Skeletal Structure of Printed Words: Evidence From the Stroop Task

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Do readers encode the sequencing of consonant (C) and vowel (V) phonemes (skeletal structure) in printed words? The authors used the Stroop task to examine readers' sensitivity to skeletal structure. In Experiment 1, CVC nonwords (e.g., *pof*) facilitated the naming of colors with congruent frames (e.g., *red*, a CVC word) but not with incongruent ones (e.g., *green*). In Experiment 2, the color *black* (a CCVC frame) was named faster with a congruent CCVC frame (e.g., *grof*) compared to either CCVCC (e.g., *groft*) or CVC (e.g., *gof*) incongruent controls. Finally, in Experiment 3, the color *pink* (a CVCC frame) was named faster with a CVCC frame (e.g., *goft*) compared to either CCVCC or CVC incongruent controls. In most cases, congruent frames shared no segments with the color name. These findings demonstrate that readers automatically assemble the skeletal structure of printed words.

There is considerable evidence that the computation of adequate representations for printed words hinges on linguistic competence (e.g., Perfetti, 1985, 1992). The existence of intact linguistic knowledge has been shown to facilitate the acquisition of grapheme to phoneme correspondences (e.g., Harm & Seidenberg, 1999), whereas deficits in linguistic competence are linked to reading disability (e.g., Molfese, 2000; Paulesu et al., 2001; Ramus et al., 2003). Reading research has further demonstrated that the representation of printed words encodes various aspects of their linguistic structure, including syllable structure (e.g., Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995; Treiman & Zukowski, 1988), phonological features (Lukatela, Eaton, & Turvey, 2001), and metrical structure (Colombo & Tabossi, 1992; Miceli & Caramazza, 1993), and that these representations are subject to linguistic constraints, such as the constraint on minimal sonority (Alonzo & Taft, 2002; Levitt, Healy, & Fendrich, 1991) and the obligatory contour principle (Berent, Shimron, & Vaknin, 2001). The intimate link between reading skill and linguistic competence gives rise to the hypothesis that the assembly of structured linguistic representations to print is automatic—a default setting of the skilled reading system that is computed even when it is not required by task demands.

In the following research, we use Stroop methodology (Stroop, 1935) to examine the automaticity of linguistic constraints on reading. Because the Stroop task does not require word reading, the demonstration of word reading using this methodology suggests that reading is automatic. We propose to extend this logic to study the automatic computation of linguistic structure. If linguistic competence constrains reading, then performance under the Stroop task should reveal the assembly of structured linguistic representations to print. As a case study, we examine the representation of the phonological skeleton—a linguistic structure that has received little attention in the reading literature. Thus, the goal of our investigation is twofold: We examine whether the Stroop methodology can be used for probing the linguistic structure of printed words, and, in doing so, we investigate a relatively unfamiliar aspect of their representation—the phonological skeleton.

The skeleton plays a central role in autosegmental phonological representations. Autosegmental phonology views phonological representations as multidimensional entities (for reviews, see Broselow, 1995; Goldsmith, 1990; Kenstowicz, 1994). These representations segregate phonological elements (e.g., phonological features, tones, syllable structure) onto separate levels of representation (autosegments). These multiple levels are anchored to a skeleton—a set of timing units, each captured by an abstract slot. For instance, the word *tip* includes three timing slots, whereas *trip* comprises four slots. In these examples, each timing slot holds a single phoneme. In languages that contrast phonemes in terms of length, a single phoneme may be anchored to multiple slots. For instance, the lax vowel in the word *sit* is anchored to a single slot, whereas the tense vowel in *seat* is associated with two slots (Giegerich, 1992; see Figure 1). Some models of the skeleton further distinguish between skeletal slots according to their syllabic roles (McCarthy, 1985). Such models distinguish between words that are matched on their total number of slots depending on the arrangement of consonants (C) and vowels (V). For instance, the words *cat* and *act* each include three slots, but the former, *cat*, is represented by a CVC structure, whereas the latter, *act*, is assigned a VCC structure. The skeleton thus serves numerous functions in phonological representations. First, it is an organizational core—an anchor to which subsegmental (i.e., phonological features) and suprasegmental (e.g., syllable structure) information is linked. Second, the skeleton allows one to distinguish segments in terms of their length (e.g., to contrast *sit* and *seat*). Finally, the skeleton encodes the word's prosodic shape. For instance, the words *cat, dog,* and *ship* share a CVC frame. The shared skeletal frame captures a prosodic invariance among words that differ on their segmental contents.

C   V   C   skeletal tier

| | |

s   I   t   segmental tier

C   V   V   C   skeletal tier

| \   / |

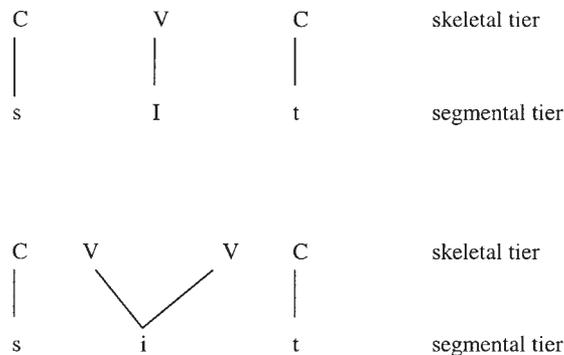s   i   t   segmental tier

Figure 1. The skeletal structures of the words *sit* (top) and *seat* (bottom). The contrast in vowel length is due to the association of the vowel segment to one skeletal position in *sit* versus two positions in *seat*. C = consonant; V = vowel.

Given the linguistic and psycholinguistic evidence demonstrating the representation of the skeleton in spoken language (evidence we review below), and given further the close interaction between reading ability and phonological competence, one may wonder whether the skeleton plays a role in reading. Indeed, several computational models of reading have implicitly assumed a skeleton at their core (e.g., Harm & Seidenberg, 1999; Zorzi, Houghton, & Butterworth, 1998). Despite its central role in models of phonology and reading, the representation of skeletal structure in reading has been largely unexplored experimentally. The present research examines whether skilled readers automatically encode the skeletal structure of novel printed words. Before describing our experimental manipulation, we first review the existing evidence for the skeleton in the representation of spoken and printed words.

Existing Evidence for the Skeleton

The skeleton is an abstract representation of a word's prosodic structure that is largely independent of phonemic contents. If speakers represent the skeleton, then words that share a skeletal frame (e.g., *cat*, *log*) should be perceived as similar despite sharing no segments in common. Existing research provides multiple sources of evidence that support this prediction.

