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Does a theory of language need a grammar? Evidence from Hebrew root structure

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Abstract

Hebrew constrains the occurrence of identical consonants in its roots: Identical consonants are acceptable root finally (e.g., *skk*), but not root initially (e.g., *kks*). Speakers' ability to freely generalize this constraint to novel phonemes (Berent, Marcus, Shimron, & Gafos, 2002) suggests that they represent segment identity—a relation among mental variables. An alternative account attributes the restriction on identical phonemes to their feature similarity, captured by either the number of shared features or their statistical frequency. The similarity account predicts that roots with partially similar consonants (e.g., ***sgk***) should be at least as acceptable as roots with fully identical consonants (e.g., ***skk***), and each of these roots should be less acceptable than dissimilar controls (e.g., *gdn*). Contrary to these predictions, three lexical decision experiments demonstrate that full identity is more acceptable than partial similarity and (in some cases) controls. Speakers' sensitivity to consonant identity suggests that linguistic competence, in general, and phonology, in particular, encompass a computational mechanism that operates over variables. This conclusion is consistent with linguistic accounts that postulate a symbolic grammatical component that is irreducible to the statistical properties of the lexicon.

1. Does a theory of language need a grammar?

Productivity is a defining feature of natural language: Speakers can generate and comprehend a large number of linguistic forms that they have never heard before. A central goal of linguistic theory is to account for the productivity of language (Chomsky, 1980). Symbolic and associationist theories of cognition offer radically different accounts for productivity. The symbolic approach (e.g., Pinker, 1999) attributes productivity to two sources: The lexicon and the grammar. The lexicon allows for limited productivity by associating familiar words with similar existing words. For example, speakers can form the plural to the novel noun *gog* by analogizing it to the familiar noun *dog*. The main source of productivity, however, is attributed to the grammar—a domain specific computational mechanism that operates over variables. Variables are abstract placeholders. A variable (e.g., Noun stem) can stand for a large number for instances (*dog*, *cat*, *house*, etc.). Many linguistic processes (e.g., rules, constraints) operate on variables, irrespective of the specific elements that instantiate them. The appeal to variables allows speakers to freely generalize linguistic knowledge to any novel item. For instance, because the plural rule (e.g., Nplural $\rightarrow$ Nstem + s) operates on the variable noun stem, it applies to both familiar (e.g., *dog*) and novel (e.g., *gog*) nouns, including nouns whose phonological form is highly unusual (e.g., *xog*, Berent, Pinker, & Shimron, 1999). Operations over variables are thus central to the generative account of linguistic productivity.

An alternative associationist account rejects the role of operations over variables in linguistic competence (e.g., Elman et al., 1996; Rumelhart & McClelland, 1986). Productivity is explained solely by an associative process that generates new words by analogy to existing words (e.g., the plural *gogs* is produced by analogy to *dogs*). Linguistic generalizations are guided by the statistical properties of the lexicon. A grammatical

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component, separate from the associative lexicon, is obsolete.

Does a theory of language need a grammar? The debate regarding this fundamental question has been largely informed by research on inflectional morphology (for recent reviews, see McClelland & Patterson, 2002; Pinker, 1999; Pinker & Ullman, 2002a, 2002b). Here, we present evidence from phonology. We feel that the role of operations over variables in phonology is of particular interest because, on many accounts, phonology is the linguistic component that is least likely to appeal to variables. First, phonology is an interface between the grammar and the perceptual system, hence, its design principles may be determined, in part, by articulatory properties that are not shared with the grammar as a whole. Second, many phonological processes are explained in terms of the similarity among interacting segments. Such phenomena are particularly prone to associative explanations. Finally, proponents of associative accounts of cognition have often interpreted the success of connectionist models of printed word naming as evidence for their potential to account for phonological competence (Plaut, McClelland, Seidenberg, & Patterson, 1996; Van Orden, Pennington, & Stone, 1990): If a model that lacks operations over variables can adequately account for the computation of phonological representations from print, including generalization to novel printed words, then such operations may be obsolete in an account of linguistic productivity (But see Berent, 2001 for critic).

