

Phonological Constraints on the Assembly of Skeletal Structure in Reading

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Abstract Linguistic research suggests that certain skeletal frames (e.g., CVC) are preferred to others (e.g., VCC). We examine whether such preferences constrain reading in the Stroop task. We demonstrate that CCVC nonwords facilitate naming the color *black* (/bɪlæk/, a CCVC frame) relative to CVC controls. Conversely, CCVC items inhibit *red* (a CVC frame) relative to CVC controls. These results suggest that readers are sensitive to the congruency between the skeletal structure of color names and printed nonwords. However, various frames are not all equally preferred: the color *black* is named faster with a VCC frame, an infrequent and ill-formed frame, relative to a CVC frame, a frequent and grammatically preferred frame. These findings suggest that the representation of printed words specifies distinct slots for consonants and vowels, and readers are equipped with preferences (either grammatical or statistical) concerning skeletal frames. These conclusions underscore the contribution of linguistic knowledge to skilled reading.

Keywords Skeleton · Frames · Markedness · Phonology · Reading · Optimality theory

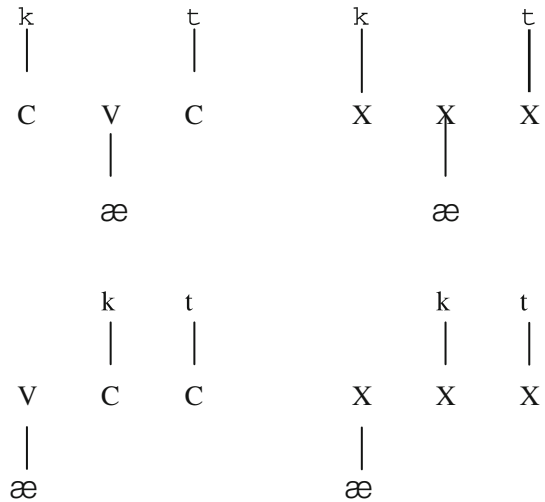
A large body of research suggests that the representation assembled to printed words is shaped by phonological knowledge. Readers routinely compute the sound-structure of printed words using phonology assembly—the process of mapping graphemes to phonemes (e.g., Berent 1997; Perfetti and Bell 1991; Van Orden 1991). Moreover, the representation of printed words specifies various phonological properties of spoken language, such as the syllable structure (e.g., Treiman et al. 1995), feature composition (Abramson and Goldinger 1997; Lukatela et al. 2001) and morphological structure (Taft and Kougious 2004). These findings

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Fig. 1 A comparison of the CV-slot and X-slot representations of *cat* and *act*



suggest that the representation of print is shaped by linguistic knowledge. The following research further tests this hypothesis by examining the phonological skeleton—a structure whose role in reading has not been widely explored.

The skeleton captures the word's prosodic structure as an arrangement of abstract timing slots. Each segment is assigned either one or several slots, depending on its length: short segments are assigned a single slot, whereas long ones, such as consonant geminates or tense vowels, are assigned multiple slots. For example, the contrast between the lax and tense vowels in *sit* versus *seat* is expressed by assigning one slot to the lax /ɪ/ in *sit* and two slots to the tense /i/ in *seat*. In some models, consonant and vowel segments are represented by distinct slots (McCarthy 1981). For example, the words *cat* and *act* are represented as CVC and VCC, respectively (see Fig. 1). Other proposals represent both consonants and vowels by generic X-slots (Levin 1985, for comparison, see Kenstowicz 1994). For example, the words *cat* and *act* are each represented by three generic slots, XXX.

Although the role of the skeleton has been subject to criticism (e.g., McCarthy and Prince 1995), experimental findings suggest that speakers are sensitive to skeletal structure. Several studies have demonstrated the effect of the skeleton on the production of spoken words. For example, Sevald et al. (1995) showed that English speakers find it easier to repeat non-words that share their skeletal structure (e.g., kem-til.fer—CVC-CVC) compared to non-words that differ on their skeletal frames (e.g., kem-tilf.ner—CVC-CCVC). Likewise, Meijer (1996) observed facilitation in translating English words into Dutch when the target Dutch word (e.g., *das*, a necktie) is preceded by an auditory prime that shared its skeletal frame (e.g., *nok* -DAS) compared to mismatching controls (e.g., *nerf*-DAS). Finally, Costa and Sebastian-Gallés (1998) report that picture naming is facilitated when the picture is preceded by Spanish words that share the CV structure of its name. For example, the word *cola* (tail, beginning with a CV syllable) was named faster preceded by words beginning with a CV syllable (*nido*) relative to controls beginning with a CVC syllable (e.g., *ninfa*). Similar results are reported in French (Ferrand and Segui 1998). Note that in all cases, the effects of skeletal congruency obtained in the absence of segmental overlap (e.g., *pino* and *casa* do not share segments)—the overlap between the prime and target concerned skeletal structure alone. Additional evidence supporting the representation of the skeleton is obtained in speech errors (Fromkin 1973; MacNeilage 1998; Stemberger 1984), spelling disorders due to

neurological damage (Caramazza and Miceli 1993; Rapp and Caramazza 1997), and language discrimination (Nespor et al. 2003; Ramus et al. 1999; Ramus and Mehler 1999); for review, see Berent and Marom (2005).

In view of the contribution of the skeleton to the representation of spoken language, one might wonder whether it also plays a role in silent reading. Several results suggest that readers encode the skeletal structure of printed words even when they are not required to articulate them. Berent et al. 2001 demonstrated that English readers are sensitive to the skeletal overlap between two printed nonwords—a target, to be named, and a prime, which participants were instructed to ignore (e.g., *fap*—DUS vs. *ift*—DUS). Similar results are reported in Arabic using cross modal priming: Boudelaa and Marslen-Wilson (2004) found that lexical decision for visual words is facilitated when they are preceded by an auditory prime that shares their skeletal structure (e.g., the shared CVVCVCV frame in [fuuziʔa] – [ʔaaraka] *be surprised-participate*). A similar trend was observed in a parallel experiment using visual targets and primes.

Note that these effects of the skeleton are obtained in tasks that require word reading—tasks eliciting an intentional processing of the printed stimulus. However, the representation computed under intentional processing might differ from the one computed automatically (Tzelgov et al. 1992b). A stronger test might gauge the role of the skeleton in nonintentional reading, using Stroop-like procedures: because the processing of the printed stimulus is not required by task demands, such evidence would suggest that the representation of the skeleton might be automatic. Such results have been recently reported by Berent and Marom (2005) using a variant of the Stroop task. In their experiments, participants were presented with nonwords printed in color. Participants were asked to name the color of the nonwords while ignoring their contents. The skeletal structure of these nonwords was either congruent with the skeletal structure of the color name or incongruent. For example, the color *red* (a CVC) was presented with either congruent, CVC nonwords (e.g., GOF) or incongruent, CCVCC nonwords (e.g. GROFT). Berent and Marom (2005) observed faster color naming in the skeletal-congruent condition compared to the skeletal-incongruent condition. For example, CVC nonwords facilitated naming the color *red* (a CVC frame) compared to longer, CCVCC and CCVVC frames. In contrast, when similar nonwords were presented with the color *black* (/bɫæk/), the pattern reversed: CCVC nonwords now facilitated color naming compared to CVC nonwords or CCVCC nonwords. The observed facilitation by CCVC relative to CCVCC nonwords further suggests that the representation available to readers encodes the phonological structure of /bɫæk/ (a CCVC), rather than the arrangement of consonant letters in the orthography (a CCVCC). These results demonstrate that readers automatically encode the phonological skeleton of printed words that they are asked to ignore.