One source of evidence is offered by speech errors. It is well known that exchange errors are constrained by syllable position: Onset consonants exchange with onset consonants (e.g., *keep a tape → teep a cape*), coda consonants exchange with coda consonants, and vowels exchange with vowels (Fromkin, 1973). However, consonants and vowels never undergo exchange errors, even when such exchanges are phonotactically feasible (e.g., *tea → eat*; MacNeilage, 1998). Speech errors are constrained not only by the status of the segment as a consonant or vowel but also by its length. Recall that skeletal representations capture vowel length in terms of the number of skeletal slots linked to the vowel segment: Short vowels take a single skeletal slot, whereas long vowels are linked with two slots. Stemberger (1984) observed that substitution errors in German and Swedish tend to maintain vowel length despite changes in segmental contents (e.g., *i: → y:*, wi:se → wü:se). Similar evidence for the preservation of skeletal structure in the face of segmental errors has been reported in spelling disorders that result from neurologic damage (Caramazza & Miceli, 1993; Rapp & Caramazza, 1997). The arrangement of

consonant and vowel placeholders not only serves as an anchor of phonological and graphemic representations, but it may also assist the language learner in discriminating between languages (Ramus, Nespor, & Mehler, 1999) and inferring their syntactic properties (Nespor, Peña, & Mehler, 2003). Ramus et al. (1999) have shown computationally that the relative durations of consonants and vowels distinguish between languages of various rhythmic classes. Furthermore, Ramus and Mehler (1999) demonstrated experimentally that this information is sufficient for discriminating English from Japanese by adult French speakers. These findings suggest that speakers encode the length of segments independent of their contents and distinguish between consonant and vowel categories.

The encoding of abstract timing units is further implicated by the experimental investigation of speech production in various languages. These experiments demonstrate that the production of a word is facilitated by previously presented words that share its abstract skeletal structure relative to controls matched for length. For instance, Sevald, Dell, and Cole (1995) asked participants to repeat two English nonwords for a period of 4 s. They observed facilitation for stimuli that shared skeletal structure (*kem til-fer* or *kemp-tilf-ner*) compared to length-matched controls (*kem tilf-ner* or *kemp til-fer*). Likewise, picture naming in Spanish is facilitated when the picture is preceded by an auditory prime that shares the picture's skeletal structure (Costa & Sebastian-Gallés, 1998; Experiments 1–2). For instance, naming the target picture *cola* is facilitated by the auditory word *nido* relative to *ninfa*. In a related task, participants are presented with a picture (e.g., *pinza*, whose initial syllable has a CVC structure) preceded by a series of printed words or nonwords that either share the skeletal structure of its initial syllable (e.g., *cesta, bolsa, salto)* or manifest a different skeletal structure (e.g., words whose initial syllable is a CV syllable, such as *cesa, bolo, sala*). Participants are asked to read aloud each of the primes and then name the picture targets. Picture naming is facilitated by primes that share the target's skeletal structure compared to controls (in Spanish: Costa & Sebastian-Gallés, 1998, Experiments 3–4; in French: Ferrand & Segui, 1998). Additional evidence for the representation of the skeleton is observed in Dutch using a translation task. Meijer (1996) observed that the translation of printed English words into Dutch (e.g., the English *necktie*, whose Dutch translation is *das*) is facilitated when the target is preceded by an auditory word prime that matches the translation's skeletal structure (e.g., *nok*, matching the Dutch *das*) relative to mismatching controls (e.g., *norf*).

Although these results converge to support the role of the skeleton in processing spoken language (but see Roelofs & Meyer, 1998, and Schiller & Caramazza, 2002, for conflicting results), they cannot determine whether the skeleton plays a role in silent reading. To address this question, it is necessary to show that the skeleton is assembled to print online, rather than retrieved from memory. Furthermore, one must rule out overt articulation as the source of skeletal encoding. The existing evidence does not address these questions: Most previous research has examined the representation of skeletal structure for existing words, hence, these results could reflect the retrieval of a stored skeletal frame from the mental lexicon rather than its assembly. The only experiment to examine the effect of skeletal similarity on the representation of novel printed target words (Sevald et al., 1995) entailed repeated articulation. Likewise, in priming experiments, primes were either presented auditorily (e.g., Costa & Sebastian-Gallés, 1998, Experiments 1–2; Meijer, 1996) or read aloud (e.g., Costa & Sebastian-

Gallés, 1998, Experiments 3–4; Ferrand & Segui, 1998, Experiment 2). The role of the skeleton in the representation of such stimuli may thus be due to the generation or retrieval of an articulatory plan, rather than phonological encoding. Such findings cannot determine whether readers assemble the skeletal structure for printed words that they are not required to articulate.

A recent investigation by Berent, Bouissa, and Tuller (2001) specifically examined the role of skeletal structure in the representation of printed nonwords. Participants in their experiments were asked to name printed nonword targets (e.g., *dus*) primed by nonwords that either shared (e.g., *fap*) or did not share (e.g., *ift*) the skeletal structure of the target. Target identification was modulated by skeletal similarity, and this finding emerged even when the target and prime shared no segments (Experiments 3–4), and when participants were not required to articulate the prime (Experiment 4). In the present research, we seek to examine if the assembly of skeletal structure in reading is automatic. Sensitivity to skeletal structure requires the computation of abstract, fine-grained linguistic structure for printed words. Although such detailed representation might be available to readers upon deliberate, controlled processing of printed words, it is unknown whether it is computed automatically. In particular, it is uncertain if the assembly of skeletal structure is a routine aspect of skilled reading. To address these questions, in the following experiments we examine the representation of skeletal structure of nonwords—stimuli for which a stored skeletal representation is unavailable. The assembly of skeletal structure is assessed in a task that does not require any response to printed words (articulatory or otherwise). In fact, participants are advised to avoid reading altogether. If the assembly of skeletal structure is an integral aspect of reading, then readers may be sensitive to the skeletal structure of printed nonwords they are instructed to ignore.

The Present Experiments

In our experiments, we used the Stroop task to examine the role of skeletal structure. Participants were presented with letter strings displayed in color. These letter strings correspond to nonwords whose skeletal similarity to the color name is manipulated. For instance, consider the nonwords *pof* and *ploof* printed in the color red. The word *red* bears a CVC structure. Accordingly, the skeletal structure of *pof* (CVC) is congruent with the skeletal structure of the color name, whereas the structure of *ploof* (CCVVC) is incongruent. Note that the printed nonwords share no segments with the color name—their congruency is defined solely in terms of abstract skeletal structure. Participants are asked to name the color of the printed stimulus while ignoring its contents. Because skilled reading is highly automated, we expect that readers will be unable to ignore the printed stimulus. Indeed, highly automated processes are typically ballistic—they tend to run to completion even when their execution is not required (Logan & Cowan, 1984; Tzelgov, 1997). Certain aspects of the printed words will thus be encoded even though participants are not required to process them. A critical question is whether such aspects include skeletal structure. If the assembly of skeletal structure is automatic, then it might be evident in the Stroop task. Thus, color naming should be affected by the skeletal congruency between a nonword and its color: Color naming should be faster for nonwords that share the skeletal structure of the color name compared with nonwords with a mismatching skeletal structure.[1]

