in object and color naming) and the reading of words seem to share several word-planning components in common. In particular, both speaking and oral reading require the construction of output phonological forms and articulatory programs. Consequently, it is generally assumed that phonological planning mechanisms are shared between speaking and reading words. For example, Cohen, Dunbar, and McClelland (1990); Coltheart, Rastle, Perry, Langdon, and Ziegler (2001); and Roelofs (1992, 2003), among many others, assumed that output representations are shared between naming colors and reading their names. Although the assumption of shared mechanisms is widely accepted, it has not been subjected to extensive experimental testing. Moreover, in spite of the apparent commonalities and the generally accepted assumption that mechanisms are shared between speaking and oral reading, the word-form planning mechanisms in speaking and reading have been investigated in different research traditions and with different techniques, such as object naming in studies of speaking and word and nonword naming in studies of reading. Moreover, the models that have been developed for phonological planning in speaking and reading differ in several of their claims.

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The WEAVER++ model of spoken word production (Levelt, Roelofs, & Meyer, 1999; Roelofs, 1992, 1996b, 1997a, 1997b, 2003) implements the claim that after conceptually driven retrieval of "lemmas" in object naming, word forms are encoded in three steps: morphological encoding, phonological encoding, and phonetic encoding. In phonological encoding, the phonological segments of the morphemes of a word are spelled out in parallel and they are "prosodified" in a sequential fashion from the beginning of a word to its end. Prosodification involves syllabification and stress assignment (Roelofs, 1997a; Roelofs & Meyer, 1998), yielding phonological word representations that make explicit the syllables of a word and, for polysyllabic words, the stress pattern across syllables. Phonetic encoding translates the abstract phonological word representation into a context-dependent phonetic representation that can guide articulation (i.e., it makes explicit articulatory tasks such as lip protrusion and lowering of the jaw). In oral reading, the orthography of the word activates output morphemes and phonological segments (i.e., segmental spellout), which are then prosodified in a sequential fashion using the same mechanism as in object naming (Roelofs, 2003). Figure 1 illustrates the processes assumed by WEAVER++.[1]

The dual-route cascaded (DRC; Coltheart et al., 2001) model of reading describes the processes by which an abstract orthographic representation is mapped onto an abstract phonological segmental representation. The model assumes that in oral reading the lexical activation of phonological segments happens in parallel, whereas the sublexical activation of phonological segments by graphemes (the phonological "assembly") occurs serially from left to right. The seriality arises from the left-to-right application

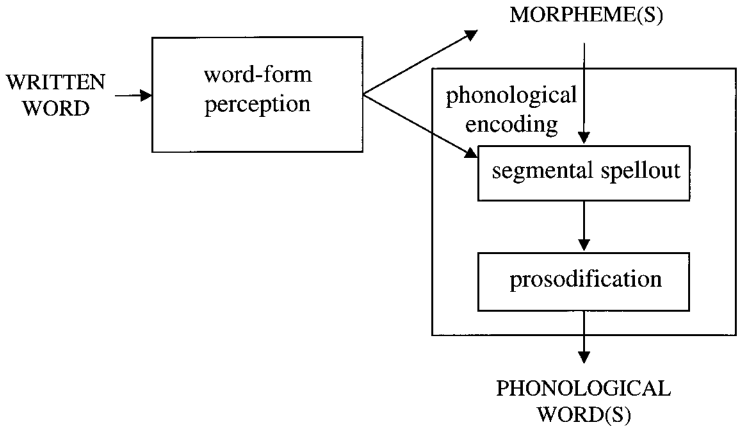

Figure 1. Orthographic word-form perception and phonological encoding in naming objects and reading their names in the WEAVER++ model. During phonological encoding in object naming, the phonological segments of the morphemes of a word are spelled out in parallel (not shown is that for words with irregular stress, metrical structures are spelled out as well), and they are prosodified in a serial fashion from the beginning of a word to its end. In oral reading, orthographic word-form perception activates output morphemes and phonological segments, which are prosodified in a sequential fashion using the same mechanism as in object naming.

of grapheme-to-phoneme correspondence rules to the letter string in reading. In object naming, the activation of phonological segments happens in parallel (Coltheart et al., 2001). Processes such as prosodification and phonetic encoding are outside the scope of the DRC model. Other reading models assume serial activation (Plaut, 1999) or parallel activation of phonological segments (e.g., Plaut, McClelland, Seidenberg, & Patterson, 1996; Zorzi, Houghton, & Butterworth, 1998) or their phonological features (Seidenberg & McClelland, 1989) by the orthography. Similarly, in reading words via their meaning or in object naming, phonological segments are activated in parallel (Plaut et al., 1996). So far, most reading models have been developed for the reading of monosyllabic words only (e.g., Coltheart et al., 2001; Plaut, 1999; Plaut et al., 1996; Seidenberg & McClelland, 1989; Zorzi et al., 1998; but see Ans, Carbonnel, & Valdois, 1998).

To summarize, as concerns phonological encoding, both models of reading and speaking words assume a process of segmental spellout, which is followed by serial prosodification in models of speaking (e.g., Levelt et al., 1999; Roelofs, 1997b). A natural place to merge models of reading aloud such as DRC with models of speaking such as WEAVER++ would therefore be at the level of segmental spellout. On this view, segmental spellout would be followed by serial prosodification in both speaking and oral reading (Figure 1). If this architecture is correct, then we should observe similar seriality effects in naming objects and reading their names.

