The autonomous computation of morpho-phonological structure in reading
Evidence from the Stroop task

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Is morphological decomposition automatic? To address this question, we examine whether Hebrew readers decompose morphologically complex words when reading is not required, in the Stroop task. Morphological decomposition is assessed using two markers. One marker examines whether color-naming is modulated by morphologically complex words generated from color roots. For example, we compare words generated from the Hebrew root of “blue” displayed in either blue or an incongruent color. The second marker examines whether color-naming is sensitive to root phonotactics. Here we compare color-naming with words whose (color-unrelated) roots are either phonologically illicit (e.g., \textit{srm}) or well-formed (e.g., \textit{smm}). Results suggest that morphological decomposition proceeds even when reading is discouraged, but unlike previous research with intentional reading tasks, Stroop-like conditions do not allow for a detailed representation of the root's internal structure.

Keywords: phonology, morphology, Hebrew, root, reading, Stroop, automaticity

Printed words are ciphers for structured linguistic objects. There is evidence that skilled readers compute various structural properties of printed words, including their syllable structure (e.g., Treiman, Mulvennix, Bijeljac-Babic, & Richmond-Welty, 1995), phonological features (e.g., Lukatela, Eaton, & Turvey, 2001), metrical structure (e.g., Berent & Marom, 2005; Miceli & Caramazza, 1993), sonority (e.g., Alonzo & Taft, 2002), and morphological structure (e.g., Feldman & Larabee, 2001; Marslen-Wilson, Komisarjevsky, Waksler, & Older,

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1994). Although it is clear that the linguistic structure of printed words is often recovered when reading is intended, less is known on whether this computation is automatic.

Automaticity is often marked by several features: Automatic processes tend to be effortless, unconscious, and involuntary (e.g., Posner, 1978). However, these features do not always co-occur simultaneously (e.g., Carr, 1992). Of the various hallmarks of automaticity, only one appears to define all automatic processes, namely, autonomy. An autonomous process is reflex-like — it proceeds without monitoring (Bargh, 1992). As cognitive processes are automated they become autonomous — they are launched even when they are not required by task demands (e.g., Besner, 2001; Tzelgov, 1997; Tzelgov, Yehene, Kotler, & Alon, 2000). Because autonomy is a defining feature of automaticity, it is particularly significant in gauging the automaticity of mental functions: To determine whether a mental function is automatic, it is necessary to determine whether it is autonomous. Stroop-like tasks (Stroop, 1935) examine the autonomous processing of an unattended dimension. The classic Stroop task investigates whether word reading proceeds despite instructions to attend to the word's color. In the present work, we extend the use of the Stroop task to examine how automatically-processed words are represented: Do people compute the linguistic structure of printed words even when they are asked to ignore them? Our interest here specifically concerns the representation of morphological structure: Is the processing of morphological structure autonomous?

We consider two competing accounts of morphological processing. One view holds that the processing of morphological structure is fully autonomous. In that view, morpho-phonological structure is always fully specified, irrespective of whether people attend to a target word or ignore it (e.g., Berent, Pinker, Tzelgov, Bibi, & Goldfarb, 2005). In an alternative account, the encoding of morphological structure is not fully autonomous. Accordingly, the representations available when people attend to a target word might differ from the ones available when target processing is unintentional. The hypothesis that the representation of morpho-phonological structure might vary qualitatively according to the task's attention demands is not only logically possible — existing evidence from the automaticity literature shows qualitative differences between representations computed automatically and those available under direct probing (Tzelgov & Ganor-Stern, 2005; Tzelgov & Pinku, 2002). But whether morpho-phonological processing is in fact fully or partially autonomous is not entirely clear from the present literature.

Although the literature on morphological processing is large, the autonomy of morphological processing is rarely addressed explicitly. Most existing studies
employ tasks that require participants to process a target word, attending to its linguistic properties (e.g., decide whether the target is a word). Such studies cannot determine whether the processing of the word proceeds autonomously when it is not required by the task demands. This limitation applies even to the strong evidence for morphological processing with masked-priming methods (e.g., Badecker & Allen, 2002; Boudelaa & Marslen-Wilson, 2004; Diependaele, Sandra & Grainger 2005; Frost, Forster, & Deutsch, 1997; Giraudo & Grainger, 2001; Rastle, Davis, & New, 2004; Taft & Kougious, 2004). The results from masked-priming show that morphological structure is quickly computed despite the lack of conscious awareness of the prime. Although these findings are certainly consistent with the hypothesis of autonomous morphological processing, they do not necessarily support it. Because people are required to process the target, one cannot rule out the possibility that the computation of morphological structure for the prime might be called upon by the demand to process the target. Moreover, critiques of masked-display methods argue that the disruption of orthographic information might overestimate the contribution of non-orthographic sources (Verstaen, Humphreys, Olson, & D’Ydewalle, 1995; but see also Berent & Van Orden, 2003).

Additional evidence for the autonomy of morphological processing is offered by the picture-word naming task. Participants in these experiments are asked to name pictures (e.g., of a rose), presented with printed word distractors, either morphologically related to the picture (e.g., rosetbud) or controls. Findings with German compounds and derived words demonstrate facilitation in picture naming by morphologically related distractors that participants are instructed to ignore (e.g., Dohmes, Zwitserlood, & Bolte, 2004; Zwitserlood, Bolte, & Dohmes, 2002). But whether participants do, in fact, ignore the distractors is not entirely clear: Because the morphological structure of the distractor facilitates the picture-naming task, participants might be encouraged to process the distractor intentionally. These results nonetheless suggest that, in German, a concatenative morphology, morphological processing might proceed in an autonomous fashion.

In the following research, we examine the autonomy of morphological and phonological processing in Hebrew, a nonconcatenative morphology, using the Stroop task. Because, in this task, the processing of morphological structure can interfere with performance, these experiments offer a stronger test of the autonomy of morphological processing. To explain our manipulation, we must first briefly describe the morphological structure of Hebrew words. Two aspects of Hebrew morphology are relevant to our manipulation. The first is that Hebrew words are formed by inserting a root in a word pattern. The root
Table 1. An illustration of morphologically-related words generated form the root kxl