Experiment 1

In Experiment 1, we compared the effect of two types of nonwords on naming the color *red*. One type had a CVC skeletal structure (e.g., *pof*), a structure congruent with the color name. The other type of nonword had an incongruent skeletal structure: These nonwords had a complex onset and a long vowel, either a monothong (e.g., *ploof*, a CCVVC structure), or a diphthong, (e.g., *plaif*, a CCVCC structure). If participants are sensitive to the congruency between the skeletal structure of nonwords and the color name, then the color *red* should be named faster in the presence of a CVC frame relative to a CCVVC/CCVCC frame. Furthermore, the facilitation by CVC nonwords should be found only in the presence of colors with a congruent skeletal structure—color names whose structure does not include a CVC syllable should not be facilitated by CVC nonwords. To examine this prediction, we presented the same set of nonwords with two additional colors: *green* (CCVVC structure) and *yellow* (a CVCVC frame). Although the skeletal frames of these colors manifest a certain overlap with the nonword targets, we do not expect strong effects of skeletal congruency for these colors. In the case of *yellow,* it is uncertain whether the initial syllable is parsed as a CVC because the medial consonant is ambisyllabic (see Cutler, Mehler, Norris, & Segui, 1989; Ferrand, Segui, & Humphreys, 1997). Likewise, there is reason to doubt the potential of CCVVC/CCVCC frames to facilitate *green.* Because the assembly of phonology for orthographically complex English vowels is particularly slow (see Berent & Perfetti, 1995, Experiment 4), the phonological representation of CCVVC nonwords may be too coarse to facilitate the naming of the color *green.* Even if the phonology of complex vowels was rapidly available, in the case of diphthong targets (e.g., *plaif*, a CCVCC), it would not be fully congruent with the frame of *green* (a CCVVC). Although it is unclear whether the skeletal structure of *green* is congruent with the frame assembled to CCVVC/CCVCC targets, it should surely be incongruent with CVC nonwords. If skeletal congruency depends on the relationship between the skeletal structure of a printed nonword and the color name, then nonwords with a CVC frame should facilitate naming the color *red* (and, possibly, *yellow*), but not *green*.

Method

Participants

Twenty-five Florida Atlantic University students participated in the experiment in partial fulfillment of a course requirement. They were all native English speakers who were skilled readers. Reading skill was assessed by a test of nonword reading, which was administered at the end of the experimental session. The test included 20 monosyllabic, 20 disyllabic, and 20 trisyllabic nonwords. All participants could correctly decode a minimum of 80% of the stimuli in each of the three sublists (monosyllabic, disyllabic, and trisyllabic sublists). In addition, they had normal or corrected-to-normal vision and normal color vision.

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[1] Our prediction compares congruent frames to incongruent frames. This approach allows us to establish if people are sensitive to skeletal frames, but we cannot determine their precise effect on color naming. In particular, we cannot determine whether skeletal congruency results in actual savings to color naming or merely lesser interference. This question awaits future research.

Materials

The materials were letter strings presented in color. There were two groups of materials. The first group consisted of nonwords whose skeletal similarity to the color name was manipulated (the skeletal-congruency condition). The second group corresponded to color names whose congruency with the color was manipulated (color-congruency condition).

Skeletal-congruency targets. The skeletal-congruency targets were 28 pairs of nonwords that were orthographically and phonologically legal. Pair members were matched on their phonemes (see Appendix A): One member exhibited a CVC skeletal structure (e.g., *pof*), whereas the other had an onset cluster and a long vowel, either a monothong (e.g., *ploof*, a CCVVC structure) or diphthong (e.g., *plaif*, a CCVCC structure). These targets were presented in three colors: red (a CVC structure), green (a CCVVC structure), and yellow (a CV[C]VC structure, where the middle consonant is ambisyllabic). The targets did not share the initial phoneme with any of the color names. The letter *E*, which is common to all three color names, appeared five times in the CVC items and six times with the CCVVC/CCVCC items. Likewise, the occurrence of the letter *D* in the final position was equated across the CVC and the CCVVC frames (one occurrence per frame). There was a total of 168 skeletal congruency trials (28 pairs × 3 colors).

Color-congruency targets. To probe for the standard Stroop effect (the congruency between the color and the meaning of a printed color word), we included color words in the experiment. There were a total of 420 color-congruency trials presented in the same colors as the skeleton-congruency trials (red, green, and yellow in equal proportions). The word and the color were congruent on 40% of the trials (e.g., the word *red* printed in red) and incongruent on 40% (e.g., the word *red* printed in green). In the remaining 20% of trials, the colored stimulus was a set of Xs (the neutral condition).

To familiarize the participants with the experimental task, we presented them with a short practice phase. The practice consisted of 12 color-congruency trials (3 congruent, 3 neutral, and 2 incongruent trials in each of the three colors) and 6 skeletal-congruency trials (2 skeletal-congruency conditions × 3 colors). None of the nonwords that we presented in the practice appeared in the experimental trials. The color-congruency and skeletal-congruency trials were mixed and presented in random order in both the practice and the experimental phase.

Procedure

Participants were presented with a letter string (a nonword, in the skeletal-congruency condition, or a color word, in the color-congruency condition) printed in color. They were asked to name the color of the printed stimulus and ignore its content. Each trial began with a fixation point, which was presented at the center of the computer screen for 500 ms. The fixation point was immediately replaced by a string of upper case letters that remained on the screen until the participant responded. Response accuracy was coded by the experimenter. Slow responses (responses slower than 2,000 ms) and inaccurate responses were followed by a short warning signal in the form of a beep and a written computer message. The experiment was conducted using the Micro Experimental Laboratory (MEL; Psychology Software Tools, Inc., Pittsburgh, PA) pro-

gram. The stimuli were presented in the colors red, green, and yellow (in the MEL program, these were the colors 4, 2, and 14, respectively) on a black background (the color 0 in MEL). Participants were tested individually in a dimly lit room.

Results

We lost 0.9% of the response latency data due to microphone failures. Correct responses that were slower or faster than 2.5 standard deviations from the grand mean of each color (a total of 2.64% for the color red, 4.94% for green, and 2.52% for yellow) were removed. The data were next submitted to two analyses, to examine the effect of color and skeletal congruency across the three colors.