The aim of the research reported in this paper was to examine whether phonological encoding mechanisms are shared between speaking words and orally reading them, and whether some encoding components operate serially. These issues were examined using a chronometric technique that has been shown to be able to diagnose whether processes and representations are shared among different stimuli and tasks, namely the form-preparation paradigm developed by Meyer (1990, 1991). The preparation paradigm has been described in depth in various other places, and I refer to these publications for an extensive discussion and motivation of it (see especially Meyer, 1990, and Roelofs, 1998). Meyer's preparation technique shares several aspects in common with precuing techniques that have been used in studying the planning of skilled action. For example, Rosenbaum (1980) used precuing to control the amount of preparation in arm movement. He manipulated the uncertainty in the specification of arm direction and extent, and observed that as more information was available to allow preparation, movement initiation time decreased. The preparation task of Meyer (1990, 1991) differs from precuing in that no explicit cues are given in advance but the cue is implicit among the responses. However, the logic is the same in that both implicit and explicit precuing allow for preparation of an action.

In the experiments of Meyer (1990, 1991), participants first learned small sets of word pairs such as FRUIT–*melon*, IRON–*metal*, GRASS–*meadow*. During the following test phase, they had to produce the second word of a pair (e.g., *melon*) upon visual presentation on a computer screen of the first word (FRUIT), called the prompt. On each trial, one of the prompts was presented. The order of prompts across trials was random. The naming latency—the interval between prompt onset and speech onset—was the main dependent variable. Each experiment contained two types of sets, homogeneous and heterogeneous. In a homogeneous set, the response words shared part of their form—for example, the first syllable, as in *melon*, *metal*, *meadow*, or the second syllable, as in *pocket*, *ticket*, *bucket*. In the heterogeneous sets, the response words were unrelated in word form. Regrouping the pairs from the homogeneous sets created the heterogeneous sets. Therefore, each word pair was tested under both conditions, and all uncontrolled item effects were kept constant across conditions.

Meyer found shorter naming latencies in homogeneous than in heterogeneous sets, henceforth called the *preparation benefit*. This preparation effect was obtained only when the response words in homogeneous sets shared word-initial segments (as in *melon*, *metal*, *meadow*), but not when they shared word-final segments (as in *pocket*, *ticket*, *bucket*). The magnitude of the preparation benefit increased with the number of shared word-initial segments. These findings suggest that the facilitation from homogeneity is due to preparation of word production rather than to general memory retrieval processes. Research on paired-associate learning has shown that form overlap helps memory retrieval independent of the place of overlap (see Meyer, 1990, for a review of the memory literature). Furthermore, immediate verbal recall is hampered (i.e., a lower rather than a higher level of recall is observed) when the items are similar in sound or articulatory characteristics (see Baddeley, 1997, for a review). Thus, the findings from the memory literature differ from the results of Meyer (1990, 1991). In addition, when the responses of paired associates were Dutch particle–verb combinations, tested in the verb–particle (e.g., *zoek op*, English *look up*) or particle–verb orders (*opzoeken*) allowed in Dutch, only initial overlap yielded facilitation, regardless of whether the overlap concerned the particle or the verb (Roelofs, 1998). Furthermore, initial overlap also yields a preparation benefit in object naming (Roelofs, 1999). The findings from the research on paired-associate learning, the particle verbs (Roelofs, 1998), and object naming (Roelofs, 1999) rule out a general memory account of preparation benefits.

Meyer's (1990, 1991) findings have been replicated with several other types of morphologically simple words, but also with morphologically complex words, as well as phrasal constructions (Roelofs, 1996b, 1997a, 1998). Roelofs and Meyer (1998) showed that syllable structures and stress patterns cannot be prepared. Evidence for seriality in phonological encoding has also been obtained with other experimental paradigms such as picture–word interference (Meyer & Schriefers, 1991), where spoken primes are presented during picture naming. Moreover, serial phonological encoding predicts effects of word length, which has been confirmed in object-naming experiments (Meyer, Roelofs, & Levelt, 2003).

Several findings suggest that the preparation benefit reflects phonological planning processes rather than articulatory preparation—that is, moving the tongue, jaw, and lips in the correct starting position before the trial. It is unlikely that bringing the speech organs into the optimal starting position can span more than one syllable (although there may be some coarticulation beyond a syllable boundary). Therefore, the larger preparation benefit (i.e., doubling of the effect) observed when two syllables are shared compared with one syllable (Meyer, 1990; Roelofs, 1998) remains unexplained by articulatory preparation. Perhaps more convincingly, articulatory preparation fails to explain why the magnitude of the preparation benefit depends on morpheme structure and other abstract linguistic variables (e.g., Janssen, Roelofs, & Levelt, 2002; Roelofs, 1996b; Roelofs & Meyer, 1998). For example, the preparation benefit is larger when the shared segments make up a morpheme in the response words than when the same segments do not make up a morpheme (Roelofs, 1996b; Roelofs & Baayen, 2002) and the preparation benefit is larger for low-frequency morphemes than with high-frequency morphemes (Roelofs, 1996a, 1998). These findings suggest that preparation benefits are unlikely to be exclusively caused by articulatory preparation.