How is one to account for linguistic productivity? Is a separate grammatical component required? To address these questions, we investigate the scope of linguistic generalizations. The symbolic account predicts that speakers should generalize their linguistic knowledge across the board, irrespective of the statistical properties of novel items. Our investigation demonstrates such generalizations with respect to phonological knowledge. As we explain in Section 6, there is reason to doubt that such generalization are attainable by associationist systems–systems that are not equipped with the ability to operate over variables prior to learning. The appeal to variables in phonology, a linguistic component that is arguably prone to strictly associationist explanations, suggests that linguistic productivity is irreducible to the statistical properties of the lexicon—a separate mechanism operating over variables is required. These findings are consistent with the view of the grammar as central for the adequacy of theories of language.

2. A case study: The constraint on identical consonants in Hebrew roots

To examine the role of operations over variables in phonology, we consider the restrictions on the Hebrew root morpheme. Hebrew words include two ingredients: The root and the word pattern. The root is an abstract sequence of typically three consonants. The word pattern, in turn, provides the vowels and affixes, and delineates the location of root consonants by means of placeholders. Words are formed by inserting the root in the word pattern. For instance, one can form a verb from the root *smm* (associated with drugs) by inserting it in the verbal word pattern CiCeC (second masculine past tense in the verbal pattern *piʔel*). The outcome is the verb SiMeM, whose meaning is roughly “he intoxicated someone with drugs.” Notice that the root *smm* and the verbal output SiMeM include two identical consonants: *mm*. Consonant identity is the focus of our investigation. Consonant identity is quite frequent in Semitic, but its position is strictly constrained: Consonant identity is frequent at the end of the root (e.g., *smm*) but is quite rare in its beginning (e.g., *ssm*, Greenberg, 1950). In several previous experiments we have demonstrated that speakers are sensitive to the restriction on the location of identical root consonants and generalize it to novel roots. For instance, speakers consider the novel form *didel* (whose root, *ddl*, manifests root initial identity) as less acceptable than a novel form with root final identity (e.g. *lided*, from the root *ldd*, see Berent, Everett, & Shimron, 2001a; Berent & Shimron, 1997). How is one to account for such generalizations?

Symbolic accounts could attribute this behavior to a mental constraint that specifically concerns segment identity (e.g., McCarthy, 1986). We will discuss in detail one such symbolic account in the next section. For the moment, suffice it to note that central to such symbolic accounts is the assumption that speakers represent identity among segments and distinguish it from non-identical radicals. In addition, such accounts predict that identity is preferred at the end of the root over its beginning. The appeal to identity is critical: Identity is a formal relationship among any two elements. Thus, the representation of identity (XX) appeals to an operation over variables ($X \rightarrow XX$). Any account that constrains identity assumes that speakers have the capacity to represent variables and to operate over variables.

An alternative associative account could capture the constraint on root structure without appealing to identity. This view attributes the relative acceptability of roots to the statistical properties of specific consonant combinations, rather than to their identity. For instance, the relative unacceptability of the root *ddl* is explained by the rarity of the consonant combination *dd* at root initial position. The fact that these two segments happen to be identical is inconsequential to this account. Indeed, in the absence of operations over variables, identity (a relationship among variables) cannot be represented. Accordingly, this view predicts that, once frequency is controlled for, the acceptability of *ddl* type roots should be equivalent to that of roots that do not contain identity (e.g., *dbl*). As we next show, the existing empirical findings do not support this prediction.

2.1. Is the constraint on identical root consonants explicable by the statistical co-occurrence of root segments?

Our past research has offered two arguments against the attribution of the constraint on root structure to the statistical distribution of root consonants. First, speakers distinguish between roots with identical and nonidentical consonants even when roots are controlled for their statistical properties. For instance, Berent, Shimron, and Vaknin, 2001b compared lexical decision to nonword foils with either root initial identity (e.g., *ddl*), root final identity (e.g., *ldd*), or no identity (e.g., *dbl*). As expected, roots with initial identity were easier to reject compared to roots with final identity, a finding suggesting that they are ill formed. Importantly, however, speakers had difficulties rejecting roots with final identity (e.g., *ldd*) relative to nonidentity controls (e.g., *dbl*) even though these two root types were equated for their bigram frequency. Sensitivity to consonant identity is thus inexplicable by consonant co-occurrence (for similar conclusions in production and rating tasks, see Berent et al., 2001b).