These results nonetheless leave several open questions regarding the precise nature of the frames assembled in reading. One question concerns the distinction between consonant and vowel slots. Recall that, on some proposals, the skeleton includes distinct slots for consonants and vowels (a CV-skeleton), whereas other accounts postulate generic slots, irrespective of consonant/vowel quality (the X-slot model). The existing experimental results cannot adjudicate between these proposals. Because in previous work (e.g., Berent and Marom 2005; Boudelaa and Marslen-Wilson 2004; Costa and Sebastian-Gallés 1998; Ferrand and Segui 1998; Meijer 1996), the incongruent and congruent conditions differed both on the number of skeletal slots and their CV arrangement, it is uncertain which of those dimensions is responsible for the observed effects of congruency.

Another open question is whether readers possess preferences concerning skeletal structure. Previous research has demonstrated that speakers encode various types of skeletal frames. However, there is reason to believe that not all frames are equally preferred. One

Table 1 The violation of two markedness constraints, Onset and *Complex, by the CVC, CCVC and VCC frame

	Onset (syllables must begin with an onset)	*Complex (complex onsets and codas are dispreferred)
CVC		
CCVC		*
VCC	*	*

Constraint violation is indicated by asterisks

indication of such preferences comes from the distribution of various syllable types across languages. For instance, compare the syllables CV (e.g., *begin*) VC (as in *elbow*). Both syllables have a consonant at their edge, either at the onset (CV) or the coda (VC), but they greatly differ on their distribution across languages. Many languages require onsets and disallow codas (i.e., require CV syllables), but no language is known to require coda and disallow onsets (i.e., require VC syllables; Prince and Smolensky 1993/2004). Such distributional evidence suggests that CV frames might be preferable to VC ones. Similar asymmetries concern the structure of the onsets. Across languages, syllables that begin with a simple onset (e.g., CVC) are more frequent than those beginning with a complex one (e.g., CCVC). Moreover, if any given language tolerates the less frequent, complex onset, it is likely to allow a simple onset, whereas the reverse doesn't follow: languages with simple onsets do not necessarily tolerate complex ones (Greenberg 1978). This observation suggests that frames with simple onsets might be preferable to those with complex onsets.

According to optimality theory (Prince and Smolensky 1993/2004), the rarity of certain linguistic structures (e.g., VC vs. CV; CCVC vs. CVC) might reflect their violation of universal grammatical well-formedness restrictions, called markedness constraints. For example, the CCVC structure might be dispreferred relative to CVC because the grammar is equipped with a constraint that bans complex onsets and codas (*Complex), a constraint violated by CCVC, but not CVC syllables. Likewise, the rarity of the VC relative to the CV frame is attributed to a constraint that requires an onset (Onset)—a constraint violated by VC, but not CV syllables. Combining these considerations, one would expect the VCC frame to be particularly dispreferred: not only does it violate the requirement for an onset, but it also manifests a complex coda. Structures violating markedness constraints (e.g., CCVC, VCC) are considered *marked* whereas those escaping constraint violation (e.g., CVC) are relatively *unmarked*. Summarizing then (see Table 1), one would expect the unmarked, CVC frame to be preferred to the more marked, CCVC frame (which violates *Complex), and both frames to be preferred to the highly marked VCC frame (which violates both *Complex and Onset). A comparison of the distribution of CVC, CCVC and VCC words in a computerized database of English (an on-line neighborhood calculator, prepared by Mitch Sommers, <http://128.252.27.56/Neighborhood/Home.asp>) is consistent with these expectations: English has 1,338 CVC words, 758 CCVC words, and only 70 VCC words.¹

The following experiments examine whether such preferences constrain the representations assembled in automatic reading. In particular, we address the following three questions (a) Are readers sensitive to skeletal structure; (b) Does the skeletal structure of printed words

¹ These figures are based on a representation that tags each segment as a single consonant or vowel, irrespective of length.

assign different slots to consonants and vowels, and (c) Are readers equipped with preferences that favor unmarked skeletal frames to relatively marked ones.

We examine these questions using the modified Stroop-task employed by [Berent and Marom \(2005\)](#). Participants in our experiments are presented with nonwords printed in color. These nonwords manifest three types of skeletal frames: CVC, VCC and CCVC. In Experiment 1, these frames are presented with the color *black*, /bɪlək/, a color whose name bears a CCVC frame, whereas in Experiments 2 and 3, these nonwords are presented in *red*, a CVC frame. If readers automatically represent the skeletal structure of printed words, then we expect nonwords whose skeletal structure is congruent with the color name to facilitate color naming relative to incongruent ones. The nature of these effects can further attest to the specific representation of the skeleton. If readers only encode generic X-slots, then they should distinguish the CCVC from the CVC and VCC frames, which, in turn, should not differ. Conversely, if the skeleton assigns distinct slots to consonants and vowels, then CVC and VCC frames should exert different effects on color naming. Our final question concerns skeletal preferences. The three types of frames used in our experiments differ on their markedness and frequency: CVC is both frequent and relatively unmarked, whereas CCVC and VCC are more marked and infrequent. Because the distribution of these frames in English correlates with their grammatical well-formedness, we cannot determine the source of skeletal preferences—whether they are due to frequency, or to markedness (for a dissociation of these factors in another case study, see [Berent et al. 2007, 2008](#)). Our interest here is in the existence of such preferences. If speakers are equipped with preferences (either grammatical or statistical) concerning skeletal structure, then dispreferred skeletal frames might be considered less wordlike, hence, they should be ignored more easily than preferred frames. Accordingly, we expect color naming to be faster in the presence of dispreferred frames.

Experiment 1

Experiment 1 compared the effect of three skeletal frames on naming the color *black*, /bɪlək/, a color whose name bears a CCVC frame. One skeletal frame, the CCVC frame, was congruent with the skeletal frame of the color name (e.g., GROP). The other two skeletal frames did not match the skeletal frame of the color name (i.e., *incongruent frames*). One incongruent frame had a CVC structure, a structure that is relatively unmarked (e.g., GOP), whereas a second incongruent frame, a VCC, had a relatively marked structure (e.g., OSP, see [Table 2](#)). Note that these two frames are matched on their number of slots, and differ solely on their consonant-vowel sequencing. Moreover, most nonwords with congruent and incongruent frames shared no letters or phonemes with the color name *black*—congruency concerned only skeletal structure. If participants are sensitive to the congruency of skeletal frames, then color naming should be faster in the presence of the congruent, CCVC frame, relative to the incongruent VCC and CVC frames. If skeletal frames further assign different slots to consonants and vowels, and if unmarked CV-frames are preferred to marked frames, then readers should be able to ignore the marked VCC frame more easily than the CVC frame. Accordingly, color naming should be faster with the incongruent VCC frame relative to the unmarked incongruent CVC frame.

As a further test that readers process the printed stimulus, our experiment also included a replication of the standard Stroop manipulation ([Stroop 1935](#)). To this end, we presented participants with several color words displayed in color. These color words were either congruent with the color name (e.g., the word *black* presented in the color black), or incongruent

Table 2 An illustration of the skeletal congruency targets for the target color *black* used in Experiment 1

Skeletal congruency	Skeletal frame	Non-word
CV-congruent	CCVC	GROP
CV-incongruent		
Unmarked	CVC	GOP
Marked	VCC	OSP

(e.g., the word *pink* presented in the color black). Thus, our experiment examines two forms of congruency: color-congruency (the standard color-word Stroop interference), and skeletal congruency (the congruency between the color name and the skeletal structure of color-unrelated nonwords)—the target of our investigation. If readers encode some aspects of the unattended printed stimulus, then we expect them to demonstrate the typical color-congruency effect: color naming should be inhibited in the incongruent relative to the neutral color condition, and, possibly, facilitated in the congruent relative to the neutral condition. Of interest is whether readers also encode more subtle aspects of letter strings they have never seen before—the skeletal structure of nonwords.