Several findings also suggest that the preparation benefit reflects phonological rather than phonetic encoding processes. Roelofs (1999) observed that phonological features alone cannot be prepared to facilitate spoken word production. When disyllabic words were produced in sets different in form, or in sets sharing either the first syllable (e.g., as in *baby*, *bagel*, *baker*) or the first syllable except for a single phonological feature in the initial segment (e.g., as in *data*, *baby*, *bagel*, where the syllables *da* and *ba* share all phonological features except that /d/ and /b/ differ in place of articulation), only fully shared first syllables yielded facilitation. A similar pattern of results was observed when voicing rather than place of articulation was manipulated. The special status of segmental identity suggests that preparation happens at the level of phonological encoding rather than phonetic encoding.

Preparation benefits occur when the orthography is not shared (but see Damian & Bowers, 2003). Meyer (1990) observed preparation benefits for shared syllables (i.e., *si*) of 42 msec (her Experiment 1) and 49 msec (her Experiment 3) with varying orthography (i.e., CI vs. SI). Similarly, Chen, Chen, and Dell (2002) demonstrated in Mandarin Chinese that preparation of syllables is not dependent on shared orthography by using two-syllable two-character response words. When the first syllable but not the character was shared, the preparation benefit was as large as when the syllable and its character were shared.

Preparation benefits have been simulated by WEAVER++ (e.g., Roelofs, 1997a). The model has a suspend-resume mechanism that supports a rightward incremental prosodification of phonological segments. Incrementality means that encoding processes can be triggered by a fragment of their characteristic input. In phonological encoding, prosodification of a word can start as soon as the first few phonological segments are available. The resulting partial phonological representation can be buffered until the missing segments are available and prosodification can continue. Thus, when given partial information, computations are completed as far as possible, after which they are put on hold. When given further information, the encoding processes continue from where they stopped. Buffered phonological forms in WEAVER++ are only expandable toward the end of a word.

According to the model, shorter latencies in homogeneous sets than in heterogeneous sets are observed when participants prepare and buffer partial phonological representations of the response words before prompt presentation. The confinement of the facilitatory effect to begin-homogeneous sets (e.g., Meyer, 1990) reflects the suspend-resume mechanism that underlies the rightward incremental prosodification. If, for example, the set of response words consists of *melon*, *metal*, *meadow*, the phonological encoder can construct the first phonological syllable before the beginning of a trial. In the heterogeneous condition (*melon*, *table*, etc.), nothing can be prepared before prompt presentation. There will be no advance phonological encoding. In the end-homogeneous condition (*pocket*, *ticket*, *bucket*), nothing can be encoded in advance either. Although the phonological segments of the second syllable are known, the corresponding part of the phonological form cannot be computed in advance because the missing segments precede the suspension point. In WEAVER++, this means that after prompt presentation, prosodification must simply start with the first segment (yielding no preparation benefit) or, when the second syllable has been encoded, the preparation must be undone and prosodification must restart with the first segment of the word (yielding a preparation cost). With paired-associate naming, no benefit is empirically observed for end-homogeneity, suggesting that participants avoid the cost by not trying to prepare shared noninitial fragments.

OVERVIEW OF THE EXPERIMENTS

Experiments 1 and 2 tested for rightward phonological encoding in object naming and oral reading using the form-preparation paradigm. Instead of producing words from paired associates, participants simply had to name pictures or orally read their names. If the mechanisms of phonological encoding are shared between speaking and reading, then reading words aloud should exhibit the same seriality phenomenon that Meyer (1990, 1991) observed for speaking words. Experiment 1 tested for seriality effects within the syllables of words by using monosyllables, and Experiment 2 tested for seriality effects between the syllables of words by using disyllables. Seriality effects in both object naming and reading would be consistent with models that assume a serial word-form planning mechanism. Serial phonological planning in itself does not necessarily predict an absence of preparation benefits for noninitial overlap among responses. One might imagine a system that in principle plans phonological representations from the beginning of a word to its end but under specific circumstances can leave some parts of the phonological code temporarily unspecified. Rather, the impossibility to plan noninitial fragments in advance is true under the specific assumption of the suspend-resume mechanism of WEAVER++. Moreover, equivalent seriality effects in object naming and reading would suggest that the obtained seriality is due to the prosodification of phonological segments rather than grapheme-to-phoneme conversion.

Seriality effects for both object naming and reading may indicate that phonological encoding mechanisms are shared by speaking and reading, as most models of speaking and reading assume, or that there are separate mechanisms for speaking and reading both operating in a serial fashion. Experiment 3 tested between these alternatives (shared vs. separate mechanisms) by examining whether preparation benefits are obtained when object-naming and reading trials are mixed. If phonological encoding mechanisms are shared between speaking and reading, participants should be able to plan initial phonological segments regardless of whether object-naming and reading trials are mixed or not. However, if separate representations and mechanisms underlie phonological encoding in speaking and reading, preparation should not be possible when object-naming and reading trials are mixed within a block of trials. With separate representations and mechanisms, the token phonological representation prepared by the reading mechanism would differ from the token phonological representation needed for object naming, even when the token representations consist of the same segment types.

EXPERIMENT 1

The first experiment examined whether reading words exhibits the same seriality phenomenon that Meyer (1991) observed for the encoding inside a syllable in speaking words. Are readers able to plan the initial phonological segments of monosyllabic words without knowing the remaining segments, but not the noninitial segments without also knowing the initial segments? With serial planning, advance knowledge of initial segments should yield facilitation, but advance knowledge of noninitial segments should not. Seriality effects in both object naming and reading would support models that assume a serial phonological planning mechanism in general and a suspend-resume mechanism in particular. Moreover, equivalent preparation benefits in object naming and reading would suggest that the seriality is not specific to a grapheme-to-phoneme mapping process in oral reading but that it is inherent to the prosodification of phonological segments (which does not exclude the possibility that the grapheme-to-phoneme mapping also occurs in a serial fashion; see Coltheart et al., 2001).