Color Congruency

Mean color-naming latency and accuracy as a function of color congruency is presented in Table 1. To assure that the three colors under investigation are comparable, we evaluated the Stroop effect in the three colors by means of a two-way analysis of variance (ANOVA; 3 color × 3 congruency) by participants (F_1). These analyses yielded a significant effect of congruency, $F_1(2, 48) = 130.71$, $MSE = 1,658.34$, $p < .0001$; $F_1(2, 48) = 23.21$, $MSE = 0.002$, $p < .0001$, in latency and accuracy, respectively. The effect of color name was significant only in the latency data, $F_1(2, 48) = 15.79$, $MSE = 2,254.38$, $p < .0001$; $F_1(2, 48) < 1$, $MSE = 0.001$, in latency and accuracy, respectively. Importantly, there was no evidence of a Congruency × Color interaction (all $Fs < 1$). Planned comparisons showed that color naming was significantly faster (albeit no more accurate) with the congruent relative to the neutral condition, $F_1(1, 48) = 8.75$, $p < .005$; $F_1(1, 48) < 1$, for latency and accuracy, respectively. Conversely, color naming was significantly slower and less accurate with the incongruent relative to the neutral condition, $F_1(1, 48) = 150.98$, $p < .0001$; $F_1(1, 48) = 30.98$, $p < .0001$, in latency and accuracy, respectively.

Skeletal Congruency

Mean color-naming latency as a function of color name and the nonwords' skeletal structure is presented in Table 2. These data were submitted to a two-way ANOVA (3 color × 2 skeletal structure) by participants (F_1) and items (F_2). The analyses of response latency revealed significant main effects of skeletal structure, $F_1(1, 24) = 7.70$, $MSE = 626.85$, $p < .02$; $F_2(1, 27) = 12.54$, $MSE = 388.85$, $p < .002$, and color, $F_1(2, 48) = 10.70$, $MSE = 1,997.39$, $p < .0001$; $F_2(2, 54) = 22.10$, $MSE = 957.35$, $p < .0001$. The Color × Skeletal Structure interaction was marginally significant, $F_1(2, 48) = 2.60$, $MSE = 706.11$, $p < .09$; $F_2(2, 54) =$

Table 1

Color Naming Latency (in Milliseconds) and Accuracy (% Correct) as a Function of Color and Congruency in Experiment 1

Color	Latency			Accuracy		
	Congruent	Neutral	Incongruent	Congruent	Neutral	Incongruent
Red	615	629	715	99.6	99.4	93.8
Green	644	669	749	99.2	98.3	94.3
Yellow	608	628	706	99.3	98.9	95.2

Table 2

Color Naming Latency (in Milliseconds) and Accuracy (% Correct) as a Function of Skeletal Frame and Color in Experiment 1

	Latency		Accuracy	
Color	CVC	CCVVC/ CCVCC	CVC	CCVVC/ CCVCC
Red	636	661	98.9	98.3
Green	681	683	98.4	98.5
Yellow	641	648	99.7	98.8

Note.   C = consonant; V = vowel.

2.78, $MSE = 792.42$, $p < .08$, which suggests that the effect of the nonwords' skeletal structure depends on the color name. The effect of CVC and CCVVC/CCVCC nonwords on naming the three colors was compared by using a simple effects analysis. CVC nonwords facilitated naming the color *red* significantly, $F_1(1, 24) = 9.44$, $MSE = 836.22$, $p < .006$; $F_2(1, 27) = 18.83$, $MSE = 464.83$, $p < .002$, but they did not reliably facilitate the colors *green*, $F_1(1, 24) < 1$, $MSE = 800.10$; $F_2(1, 27) < 1$, $MSE = 1001.60$, or *yellow*, $F_1(1, 24) = 1.35$, $MSE = 402.76$, $p < .26$; $F_2(1, 27) = 1$, $MSE = 507.29$, $p < .33$. The analyses on response accuracy yielded no significant effects (all Fs < 1.39).

Discussion

The results of Experiment 1 demonstrate that people name the color *red* faster in the context of unrelated nonwords that share its skeletal structure (CVC) relative to those with a mismatched structure (CCVVC or CCVCC). The facilitation of the congruent CVC structure was obtained despite minimal phonemic overlap with the color name—CVC targets rarely exhibited the letters *r, e,* and *d* (in 1/28, 5/28, and 2/28 pairs, respectively), and these rare cases of letter overlap were equated among the congruent and incongruent pair members. These observations suggest that the facilitation is due to the abstract skeletal structure of CVC nonwords. Crucially, the same set of CVC nonwords did not facilitate color names that do not exhibit a clear CVC syllable, *green* and *yellow*. As discussed earlier, it is uncertain if English speakers represent the initial syllable of *yellow* as CVC because its medial consonant is ambisyllabic. The observation of weak, unreliable facilitation for *yellow* by CVC targets is consistent with this interpretation, as well as with earlier research (e.g., Ferrand et al., 1997). Likewise, the color *green* was not facilitated by the CCVVC frame. This outcome was expected, because the assembly of phonology for orthographically complex English vowels may not be rapidly available (Berent & Perfetti, 1995, Experiment 4), and even if it were, in the case of diphthongs (e.g., *plaif*, a CCVCC), the skeletal structure of the nonwords would not be fully congruent with that of *green*. Indeed, the only a priori prediction concerning the color *green* was that, unlike the color *red*, *green* should not benefit from the CVC frame. This prediction is clearly borne out by the results. The confinement of the facilitation by CVC nonwords to the color *red* suggests that it is due to the congruency between their skeletal structure and that of the color name, rather than to some across-the-board preference for CVC items.

Experiments 2–3 extend the evaluation of skeletal congruency effects to two additional colors. To assure that the effect of skeletal structure is not due to phonemic similarity, the nonword targets shared no phonemes or graphemes with the color name. These strict constraints on the structure of the materials forced us to examine the effect of skeletal congruency by using a single color name per experiment (the experimental color). To vary the number of colors in the experiment, we presented the experimental color with additional filler colors.

Experiment 2

Experiment 2 examined the effect of skeletal congruency for the color *black* (/blæk/), a CCVC frame. This color was paired with nonwords of three types of skeletal frames: a congruent skeletal frame (CCVC; e.g., *frim*), a short incongruent frame (CVC; e.g., *fim*), and a long incongruent frame (CCVCC; e.g., *frimp*). If color naming is sensitive to skeletal congruency, then color naming should be fastest with nonwords whose skeletal frame is congruent with that of the color name. Note that in Experiment 1, the short incongruent frame, CVC, corresponds to the structure shown to facilitate the color *red*. The potential of the same frame to interfere with *black*, in Experiment 2, would offer further support to our hypothesis that the effect of skeletal frame is due to its congruency with the color name, rather than its inherent properties.

The outcomes of this experiment can further illuminate the source of congruency effects. Our definition of congruency concerns the arrangement of placeholders for consonant and vowel phonemes. An alternative orthographic account may attribute the effect of skeletal structure to the arrangement of consonant and vowel letters. Although participants are not presented with an orthographic representation of the color name, they could conceivably retrieve it from the lexicon. Skeletal effects may thus reflect congruency between two orthographic representations, one addressed from the lexicon (for the color name) and one assembled to print (for the nonword). If skeletal-congruency effects reflect the overlap of orthographic frames, then naming the color *black* should be facilitated by the CCVCC relative to the CCVC frame. Conversely, if skeletal congruency reflects the overlap of phonological frames, then the CCVC skeletal structure should be represented as congruent with /blæk/. Thus, CCVC frames should facilitate naming the color *black* relative to either CVC or CCVCC frames.