Method

Participants

Forty-three Florida Atlantic University students took part in the experiment in partial fulfillment of their course requirements. They were all native English speakers and skilled readers, with normal or corrected vision. Reading skill was assessed by means of a non-word reading test that was assigned to each participant at the end of the experimental session.

Materials

The materials included two groups of printed stimuli designed to examine the effect of skeletal-congruency (the congruency between the skeletal frame of the color name and the skeletal frame of non-words) and color congruency (the congruency between written color words and their color) on color naming.

Skeletal-Congruency Targets

The skeletal-congruency materials included 72 experimental targets and 144 filler trials. These items were all non-words that were orthographically and phonologically legal.

The main set of skeletal congruency trials (hereafter, the experimental trials) manipulated the congruency between the skeletal structure of printed nonwords and the skeletal structure of the color *black*. The nonwords were arranged in trios. Members of the trio were matched on their segmental contents and differed on their skeletal structure. One member of the trio exhibited a CCVC skeletal frame (e.g., GROP), a frame congruent with that of the color name (a skeletal-congruent condition). The other two members differed from the skeletal frame of *black* (skeletal incongruent conditions), and had either a VCC frame (e.g., OSP), or a CVC frame (e.g., GOP). The incongruent VCC frame violates two markedness constraints and is therefore relatively marked, whereas the incongruent CVC frame does not, and is therefore

Table 3 The statistical properties of the items used in Experiment 1

	Coltheart N		Neighbors' summed-frequency		Bigram count		Bigram frequency	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
CVC	9.17	4.86	1659.58	2847.49	10.17	3.61	1770	3454.11
VCC	2.54	1.93	698.41	1244.70	2.29	1.33	354.42	695.43
CCVC	3.21	2.50	809.17	1677.09	30.75	15.25	3358.50	3309.97

considered relatively unmarked (see Table 1). Most members of the trio did not share letters or phonemes with the color name *black*. In no case did members of the trio share with the color name *black* any letter or phoneme in its original position. There were 24 such trios (a total of 72 nonwords) in the experiment (see Appendix 1). To estimate the statistical properties of these nonwords, we calculated their Coltheart N (the number of neighbors—words that share the target's length and differ from it on one letter), the summed frequency of those neighbors, bigram count (the number of words that share the target's bigrams—combinations of two consecutive letters at the same word position) and bigram frequency (the summed frequency of the words that share the target's bigrams). All frequency counts are based on Kucera and Francis (1967). These statistical properties of these items are provided in Table 3.

To discourage expectations regarding the color name, the experimental trials were mixed with filler trials. Half of the filler trials were presented in yellow (CVCVC frame) and the other half were presented in pink (CVCC frame). The filler colors were presented with the same list of non-words displayed with the color *black*. There was a total 216 skeletal congruency trials in the experiment (24 nonword trios \times 3 colors).

Color Congruency Targets

A second group of trials was included in order to probe for the effect of congruency between color words and their color (i.e., the standard Stroop effect). There were 540 color-congruency targets, presented in the same colors as the skeletal-congruency trials (black, pink, and yellow). Color words were congruent with their color on 40% of the trials (e.g., the word black printed in black) and incongruent on 40% (e.g., the word black printed in pink or yellow). In the remaining 20% of trials, the printed stimulus was XXXX (the neutral condition). To allow direct comparison between the effects of color-congruency and skeletal-congruency (assessed for the color black), our analyses of color-congruency are likewise limited to the color black.

In summary, each participant was presented with 756 trials, 216 were skeletal-congruency trials and 540 were color-congruency trials. To familiarize the participants with the experimental task, they were presented with a short practice phase. The practice consisted of twelve color-congruency trials (1 congruent, 1 neutral and 2 incongruent trials in each of the three colors) and nine skeletal-congruency trials (3 skeletal-congruency conditions \times 3 colors). None of the non-words presented in the practice phase was repeated in the experimental trials. The color-congruency and skeletal-congruency trials were mixed and they were presented in random order in both the practice and the experimental phase.

Procedure

Participants were presented with a letter-string (a non-word 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, presented at the center of the computer screen for 500 ms. The fixation point was immediately replaced by a string of uppercase letters that remained on the screen until the participant responded. The experimenter next coded response accuracy. 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 message on the computer screen. The experiment was conducted using the Micro Experimental Lab program (MEL, Schneider 1988). The stimuli were presented in the colors black, yellow and pink (in the MEL program, these were coded as 0, 14, and 5, respectively) on a gray background (code 7 in the MEL program). Participants were tested individually in a dimly lit room.

Results

.47% of the total correct responses were lost due to microphone failures. To eliminate the effects of outliers, we excluded correct responses falling 2.5 SD above or below the relevant cell mean (less than 2% of the total observations in each of the cells).

The effects of color congruency (the congruency between the meaning of color words and the color *black*) and skeletal-congruency (the congruency between the skeletal frame of nonwords and the color *black*) were examined in separate one-way ANOVAs. The effect of skeletal-congruency was examined using participants (F_1) and items (F_2) as random variables. Because the color-congruency manipulation used three color-words, this effect was only assessed across participants. In this and all subsequent experiments, we adopt .05 as the level of statistical significance.

Color Congruency

Naming time and naming accuracy for the three color-congruency conditions are presented in Table 4. The effect of color congruency was significant in naming time ($F_1(2, 84) = 187.29$, $MSe = 719.15$) and naming accuracy ($F_2(2, 84) = 65.34$, $MSe = .0006$). Planned comparisons showed that color naming was significantly slower ($F(1, 84) = 210.48$) and less accurate ($F(1, 84) = 100.56$) in the incongruent relative to the neutral condition. Conversely, color naming was significantly faster in the congruent ($F(1, 84) = 14.74$) relative to neutral condition. The congruent and neutral conditions did not differ reliably on naming accuracy ($F(1, 84) < 1$; n.s.).

Skeletal-Congruency

Table 5 presents mean naming time and accuracy for the three skeletal-congruency conditions. The effect of skeletal congruency was significant in the analysis of naming time

Table 4 Color naming time (in ms) and accuracy (proportion correct) as a function of color-congruency with the color *black* (in Experiment 1)

	Reaction time		Accuracy	
	Mean	SD	Mean	SD
Congruent	564	65	.9972	.006
Neutral	586	64	.9986	.006
Incongruent	670	83	.9449	.43

Table 5 Color naming time (in ms) and accuracy (proportion correct) as a function of skeletal-congruency with the color *black* (in Experiment 1)

		Reaction time		Accuracy	
		Mean	SD	Mean	SD
CV-congruent	CCVC	595	16	.9958	.0083
CV-incongruent					
Unmarked	CVC	614	18	.9942	.0093
Marked	VCC	601	16	.995	.0088

($F_1(2, 84) = 5.91$; $MSe = 641.57$; $F_2(2, 46) = 7.68$; $MSe = 284.14$), albeit not in naming accuracy ($F_1(2, 84) < 1$; $MSe = .0003$; n.s.; $F_2(2, 46) < 1$; $MSe = .0001$; n.s.). Planned comparisons revealed that readers named the color *black* significantly faster in the congruent CCVC condition than in the unmarked incongruent CVC condition ($F_1(1, 84) = 12.39$; $F_2(1, 46) = 14.48$). Color naming was further sensitive to the markedness of the incongruent frames: color naming was significantly slower in the unmarked incongruent CVC condition than in the marked incongruent VCC condition ($F_1(1, 84) = 6.50$; $F_2(1, 46) = 7.39$). In fact, responses to the incongruent VCC condition and the congruent CCVC condition did not differ significantly ($F_1(1, 84) < 1$; n.s.; $F_2(1, 46) = 1.1809$; n.s.).