Method

Participants. The experiment was conducted with 24 paid participants from the pool of the Max Planck Institute. All participants were native speakers of Dutch.

Materials and Design. The stimuli consisted of 18 pictures and their 18 written names. All words were monosyllabic nouns. The pictures were line drawings of simple objects, which were selected from the picture gallery available at the Max Planck Institute. They

Table 1
Monosyllabic Response Words of Experiment 1

Position	Context	Set
Begin	Homogeneous	Set 1: bok, boor, bel (goat, drill, bell)
		Set 2: kous, kam, kat (stockings, comb, cat)
		Set 3: rok, ring, roos (skirt, ring, rose)
Begin	Heterogeneous	Set 4: roos, bok, kam
		Set 5: boor, rok, kat
		Set 6: ring, kous, bel
End	Homogeneous	Set 7: rat, krat, vat (rat, crate, barrel)
		Set 8: veer, speer, peer (feather, spear, pear)
		Set 9: kip, clip, schip (chicken, clip, ship)
End	Heterogeneous	Set 10: peer, rat, clip
		Set 11: veer, schip, krat
		Set 12: kip, vat, speer

were digitized and scaled to fit into a virtual frame of 10 cm × 10 cm. The words were presented in 36-point lowercase Arial font. The pictures had to be named and the words had to be read aloud, which is the first independent variable, henceforth referred to as *task* (object naming, word reading). The pictures were grouped into 12 response sets of 3 stimuli each (see Table 1) and the same was done with their written names. Each set was tested in a separate block of trials. The grouping was such that in 6 picture sets and 6 word sets (the homogeneous sets), the response words shared part of their form, and in the remaining sets (the heterogeneous sets) they were unrelated in form. Thus, in the homogeneous condition, each response word was tested together with other response words with common segments, whereas in the heterogeneous condition, the response words tested together in a block did not share segments. Following Meyer (1990), the second independent variable—homogeneous versus heterogeneou s sets—is called *context*. The same pictures and written words were tested in the homogeneous and heterogeneous conditions. Only their combinations into sets differed.

In half the homogeneous sets, all responses shared the beginning of the word (the first segment) and in the corresponding heterogeneous sets they did not. The shared first segments were /k/, /b/, and /r/. In the other half of the homogeneous sets, the response words shared the end of the word and in the corresponding heterogeneous sets they did not. The shared end-segments were /at/, /er/ and /ɪp/. The third independent variable, which had two levels (begin, end), is called *position*.

Each participant was tested once on each set. Each of the pictures and words in a set was tested five times within a block of trials. The order of testing the pictures and words was random, except that immediate repetitions of stimuli were excluded. A different order was used for each block and each participant. The order of the sets was fully counterbalanced across participants. Half the participants were first tested on the sets in the begin condition and then on those in the end condition. For the remaining participants, the order of testing the begin and end conditions was reversed. Half the participants were first tested on the homogeneous sets and then on the heterogeneous ones, and for the other half of the participants the order of homogeneous and heterogeneous sets was reversed. Finally, half the participants were first tested on the pictures, then on the written words, and for the other half, this order was reversed.

Procedure and Apparatus. The participants were tested individually in all experiments. Participants were seated in a quiet room in front of a computer screen (NEC Multisync 30) and a microphone (Sennheiser ME40) connected to an electronic voice key. The distance from the screen was approximately 50 cm. Before the experiment, a participant received written instructions about the tasks. Before the picture and word trial blocks, the task was indicated on the screen. The structure of a trial was as follows. A trial was started by the display of a picture or word (depending on the task) for 1.0 sec. The pictures and words were presented in white on a black background. Before the start of the next trial there was a blank interval of 1.5 sec. Thus, the total duration of a trial was 2.5 sec. A Hermac computer controlled the stimulus presentation and data collection, including the voice key.

Analyses. The response coding and analyses were the same in all experiments. After each trial, the experimenter coded the response for errors. Five types of incorrect responses were distinguished: wrong response words, wrong pronunciation of the words, disfluencies (stuttering, within-utterance pauses, repairs), triggering of the voice key by nonspeech sounds (noise in the environment or smacking sounds participants produced with the lips or tongue), and failures to respond within 1.5 sec after picture or word presentation. Incorrect responses were excluded from the statistical analysis of the production latencies. For all experiments, analyses of variance (ANOVAs) were performed on the error rates using the same design as for the production latencies.

Results and Discussion

Table 2 gives the mean object naming and word reading latencies, their standard deviations, and the error percentages for Experiment 1. The column labeled "preparation" indicates the difference between the homogeneous and heterogeneous conditions. The table shows that facilitation from segmental overlap was obtained for the begin condition regardless of whether the task was object naming or reading. Segmental overlap in the end condition increased the object naming and reading times. The latencies and errors were submitted to by-participants and by-items ANOVAs with the crossed variables task, context, and position. All variables were tested within participants. Context was tested within items and position and task were tested between items.