<table>
<thead>
<tr>
<th>Condition</th>
<th>Hebrew orthography</th>
<th>Phonological representation</th>
<th>Word pattern</th>
<th>Grammatical/semantic features</th>
<th>Gloss</th>
<th>Used in Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>נָזָל</td>
<td>kaxol</td>
<td>CaCoC</td>
<td>Color names</td>
<td>Blue</td>
<td>1 &amp; 2</td>
</tr>
<tr>
<td>2</td>
<td>חוֹל</td>
<td>kaxal</td>
<td>CaCaC</td>
<td>Unaffixed</td>
<td>He turned blue</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>חָלַתי</td>
<td>kaxalti</td>
<td>CaCaC-suffix</td>
<td>1st past tense</td>
<td>I turned blue</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>מַקְסָלִים</td>
<td>makxalim</td>
<td>ma-CCiC-suffix</td>
<td>Participle</td>
<td>They/we are turning blue</td>
<td>1 &amp; 2</td>
</tr>
<tr>
<td>5</td>
<td>חֲקָשָלִים</td>
<td>hitkaxalim</td>
<td>hitCaCaC-suffix</td>
<td>Reflexive past tense</td>
<td>You turned (yourselves) blue</td>
<td>1 &amp; 2</td>
</tr>
</tbody>
</table>

is a sequence of typically three consonants. For instance, the root kxl indicates blueness. To form a word, the root must be inserted in a word pattern, including placeholders for the root consonants, vowels and (possibly) affixes. For instance, the root kxl may be inserted in the word pattern CaCoC (characteristic of nouns and adjectives), resulting in an adjective, the color name kaxol. The same root can also be inserted in verbal word patterns, resulting in a family of verbs that are morphologically related to blue (see Table 1).

A second relevant fact about Hebrew morphology is that root consonants are subject to co-occurrence restrictions (Greenberg, 1950; for an account, see McCarthy, 1986). Consider the root smm, for instance. This root includes identical consonants. Identical consonants are quite common in Hebrew roots, but their location is strictly constrained: Identical consonants are frequent at the end of the root (e.g., smm), but they are extremely rare in its beginning (e.g., ssms).

There is ample evidence that these two properties of Hebrew morphology are computed upon intentional reading. Numerous studies demonstrate that Hebrew readers decompose the root from the word pattern (e.g., Deutsch & Rayner, 1999; Deutsch, Frost, Pollatsek, & Rayner, 2000; Feldman & Bentin, 1994; Feldman, Frost, & Pnini, 1995; Frost, Forster, & Deutsch, 1994; Frost et al., 1997). There is also evidence that readers constrain the internal phonological structure of the root. Several reports have shown that roots with initial identical consonants (e.g., ssms) are disliked relative to those with either final (e.g., smm) or no identical consonants (e.g., psm). For instance, Hebrew speakers rate novel words including a novel ssms-type root as less acceptable than those containing smm or psm type controls (e.g., Berent & Shimron, 1997; Berent,
Marcus, Shimron, & Gafos, 2002; Berent & Shimron, 2003). Likewise, in the lexical decision, foils containing novel \textit{ssm}-type roots are rejected faster than \textit{ssm} and \textit{psm} type controls (e.g., Berent, Shimron, & Vaknin, 2001b; Berent et al., 2002; Berent, Vaknin, & Marcus, 2006). Crucially, the restriction on root structure is observed regardless of the position of the root in the word. For instance, participants dislike the word \textit{histasamti} (from the root \textit{ssm}) relative to \textit{histamamti} (from the root \textit{ssm}). The distinction between such morphologically complex words is inexplicable by their surface properties (Berent, Everett, & Shimron, 2001a): There is no phonological motivation for the dislike of surface forms such as \textit{histasamti} relative to \textit{histamamti} — the dislike is explicable only by the structure of their roots, \textit{ssm} versus \textit{ssm}. Accordingly, readers' sensitivity to the internal well-formedness of roots inserted in morphologically complex words offers converging evidence for the decomposition of the root from the word pattern.

Although existing results firmly establish that the root is decomposed from the word pattern and its structure is constrained when reading is intended, it is unknown whether this process is autonomous. Do readers decompose the root and constrain its structure even when reading is not required? To examine this question, we investigate whether readers are sensitive to morphological structure in the Stroop task. Our previous findings (Berent et al., 2005) demonstrate that Hebrew speakers automatically extract morphological and semantic number from the suffix under Stroop-like conditions. The present research extends the use of the Stroop task to investigate the morphological decomposition of the root. Participants in our experiments are presented with Hebrew letter strings displayed in color. Their task is to name the color of the string while ignoring its content. Of interest is whether participants are nonetheless sensitive to the morphological structure of the string. We examine sensitivity to morphological structure using two marker effects. The first probes for the effect of congruency between color names and color roots inserted in various word patterns. The second marker examines whether readers are sensitive to the phonological well-formedness of novel roots that are unrelated to color terms.

1. \textit{The effect of congruency with color roots.} To examine whether readers automatically decompose morphologically complex words, we presented them with nonwords constructed from the roots of color-words (hereafter, color roots). For instance, the word \textit{hitkaxaltem} (you turned blue) was constructed from the root \textit{kx}l — the root of the color-word blue, \textit{kaxol}. The resulting forms are not color words themselves, but their root is related to color terms, hence their meaning can be productively discerned from their morphological con-
stituents. These target words were displayed in colors that are either congruent with the color-root (e.g., hitkaxalem, presented in blue) or incongruent (e.g., hitkaxaltem in green). Of interest is whether congruency with color-roots affects color naming.

To assure that these effects reflect the congruency with the target’s root (e.g., kzd), it is necessary to demonstrate that they could not be caused by the target word as a whole (e.g., hitkaxaltem). The structure of the Hebrew verbal system allows us to dissociate the effect of the root from the word. Although the Hebrew verbal system is productive, it manifests systematic gaps: Some roots are rare or even non-existent in certain word patterns. In the verbal system, color-roots are typically inserted in the participle (e.g., makxilim), but they are rarely used in the reflexive (e.g., hitkaxaltem). Our experiments systematically compare the effect of congruency with participle and reflexive forms. Because the surface frequency of reflexive forms is low (far lower than their root), they are not easily accessible from the lexicon. In some cases, these surface forms are altogether non-existent: Reflexive forms generated from the color roots of yellow and green are non-existent in Modern Hebrew (Even-Shoshan, 1993). The congruency of such nonwords with color words cannot be explained by the semantic properties of unanalyzed surface forms.

The effect of root-color congruency is also unlikely due to the orthographic and phonological properties of surface forms. The phonological and orthographic overlap of our experimental targets with congruent color names is not necessarily larger than with incongruent ones. For instance, compare the orthographic overlap of the color-name cahov (yellow) with a target including a congruent color-root (the reflexive word hictahavti) and one with an incongruent color-root (the unaffixed form kaxal, derived from the color name kaxol, blue). The congruent target manifests a gross length mismatch with the color name and their letter overlap is low (hictahavti and cahov do not share any letters in the same position), whereas the incongruent target and the color name (kaxal-cahov) have similar length and word structure.