Discussion

The findings of Experiment 1 suggest that readers are sensitive to skeletal congruency: participants named the color *black* (/bɪlæk/) significantly faster given nonwords whose structure was congruent with the skeletal structure of the color name (a CCVC, e.g., GROP) compared to nonwords whose skeletal structure is a CVC, a structure incongruent with the skeletal structure of the color name (e.g., GOP). The effect of congruency was further modulated by the markedness of the incongruent frame: color naming was significantly faster in the presence of VCC nonwords (e.g., OSP), nonwords whose skeletal structure is marked, relative to a CVC nonwords (e.g., GOP), nonwords whose skeletal structure is unmarked. The greater ease of ignoring incongruent VCC relative to CVC frames suggests that readers encode the sequencing of consonant and vowel slots, and that they favor CVC to VCC frames. This effect of markedness might also account for the failure of the incongruent VCC nonwords to inhibit color naming: the null effect of skeletal congruency might reflect the offsetting of the inhibitory effect of skeletal incongruency by the facilitation associated with the marked VCC structure. As a whole, these findings are consistent with the hypothesis that readers constrain the markedness of CV-frames.

Experiment 2

Experiment 1 showed that people name the color *black* (a CCVC frame) faster in the presence of nonwords with a CCVC relative to a VCC frame. We attribute this result to the congruency between the skeletal frame of the color name and the printed nonword. On alternative explanation, the pattern of results might reflect the inherent properties of the frame, rather than their relationship to the color name. For example, the facilitation with the CCVC frame might be due to its greater length, rather than its congruency with the skeletal structure of

Table 6 An illustration of the skeletal congruency targets used with the color RED used in Experiment 2

CV-congruency	Skeletal frame	Non-word
CV-congruent	CVC	TUP
CV-incongruent		
Unmarked	CCVC	TWUP
Marked	VCC	UPT

black. To adjudicate between these interpretations, it is necessary to compare the effects of these frames across color names of various frames. Accordingly, Experiment 2 gauges the effect of the same frames on naming the color *red*, a color name that manifests a CVC frame. Note that the CVC frame is now congruent with the color name whereas the CCVC frame is incongruent (see Table 6). If the previous facilitation of *black* by CCVC relative to CVC nonwords is due to skeletal congruency, then the pattern of results should reverse with the color *red*: color naming should be faster in the presence of the congruent, CVC frame relative to the incongruent, CCVC and VCC frames.

In addition, Experiment 2 examines whether the effect of skeletal congruency depends on the markedness of the incongruent skeletal frames, VCC versus CCVC. These two incongruent frames differ with respect to the violation of the Onset and *Complex constraints (see Table 1): the VCC frame violates two constraints (Onset and *Complex), whereas the CCVC frame violates only one (*Complex). If the VCC frame is indeed dispreferred relative to the CCVC frame, then participants should ignore it more easily. Accordingly, color naming should be faster with marked incongruent items (VCC) relative to unmarked incongruent ones (CCVC).

Method

Participants

Twenty Florida Atlantic University students took part in the experiment in partial fulfillment of their course requirements. They were all native English speakers, and skilled readers, with normal or corrected vision. Reading skill was assessed by means of a non-word reading test administered at the end of the experiment.

Materials

As in Experiment 1, there were two groups of materials: a set of non-words whose skeletal congruency with the color name was manipulated (the skeletal-congruency targets), and a second set of color words, presented in different colors (the color congruency targets).

Skeletal Congruency Targets

Skeletal-congruency targets were arranged in trios, including CVC, CCVC and VCC non-words (e.g., GOM, GROM, OLM). There were 24 such trios in the experiment (see Appendix 2). As in Experiment 1, most nonwords did not share any letters or phonemes with the color name *red*, and in no case did a shared letter maintain its original position in the

Table 7 The statistical properties of the items used in Experiment 2

	Coltheart N		Neighbors' Summed-frequency		Bigram count		Bigram frequency	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
CVC	8.25	4.92	3167.75	4455.12	9.37	3.75	3250.5	4779.76
VCC	2.41	2.12	686.37	1240.27	2.04	1.43	402.13	684.93
CCVC	2.83	2.25	445.75	1237.96	28.29	15.78	2699.46	3014.23

color name. Because it was impossible to find a large number of phonotactically legal items that do not share letters with either *red* and *black* (the experimental colors in Experiments 2 and 1), it was necessary to construct a new set of items for this experiment. An inspection of the statistical properties of these items (see Table 7) suggests that they are indeed comparable to the nonwords used in Experiment 1. A series of paired t-tests comparing the items representing each skeletal frames in the two experiments (e.g., the CVC nonwords in Experiments 1 and 2) showed that they did not reliably differ on their statistical properties (all $p > .14$).

Our main interest is in the effect of congruency between the skeletal structure of these nonwords and color *red* (assessed by the experimental trials). As in Experiment 1, however, we attempted to discourage expectations regarding the color name by means of filler trials, presenting the same set of 72 nonwords with two additional colors, green and yellow. There were 216 color-congruency trials in the experiment (24 nonword triplets \times 3 colors).

Color-Congruency Targets

To probe for the standard Stroop effect (the congruency between color words and their color) we also included color words in the experiment. There were 540 color-congruency trials (40% congruent, 40% incongruent and 20% neutral), presented in the same colors as the skeletal-congruency trials (red, green and yellow). As in Experiment 1, all analyses of color-congruency are based on the color *red*, the color used to gauge the effect of skeletal congruency.

In summary, each participant was presented with 756 trials, 216 were skeletal-congruency trials and 540 were color-congruency trials. To familiarize participants with the experimental task, they were presented with a short practice phase, as described in Experiment 1.

Procedure

The procedure was the same as in Experiment 1, with the only exception that stimuli were presented in the colors red, yellow, and green (in the MEL program, these were coded as 4, 14, and 2, respectively) on a black background (the color 0 in MEL).

Results

0.43% of the total correct responses were lost due to microphone failures. To eliminate the effect of outliers, we excluded correct responses falling 2.5 SD above or below the relevant cell mean (less than 3.2% of each of the cell means). The effects of color congruency (the congruency between color-words and the color *red*) and skeletal-congruency (the congruency

between the skeletal frame of nonwords and the color *red*) were examined using separate one-way ANOVAs.

Color Congruency

Mean naming time and accuracy as a function of color-congruency is presented in Table 8. A one-way ANOVA revealed a significant main effect of color congruency in both naming latency ($F(2, 38) = 55.43$, $MSE = 1739.62$) and accuracy ($F(2, 38) = 26.13$, $MSE = 0.0009$). Planned comparisons showed that color naming was significantly slower ($F(1, 38) = 66.97$) and less accurate ($F(1, 38) = 34.57$) in the incongruent relative to the neutral condition. The congruent and neutral conditions did not differ reliably on either speed or accuracy ($F(1, 38) = 2.69$, n.s.; and $F(1, 38) < 1$; n.s. respectively).

Skeletal-Congruency

Table 9 presents naming time and accuracy as a function of skeletal congruency. The ANOVA on response time did not reveal a significant main effect of skeletal-congruency ($F_1(2, 38) < 1$, n.s.; $F_2(2, 46) < 1$; n.s.). Likewise, the effect of skeletal-congruency was not significant in the analysis of response accuracy ($F_1(2, 38) < 1$, n.s.; $F_2(2, 46) < 1$, n.s.).