Table 2
Mean Response Times (in Milliseconds), Standard Deviations, Error Percentages (PE), and Preparation Effects per Task, Position, and Context for Experiment 1

		Context							
		Homogeneous			Heterogeneous			Preparation	
Task	Position	*M*	*SD*	PE	*M*	*SD*	PE	*M*	PE
Object naming	Begin	555	131	4.9	573	130	4.7	−18	0.2
	End	593	152	8.3	575	137	7.2	18	1.1
Word reading	Begin	436	80	4.7	454	83	3.6	−18	1.1
	End	466	96	6.2	450	84	4.8	16	1.4

The analysis of the naming and reading latencies yielded main effects of task [$F_1(1,23) = 231.10$, $MS_e = 3{,}100$, $p < .001$, $F_2(1,32) = 599.67$, $MS_e = 454$, $p < .001$] and position [$F_1(1,23) = 16.73$, $MS_e = 782$, $p < .001$, $F_2(1,32) = 10.85$, $MS_e = 454$, $p < .001$], but not of context [$F_1(1,23) < 1$, $F_2(1,32) < 1$]. The effect of context depended on position [$F_1(1,23) = 9.51$, $MS_e = 1{,}670$, $p < .005$, $F_2(1,32) = 15.38$, $MS_e = 357$, $p < .001$], but not on task [$F_1(1,23) < 1$, $F_2(1,32) < 1$]. Furthermore, there was no three-way interaction of context, position, and task [$F_1(1,23) < 1$, $F_2(1,32) < 1$]. Pairwise comparisons showed that the latencies were shorter in the homogeneous than the heterogeneous sets in the begin condition [$t_1(23) = -2.24$, $p < .018$, $t_2(17) = -6.57$, $p < .001$], but they were longer in the homogeneous than the heterogeneous sets in the end condition [$t_1(23) = 2.50$, $p < .01$, $t_2(17) = 2.02$, $p < .03$]. The analysis of the naming and reading errors yielded a main effect of position only [$F_1(1,23) = 5.67$, $p < .026$, $F_2(1,32) = 10.85$, $p < .001$, all other ps $> .05$]. Table 2 shows that more errors were made in the end condition than in the begin condition.

To summarize, in both object naming and reading, participants could benefit from foreknowledge of initial segments of a word without knowing the remainder of a word, but they could not benefit from foreknowledge of noninitial segments of a word without also knowing the preceding segments. The latencies were shorter for the homogeneous than for the heterogeneous sets in the begin condition, but they were longer for the homogeneous than for the heterogeneous sets in the end condition. The latter is a finding not previously obtained with the preparation paradigm. It is unclear why end overlap yielded interference in the experiment. One possibility may be that participants attempted to prepare their responses in the end-homogeneous condition at the cost of having to undo the preparations. Regardless of the cause of the end effect, the observation of facilitation for begin overlap and interference for end overlap agrees with serial but not with parallel encoding. Thus, the seriality phenomenon in form preparation first reported by Meyer (1991) for speaking words was replicated for reading words. This suggests that the successive segments of a syllable of a word are encoded serially both in naming objects and reading their names.

EXPERIMENT 2

The second experiment examined whether reading words exhibits the same seriality phenomenon that Meyer (1990) observed for the encoding of successive syllables in speaking words. Are readers able to plan the first syllable of a disyllabic word without knowing its second syllable, but not the second syllable without also knowing the first syllable? With serial planning, advance knowledge of the first syllable should yield facilitation, but advance knowledge of the second syllable should not.

Method

Participants. The experiment was conducted with 16 paid participants from the pool of the Max Planck Institute. All participants were native speakers of Dutch.

Materials, Design, Procedure, Apparatus, and Analyses. These were the same as in Experiment 1 except that all words were disyllabic nouns (see Table 3). The shared first syllables were /be/, /wa/, and /le/, and the shared second syllables were /vər/, /kən/, and /bəl/.

Results and Discussion

Table 4 gives the mean object-naming and reading latencies, their standard deviations, and the error percentages for Experiment 2. The column labeled "preparation" indicates the difference between the homogeneous and heterogeneous conditions. The table shows that facilitation from shared syllables was obtained for the begin condition but not for the end condition, regardless of whether the task was object naming or reading.

The analysis of the naming and reading latencies yielded main effects of task [$F_1(1,15) = 91.18$, $MS_e = 3{,}895$, $p < .001$, $F_2(1,32) = 314.84$, $MS_e = 623$, $p < .001$] and position [$F_1(1,15) = 27.61$, $MS_e = 1{,}381$, $p < .001$, $F_2(1,32) = 33.22$, $MS_e = 623$, $p < .001$], but not of context [$F_1(1,15) = 1.17$, $MS_e = 1{,}439$, $p > .30$, $F_2(1,32) = 6.16$, $MS_e = 181$, $p < .02$]. The effect of context depended on position [$F_1(1,15) = 13.65$, $MS_e = 567$, $p < .002$, $F_2(1,32) = 20.25$, $MS_e = 181$, $p < .001$], but not on task [$F_1(1,15) < 1$, $F_2(1,32) < 1$]. Furthermore, there was no three-way interaction of context, position, and task [$F_1(1,15) < 1$, $F_2(1,32) < 1$]. Pairwise comparisons showed that the latencies were shorter in the homogeneous than the heterogeneous sets in the begin condition [$t_1(15) = -3.2$, $p <$

Table 3
Disyllabic Response Words of Experiment 2

Position	Context	Set
Begin	Homogeneous	Set 1: baby, bezem, beker (baby, broom, beaker)
		Set 2: wapen, waaier, water (weapon, fan, water)
		Set 3: leraar, lepel, lelie (teacher, spoon, lily)
Begin	Heterogeneous	Set 4: baby, wapen, leraar
		Set 5: bezem, waaier, lepel
		Set 6: beker, water, lelie
End	Homogeneous	Set 7: klaver, bever, vijver (clover, beaver, pond)
		Set 8: varken, baken, pauken (pig, beacon, drums)
		Set 9: bijbel, label, sabel (bible, label, sword)
End	Heterogeneous	Set 10: klaver, varken, bijbel
		Set 11: bever, pauken, label
		Set 12: vijver, baken, sabel