In summary, the effect of color congruency is difficult to explain in terms of the semantic or orthographic/phonological properties of unanalyzed whole words: These words are either unfamiliar or non-existent (hence, in the absence of decomposition, their surface, whole-word forms are devoid of semantic properties), and their form overlap with congruent color words is not larger than with incongruent ones. Accordingly, an effect of root-congruency reflects morphological decomposition of the root². If root decomposition is automatic, then we expect color naming to be faster for letter strings whose roots are congruent with the color relative to those that are incongruent. To the extent that
morphological decomposition is robust, the effect of root congruency should be obtained even when the morphological structure of the word is opaque (in the presence of prefixes and suffixes) and when its surface form is highly unfamiliar (in the reflexive) or even nonexistent in the language (i.e., for reflexive words with the roots of green and yellow).

2. The sensitivity to the phonological well-formedness of novel roots. As a second marker of morphological decomposition, we examined whether speakers are sensitive to the internal phonotactics of the root. As noted above, Hebrew constrains the structure of the root morpheme: It allows roots with identical consonants at their end (e.g., *ssmm*) but not in their beginning (e.g., *ssm*). To examine whether the restriction on root structure applies in an autonomous fashion, we examine the effect of root phonotactics on color naming. To this end, our experiments employed a second set of materials consisting of novel roots — combinations of three consonants that do not occur in Hebrew. These novel roots were arranged in matched triplets: One root type had identical consonants root-initially (e.g., *ssm*), another had identical consonants root-finally (e.g., *ssmm*), and a third one had no identical consonants (e.g., *psm*). The roots were conjugated in the various word patterns described above (see Table 2). Past research using intentional reading tasks suggests that *ssm*-type roots are less acceptable than either *ssmm* or *psm* type roots. If the constraint on root structure applies automatically, then color naming might differ with *ssmm*-type roots compared to *ssm-* or *psm-* type controls. The direction of this difference is unclear a priori: If ill-formed roots are more difficult to represent, then their reading might impair color naming relative to controls. Conversely, ill-formed words might be easier to ignore: There is ample evidence that color naming is faster with nonwords relative to words (e.g., Tzelgov, Henik, & Berger, 1992), a phenomenon attributed to the lexical component of the Stroop effect (Sharma & McKenna, 1998). If ill-formed roots such as *ssm* are less word-like, then they

<table>
<thead>
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<th>Table 2. An Illustration of the Manipulation of Root Phonotactics</th>
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<tbody>
<tr>
<td><strong>Word pattern</strong></td>
</tr>
<tr>
<td>Unaffixed⁹</td>
</tr>
<tr>
<td>CaCaC</td>
</tr>
<tr>
<td>(used in Exp. 1)</td>
</tr>
<tr>
<td>root <em>ssm</em></td>
</tr>
<tr>
<td><em>ssmm</em></td>
</tr>
<tr>
<td><em>psm</em></td>
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</tbody>
</table>
might result in faster color naming relative to their well-formed controls, \textit{snnm} and \textit{psm}.

In summary, our experiments employ two markers of morphological decomposition: One examines the effect of color-root congruency and the other assesses the restriction on consonant-co-occurrence in novel roots. These markers are compared in two experiments that differ on the extent they encourage reading. Although the Stroop task does not require reading, under some conditions, it might offer some incentive to process the printed stimulus intentionally. This might happen, for example, when the proportion of congruent color words (e.g., the word \textit{red} printed in red) or the frequency of color words is high relative to the neutral condition (e.g., Logan & Zbrodoff, 1979; Logan, 1980; Lowe & Mitterer, 1982; Tzelgov et al., 1992). It is important to emphasize that the sensitivity of Stroop-like phenomena to such experimental manipulations does not imply that the very process of reading is intentionally monitored. Indeed, it has been shown that people benefit from the statistical structure of their environment without intentionally processing it (Gotler, Meiran, & Tzelgov, 2003; for computational simulation, see Botvinick, Braver, Barch, Carter, & Cohen, 2001).

To examine whether morphological decomposition under the Stroop task is subject to some control our experiments manipulate the proportion of color-congruent words. In Experiments 1, the proportion of color-congruent stimuli is large (54%), whereas in Experiment 2, color-congruent stimuli are either rare (17%) or altogether nonexistent. If morphological decomposition is fully autonomous, then it should apply across the board, irrespective of the incentive to read. Conversely, if morphological decomposition is subject to control, then the effect of root-structure and meaning on color naming might vary depending on the proportion of congruent color trials.

**Experiment 1**

Experiment 1 examines the effects of color congruency (the congruency between color roots and their color, see Table 1) and root structure (i.e., the distinction between novel, \textit{snnm}, \textit{snnm}- or \textit{psm}-type roots, see Table 2) on color naming. The color roots and novel roots were presented in morphological patterns that are either fully transparent (without prefixes or suffixes attached to the stem), or opaque, in which the stem is "sandwiched" between a prefix and a suffix. To maximize sensitivity to morphological structure, we include a high proportion of color words in a congruent color (54% of the word-like trials).
If speakers decompose words into their morphological constituents and constrain their structure, then (a) color naming should be faster in the presence of color-congruent roots (the root *kxl*, indicating blueness, presented in blue) relative to incongruent ones (*kxl* presented in green); and (b) color naming should differ in the presence of ill-formed novel roots with identical consonants root-initially (e.g., *ssm*) relative to controls, roots with identical consonants at the root’s end (e.g., *ssm*) or no identical consonants (e.g., *psm*).

**Method**

**Participants.** Thirty native Hebrew speakers, students at Ben-Gurion University served as participants in partial fulfillment of a course requirement.

**Materials.** The experiment included three types of letter strings printed in color. The first type of materials was color words corresponding to the colors green (*yarok*), yellow (*cahow*), blue (*kaxol*), and red (*?adom*), presented in a congruent color (4 words × 86 repetitions per word = a total of 344 congruent color-word trials).

The second type of materials was generated by inserting four color-related roots (the roots *?dm, chv, kxl, yrk*, corresponding to the roots of the colors red, yellow, blue and green, respectively) in an unaffixed word pattern⁴, the participle (maCCiC-suffix) and reflexive (hit-CaCaC-suffix) word patterns (conditions 2, 4 & 5 in Table 1). For example, the root *kxl* (indicating blueness) was presented as *kxl, maksilim, hitkaxaltem*. To assess the familiarity with these surface forms, we asked a group of sixteen Ben-Gurion University students to rate them on a 1–5 scale (1 = impossible, 2 = possible but nonexistent, 3 = rare, 4 = medium, 5 = frequent). As expected, the reflexive forms were rated as non-existing words (*M = 1.87*), and their subjective frequency was significantly lower than either the unaffixed (*M = 4.01, F(1, 30) = 90.06, p < .0001*) or participle forms (*M = 3.62, F(1, 30) = 60.21, p < .0001*). The rating results also confirmed that the two reflexive forms listed in the Hebrew dictionary (*hit?adamtem, hitkaxaltem*) were unfamiliar to our participants (*M = 2.5, SD = 1.46; M = 1.7, SD = .70 respectively). The resulting words were presented in a color that was either congruent or incongruent with the color indicated by the root. Congruent and incongruent items were each repeated three times. There were 36 congruent trials (4 color roots × 3 word patterns × 3 repetitions) and 36 incongruent trials (a total of 72 color-root congruent trials).