Discussion

Experiment 2 was designed to investigate the source of the skeletal-congruency effects observed in Experiment 1. Recall that in Experiment 1, color naming was faster in the presence of CCVC relative to CVC nonwords, an effect we attribute to the congruency of CCVC nonwords with the skeletal frame of the color name *black*, /bɪlək/, a CCVC frame. To test this explanation, Experiment 2 investigated the effect of the same frames on naming the color

Table 8 Color naming time (in ms) and accuracy (proportion correct) as a function of color-congruency with the color *red* (in Experiment 2)

	Reaction time		Accuracy	
	Mean	SD	Mean	SD
Congruent	606	80	.999	.0031
Neutral	628	52	.9925	.0133
Incongruent	736	113	.9375	.054

Table 9 Color naming time (in ms) and accuracy (proportion correct) as a function of skeletal-congruency with the color *red* (in Experiment 2)

		Reaction time		Accuracy		
		Mean	SD	Mean	SD	
CV-congruent	CVC	635	75	.9955	.0139	
CV-incongruent						
	Unmarked	CCVC	639	72	.994	.0147
	Marked	VCC	633	71	.9935	.016

red, whose name bears a CVC frame. If the advantage of the CCVC over the CVC frame is due to the internal properties of these frames, then similar findings should be obtained with *red*. Conversely, if the previous facilitation by the CCVC frame is due to its skeletal congruency with the color name, then the pattern should reverse with *red*. The results of Experiment 2 did not support either explanation: readers were utterly insensitive to the skeletal structure of the nonwords. This finding is not due to an across-the-board failure to process the printed stimuli, since the same experiment did yield a significant effect of color-congruency. Thus, the null effect of skeletal structure reflects either a failure to process nonword strings, or specifically, the assembly of their skeletal structure.

This null effect conflicts with the findings of Experiment 1, as well as previous research demonstrating significant effects of skeletal-congruency using the color red (Berent and Marom 2005). Specifically, Berent and Marom observed that the color red was named significantly faster in the presence of congruent CVC nonwords relative to incongruent CCVVC or CCVCC nonwords. The same CVC items did not facilitate the naming of colors with incongruent frames (i.e., *green* and *yellow*), suggesting that these effects are not due to the inherent properties of CVC items. Indeed, subsequent experiments demonstrated that the advantage of CVC frames reverses in the presence of incongruent color names. Specifically, when presented with the color black, CVC nonwords inhibited color naming relative to CCVC nonwords. These findings suggest that readers automatically assemble the skeletal structure of CVC and CCVC nonwords, and they are sensitive to skeletal congruency. The failure of the same frames, CVC and CCVC, to affect color naming in the present experiment is thus puzzling.

A comparison of Berent and Marom (2005) experiments to the present Experiment 2 suggests one major difference: Experiment 2 included VCC non-words, a frame that has not been used in our past research. Accordingly, the null effects found in Experiment 2 might be due to the inclusion of VCC items. Because this frame is similar in length to the structure of the color name red (a CVC), VCC nonwords might be difficult to ignore. The interference from the incongruent frame might have been particularly disruptive with the color *red* since its naming was overall slow—a comparison of the neutral conditions in Experiments 1 and 2 shows that the color *red* was named slower than *black* by about 42 ms. Likewise, *red* was named slower than *black* in each of the color- and skeletal-congruency conditions. The slower color identification could have exacerbated the interference from the incongruent conditions, especially the similar VCC condition, and encouraged participants to suppress the processing of the printed stimuli. Evidently, such an attempt to avoid reading was not fully successful, as participants could not abolish the effect of color-congruency with familiar color-words. It is nonetheless conceivable that the attempt to ignore the printed stimulus could be more successful given unfamiliar (hence, less automatized) novel words. Such selective, strategic suppression of nonword processing in the face of intact processing of color-words is reported in previous research (e.g., Berent et al. 2006).

As a preliminary assessment of the hypothesis that readers learn to suppress the processing of printed nonwords, we probed for changes in the effect of skeletal-congruency along the trials. We reasoned that a “no-reading” strategy should take time to develop. Accordingly, an effect of skeletal congruency might be seen at the beginning of the experiment, but not at its end. A post-hoc analysis suggested that at the first half of the experiment, color naming was faster with the congruent, CVC frame ($M = 628$ ms), relative to the incongruent frames (CCVC = 635 ms; VCC = 643 ms). This trend was virtually erased in the second half (CVC = 630; CCVC = 637; & VCC = 628). However, the relevant interaction (2 half \times 3 skeletal frames) was not significant ($F(2, 46) < 1$; n.s.). Moreover, because the order of the trials in the experiment was randomly determined, the two halves were not

balanced for the distribution of trials across conditions. Experiment 3 directly examines the hypothesis that participants learn to suppress nonword reading throughout the experiment by repeating the design of Experiment 2 while controlling for item composition at the two halves of the experiment.

Experiment 3

Experiment 3 re-examines the effect of skeletal congruency on naming the color *red*. This experiment uses the same materials, design and procedure as in Experiment 2, while controlling for the composition of items in the first and second half of trials. If readers learn to suppress the processing of printed nonwords, then skeletal congruency effects might be found in the first, but not second half of the experiment. Thus, in the first half, readers should name the color red faster with the congruent (CVC) relative to the incongruent frames (CCVC & VCC). Moreover, the relatively unmarked incongruent frame (CCVC) should interfere with color naming more than the marked incongruent frame (VCC). In contrast, no skeletal congruency effects are expected in the second half.

Method

Participants

Twenty-six Florida Atlantic University students took part in the experiment in partial fulfillment of their course requirements. They were all native English speakers, and skilled readers, with normal or corrected vision. Reading skill was assessed by means of a reading test administered at the end of the experimental session.

Materials

The materials were the same as in Experiment 2. These items were divided into two lists, A and B. Each list contained half of the non-words and half of the color words in each of the congruency conditions. Specifically, each list was matched for the distribution of congruent, neutral, and incongruent items in each of the three colors. Likewise, the non-word trios were randomly assigned to the two lists, and the two lists were further matched for the pairing of the nonwords with the three colors. Participants were presented with the two lists in counter-balanced order.

Procedure

The procedure was the same as in Experiment 2. The participants were not aware that the materials were divided into two lists, and they had no break between the lists. The order of trials within a list was randomly determined.

Results

.62% of the total correct responses were lost due to microphone failures. To eliminate the effect of outliers, we excluded correct responses falling 2.5 SD above the relevant cell means (less than 3.35% in each of the cell means). The effect of color congruency (the congruency

Table 10 Color naming time (in ms) and accuracy (proportion correct) as a function of color-congruency and order (first vs. second half) in Experiment 3

	First half		Second half	
	Mean	SD	Mean	SD
Reaction time				
Congruent	629	88	630	83
Neutral	653	83	635	81
Incongruent	785	114	753	94
Accuracy				
Congruent	.9977	.0082	.9977	.0082
Neutral	.9973	.0137	.9931	.0195
Incongruent	.9592	.044	.9635	.0279

between the color word and the color in which it was displayed) and skeletal-congruency (the congruency between the skeletal frame of the nonword and its color name) were assessed separately.