Table 4
Mean Response Times (in Milliseconds), Standard Deviations, Error Percentages (PE), and Preparation Effects per Task, Position, and Context for Experiment 2

		Context							
		Homogeneous			Heterogeneous			Preparation	
Task	Position	*M*	*SD*	PE	*M*	*SD*	PE	*M*	PE
Object naming	Begin	513	115	6.3	538	137	6.8	−25	−0.5
	End	577	147	5.6	573	151	5.8	4	−0.2
Word reading	Begin	427	88	4.2	446	107	5.7	−19	−1.5
	End	458	99	8.0	451	91	4.3	7	3.7

.003, $t_2(17) = -5.6, p < .001$], but they did not differ in the end condition [$t_1(15) < 1, t_2(17) = 1.3, p > .10$]. The analysis of the naming and reading errors yielded no significant results (all ps $> .05$).

The facilitation for begin but not for end overlap agrees with what is normally obtained with the preparation paradigm. In contrast to Experiment 1, no interference was obtained for end overlap. It is unclear why end interference was obtained in Experiment 1 but not in the present experiment. One possible reason may be that whereas the monosyllabic response words in the end-overlap condition of Experiment 1 shared all segments except the onset, the disyllabic response words in the end-overlap condition of the present experiment shared only the second syllable and had different first syllables. It may be that the participants were tempted to prepare the end of the words in Experiment 1 because the overlap was proportionally large (almost the whole word form was shared) and that they refrained from preparing the end of the response words in the present experiment because the overlap was proportionally much smaller (only half of the form of the response words was shared). If this was the case, participants had to undo their end preparations in Experiment 1, yielding interference for end overlap, whereas there was no end preparation in the present experiment, yielding no effect for end overlap.

To summarize, in both object naming and reading, participants could benefit from foreknowledge of the first syllable of a word without knowing the remainder of the word, but they could not benefit from foreknowledge of the second syllable of a word while not knowing the first syllable. Thus, the seriality effect in the phonological encoding of successive syllables of a word first reported by Meyer (1990) for speaking words was replicated for reading words. This suggests that the successive syllables of a word are encoded serially both in naming objects and reading their names.

EXPERIMENT 3

If phonological encoding mechanisms are shared between speaking and reading, participants should be able to plan initial segments regardless of whether object-naming and reading trials are mixed or blocked. However, if separate representations and mechanisms underlie phonological encoding in speaking and reading, preparation with mixed object naming and reading trials should not be possible. These predictions were tested in the third experiment. The experiment was the same as Experiment 2, except that object-naming and reading trials were mixed in a block of trials rather than tested in separate trial blocks.

Method

Participants. The experiment was conducted with 16 paid participants from the pool of the Max Planck Institute. All participants were native speakers of Dutch.

Materials. This was the same as in Experiment 2 except that the pictures and their names were now combined into single sets. That is, the three pictures and three words of each begin-homogeneous set for object naming and reading in Experiment 2 were pooled into a combined begin-homogeneous set including the three pictures and their names. For example, the first begin-homogeneous set now included the pictures of a baby, a broom, and a cup and their Dutch written names, BABY, BEZEM, and BEKER.

Design, Procedure, Apparatus, and Analyses. These were the same as in Experiment 2 except that naming and reading trials were combined into trial blocks. Half the participants were first tested on the sets in the begin condition and then on those in the end condi-

Table 5
Mean Response Times (in Milliseconds), Standard Deviations, Error Percentages (PE), and Preparation Effects per Task, Position, and Context for Experiment 3

		Context							
		Homogeneous			Heterogeneous			Preparation	
Task	Position	*M*	*SD*	PE	*M*	*SD*	PE	*M*	PE
Object naming	Begin	526	110	5.8	548	118	7.9	−22	−2.1
	End	596	141	11.1	597	157	6.0	−1	5.1
Word reading	Begin	444	81	7.2	466	107	9.2	−22	−2.0
	End	493	87	10.3	479	96	10.7	14	−0.4

tion. For the remaining participants, the order of testing the begin and end conditions was reversed. Half the participants were first tested on the homogeneous sets, then on the heterogeneous ones, and for the other half, the order of homogeneous and heterogeneous sets was reversed.

Results and Discussion

Table 5 gives the mean object-naming and reading latencies, their standard deviations, and the error percentages for Experiment 3. The column labeled "preparation" indicates the difference between the homogeneous and heterogeneous conditions. The table shows that facilitation from syllable overlap was obtained for the begin but not for the end condition, regardless of whether the task was object naming or word reading.