Method

Participants

Twenty-three Florida Atlantic University students participated in the experiment in partial fulfillment of a course requirement. They were all native English speakers and skilled readers with normal color vision, as described in Experiment 1.

Materials

As in Experiment 1, the materials included two groups of targets designed to examine the effect of skeletal congruency and color congruency on color naming.

Skeletal-congruency targets.   The skeletal-congruency targets were nonwords whose skeletal similarity to the color name was manipulated. Seventy-two of these nonwords served as experimental targets, and an additional 144 nonwords were used as fillers (for a total of 216 skeletal-

congruency trials). All targets were orthographically and phonologically legal and further, the experimental targets shared no phonemes with the experimental color, *black*. The experimental targets were arranged in trios (see Appendix B). Members of the trio were matched on their phonemes, but differed on their skeletal similarity to the color name. The congruent trio member had a CCVC skeletal structure (e.g., *frim*), whereas the incongruent members had a CVC (e.g., *fim*, a short incongruent condition), or a CCVCC (e.g., *frimp*, a long incongruent condition) structure. There were 24 experimental trios.

To discourage expectations regarding the color's name, we included filler trials in two additional colors: *yellow* (CV[C]VC) and *pink* (CVCC).[2] These fillers consisted of nonwords whose skeletal structures matched those of the experimental targets (48 nonwords with a CVC structure, 48 nonwords with a CCVCC structure, 12 nonwords with a CCVC structure, and 36 nonwords with a CVCC structure). We also attempted to eliminate expectations regarding the color based on the letters (or phonemes) of the target words (in both fillers and experimental targets). To this end, the targets and fillers never shared the initial phoneme of the color name in which they were presented, nor did they share onset with competing colors (i.e., *p, pl, b, bl*, or *y*). Because of these tight constraints on the structure of the targets, we had to reuse 4 of the filler nonwords in the practice session. In addition, 2 of the filler trios were repeated twice. None of the experimental targets was repeated in the experiment.

Color-congruency targets. A second group of trials was included in order to probe for the standard Stroop effect, namely, the congruency between the color and the meaning of a printed word. There was a total of 360 color congruency targets (40% congruent, 40% incongruent, and 20% neutral), presented in the same colors as the skeletal-congruency trials (*black, pink,* and *yellow*).

To familiarize participants with the experimental task, they were presented with a short practice list. The practice consisted of 9 color-congruency words (3 color congruency, 3 neutral, and 3 incongruent words) and 12 skeletal-congruency trials (1 skeletal trio presented in *pink* and *black* and 2 skeletal trios presented in *yellow*). The color-congruency and skeletal-congruency trials were mixed and presented in random order in both the practice and experimental sessions.

Procedure

The procedure was as described in Experiment 1, with the only exception being that the screen background was set to gray (code 7 in the MEL program), in order to allow for the presentation of the target color *black*. The colors *black, yellow,* and *pink* were selected as black (0), yellow (14), and magenta (5) in MEL, respectively.

Results

We lost 0.37% of the total correct responses due to microphone failures. To eliminate the effect of outliers, we excluded from the analyses responses slower or faster than 2.5 standard deviations from the grand mean of the target color *black* (2.44% of the total correct responses). The effects of color congruency and skeletal congruency on color naming and accuracy were assessed using ANOVAs. All congruency levels were further compared by planned contrasts.

Color Congruency

Mean response latency and accuracy as a function of color congruency are listed in Table 3. The main effect of color congruency was significant in both naming latency, $F_1(2, 44) = 101.62$, $MSE = 678.89$, $p < .0002$, and accuracy, $F_1(2, 44) = 29.78$, $MSE = 0.001$, $p < .0002$. Planned comparisons showed that color naming was impaired in the incongruent condition relative to

Table 3

Color Naming Latency (in Milliseconds) and Accuracy (% Correct) as a Function of Color Congruency in Experiment 2

Color congruency	Latency	Accuracy
Congruent	605	99.6
Neutral	621	99.1
Incongruent	707	93.0

the neutral condition: in latency, $F_1(1, 44) = 126.33$, $p < .0001$; in accuracy, $F_1(1, 44) = 41.47$, $p < .0001$. Conversely, congruency between the word's meaning and its color facilitated color-naming latency (albeit not accuracy) compared with the neutral condition, $F_1(1, 44) = 3.88$, $p < .06$; $F_1(1, 44) < 1$, for latency and accuracy, respectively.

Skeletal Congruency

Table 4 provides the mean response latency and accuracy in the three skeletal-congruency conditions. The ANOVAs on response latency yielded a significant main effect of skeletal congruency, $F_1(2, 44) = 4.78$, $MSE = 540.07$, $p < .02$; $F_2(2, 46) = 3.76$, $MSE = 691.16$, $p < .04$. There was no effect of skeletal congruency in the accuracy data (all $Fs < 1$). Planned comparisons showed that color naming was significantly faster with the congruent structure (CCVC) relative to the CCVCC structure, $F_1(1, 44) = 9.13$, $p < .0005$; $F_2(1, 46) = 7.25$, $p < .01$, and marginally significant relative to the CVC structure, $F_1(1, 44) = 4.34$, $p < .05$; $F_2(1, 46) = 3.24$, $p < .08$. Color naming latency in the two incongruent conditions did not differ significantly, $F_1(1, 44) < 1$, and $F_2(1, 46) < 1$.

Discussion

Experiment 2 extended the investigation of skeletal congruency effects to a second skeletal frame, a CCVC frame. The findings demonstrate that the color *black* (a CCVC frame) is named faster in the presence of nonwords with a congruent skeletal frame relative to incongruent ones, either CCVCC or CVC frames. Although the disadvantage of the CVC frame fell short of significance in the item analysis, the trend nonetheless stands in marked contrast to the robust advantage of the same frame with the color *red* (in Experiment 1). The potential of the CVC frame to facilitate the color *red* (in Experiment 1), but to impair naming the color *black* (in Experiment 2) suggests that its effect is due to its congruency with the skeletal frame of the color name, rather than its intrinsic properties.

The present results also allow us to adjudicate between orthographic and phonological explanations for the effect. The color

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[2] The color pink was initially included in order to examine the effect of congruency with the CVCC skeletal frame (as an experimental color). However, because most participants (at least 90%) identified this color as purple, and these identification responses were observed throughout the experimental session, we decided to exclude this color from the analyses. Experiment 3 revisits the effect of color congruency with *pink* using an improved visual presentation over a black background. Because *black* was used as an experimental color in Experiment 2, it was impossible to apply these visual conditions in Experiment 2.