Color Congruency

Mean naming latency and accuracy as a function of color-congruency and order (first vs. second half) are presented in Table 10. A two-way ANOVA (3 color congruency \times 2 order) revealed a significant main effect of color congruency ($F(2, 50) = 100.06$; $MSe = 3, 050.91$; $F(2, 50) = 29.41$; $MSe = .001$, for response time and accuracy, respectively). The effect of list order approached significance in response time ($F(1, 25) = 3.51$; $MSe = 2, 833.76$, $p < .08$), albeit not in response accuracy ($F(1, 50) = 1$; n.s.). However, the effect of color-congruency was reliably modulated by order in the analysis of response time ($F(2, 50) = 4.52$; $MSe = 761.63$; for response accuracy, $F < 1$). The simple main effect of order was significant only in the incongruent condition ($F(1, 25) = 8.76$; $MSe = 1, 460.04$), suggesting that participants ignored the incongruent condition more easily in the second half compared to the first one. Nonetheless, the simple main effect of congruency was significant in both the first ($F(2, 50) = 96.62$; $MSe = 1, 889.02$; $F(2, 50) = 16.55$; $MSe = .00008$; for response time and response accuracy, respectively) and second ($F(2, 50) = 65.60$; $MSe = 1, 923.52$; $F(2, 50) = 23.45$; $MSe = .0004$; for response time and response accuracy, respectively) halves of the experiment. Planned comparisons showed that, in each half, responses to the incongruent were significantly slower ($F(1, 50) = 119.77$; $F(1, 50) = 94.28$; for the first and second half, respectively) and less accurate ($F(1, 50) = 24.57$; $F(1, 50) = 29.81$; for the first and second half, respectively) relative to the neutral condition. Responses to the congruent and neutral condition did not differ significantly on response accuracy ($F < 1$, in both halves). However, response to the congruent condition tended to be faster compared to the neutral condition in the first ($F(1, 50) = 3.81$, $p < .06$), but not in the second half ($F < 1$).

Skeletal-Congruency

Figure 2 plots naming time as a function of skeletal structure and order (first vs. second half). The corresponding accuracy means are presented in Table 11. These effects were assessed in

Fig. 2 Color naming time as a function of skeletal congruency in the first and second halves of Experiment 3. *Error bars* reflect confidence interval for the difference between the means

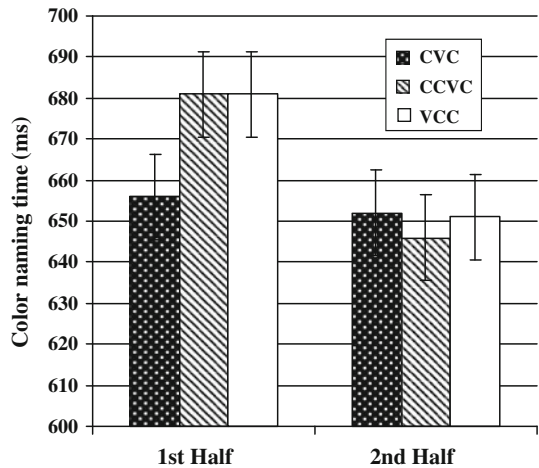


Table 11 Naming accuracy (proportion correct) as a function of order (first vs. second half) and skeletal congruency with the color *red* (Experiment 3)

CV structure		First half		Second Half	
		Mean	SD	Mean	SD
CV-congruent	CVC	.997	.0157	.997	.027
CV-Incongruent	Unmarked	.991	.0261	.99	.0157
	Marked	.997	.0157	.99	.0379

a two-way ANOVA (3 skeletal frames \times 2 order) on response time and response accuracy. The analysis of response accuracy did not yield any significant effects (all $F < 1.2$). Likewise, the analysis of naming time did not yield a significant main effect of skeletal congruency ($F_1(2, 50) = 1.60$; $MSe = 1232.39$; $F_2(2, 46) = 1.40$; $MSe = 1242.96$; n.s.), a result consistent with the findings of Experiment 2. However, there was a significant main effect of list order ($F_1(1, 25) = 6.75$; $MSe = 3100.85$; $F_2(1, 23) = 8.73$; $MSe = 2097.89$). Moreover, the interaction was significant by items ($F_2(2, 46) = 3.46$; $MSe = 1099.62$) and marginally significant by participants ($F_1(2, 50) = 2.76$; $MSe = 1351.74$; $p < .075$). Accordingly, the effect of skeletal congruency was assessed separately for the first and second halves of the experiment using planned comparisons.

In the first half of the experiment, readers named the color *red* significantly faster in the CVC congruent condition relative to each of the incongruent conditions, both the unmarked incongruent CCVC condition ($F_1(1, 50) = 5.81$; $F_2(1, 46) = 5.91$) and the marked incongruent VCC condition ($F_1(1, 50) = 5.52$; $F_2(1, 46) = 4.97$). Conversely, in the second half of the experiment, responses to the congruent, CVC condition did not differ from either of the incongruent skeletal conditions (All $F < 1$).

Discussion

Experiment 3 examined whether readers learn to suppress the processing of printed non-words throughout the experimental session. To assess learning, we examined the effect of

skeletal-congruency in the first and second half of the experiment. We found that the effect of list order modulated the effects of color congruency and skeletal congruency. Our manipulation of color congruency showed that participants were better able to ignore incongruent color-words in the second half of the experiment. Similar evidence of strategic learning was observed in the analysis of skeletal congruency. An analysis of the first half of trials yielded a reliable effect of skeletal congruency: Color naming was significantly faster in the presence of the congruent, CVC, items relative to the incongruent, VCC and CCVC items, which, in turn, did not differ from each other. In contrast, no significant effects of skeletal congruency were obtained in the second half. A comparison of the two halves suggests that the elimination of the skeletal-congruency effect might reflect a release from inhibition. Specifically, the congruent CVC items yielded similar response time in the first and second half (656 and 652 ms, respectively). In contrast, responses to the incongruent conditions were reduced by about 30 ms in the second half compared to the first. These findings suggest that readers learn to disregard the printed stimulus throughout the experimental session. This strategic blocking of the printed stimulus is incomplete, as it did not eliminate the effect of color-congruency. Because color words are highly familiar, their processing might be more automatic, and consequently, more resistant to suppression by learning relative to the processing of novel-letter strings. Conversely, the differences in the vulnerability of the color- and skeletal-congruency to learning might reflect the greater automaticity of processing a word's meaning compared to its skeletal structure. Because the stimuli used to assess skeletal and color congruency differed on their familiarity, our results do not allow us to discriminate between these interpretations. Either way, it appears that the suppression of the effect of skeletal congruency in Experiments 2 and 3 is due to strategic learning acquired throughout the experimental session.

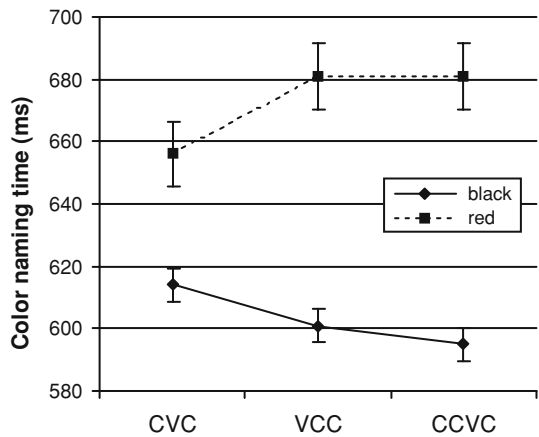
Although the effects of skeletal congruency can be suppressed, it is nonetheless remarkable that, in the absence of learning (i.e., in the first half of trials), participants were sensitive to the skeletal structure of nonwords which they were instructed to ignore. CVC nonwords, whose skeletal structure was congruent with the color name *red* facilitated color naming, whereas incongruent VCC and CCVC nonwords impaired color naming. These results converge with the findings of Experiment 1 to suggest that readers compute the skeletal structure of printed words automatically.

General Discussion

Three experiments investigated the effect of linguistic knowledge on skilled reading. As a case study, we examined the role of skeletal structure in the representation of novel printed words. Previous linguistic and psycholinguistic research has suggested that speakers encode the skeletal structure of spoken words. Linguistic evidence further indicates that certain skeletal frames are universally preferred to others. Our goal here was to determine whether readers assemble the skeletal structure of printed nonwords automatically, and whether they are further equipped with preferences for certain skeletal frames. To this end, we manipulated the congruency between the skeletal structure of color names (e.g., *red*, a CVC) and the skeletal structure of novel words which participants were asked to ignore (e.g., *GOP*, a CVC). We also examined whether skeletal frames that are universally infrequent and violate grammatical markedness constraints (i.e., *marked* frames) are dispreferred to more frequent structures that violate fewer constraints (i.e., *unmarked* frames).