The analysis of the naming and reading latencies yielded main effects of task [$F_1(1,15) = 114.68$, $MS_e = 2{,}566$, $p < .001$, $F_2(1,32) = 144.59$, $MS_e = 1{,}145$, $p < .001$] and position [$F_1(1,15) = 42.88$, $MS_e = 1{,}526$, $p < .001$, $F_2(1,32) = 31.97$, $MS_e = 1{,}145$, $p < .001$], but not of context [$F_1(1,15) < 1$, $F_2(1,32) = 6.33$, $MS_e = 154$, $p < .02$]. The effect of context depended on position [$F_1(1,15) = 9.13$, $MS_e = 686$, $p < .009$, $F_2(1,32) = 24.41$, $MS_e = 154$, $p < .001$], but not on task [$F_1(1,15) = 1.48$, $MS_e = 430$, $p > .24$, $F_2(1,32) = 1.62$, $MS_e = 154$, $p > .21$]. Furthermore, there was no three-way interaction of context, position, and task [$F_1(1,15) < 1$, $F_2(1,32) = 1.61$, $MS_e = 154$, $p > .21$]. Pairwise comparisons showed that the latencies were shorter in the homogeneous than the heterogeneous sets in the begin condition [$t_1(15) = -2.1$, $p < .03$, $t_2(17) = -5.6$, $p < .001$], but they did not differ in the end condition [$t_1(15) < 1$, $t_2(17) = 1.6$, $p > .10$].

The analysis of the naming and reading errors yielded an effect of context by position only [$F_1(1,15) = 7.42$, $p < .02$, $F_2(1,32) = 6.14$, $p < .02$, all other ps $> .05$]. Inspection of the error rates (Table 5) revealed that more errors were made in the end homogenous condition (10.7%) than in the other conditions (begin homogeneous 6.5%, begin heterogeneous 8.5%, and end heterogeneous 8.3%). Because this is also the slowest condition, there is no evidence for a speed–accuracy tradeoff.

A comparison of Tables 4 and 5 reveals that the magnitude of the preparation effects is almost the same when the tasks are blocked (Experiment 2) and when they are mixed (Experiment 3). To statistically verify that there are indeed no differences in preparation effects between experiments, the naming latencies obtained in the two experiments were submitted to combined by-participants and by-items ANOVAs with *blocking* (yes/no) as between-participants variable. The analysis yielded no main effect of blocking [$F_1(1,30) < 1$, $F_2(1,64) = 17.45$, $MS_e = 884$, $p < .001$]. Blocking did not interact with any other variable or combination of variables, either (most Fs < 1, all ps $> .05$). To conclude, the magnitude of the preparation effects did not differ between blocking and mixing object-naming and reading trials.

To summarize, as in Experiment 2, participants could benefit from foreknowledge of the first syllable of a word without knowing the remainder of a response word, but they could not benefit from foreknowledge of the second syllable of a word while not knowing the first syllable. Thus, the preparation benefit for initial syllables was obtained regardless of whether object-naming and reading trials were tested separately (Experiment 2) or whether they were mixed (Experiment 3). Furthermore, the magnitude of the preparation effects did not differ between blocking and mixing object-naming and reading trials. This suggests that there exists a serial encoding mechanism that is shared between object naming and reading rather than two serial mechanisms used for object naming and reading separately.

GENERAL DISCUSSION

The aim of the research reported in this paper was to investigate whether phonological encoding mechanisms are shared between speaking and oral reading and whether they operate serially or in parallel. Experiment 1 showed that the seriality of encoding inside a syllable revealed in previous studies of speaking is observed for both naming objects and reading their names. Experiment 2 showed that the same holds for the seriality of the encoding of successive syllables. Experiment 3 showed that the seriality effects are also obtained when object-naming and reading trials are mixed rather than tested in separate blocks of trials, as in Experiments 1 and 2.

The seriality effects within the syllables of words observed in Experiment 1 and the seriality effects between the syllables of words observed in Experiments 2 and 3 support serial models of phonological encoding. Serial planning in itself does not exclude preparation benefits for shared noninitial segments. A serial system may leave both initial and noninitial parts of the phonological code temporarily unspecified. Instead, the impossibility of planning noninitial segments in advance is implied by the suspend-resume mechanism of WEAVER++. Furthermore, the finding of equivalent seriality effects for object naming and reading in Experiments 1–3 suggests that the observed seriality is due to serial phonological encoding in both object naming and reading rather than a serial grapheme-to-phoneme mapping process in oral reading. Of course, this does not exclude the possibility that a grapheme-to-phoneme mapping in reading also happens serially. Coltheart et al. (2001) review empirical findings that support such a serial mapping, such as a position of spelling-irregularity effect on reading latencies. The findings from the present Experiments 1–3 suggest that there is seriality in phonological encoding beyond a grapheme-to-phoneme mapping, shared by naming objects and reading their names.

The equivalent effects for object naming and reading observed in Experiments 1 and 2 leave open the question of whether phonological encoding mechanisms are shared by speaking and reading, as most models of speaking and reading assume, or whether there are separate mechanisms for speaking and reading both operating in a similar fashion. Experiment 3 showed that participants were able to plan initial segments even when speaking and reading trials were mixed. With separate mechanisms, the token phonological representation prepared by the reading mechanism would differ from the token phonological representation needed for object naming, and a preparation benefit should not be obtained with mixing trial types. Thus, the results of Experiment 3 suggest that a serial phonological encoding mechanism is shared between speaking and reading. Taken together, the results of Experiments 1–3 support the merging of models of reading aloud such as DRC with models of speaking such as WEAVER++ at the level of segmental spellout. On this view, segmental spellout is followed by serial prosodification in both speaking and oral reading. Note that if facilitation from end overlap had been obtained in the present Experiments 1–3, and if the facilitation had been similar for object naming and reading, this would also have supported the assumption that phonological encoding mechanisms are shared between speaking and reading, but it would have contradicted earlier findings (e.g., Meyer, 1990, 1991) and have falsified WEAVER++.