Table 4
*Color Naming Latency (in Milliseconds) and Accuracy
(% Correct) for the Color Black as a Function of Skeletal
Congruency in Experiment 2*

Skeletal congruency	Latency	Accuracy
Congruent (CCVC)	623	99.3
Incongruent short (CVC)	634	99.6
Incongruent long (CCVCC)	644	99.1

Note. C = consonant; V = vowel.

name *black* manifests a mismatch between the number of letters and phonemes. If skeletal congruency were determined by the number of shared slots for consonant and vowel letters, then CCVCC words should have facilitated naming *black* compared with CCVC structures. Conversely, if skeletal congruency reflects shared slots for consonant and vowel phonemes, then naming latency should be fastest with the CCVC structure. The observed advantage of CCVC over CCVCC frames is consistent with the phonological account.

Experiment 3

Experiment 3 extended the investigation of skeletal congruency effects to a third skeletal frame, CVCC, the frame of the color name *pink* (/pɪŋk/).[3] We compared the effect of nonwords whose skeletal structure is either congruent with the color name (CVCC) or incongruent—either shorter (CVC) or longer (CCVCC). If participants are sensitive to the congruency between the skeletal structure of the printed target and the color name, then CVCC targets should facilitate color naming compared to CVC and CCVCC targets.

Method

Participants

Twenty-four Florida Atlantic University students participated in the experiment in partial fulfillment of a course requirement. They were all native English speakers and skilled readers with normal color vision, as described in Experiment 1.

Materials

As in previous experiments, we used two groups of materials: skeletal-congruency targets and color-congruency targets.

Skeletal-congruency targets. The skeletal-congruency targets were orthographically and phonologically legal nonwords whose skeletal similarity to the color name was manipulated. Seventy-two of these nonwords served as experimental targets and 144 additional nonwords were used as fillers (for a total of 216 skeletal-congruency trials). These targets shared no phonemes with the experimental color, *pink*. The experimental targets were arranged in trios (see Appendix C), matched on their phonological contents. The congruent trio member had a CVCC skeletal structure (e.g., *dult*), whereas the incongruent members had either a CVC (e.g., *dut,* a short incongruent condition) or a CCVCC (e.g., *drult,* a long incongruent condition) structure. As in Experiment 2, we attempted to minimize expectations regarding color by mixing the experimental trials with two filler colors: *yellow* (CV[C]VC) and *white* (CVVC). The experimental targets and fillers never shared the initial phoneme with the color name in which they were presented, nor did they share the initial consonant (or onset cluster) of competing colors (i.e., *pl, bl, w, wh,* or *y*). Further experimental

targets shared no phonemes or letters with the color name in which they were presented. The filler trials presented with *yellow* and *white* corresponded to the items presented in Experiment 2 with *yellow* and *black,* respectively.

Color-congruency targets. There were 360 color-congruency targets (40% congruent, 40% incongruent, and 20% neutral), presented in the same colors as the skeletal-congruency trials (*pink, white,* and *yellow*).

Procedure

The procedure was the same as described in Experiment 2, with the only exception being that the screen background was set to black (black in the program MEL is code 0). The experimental color *pink* was changed to the hi-magenta color in MEL (code 13). The colors *white* and *yellow* were displayed as white (code 15) and yellow (code 14).

Results and Discussion

We lost 0.14% of the total correct responses due to microphone failures. To eliminate the effect of outliers, we excluded from the analyses responses slower or faster than 2.5 standard deviations from the total grand mean of the color *pink* (2.93% of the total correct responses). The effects of color congruency and skeletal congruency on naming the experimental color *pink* were assessed using separate ANOVAs. All congruency levels were further compared by planned contrasts.

Color-Congruency Effects

Mean response latency and accuracy as a function of the congruency between the color and the meaning of the letter string is provided in Table 5. The one-way ANOVAs revealed a significant main effect of color congruency on naming latency, $F_1(2, 44) = 80.384$, $MSE = 1,458.27$, $p < .0002$, and accuracy, $F_1(2, 44) = 33.54$, $MSE = 0.001$, $p < .0002$. Planned comparisons indicated that, in the incongruent condition, color naming was significantly slower, $F_1(1, 44) = 111.30$, $p < .0001$, and less accurate, $F_1(1, 44) = 51.19$ $p < .0001$, than in the neutral condition. The congruent and neutral conditions did not differ significantly on either latency or accuracy (all Fs < 1).

Skeletal-Congruency Effects

Table 6 provides mean response latency and accuracy as a function of skeletal congruency. The ANOVA on response latency yielded a main effect of skeletal congruency, $F_1(2, 44) = 8.97$, $MSE = 866.51$, $p < .0006$; $F_2(2, 46) = 5.67$, $MSE = 1,375.31$, $p < .007$. There was no significant effect of skeletal congruency on naming accuracy, $F_1(2, 44) = 1.98$, $MSE = 0.001$, $p < .15$; $F_2(2, 46) = 1.68$, $MSE = 0.001$, $p < .20$. Planned comparisons indicated that the color *pink* was named significantly faster with skeletal-congruent targets (CVCC) than with incongruent targets, either the shorter, CVC-incongruent targets, $F_1(1, 44) = 7.73$, $p < .009$; $F_2(1, 46) = 4.16$, $p < .05$, or the longer, CCVCC-incongruent targets, $F_1(1, 44) = 17.30$, $p < .0002$; $F_2(1, 46) = 11.15$, $p < .002$. Naming latency in the two incongruent conditions did not

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[3] Note that the velar nasal stop in *pink* is followed by a voiceless stop. Thus, unlike orthographically similar words (e.g., *ping* /pɪŋ/, whose skeleton is a CVC), the phonemic representation of the word *pink* includes four skeletal slots.

differ significantly, $F_1(1, 44) = 1.89$, $p < .18$; $F_2(1, 46) < 1.69$, $p < .21$. These findings extend the conclusions of previous experiments to an additional skeletal frame (CVCC). These results suggest that readers represent the skeletal structure of printed nonwords that they are asked to ignore, and are affected by the congruency between their skeletal structure and that of a color name.

General Discussion

In three experiments, we examined the effect of congruency between the skeletal structure of color names and unrelated nonwords that shared no letters or phonemes with the color name. We investigated the effect of skeletal congruency for three color names (*red*, *black*, and *pink*) that corresponded to three skeletal frames (CVC, CCVC, and CVCC). In each case, color naming was significantly faster when the abstract arrangement of consonants and vowels in the printed nonword matched the color name. Furthermore, the effect of skeletal congruency critically depended on the relationship between the skeletal structure of the color name and the set of nonwords: Nonwords with a given skeletal frame (e.g., CVC) were shown to facilitate the naming of a color whose name manifests the same skeletal frame (e.g., *red*, in Experiment 1) but impair the naming of colors with an incongruent frame (e.g., *black* and *pink* in Experiments 2–3).