The third type of letter strings consisted of nonwords generated by inserting a novel root (a combination of three consonants that does not exist
in Hebrew) in an existing word pattern. These novel roots were arranged in triplets: One triplet member had identical consonants root initially (e.g., ssr), one had identical consonants root-ﬁnally (e.g., ssm), and one had no identical consonants (e.g., psm). Twenty-four such triplets were inserted in an unafﬁxed, the participle (maCCiC-sufﬁx) and reﬂexive (hit-CaCaC-sufﬁx) word patterns (see Table 2). The resulting 216 nonwords were each presented in either red, green blue, or yellow (a total of 216 trials including novel roots). Each color appeared with equal frequency with each of the root type × word pattern combinations, and a root never shared any consonants with the color-name in which it was presented. All letter strings were printed in Times New Roman 24 point font without diacritic marks.

In summary, Experiment 1 included 344 color-word trials (type 1), 72 root-congruency trials (type 2) and 216 novel-root trials (type 3), for a total of 632 trials. Of the 632 trials, 344 (54.4%) were both familiar words and color-congruent.

Procedure. In each trial, participants were presented with a Hebrew letter string, printed in color at the center of a computer screen. They were asked to name the color of the string and ignore its meaning. Each trial consisted of three consecutive events (ISI = 0): A ﬁxation point (presented for 700 ms), followed by a blank screen (presented for 50 ms), which was followed by the colored letter string (presented until participant had responded). Response latency was collected via an L.P.S. 700 clock card within the computer, whereas response accuracy was coded by the experimenter. The next trial began after 500 ms. Each participant was presented with all 632 trials in a randomized order.

To familiarize participants with the experimental task, they were ﬁrst presented with a short practice session. The structure of the trials in the practice session matched the experimental session. During the practice, color-naming errors were corrected by the experimenter.

Results

Correct responses slower than 2.5 SD from the mean or faster than 300 ms were excluded from the analyses of response latency (1.23% of the total correct observations). In this and all subsequent experiments, sensitivity to morphological structure was assessed separately for color roots (including all repeated trials) and novel roots. Color words were treated as ﬁllers and excluded from all analyses.
Figure 1. Mean color-naming latency (in ms) as a function of root-congruency and word-patterns in Experiment 1. Error bars represent the confidence interval constructed for the difference among the means.

Color roots. Figure 1 presents mean color-naming latency for words whose root was either congruent or incongruent with the color name. The respective error means are presented in Table 3. An inspection of the means suggests that color naming was faster and more accurate for congruent color-roots relative to incongruent ones. In addition, color naming was affected by morphological complexity: As the morphological complexity of the word pattern increased, color naming of congruent color-roots became slower, whereas color naming of incongruent color-roots became faster. We assessed the effect of congruency on response time and accuracy by means of an ANOVA (2 congruency × 3 word pattern) using participants \( F_s \) as a random variable (because we used only four color-roots, these effects could not be assessed across items). The ANOVA yielded a significant main effect of congruency \( F_s(1, 29) = 147.505, \) \( MSE = 1089667, p < .0001; F_s(1, 29) = 35.95, MSE = 49.31, p < .0001, \) in latency and accuracy, respectively), as well as a significant interaction of congruency × word pattern \( F_s(2, 58) = 11.98, MSE = 2076, p < .0001; F_s(2, 58) = 27.75, MSE = 21.74, p < .0001, \) in latency and accuracy, respectively). The simple effect of word pattern was significant in both the congruent \( F_s(2, 58) = 6.07, MSE = 1242, p < .005 \) and incongruent conditions \( F_s(2, 58) = 5.47, MSE = 3520, p < .007 \). Scheffe post-hoc tests indicated that when color-roots were presented
Table 3. Mean Errors (%) in Color Naming as a Function of Root-Congruency (the Congruency Between Color-Roots and Color Name) and Word Pattern in Experiment 1

<table>
<thead>
<tr>
<th></th>
<th>Incongruent</th>
<th>Congruent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unaffixed</td>
<td>13.86</td>
<td>0.30</td>
</tr>
<tr>
<td>Participle</td>
<td>2.49</td>
<td>0.55</td>
</tr>
<tr>
<td>Reflexive</td>
<td>3.33</td>
<td>0.00</td>
</tr>
</tbody>
</table>

In a congruent color, color naming was faster for the unaffixed word pattern compared to either the participle or reflexive word patterns (both $p < .05$). Conversely, in the incongruent condition, color naming was slower in the unaffixed compared to the participle and reflexive word patterns (both $p < .05$). Although the effect of congruency was larger in the unaffixed word pattern ($F(1, 29) = 148.39, p < .001; F(1, 29) = 45.19, p < .001$, in latency and accuracy, respectively), the simple effect of congruency was significant in the two opaque word patterns as well, namely, the participle ($F(1, 29) = 63.76, p < .001; F(1, 29) = 4.17, p < .06$ in latency and accuracy, respectively) and reflexive ($F(1, 29) = 80.64, p < .001; F(1, 29) = 9.14 p < .006$ in latency and accuracy, respectively) word patterns.

Because in Hebrew color roots are rarely inflected in the reflexive, the effect of congruency for reflexive words is unlikely due to the semantic properties of unanalyzed surface forms. Indeed, these forms are unfamiliar to Hebrew speakers (see Method). A subset of our materials allows us to fully reject the possibility that the effects of congruency reflect the properties of the surface form as a whole. Recall that two of the color roots used in our experiment are unattested in the reflexive (the roots chv and yrk, for yellow and green, respectively). Because these reflexive verbs are nonwords, their effect on color naming must be due to the properties of their root, rather than to the surface form. A separate analysis of these two roots in the reflexive converges with our main results: Responses to congruent color-roots ($M = 629$ ms) were faster than to incongruent ones ($M = 719$ ms, $F(1, 29) = 24.26, MSE = 5097, p < .0002$; there were no differences in response accuracy, $F < 1$). These results suggest that readers decompose morphologically complex words automatically.