The results of Experiments 1 and 3 suggest that readers are sensitive to the congruency between the skeletal structure of color names and nonwords which they were asked to ignore.

Fig. 3 Color naming time as a function of skeletal structure for the color *black* (in Experiment 1) and *red* (in the first half of Experiment 3). Error bars reflect confidence interval for the difference between the means



In Experiment 1, the color *black* (/blæk/, a CCVC frame) was named faster with CCVC relative to CVC nonwords (see Fig. 3). By contrast, CVC nonwords facilitated color naming relative to CCVC with the color *red*, a CVC frame (in Experiment 3). In both cases, skeletal congruency was determined by the abstract ordering of consonant and vowel slots, rather than by shared letters or phonemes. A comparison of the two experiments by means of an ANOVA (2 experiments \times 3 skeletal frames) indeed yielded a significant interaction ($F_1(2, 134) = 9.74$, $MSe = 931.86$; $F_2(2, 92) = 8.13$, $MSe = 861.41$). The reversal in the effect of the same two frames, CVC and CCVC, depending on the color name (e.g., red vs. black) must be due to their skeletal congruency with the color name, rather than their internal properties (e.g., the frequency of CVC frames or the statistical properties of the CVC items).

Although participants in our experiments were sensitive to the skeletal structure of novel printed words, the computation of skeletal frames was subject to some strategic control. The results of Experiment 2 indicated no sensitivity to skeletal structure with the color *red*, a finding we attributed to strategic suppression of processing the printed stimuli. Indeed, Experiment 3 revealed systematic changes in skeletal congruency throughout the experimental session: in the first half of trials, participants were highly sensitive to skeletal congruency, whereas in the second half, there was a release from the inhibition by incongruent frames, resulting in the elimination of the skeletal-congruency effect altogether. Unlike the color *red*, there was no evidence for such learning with the color *black*, in Experiment 1.² The strategic learning with *red* might be triggered by the similarity of the interfering VCC frame to the color name and the relative difficulty in naming the color *red*, evident by its slower naming time relative to *black*. Such control could reflect either a global suppression of processing the printed stimulus or one that is specific to the computation of skeletal frames—our results cannot adjudicate between these possibilities. These findings underscore participants' ability to exercise strategic adjustment in the Stroop task (e.g., Berent et al. 2006; Besner 2001; Crump et al. 2006; Kello et al. 2000; Raz et al. 2005; Tzelgov et al. 1992a). It is nonetheless remarkable that, in the absence of learning (e.g., at the beginning of Experiment 3),

² A comparison of the first versus second halves of Experiment 1 showed comparable effects of skeletal congruency (In the first half: CCVC = 608 ms; CVC = 620 ms; VCC = 607 ms; In the second: CCVC = 604 ms; CVC = 618 ms; VCC = 609). The skeletal congruency \times order (first vs. second half) interaction did not approach significance (In naming time: $F_1(2, 84) < 1$; n.s.; $F_2(2, 46) = 1.416$; $MSe = 969.2327$; In naming accuracy: $F_1(2, 84) < 1$; n.s.; $F_2(2, 46) < 1$; n.s.).

participants are sensitive to the congruency between the skeletal structure of color names and printed nonwords which they are asked to ignore.

Although participants were sensitive to skeletal congruency, not all skeletal frames were treated alike. Experiment 1 compared two incongruent skeletal frames: a VCC and CVC. We noted that across languages, VCC frames are less frequent. Likewise, VCC frames are more marked, in the sense that they incur a more severe violation of grammatical well-formedness constraints, called markedness constraints. We reasoned that if CVC frames are preferred to VCC (based on either grammatical markedness or frequency), then incongruent VCC frames should be ignored more easily than CVC frames. The results of Experiment 1 supported this prediction: color naming with the marked incongruent VCC frame was significantly faster relative to the less marked CVC frame. Another test of skeletal preferences was conducted in Experiment 3. Here, we compared among the marked VCC and the less marked CCVC frames, which were both incongruent with the color name *red*. Unexpectedly, responses to these two frames did not differ. The absence of a preference for CCVC vs. VCC frames in our experiment could be due to the fact that, contrary to our predictions, VCC is no more marked than CCVC. This explanation, however, is countered by the greater frequency of CCVC relative to VCC words in English (758 vs. 70), an observation consistent with the view of CCVC as preferred to VCC. On an alternative explanation, the lack of a CCVC preference is due to specific properties of the Stroop manipulation. Note that the two frames differ on the location of the complex constituent: CCVC manifests a complex onset, whereas VCC manifests a complex coda. Although our analysis (presented in Table 1) considers onset and coda complexity as equally marked, there is evidence that participants in the Stroop task are more sensitive to onset structure (Bibi et al. 2000). The salience of the onset could have underscored the violation of *Complex in CCVC nonwords, and offset the expected disadvantage of VCC items (due to their lack of onset). An investigation of this possibility awaits future research. The results of Experiment 1 nonetheless suggest that readers might favor frames that are universally frequent and well-formed to less frequent and less optimal ones.

These preferences also shed light on the nature of skeletal representations. Recall that linguistic evidence has supported two competing models for the skeleton: a CV-model, assigning distinct slots for consonants and vowels, versus an X-slot model, assigning generic slots, irrespective of consonant/vowel status. To illustrate, on the CV model, the words *act* and *cat* are assigned different frames, CVC and VCC respectively, whereas on the X-slot, they are represented alike, as XXX. Our results allow us to adjudicate between these proposals: participants in Experiment 1 named the color *black* slower with CVC compared to VCC frames—frames that differ only on the arrangement of consonants and vowels. These results suggest that the representation available to readers assigns distinct skeletal slots to consonants and vowels (i.e., a CV-skeleton). Nonetheless, these findings do not allow us to assess the source of skeletal preferences. Because the type frequency of CVC/VCC frames in English correlates with their grammatical markedness, we cannot determine whether the observed preferences reflect the grammatical properties of these frames or their statistical distribution. Either way, linguistic knowledge concerning spoken language appears to be available in the representation of print.

Readers' sensitivity to the skeletal structure of stimuli that they are asked to ignore suggests that the effect of linguistic knowledge on reading is automatic. Moreover, the observation of such effects for nonwords, stimuli whose skeletal structure is not stored, suggests that readers compute the skeleton using a productive process that assembles skeletal frames from print. These conclusions reaffirm the role of linguistic knowledge in shaping the representation assembled to print.

Appendix 1

See Table 12.

Table 12 The targets presented with the experimental colors *black* (Experiment 1)

CV-congruent	CV-incongruent	
	Unmarked (CVC)	Marked (VCC)
GROP	GUF	OSP
TREP	TEP	EPT
TWUD	TUD	UST
FREG	REG	ERD
GRUD	RUD	URB
FROP	FUP	OMP
TRUP	TUP	UPT
DRUF	DUR	UNT
TWEL	TER	ELT
DRUT	DUT	ULT
DROF	DOF	OLF
TROB	TOB	OLB
TWOF	TOF	ONT
FRUB	FUB	ULB
TWUM	TUS	ULM
FLOT	FOT	OLT
GROM	GOM	OLM
FRUT	FUT	UFT
FROD	LOD	ELD
TREB	LEB	ELB
FROT	FEP	OST
TRET	TEF	EST
FRUP	RUP	USP
DWOP	DOP	OLP

Appendix 2

See Table 13.