The preparation paradigm used in Experiments 1–3 involves repetition of words and foreknowledge of words, neither of which is representative of tasks used in the word-reading literature. To examine whether the present results generalize to these other tasks, future studies might test whether classic word-reading findings such as spelling regularity effects are reflected in the latencies of the preparation paradigm. Repetition and foreknowledge of words do not exclude the possibility, however, that aspects of reading are assessed. For example, Coltheart, Woollams, Kinoshita, and Perry (1999) observed a seriality effect on color naming caused by written distractor words in the color–word Stroop task (Stroop, 1935), which also involves massive repetition of words and colors (red, green, and blue). Coltheart et al. (1999) took the seriality effect in the Stroop task as evidence for a left-to-right component in print-to-speech conversion. In general, evidence from the Stroop task is taken to bear on the processes of naming and reading, despite the massive repetition of words in the task (e.g., MacLeod, 1991; Roelofs, 2003). Obviously, performance on preparation and Stroop tasks differs in several ways from ordinary speaking and reading. Speakers and readers rarely say the same three words over and over again, and they cannot normally predict how the next word to be uttered will begin. Yet, the preparation and Stroop effects show very systematic patterns. In preparation experiments, participants can exploit certain types of foreknowledge, whereas other types of foreknowledge are completely useless (or even hinder). A natural account of these patterns is to relate them to the way speech is normally planned, and the same holds for Stroop effects (Roelofs, 2003; Roelofs & Hagoort, 2002). Thus, I assume that the reason why preparation effects were obtained only for initial overlap in object naming and reading is that in normal word production the planning proceeds from the beginning of a word form to its end.

Even under the assumption of shared phonological encoding mechanisms, reading and object naming differ in so many other respects that differences in experimental results between reading and object naming are to be expected. The easiest explanation of the differences would be in terms of the processing components that are not shared. For example, in Experiments 1–3, object naming took longer than reading (as is usually the case), which is most easily explained by assuming that object naming engages extra processing components (e.g., conceptual identification and lemma retrieval; see Roelofs, 2003). In contrast, striking similarities between reading and object naming (e.g., the preparation effects in Experiments 1–3) are most easily explained by assuming shared processing components.

Although the present findings may be explained in terms of the phonological encoding mechanisms shared by normal speaking and reading, it remains possible that participants adopted a special strategy in the experiments. For example, if the encoding mechanisms were not shared between object naming and reading, participants may adopt the strategy of using the reading mechanism to prepare the responses on all trials (including the object-naming trials) or using the object-naming mechanism to prepare the responses on all trials (including the reading trials) in the homogeneous sets of the mixed-task blocks (Experiment 3). However, this strategy would imply a type of planning that would be successful on only half of the trials, namely those that involve the prepared task (reading or object naming). Thus, one would expect that the facilitation is reduced more for object naming than for reading (or vice versa). This, however, appears not to be the case. The preparation benefits for object naming and reading in the variable-task blocks of Experiment 3 were equally large for the two tasks and the benefits were also equal in size to the effects in the constant-task blocks of Experiment 2. So, preparation in homogeneous variable-task blocks implies no reduction of the preparation benefit, which supports the idea that a single encoding mechanism is shared between object naming and reading.

Kawamoto (1999) argued that the seriality effects from the preparation paradigm reflect the fact that initial speech segments are articulated rather than phonologically encoded before later segments. According to Kawamoto and colleagues (Kawamoto, 1999; Kawamoto, Kello, Jones, & Bame, 1998), speakers initiate articulation immediately after having planned the first phonological segment of a word both in object naming and reading. Consequently, preparation of the first segment of a word will yield a latency benefit but preparation of noninitial segments will not, as observed in the present experiments.

There are, however, problems with Kawamoto's initial-segment articulation proposal (discussed by Roelofs, 2002). As Kawamoto (1999) admitted, his proposal fails to explain the finding that the preparation benefit increases when more phonological segments are shared (Meyer, 1990, 1991), even when the shared part crosses a phonological word boundary (Roelofs, 1998). If articulation were initiated after the first phonological segment is planned, the magnitude of preparation benefits should be independent of the number of later segments that can be prepared, contrary to what is empirically observed. Moreover, the initial-segment articulation proposal fails to explain coarticulation effects, which are observed both in object naming and reading words (Rastle, Harrington, Coltheart, & Palethorpe, 2000).

To conclude, the results of the reported experiments confirmed the widely accepted but not much tested assumption that phonological planning mechanisms are shared between naming objects and reading their names. Moreover, the results suggest that some components of phonological planning operate serially in both object naming and reading. Furthermore, the results suggest that the serial planning mechanism can leave noninitial but not initial parts of the phonological code temporarily unspecified. Finally, the finding of similar results for object naming and reading suggests that the observed seriality is due to phonological encoding mechanisms shared by naming and reading rather than a grapheme-to-phoneme conversion in oral reading. The results support the merging of models of reading aloud such as DRC with models of speaking such as WEAVER++ at the level of segmental spellout. On this view, segmental spellout is followed by serial prosodification in both speaking and oral reading, causing the seriality effects in naming objects and reading their names obtained in Experiments 1–3.

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NOTE

1. In WEAVER++, a distinction is made between words with regular and irregular stress patterns (Levelt et al., 1999; Roelofs, 1997a). For words with irregular stress (about 10% of the words in Dutch), metrical structures are stored in memory and retrieved in parallel with segmental spellout. This is not shown in Figure 1 in order to keep the figure simple. The experiments in the present paper tested words with regular stress only.

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