**Novel roots.** Additional evidence for morphological decomposition was sought by examining whether readers are sensitive to the phonological structure of novel roots, presented in morphologically complex nonwords. If readers constrain root structure, then color naming should differ in the presence of ill-formed, ssm-type roots relative to smm and psm-type controls. Mean color
naming latency for novel roots as a function of root type and word pattern are presented in Figure 2. The corresponding error means are described in Table 4.

Color naming latency and accuracy were assessed by means of a 2 way ANOVA (3 root type x 3 word pattern) over participants ($F_s$) and items ($F_i$). The analyses of response accuracy did not yield any significant effects of root type (all $F < 1$). The analyses of response latency revealed a significant main effect of word pattern ($F_s(2, 58) = 7.45$, $MSE = 345.79$, $p < .002$; $F_i(2, 46) = 3.25$, $MSE = 635.37$, $p < .05$), but not of root type ($F_s(2, 58) = 2.06$, $MSE = 512.70$, $p < .14$; $F_i(2, 46) = 1.69$, $MSE = 543.57$, $p < .19$). The interaction of root type x word pattern was marginally significant ($F_s(4, 116) = 2.32$, $MSE = 453$, $p < .07$; $F_i(4, 92) = 2.18$, $MSE = 398$, $p < .08$). The simple effect of root type approached
significance in both the unaffixed \( F_s(2, 58) = 3.68, p < .04; F_s(2, 46) = 2.87, p < .07 \) and the reflexive word pattern \( F_s(2, 58) = 3.08, p < .06; F_s(2, 46) = 2.06, p < .14 \), but not in the participle word pattern \( F < 1 \). These effects were further investigated using planned comparisons. In the reflexive pattern, color naming tended to be faster with ill-formed \textit{ssm} type roots relative to either \textit{ssm}-type roots \( F_s(1, 58) = 5.20, p < .03; F_s(1, 46) = 3.84, p < .06 \) or \textit{psm}-type roots \( F_s(1, 58) = 3.96, p < .06; F_s(1, 46) = 2.07, p < .11 \). Conversely, in the unaffixed word pattern, responses to \textit{ssm}-type roots did not differ from \textit{ssm} type roots (all \( F < 1 \)). However, \textit{ssm} \( F_s(1, 58) = 6.05, p < .02; F_s(1, 46) = 4.84, p < .04 \) and \textit{ssm}-type \( F_s(1, 58) = 4.92, p < .04; F_s(1, 46) = 3.69, p < .07 \) roots both resulted in slower color naming latency relative to \textit{psm} type controls.

**Discussion**

Experiment 1 assessed the morphological decomposition of printed words using two markers: root congruency and root structure. The marker of root-congruency clearly showed that readers are sensitive to the morphological structure of letter strings that they are instructed to ignore. Specifically, color naming was reliably faster and more accurate in the presence of congruent color-roots relative to incongruent ones. Moreover, this effect was found for reflexive verbs, verbs that rarely take color-roots, hence their surface frequency is low, or, in some cases (for the color roots of yellow and green), zero (i.e., nonwords). Because the congruency between these letter string and their color names resides only at the level of the root, this effect implicates the decomposition of the root from the word pattern. The finding of root-congruency effects in each of the word patterns studied in our experiment suggests that the decomposition of the root from the word pattern is quite general.

Our experiment also probed for morphological decomposition by examining readers' sensitivity to the internal structure of the root. Existing research conducted using intentional reading tasks demonstrates that \textit{ssm}-type roots are disliked relative to either \textit{ssm} or \textit{psm}-type roots even when these roots are inserted in morphological patterns that are highly opaque (Berent & Shimron, 1997; Berent et al., 2001b; Berent et al., 2002; Berent & Shimron, 2003; Berent, Vaknin, & Shimron, 2004; Berent et al., 2006). The findings of Experiment 1 reflect some sensitivity to root structure even under unintentional reading (i.e., in the Stroop task). These effects, however, are relatively weak: The effect of root structure was statistically non-significant in the participle, whereas in the unaffixed and reflexive word patterns, it only approached significance. Moreover, the effect of root-structure on color-naming differed markedly across the
two word patterns. In the reflexive, heavily affixed word pattern, ill-formed ssm-type roots (e.g., histasamti) resulted in faster naming relative to either smm or psm controls, suggesting that ill-formed roots were ignored more easily. Conversely, when the same roots were presented in the unaffixed word pattern (e.g., sasam), color naming was slower relative to the no-identity (psm) condition.

It is unlikely that these differences are due to differences in word-length or affixation among the word patterns, since the reflexive and participle yielded different outcomes despite their similarity in length and affixation (both have a prefix and a suffix). Instead, such differences might reflect control on the reading task. Because this experiment included a high proportion of color-terms displayed in a congruent color, participants could be tuned to the presence of color words or words that resemble color terms. Recall that color roots typically appear as unaffixed color words, they occasionally take the participle form, but they rarely take the reflexive. On a coarse inspection, unaffixed forms are thus the most similar to color names (which are likewise unaffixed) whereas the reflexive forms are the least similar. The similarity to color terms could have encouraged participants to engage in intentional, resource-demanding strategies in processing unaffixed (and, to a lesser extent, participle) forms which might have rendered them vulnerable to resource-competition. Accordingly, the internal ill-formedness of the root might have increased the difficulty of the (secondary) reading task, and impaired the color-naming task. The proposal that unaffixed items were read intentionally can also account for the finding that compared with opaque items in the participle and reflexive, unaffixed color-roots resulted in slower naming of incongruent colors and faster naming of congruent ones. The modulation of reading strategies by the presence of color words is examined in Experiment 2.

Experiment 2

Although participants in Experiment 1 engaged in morphological decomposition when reading was not required, the large proportion of congruent color-words (e.g., red displayed in red) offered them some incentive to read (i.e., to allocate resources to the processing of the printed stimulus). One might wonder whether participants might still engage in morphological decomposition when the incentive to read is eliminated — in the absence of congruent color words. To examine this question, Experiment 2 replicates Experiment 1 while manipulating the proportion of congruent color-words across two groups of
participants. One group of participants (the "color group") was presented with color words in a congruent color (e.g., red in red). However, the proportion of such trials relative to the total number of word-like trials was 17%, a proportion that is far lower than in Experiment 1 (54%). A second group of participants was not presented with any congruent color-words (the "no color" group). As before, we gauge morphological decomposition by two markers: The congruency with color-roots, and the internal structure of novel roots. Color roots and novel roots were presented in the participle and reflexive patterns used in Experiment 1, as well as in the suffixed verbal pattern Kal (generated by adding a suffix to the unaffixed forms in Experiment 1). The addition of the suffix was designed to discourage the intentional reading of these items by decreasing their similarity to color words. If morphological decomposition is achieved by a controlled process, then it should be evident only when reading is encouraged, in the presence of congruent color words. Furthermore, the magnitude of morphological effects should be reduced compared to Experiment 1 (in which the proportion of color-congruent words was high). Conversely, if morphological decomposition is autonomous, then it should be evident even in the absence of color-congruent words.