The observation that color naming was modulated by the congruency between the skeletal structure of nonwords and color names suggests that people assemble the skeletal structure of printed nonwords. However, an alternative explanation might attribute the finding to uncontrolled variations in the statistical properties of our materials. Because of the tight constraints on the structure of the nonwords (constraints imposed in order to avoid overlap in graphemes or phonemes between nonwords and color names), we were forced to assess the effect of skeletal structure by using different item sets for some of the skeletal frames. For instance, the CVC items used in Experiment 1 are different from those used in Experiments 2–3. It is thus conceivable that the facilitation by CVC frames in Experiment 1, but not Experiments 2–3, is due to item-specific artifacts (e.g., the CVC targets are more wordlike in Experiment 1, but not Experiments 2–3). Three observations counter this possibility. First, the findings of Experiment 1 demonstrate the effect of skeletal congruency while rotating a single set of items across various colors. The potential of CVC targets to selectively facilitate color naming with *red*, but not *green*, is inexplicable by item-specific artifacts. Second, there is no evidence that the set of materials used to represent a single frame across experiments differed systematically. To evaluate the resemblance of these materials to existing English words, we calculated the number of neighbors (the number of words obtained by altering

Table 5
Color Naming Latency (in Milliseconds) and Accuracy (% Correct) for the Color Pink as a Function of Color Congruency in Experiment 3

Color congruency	Latency	Accuracy
Congruent	612	99.7
Neutral	621	99.8
Incongruent	740	92.3

Table 6
Color Naming Latency (in Milliseconds) and Accuracy (% Correct) for the Color Pink as a Function of Skeletal Congruency in Experiment 3

Skeletal congruency	Latency	Accuracy
Congruent (CVCC)	639	98.4
Incongruent short (CVC)	663	98.9
Incongruent long (CCVCC)	675	99.6

Note. C = consonant; V = vowel.

any one of the target's letters), the summed frequency of these neighbors, the targets' bigram count, and bigram frequency (see Table 7). An inspection of the item means reveals that the characteristics of any given frame (e.g., CVC) were quite similar across experiments.[4] Third, the effect of skeletal congruency is observed even when the effect of the items' properties is statistically controlled by means of a multiple regression using hierarchical procedures (i.e., forced entry of predictors in steps). To control for spurious differences among the three experiments, we entered "experiment" as the first predictor. This predictor accounted for a significant 3.3% of the variance, $\Delta F_2(1, 198) = 6.60$, $p < .02$. We next simultaneously entered into the regression model the four predictors describing the statistical properties of the targets in the three experiments (bigram count, bigram frequency, the number of neighbors, and the summed frequency of these neighbors). The unique contribution of the target's statistical properties (combined) was not significant, $\Delta F_2(4, 194) = 1.52$, $p < .20$, $\Delta R^2 = .029$. In the last step, we entered the skeletal congruency predictor (nonwords in each experiment were coded as either congruent or incongruent with the skeletal structure of their color). Skeletal congruency accounted for significant unique variance in color naming latencies while controlling for experiment artifact and the four statistical-properties predictors, $\Delta F_2(1, 193) = 22.31$, $p = <.001$, $\Delta R^2 = .097$. These results suggest that the effect of skeletal congruency is inexplicable by the statistical properties of our materials.

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[4] Each of the neighborhood measures revealed a larger neighborhood for CVC targets. Specifically, the number of neighbors of CVC targets was higher relative to the other skeletal structures with the colors *red*, $F(1, 27) = 120.30$; *black*, relative to CCVC words, $F(1, 46) = 83.39$, and relative to CCVCC words, $F(1, 46) = 126.58$; and *pink*, relative to CVCC words, $F(1, 46) = 31.46$, and relative to CCVCC words, $F(1, 46) = 91.49$. Likewise, the frequency of the neighbors of CVC targets was highest with the colors *red*, $F(1, 27) = 10.34$; *black*, relative to CCVC words, $F(1, 46) = 3.80$, and relative to CCVCC words, $F(1, 46) = 11.77$; and *pink*, relative to CVCC words, $F(1, 46) = 12.88$, and relative to CCVCC words, $F(1, 46) = 16.32$. Conversely, CVC targets tended to score lower on the bigram measures. Specifically, CVC words had a lower bigram count relative to the other skeletal structures used with the colors *red*, $F(1, 27) = 145.62$; *black*, relative to CCVC words, $F(1, 46) = 8.73$, and relative to CCVCC words, $F(1, 46) = 228.92$; and *pink*, relative to CVCC words, $F(1, 46) = 33.06$, and relative to CCVCC words, $F(1, 46) = 84.60$. Likewise, CVC targets had a lower summed bigram frequency for the color *black* relative to CCVC words, $F(1, 46) = 10.01$, and relative to CCVCC words, $F(1, 46) = 18.23$. Similar, albeit nonsignificant ($p > .23$) trends were observed for the materials used with the colors *pink* (in Experiment 3) and *red* (in Experiment 1).

Table 7

Characteristics of the Targets Used in Experiments 1–3

Experiment	Skeletal structure	Coltheart N	Neighbor frequency	Bigram count	Bigram frequency
1	CVC	11.3	2359	10.5	2350
	CCVVC	1.4	37	106	3231
2	CCVC	3.2	641	30.5	3444
	CVC	10.7	1418	10.7	1508
	CCVCC	1.5	52	112.3	4120
3	CCVCC	4.8	372	56.7	2986
	CVC	10.2	3163	10.8	3159
	CCVCC	1.0	20	84.1	3414

Note. Values are number of neighbors (Coltheart N), Neighbors summed frequency (Neighbor frequency), Bigram count, and Bigram frequency. All values are means calculated across the 24 items in each skeletal structure group. C = consonant; V = vowel.

The observation of skeletal congruency effects in the Stroop task suggests that readers automatically represent the skeletal structure of the printed nonwords that they are asked to ignore. Because our materials were nonwords, stimuli that lack a lexical representation, the representation of skeletal structure must be achieved by online computation rather than by lexical retrieval. Thus, the findings suggest that skilled readers automatically assemble the linguistic phonological structure of printed words. The sensitivity to skeletal structure is particularly striking given that the congruent skeletal structure shares with the color name neither graphemes nor phonemes. In the large literature on the role of phonology in reading, such stimuli are considered as a baseline for evaluating phonological effects. For instance, phonological priming and masking effects are assessed by comparing the contribution of a pseudohomophone (e.g., *kar*) and a graphemic control (e.g., *lar*) against the baseline *bup* (e.g., Berent, 1997; Berent & Van Orden, 2003; Perfetti & Bell, 1991; Perfetti, Bell, & Delaney, 1988). Because phonological similarity is equated with segmental overlap, it is frequently assumed that the CVC baseline, *bup*, bears no phonological similarity to the CVC target *car*. Our findings suggest that this assumption is incorrect. The representation of printed words encodes suprasegmental phonological structure. Accordingly, (non)words that share a skeletal frame share an invariant phonological structure despite having no segments in common.