Table 13 The targets presented with the experimental colors *red* (Experiments 2 and 3)

CV-congruent	CV-incongruent	
	Unmarked (CCVC)	Marked (VCC)
GOM	GROM	OLM
FOS	FLON	OSP
TUS	TWUS	AST

Table 13 continued

CV-congruent	CV-incongruent	
	Unmarked (CCVC)	Marked (VCC)
FEK	FREK	ESK
TUP	TRUP	UPT
DUR	DRUF	UNT
DUT	DRUT	ULT
DOF	DROF	OLF
TOB	TROB	OLB
TOF	TWUF	ONT
FUB	FRUB	ULB
DOM	DWOM	ULM
FOT	FLOT	OLT
FUF	FRUF	ULF
FUT	FLUT	UFT
CAS	CLUT	UCT
FOL	FROT	OST
FUP	FRUP	USP
DOP	DWOP	OLP
GUF	GLUF	ULK
TIS	TWIB	ILB
GAK	GLAK	ICT
GUK	GRUK	USK
FAM	FLUP	ULD

References

- Abramson, M., & Goldinger, S. D. (1997). What the reader's eye tells the mind's ear: Silent reading activates inner speech. *Perception and Psychophysics*, *59*, 1059–1068.
- Berent, I. (1997). Phonological priming in the lexical decision task: Regularity effects are not necessary evidence for assembly. *Journal of Experimental Psychology: Human Perception and Performance*, *23*, 1727–1742.
- Berent, I., Bouissa, R., & Tuller, B. (2001). The effect of shared structure and content on reading nonwords: Evidence for a CV skeleton. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*, 1042–1057.
- Berent, I., Lennertz, T., Jun, J., Moreno, M. A., & Smolensky, P. (2008). Language universals in human brains. *Proceedings of the National Academy of Sciences*, *105*, 5321–5325.
- Berent, I., & Marom, M. (2005). The skeletal structure of printed words: Evidence from the Stroop task. *Journal of Experimental Psychology: Human Perception & Performance*, *31*, 328–338.
- Berent, I., Steriade, D., Lennertz, T., & Vaknin, V. (2007). What we know about what we have never heard: Evidence from perceptual illusions. *Cognition*, *104*, 591–630.
- Berent, I., Tzelgov, J., & Bibi, U. (2006). The autonomous computation of morphophonological structure in reading: Evidence from the Stroop task. *The Mental Lexicon*, *1*(2), 201–230.
- Besner, D. (2001). The myth of ballistic processing: Evidence from the Stroop's paradigm. *Psychonomic Bulletin and Review*, *8*, 324–330.
- Bibi, U., Tzelgov, J., & Henik, A. (2000). Stroop effect in words that differ from color words in one letter only. *Psychonomic Bulletin & Review*, *7*, 678–683.
- Boudelaa, S., & Marslen-Wilson, W. D. (2004). Abstract morphemes and lexical representation: The CV-Skeleton in Arabic. *Cognition*, *92*, 271–303.

- Caramazza, A., & Miceli, G. (1993). The structure of graphemic representations. *Cognition*, 37, 243–297.
- Costa, A., & Sebastian-Gallés, N. (1998). Abstract structure in language production: Evidence from Spanish. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 24, 886–903.
- Crump, M. J., Gong, Z., & Milliken, B. (2006). The context-specific proportion congruent stroop effect: Location as a contextual cue. *Psychonomic Bulletin & Review*, 13, 316–321.
- Ferrand, L., & Segui, J. (1998). The syllable's role in speech production: Are syllables chunks, schemas, or both?. *Psychonomic Bulletin & Review*, 5, 253–258.
- Fromkin, V. (1973). *Speech errors as linguistic evidence*. Mouton: The Hague.
- Greenberg, J. H. (1978). Some generalizations concerning initial and final consonant clusters. In J. H. Greenberg, C. A. Ferguson, & E. A. Moravcsik (Eds.), *Universals of Human Language* (Vol. 2) (pp. 243–279). Stanford: Stanford University Press.
- Kello, C. T., Plaut, D. C., & MacWhinney, B. (2000). The task dependence of staged versus cascaded processing: An empirical and computational study of Stroop interference in speech production. *Journal of Experimental Psychology: General*, 129, 340–360.
- Kenstowicz, M. (1994). *Phonology in generative grammar*. Cambridge, MA: Blackwell.
- Kucera, H., & Francis, W. (1967). *Computational analysis of present-day American English*. Providence, RI: Brown University Press.
- Levin, J. (1985). *A metrical theory of syllabicity*. Doctoral Dissertation, MIT.
- Lukatela, G., Eaton, T., & Turvey, M. T. (2001). Does visual word identification involve a sub-phonemic level?. *Cognition*, 78, B41–B52.
- MacNeilage, P. F. (1998). The frame/content theory of evolution of speech production. *Behavioral and Brain Sciences*, 21, 499–511.
- McCarthy, J. (1981). A prosodic theory of nonconcatenative morphology. *Linguistic Inquiry*, 12, 373–418.
- McCarthy, J., & Prince, A. (1995). Prosodic morphology. In J. A. Goldsmith (Ed.), *Phonological theory* (pp. 318–366). Oxford: Basil Blackwell.
- Meijer, P. (1996). Suprasegmental structures in phonological encoding: The CV structure. *Journal of Memory and Language*, 35, 840–853.
- Nespor, M., Peña, M., & Mehler, J. (2003). On the different roles of vowels and consonants in speech processing and language acquisition. *Lingue e Linguaggio*, 2, 223–229.
- Perfetti, C. A., & Bell, L. (1991). Phonemic activation during the first 40 ms. of word identification. Evidence from backward masking and priming. *Journal of Memory and Language*, 30, 473–485.
- Prince, A., & Smolensky, P. (1993). *Optimality theory: Constraint interaction in generative grammar*. Malden, MA: Blackwell.
- Ramus, F., & Mehler, J. (1999). Language identification with suprasegmental cues: A study based on speech resynthesis. *The Journal of the Acoustical Society of America*, 105, 512–521.
- Ramus, F., Nespor, M., & Mehler, J. (1999). Correlates of linguistic rhythm in the speech signal. *Cognition*, 73, 265–292.
- Rapp, B., & Caramazza, A. (1997). From graphemes to abstract letter shapes: Levels of representation in written spelling. *Journal of Experimental Psychology: Human Perception and Performance*, 23, 1130–1152.
- Raz, A., Fan, J., & Posner, M. I. (2005). Hypnotic suggestion reduces conflict in the human brain. *Proceedings of the National Academy of Sciences, USA*, 102, 9978–9983.
- Sevold, C., Dell, G., & Cole, J. (1995). Syllable structure in speech production: Are syllables chunks or schemas?. *Journal of Memory & Language*, 34, 807–820.
- Stemberger, J. P. (1984). Length as a suprasegmental: Evidence from speech errors. *Language*, 60, 895–913.
- Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 18, 643–662.
- Taft, M., & Kougious, P. (2004). The processing of morpheme-like units in monomorphemic words. *Brain & Language*, 90, 9–16.
- Treiman, R., Mullennix, J., Bijeljac-Babic, R., & Richmond-Welty, D. (1995). The special role of rimes in the description, use, and acquisition of English orthography. *Journal of Experimental Psychology: General*, 124, 107–136.
- Tzelgov, J., Henik, A., & Berger, J. (1992a). Controlling Stroop effect by manipulating expectation for color related stimuli. *Memory & Cognition*, 20, 727–735.
- Tzelgov, J., Meyer, J., & Henik, A. (1992b). Automatic and intentional processing of numerical information. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 18, 166–179.
- Van Orden, G. C. (1991). Phonological mediation is fundamental to reading. In D. Besner & G. Humphreys (Eds.), *Basic process in reading: Visual word recognition* (pp. 77–103). Hillsdale, NJ: LEA.