Method

Participants. Two groups of native Hebrew speakers, students at Ben Gurion University, participated in the experiment in partial fulfillment of a course requirement. Each group included twenty-four participants.

Materials and procedure. The experiment included three sets of materials. One set corresponded to the novel roots employed in Experiment 1 (a total of 216 trials). These roots manifested root-initial identity, root-final identity or no identity, and they were presented in three word patterns: the participle (maCCiC-suffix) and reflexive word patterns (hitCCiC-suffix), described in Experiment 1, as well as in a suffixed verbal pattern in binyan kal (CaCaC-suffixed, see Table 2). The second set of materials consisted of three color roots (the roots of red, yellow and blue), conjugated in the same word patterns (see conditions 3–5, Table 1), and presented with either congruent (a total of 72 trials) or incongruent (a total of 72 trials) colors, as described in Experiment 1. For example, the root kxl (indicating blueness) was presented as kaxalti, makhilim, hitkaxaltem. The familiarity rating of these materials was assessed by a group of Hebrew speakers (see Method, Experiment 1). Suffixed color-terms in Kal were rated as non-existing Hebrew words (M = 1.93), a familiarity that was similar
to the reflexive ($M = 1.87$, $F < 1$), and significantly lower compared with participle forms ($M = 3.62$, $F(1, 30) = 78.39$, $p < .0001$). The third set of materials corresponded to color words, displayed only in a congruent color (a total of 72 trials). One group of participants (the color group) was presented with all three sets of materials, whereas the second (no-color) group was presented with the novel roots and color roots, but not with the color words. In each group, the materials appeared with equal frequency in the colors blue, yellow and red. The procedure is as described in Experiment 1.

Results

In view of the high individual differences in mean response latency, we excluded from the analyses of response latency correct responses slower than 2.5 SD from the mean response latency of each individual subject, as well correct responses that were faster than 200 ms. This procedure resulted in the exclusion of 1.9% of the total correct observations.

Color roots. Our initial set of analyses examined whether the presence of color-words modulated the effect of congruency with color-roots. Mean color-naming latency for color-roots as a function of word pattern and group is presented in Figure 3. The corresponding error means are given in Table 5.

The effect of root-congruency in the two groups was compared by means of 2 (group) × 2 (congruency) × 3 (word pattern) ANOVAs. An inspection of the means suggests that the effect of congruency was robust in both groups. The ANOVAs indeed revealed a significant effect of congruency ($F_s(1, 46) = 196.45$, $MSE = 3889$, $p < .0001$; $F_s(1, 46) = 31.70$, $MSE = .181$, $p < .0001$; in latency and accuracy, respectively) that was not reliably modulated by the group factor (both $p > .10$). However, the congruency effect was modulated by the properties of the word pattern, resulting in a significant interaction of congruency × word pattern in the ANOVAs of response latency ($F_s(2, 92) = 6.61$, $MSE = 1562$, $p < .003$).

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<th>No color group</th>
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<td></td>
<td>Incongruent</td>
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<tr>
<td>Kal</td>
<td>7.62</td>
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<tr>
<td>Participle</td>
<td>4.4</td>
<td>2.3</td>
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<td>Reflexive</td>
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and accuracy ($F_s(2, 92) = 12.67, MS = 0.73, p < .0001$). Simple effects demonstrated that color naming was significantly faster and more accurate in the congruent relative to the incongruent condition in the suffixed verbal pattern *kal* ($F_s(1, 46) = 146.52, p < .001; F_s(1, 46) = 35.39, p < .0001$, in latency and accu-
racy, respectively), the participle \(F_g(1, 46) = 140.70, p < .001; F_g(1, 46) = 10.75, p < .003\), in latency and accuracy, respectively) and reflexive \(F_g(1, 46) = 59.23, p < .001; F_g(1, 46) = 7.32, p < .002\), in latency and accuracy, respectively). The absence of a significant three-way interaction (both \(p < .14\)) suggests that root decomposition was independent of the presence of color words. A separate analysis of the no-color group confirmed that the effect of congruency was robust even when color-congruent words were altogether absent⁵.

To ensure that the effect of color-congruency is not caused by unanalyzed surface forms, we conducted a separate analysis of morphologically complex items that do not correspond to existing Hebrew words — the reflexive forms with the color-root yellow (hictahavtem). Responses to incongruent color-roots were significantly slower compared to congruent ones regardless of whether congruent color words were present \(\Delta = 111 \text{ ms}, F_g(1, 23) = 16.66, \text{MSE} = 8935, p < .0006\) or absent \(\Delta = 59 \text{ ms}, F_g(1, 23) = 8.83, \text{MSE} = 4763, p < .007\). The color-group also yielded a significant effect of congruency in accuracy \(\Delta = 3.6\%, F_g(1, 23) = 6.75, \text{MSE} = .002, p < .020\). The group \(\times\) congruency interaction was not significant (both \(p > .13\))

**Novel roots.** Mean color-naming latency with novel roots is presented in Figure 4. The respective error means are given in Table 6. We first examined whether sensitivity to root structure is modulated by the proportion of
Table 6. Mean Errors in Color Naming (% errors) as a Function of Root Type, Word Pattern, and Group in Experiment 2

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<td></td>
<td>Kal</td>
<td>Participle</td>
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<tr>
<td>ssm</td>
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<td>smm</td>
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<td>psm</td>
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congruent color words by means of an omnibus 2 group × 3 word pattern × 3 root type ANOVA. None of the group effects or interactions approached significance in the accuracy analysis. The analyses of response latency yielded a significant interaction of group × word pattern \(F_s(2, 92) = 4.10, MSE = 1535, p < .02; F_f(2, 46) = 8.86, MSE = 815.83, p < .0007\) as well as a marginally significant three-way interaction \(F_s(4, 184) = 1.89, MSE = 1400.74, p < .12; F_f(4, 92) = 2.95, MSE = 784.41, p < .03\). Accordingly, the effect of root structure on color naming latency was investigated for each group separately.