Our results leave several unanswered questions. One question concerns the nature of skeletal representations. Linguistic theories offer two contrasting accounts of skeletal structure: One proposal assigns different slots for consonants and vowels (CV skeletal structure), whereas a second account assumes generic units, irrespective of syllabic position (X slots). Our present results cannot distinguish between these accounts, as the congruent and incongruent conditions differed both on the number of X slot as well as their CV arrangement.[5] However, a distinction between consonant and vowel slots is suggested by previous findings (Berent, Bouissa, & Tuller, 2001), which demonstrated significant priming effects by a shared CV skeleton when the total number of X slots was controlled for (e.g., *fap-DUS* vs. *ift-DUS*). Further support for the distinction between abstract placeholders for consonants and vowels is offered by neurologic dissociations that selectively affect the production of consonants or vowels in both spoken (Caramazza, Chialant, Capasso, & Miceli, 2000) and written (Cubelli, 1991) language. Although there is no reason to expect that the

representations assembled in our experiments differ from those implicated by earlier findings, the encoding of consonant and vowel slots in the context of the Stroop task awaits future research.

A second question raised by our findings concerns the nature of the representation available to participants. The findings of Experiment 2 demonstrate that the effect of skeletal congruency is inexplicable by letter congruency, as the color *black* (a CCVC frame) was facilitated by a CCVC frame relative to a CCVCC control, matched on the number of letters. Although this finding is consistent with a phonological account of the skeleton, our results can also be captured by a graphemic representation, such that each skeletal slot holds a grapheme, rather than a phoneme. There is indeed some evidence that the CV skeleton plays a role in graphemic representations. Caramazza and Miceli (1993) and Rapp and Caramazza (1997) showed that spelling errors are constrained by the abstract arrangement of consonant and vowel placeholders. For instance, substitution errors invariably replace a consonant with a consonant and a vowel with a vowel letter. Unlike speech errors, however, the spelling errors observed by Caramazza and Miceli (1993) in Italian did not conform to phonotactic constraints (*scalda* → *slcada*, "he warms up" in English), nor did they respect the integrity of multiletter graphemes (e.g., *maschi* ["males" in English] → *masghi*). Likewise, the strong sensitivity of spelling errors to word length was affected by the number of letters, not the number of phonemes. In view of such observations, these authors concluded that the skeletal structure implicated by their results encodes graphemic rather than phonemic information. Because our present results do not offer any evidence for a graphemic skeleton, we favor a phonological account, as a phonological representation is independently required for color naming (the experimental task), and the computation of a phonological skeleton is motivated by linguistic and experimental evidence from speech perception and production, which is reviewed in the introduction. However, the representation of a phonological skeleton is not incompatible with a graphemic skeleton: It is conceivable that both formats are available to readers. The graphemic and phonemic accounts both suggest that the skeleton, a core aspect of phonological representation, serves as an anchor in the representation assembled by readers to printed words. These conclusions underscore the role of linguistic phonological competence in skilled reading.

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[5] Another alternative might attribute the effect of the target to its moraic structure (e.g., Hayes, 1989; McCarthy & Prince, 1995). Moras designate prosodic weight, and they are typically limited to vowels and postvocalic consonants (e.g., Hayes, 1989). Accordingly, the frames CVC, CCVC, CVCC, and CCVCC share the same moraic structure (two moras). If the effect of the frame on color naming was due to moraic structure, then these frames should not have differed in their effect on color naming. Our results counter this prediction. For instance, naming the color *black* was differentially affected by CVC versus CCVC frames, whereas naming the color *pink* was differentially affected by CVC versus CVCC frames (in Experiments 2–3, respectively). These results are better handled by a skeletal account.

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Appendix A

The Targets Presented in Experiment 1

CVC	CCVVC CCVCC
FOP	FLOOP
TUP	TWOUP
TOB	TWOOB
TOF	TWOAF
FUB	FLOUB
TUM	TWOUM
CAS	CLAIT
FOL	FLOAL
FUP	FLAIP
TES	TWEAB
FOS	FLOON
FAM	FLAIP
TEP	TWEAP
TUD	TWOUD
TER	TWEAL
DOP	DWAIP
BUB	BLOUB
BEF	BLEAF
BOF	BLOOF
BEM	BLEAM
BUP	BLAIP
PAB	PLEAB
PIF	PLAIF
PIM	PLAIM
POB	PLOOB
POF	PLOOF
POG	PLOOG
PUM	PLAIM

Note. C = consonant; V = vowel.

Appendix B

The Targets Presented with the Experimental Color *Black* in Experiment 2

CCVC Congruent	CVC Incongruent short	CCVCC Incongruent long
GROP	GOP	GROSP
DWUS	DUS	DWUSP
TREP	TEP	TRESP
TWUD	TUD	TWUND
DRUP	DUP	DRUMP
DROD	DOD	DROND
GRUD	GUD	GRUND
TWEG	TEG	TWENG
TWOG	TOG	TWONG
GLIG	LIG	GLING
TROP	ROP	TROSP
FRUP	RUP	FRUSP
TWIF	TIF	TWIFT
FROP	FOP	FROMP
GROF	GOF	GROFT
FRID	FID	FRIND
FREP	FEP	FRESP
FRES	FES	FREST
FRIM	FIM	FRIMP
FROS	FOS	FROSP
TWUP	TUP	TWUSP
DWES	DES	DWEST
FREG	REG	FRENG
DRUS	RUS	DRUSP

Note. C = consonant; V = vowel.

Appendix C

The Targets Presented with the Experimental Color *Pink* in Experiment 3.

CVCC Congruent	CVC Incongruent short	CCVCC Incongruent long
DULT	DUT	DRULT
DOLF	DOF	DWOLF
GOLM	GOM	GROLM
GULB	GUB	GRULB
FELF	FEF	FRELF
TELF	TEF	TREST
DOLM	DOM	DWOLM
TELB	TEB	TWELB
TOLB	TOB	TWOLB
TOLF	TOF	TWOLF
DALT	DAS	DWAST
FULB	FUB	FRULB
GULT	GOS	GRUST
TULM	TUM	TWULM
TULT	TUR	TWUFT
FOST	FOT	FLOST
GUFT	GUF	GLUFT
REFT	RET	TREFT
FOFT	FOF	FROFT
FULF	FUF	FLULF
FULT	FUT	FLUFT
LOLD	LOD	FROLD
TAST	TAS	TWAST
DELM	DEM	DWELM

Note. C = consonant; V = vowel.