An analysis of the no-color condition showed no effect of root-type (all \(F < 1.5\)). In contrast, in the color group, the effect of root type was marginally significant \(F_s(2, 46) = 2.70, MSE = 1514.21, p < .08; F_f(2, 46) = 2.55, MSE = 1270.20, p < .09\), and it did not interact with the word pattern \(F_s(4, 92) = 1.45, MSE = 1558, p < .23; F_f(4, 92) = 1.80, MSE = 1207, p < .14\). Planned comparisons showed that color naming was significantly faster for the ill-formed, ssm-type roots relative to psm-type roots \(F_s(1, 46) = 5.38, p < .03; F_f(1, 46) = 5.10, p < .03\). However, ssm type roots did not differ from smm-type roots \(F_s(1, 46) = 1.53, p < .24; F_f(1, 46) = 1.28, p < .20\). Thus, although participants distinguished roots with identical consonants from those without them, the location of consonant-identity in the root (initial vs. final) was not securely encoded.

Discussion

Experiment 2 examined whether morphological decomposition is contingent on the presence of congruent color words — a condition that might encourage reading. The findings with color-roots showed that morphological decomposition proceeds even when color words were entirely absent. In particular, participants in the no-color group were faster to respond to items with congruent color-roots even when their morphological structure was opaque (with the reflexive and participle word patterns), including when their surface form is utterly unfamiliar (with color roots whose reflexive forms do not exist in He-
brew). These findings indicate that the root was decomposed from the word pattern irrespective of the incentive to read, given by the presence of congruent color words in the experimental list.

Although the absence of color words does not eliminate the decomposition of the root, it does seem to affect the representation of its internal structure. When reading was discouraged (in the absence of congruent color-words), participants were completely insensitive to the internal ill-formedness of novel roots. In contrast, participants showed some sensitivity to root phonotactics when reading was encouraged (when congruent color-words were present): ill-formed *ssm*-type roots resulted in a significant speed-up of color naming relative to *psm*-type controls. Furthermore, the sensitivity to root structure was unaffected by the word pattern. This finding differs from the results obtained in Experiment 1 (using a high proportion of congruent color words), in which *ssm* type roots facilitated color naming exclusively in the unaffixed and reflexive word patterns. We suggested that this interaction might reflect reliance on a controlled reading strategy in the unaffixed word pattern, a strategy triggered by the high proportion of color-words in the experimental list. The replacement of the unaffixed words with suffixed ones, and the reduction in the proportion of color words in the present experiment appears to have attenuated this strategy, resulting in a general effect of root structure across all word patterns. Because the effect of root structure was not fully reliable, these results must be interpreted with caution. Our current results suggest that the presence of color words might modulate sensitivity to fine-grained aspects of morphological structure, but it is not necessary for morphological decomposition per se.

**General discussion**

Two experiments examined whether readers represent the morpho-phonological structure of letter strings that they are asked to ignore. We used two markers of morphological structure: One was the congruency between color roots, embedded in morphologically complex words, and the color in which they were presented (e.g., the congruency between the letter string *hitkaxaltem* and the color word *kaxol*, blue, both sharing the root *kxl*, blueness). The second marker was the restriction on the location of identical consonants in novel (color-unrelated) roots embedded in morphologically complex words. Specifically, we compared color naming in the presence of ill-formed roots with initial identical consonants (e.g., *ssm*) to well-formed ones (e.g., *xmm, psm*). To exam-
ine whether the computation of morphological structure depends on participants’ strategies, we compared the outcomes of these markers under conditions that either offer some incentive to read (due to the presence of congruent color words in the experimental list) or discourage reading (in their absence).

The findings from the color-congruency manipulation yielded robust evidence for morphological decomposition: Color naming was faster in the presence of congruent roots inserted in opaque word patterns, including the reflexive (e.g., hitkaxaltem, a reflexive form in which the root is prefixed and suffixed). As explained earlier, color roots are rarely inflected in the reflexive, hence, the surface frequency of these items is very low. Moreover, the effect of congruency was replicated even in reflexive items that do not exist in Modern Hebrew. Because the congruency between the color names and the target resides only at the level of the root, the findings suggest that the root is decomposed from the word pattern, and that its morphological relatedness to the color-word is sufficient to facilitate color naming. Furthermore, the effect of root-congruency in such opaque word patterns was observed regardless of the incentive to read, even when the experimental list included no color words presented in a congruent color. This finding indicates that morphological decomposition is triggered in an autonomous fashion, irrespective of its relevance to task demands.

Additional, albeit much weaker, evidence for the representation of morphological structure was obtained in readers’ sensitivity to the internal structure of the root. In each of the two experiments, color-naming differed in the presence of ill-formed, ssn-type roots relative to psm-type controls. However, the sensitivity to the root’s internal structure was modest. First, the effect of root-structure fell short of statistical significance. Second, unlike root-congruency, the sensitivity to root structure was eliminated when reading was strongly discouraged, in the absence of any color-congruent words. The contrast between the robust effect of root-congruency and the relatively frail effect of root structure could suggest the restriction on root structure is less autonomous than its decomposition: Root decomposition is triggered irrespective of the incentive to read (an unconditional automatic process), whereas the restriction on the internal structure of the root might be enforced only when reading is encouraged, in the presence of congruent color words (a conditional automatic process, Bargh, 1992).

The modest sensitivity to root structure under Stroop-like conditions also differs from the robust effects of root structure observed in tasks that require reading (Berent & Shimron, 1997; Berent et al., 2001a; Berent et al., 2001b; Berent et al., 2002; Berent & Shimron, 2003; Berent et al., 2004; Berent et al., 2005b). Before discussing these differences, it is important to establish which
aspects of root structure are reliably encoded under Stroop-like conditions. To this end, we submitted the results of Experiment 1 and 2 (for the color-congruent group) to an omnibus ANOVA (2 Experiment × 3 word pattern × 3 root type). The combined analysis of these 64 participants yielded no significant effects involving root type in the error analysis (all $F < 1$). In contrast, the analysis of response latency (see Figure 5) now yielded a significant interaction of root type × word pattern across both participants and items ($F_s(4, 208) = 2.73$, $MSE = 985, p < .04; F_i(4, 92) = 2.73, MSE = 790, p < .04$), which was not modulated by the experiment factor (all $p > .37$). The simple effect of root type was significant in the reflexive word pattern ($F_s(2, 104) = 3.90$, $p < .03; F_i(2, 46) = 3.71$, $p < .04$), but not in Kal ($F_s(2, 104) = 1.38$, $p < .26; F_i(2, 46) = 1.68, p < .20$) or participle word patterns (both $F < 1$). Planned comparisons confirmed that in the reflexive word pattern, the ill-formed $ssm$-type roots facilitated color naming significantly relative to the well-formed $psm$ type roots ($F_s(1, 104) = 6.98$, $p < .01; F_i(1, 46) = 7.00, p < .02$), and marginally so relative to $smm$ type controls ($F_s(1, 104) = 3.55, p < .07; F_i(1, 46) = 3.56, p < .07$).

Given that the representation computed in the Stroop task does encode some aspects of root structure, we can now discuss how it differs from the one available under intentional reading. One feature that distinguishes these
findings from the outcomes of intentional reading tasks concerns their
generality across word patterns. Previous research using intentional reading tasks
demonstrated the restriction on root structure across all three word patterns
(Berent & Shimron, 1997, 2003; Berent et al., 2001a; Berent et al., 2001b; Berent
et al., 2002; Berent et al., 2004). In contrast, the combined analysis of Experi-
ments 1–2 observed the effect of root structure only in the reflexive word pat-
tern and it was altogether absent in the participle. These null effects might be
carried by the similarity of the unaffixed and participle word patterns to color
terms. As noted earlier, color-roots are most likely to appear in unaffixed color-
nouns. Verbal uses of color-roots are less frequent, but when they occur, they
are far more likely in the participle than the reflexive, which rarely takes color
roots. The similarity of unaffixed and participle targets to color terms could
have encouraged participants to read them intentionally, and consequently, re-
duced sensitivity to root phonotactics. This divergence between the outcomes
of intentional versus unintentional methods might well stem from idiosyn-
cracies of the Stroop task, rather than from principle differences between the rep-
resentations available under intentional versus unintentional reading.

A second distinction between the outcomes of intentional versus uninten-
tional reading methods concerns the robustness of the constraint on root struc-
ture. When reading is intentional, there is strong evidence that ssm-type roots
are disliked relative to either smm or psm type roots (Berent & Shimron, 1997;
Berent et al., 2001a; Berent et al., 2001b; Berent et al., 2002; Berent et al., 2006).
In contrast, when reading is not required, under the Stroop task, readers were
far less sensitive to the internal structure of the root. The effect of root structure
was found only when reading was encouraged, in the presence of congruent
color-words, and even then, the effect was not fully reliable. It is hard to see
how this distinction could be explained away by idiosyncratic properties of
the Stroop task. Indeed, the divergence might reflect systematic differences
between the representations available under intentional and unintentional
conditions. Specifically, readers’ occasional failure to encode the location of
identical consonants under the Stroop task could reflect the coarse nature of
representations computed unintentionally. This conclusion agrees with previ-
ous research, demonstrating failures to correctly produce the location of identi-
tical elements under conditions of high load (Lashley, 1951) or brain damage
(e.g., Caramazza & Miceli, 1990; McCloskey, Badecker, Goodman-Schulman,
& Aliminosa, 1994). This proposal, if correct, could also account for the source
of the grammatical restriction on the location of identical consonants in the
root. If encoding the location of identical consonants requires attention con-
trol, then a grammatical restriction on the location of identity would reduce
the demands of morphological computation; Because the location of identical consonants is fully predictable (i.e., identical consonants can occur only root-finally), speakers need not engage in the (attention-demanding) process of encoding the location of identical consonants — all that is required is to note the presence of identity. Thus, the grammatical restriction on the structure of Semitic roots could be grounded in domain-general cognitive limitations, namely, the cost of encoding the location of identical elements.

In summary, our results show that performance in the Stroop task is modulated by attributes of morpho-phonological structure that are utterly unrelated to the color-naming task. These findings indicate that certain aspects of linguistic structure are recovered automatically, even when reading is unintentional. However, there appear to be some differences between the representations available under intentional and unintentional reading. When reading is unintentional, the root is still decomposed, but its internal phonological structure is less detailed relative to intentional reading tasks. The difficulty to automatically encode the location of identical consonants might account for the grammatical restriction on the location of identical consonants in Semitic. These outcomes underscore the need for convergence between methods of intentional and unintentional processing in studying the mental lexicon.

Author Note

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Notes

1. Roots beginning with a sibilant (e.g., s) undergo metathesis with the prefix hit (i.e., hit+sasamti → histasamti)

2. Throughout the paper, we use the term “decomposition” to capture the representation of morphological structure. Whether the base morpheme is in fact stripped to serve as the exclusive access-unit to the lexicon is a question that falls beyond the scope of this research. Likewise, our present results are moot with respect to the nature of the base morpheme in Semitic, whether it is a root (a special type of morpheme) or merely the stem's consonants (a phonological constituent of a universal morphological entity). For a discussion of these issues, see Berent et al., 2006)

3. The root stem exists in Hebrew — we use this example because it is frequently cited in the discussions of Semitic root structure in the linguistic literature (e.g., McCarthy, 1986). However, none of the roots used in the experiment exist in the Hebrew language.
4. Since the letter strings were presented without diacritic marks, the identity of the vowels and their location is ambiguous, and so is their precise word pattern (e.g., kal vs. pi?el). Accordingly, we refer to this word pattern as simply “unaffixed”. In contrast, the Hebrew orthography indicates the second vowel of color words by a vowel letter.

5. The ANOVA (2 congruency × 3 word pattern) on response latency yielded a significant effect of congruency ($F_2(1, 23) = 77.08$, $MSE = 38351$, $p < .0001$). The effect of root congruency was unaffected by the morphological complexity of the word pattern ($p > .23$). However, the congruency × word pattern interaction was significant in the accuracy analysis ($F_2(2, 46) = 4.76$, $MSE = .99$, $p < .02$), reflecting the enhancement of the congruency effect in the suffixed Kal word pattern.

6. One might conjecture that the greater sensitivity of the Stroop task to root congruency (relative to root-structure) is an artifact of root-lexicality. Because (unlike the root-congruency task, which used existing color-roots) the root-structure manipulation employed novel roots, speakers' insensitivity to root-structure might reflect a difficulty in decomposing unfamiliar roots from their word patterns, rather than a principled failure to encode the internal structure of the root under conditions of autonomous processing. This account, however, incorrectly predicts robust effects of root structure with unaffixed word patterns. Our findings are inconsistent with that prediction.

7. Several analyses of these differences have been proposed. Dienes & Perner (1999) argued that under conditions of unintentional processing, some aspects of the processed stimuli are represented only implicitly. Dulany (1991, 1997) proposed that while representations generated by intentional processing are propositional, unintentional processing results in representations that have less-than-propositional content, and provide only a “feeling of” the represented stimuli. Tzelgov and colleagues (Tzelgov, Ganor-Stern, & Yehene, 1999; Tzelgov, Porat, & Henik, 1997) pointed out that such representations apparently characterize the words processed in the Stroop task.

8. Because the orthographic representation of this word pattern lacks vowels, the word pattern is unspecified: CaCaC (and its gloss) is the most likely reading, but it is not the only possible one. For this reason, we refer to this word pattern as “unaffixed”.

9. Because the representation of this word pattern in Hebrew orthography lacks vowels, the word pattern is unspecified: CaCaC (and its gloss) is the most likely reading, but it is not the only possible one.

References

Morphological computation in the Stroop task


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