Second, the constraint on root structure is evident even when XXY and XYY forms are utterly (hence, equally) unfamiliar. Berent, Marcus, Shimron, and Gafos (2002) observed that speakers prefer XYY over XXY roots even when identity concerns phonemes that are foreign to the Hebrew language (phonemes corresponding to th, ch, w, and j). For instance, speakers consider the verb *thithem* as less acceptable than *mitheth*, and they reject this verb (a nonword) more easily in a lexical decision task. Because the combination *th-th* never occurs in Hebrew roots, neither root initially nor finally, the restriction cannot be explained by the frequency of these phonemes. Despite having *no* relevant statistical knowledge regarding consonant co-occurrence, speakers generalized the constraint on root structure to utterly unfamiliar instances. These results suggest that phonological knowledge generalizes across the board. One could specifically define the scope of such generalizations in reference to the phonological space of Hebrew language (see Marcus, 1998, 2001): Generalizations to novel phonemes go beyond the space of Hebrew phonemes. This observation agrees with the predictions of the symbolic hypothesis.

2.2. Can the constraint on consonant identity be captured at the feature level?

The previously presented findings speak against the attribution of the constraint on consonant identity to the frequency of specific consonants in the Hebrew lexicon. However, it is possible that the constraint could be captured at the feature level. Consider generalizations to novel phonemes. We argued that a statistical approach cannot account for generalizing the constraint on root structure to novel phonemes–phonemes whose probability of co-occurrence is clearly zero. However, it is conceivable that the restrictions on novel identical segments could be inferred from the co-occurrence of features. For instance, speakers could discern the unacceptability of the novel root *jjm* (including the novel phoneme *j)* from the co-occurrence of the palatal place of articulation, a feature that does exist in Hebrew. Because no Hebrew roots begin with the palatal–palatal combination, speakers could correctly infer the ill-formedness of *jjm* from the rare co-occurrence of the palatal feature. Foreseeing this objection, Berent et al. (2002) demonstrated that the constraint on root identity generalizes even to *th* (as in *thick*)–a phoneme whose place of articulation (the value "wide" in the feature "tongue-tip constriction area," Gafos, 1999) is unattested in *any* Hebrew phoneme. Because the place of articulation of *th* never occurs in Hebrew, either root initially or finally, the co-occurrence of this feature does not predict the acceptability of the root (e.g., *ththm* vs. *mthth*). Put differently, the *th* phoneme falls outside the space of Hebrew phonemes and feature values. Such generalizations are not only consistent with the symbolic hypothesis—Marcus (1998, 2001) argued that they are unattainable by mechanisms that are not equipped with operations over variables (for critiques, see Altmann & Dienes, 1999; Christiansen & Curtin, 1999; Christiansen, Conway, & Curtin, 2000; Dominey & Ramus, 2000; Eimas, 1999; McClelland & Plaut, 1999; Negishi, 1999; Seidenberg & Elman, 1999; Shastri, 1999; for rebuttals to the above critiques, see Marcus, 2001).[1]

Proponents of the associationist accounts of cognition could point out that the statistical information available to speakers concerning feature co-occurrence directly depends on the feature matrix used to define their phonological representation. The analysis of Berent et al. (2002) was based on a feature matrix in which the phoneme *th* does not share its place feature with any Hebrew phoneme (Gafos, 1999)—an analysis that is supported by several independent lines of evidence (for discussions, see Berent et al., 2002; Gafos, 1999). The same phoneme, however, could be fitted within the feature set of Hebrew by using a different feature matrix. It is conceivable that a revised feature analysis could

[1] In a subsequent demonstration, Altmann (2002) argued that a simple recurrent network trained on Elman's (1993) sequences could generalize the distinction between ABB and ABA forms. However, this demonstration is insufficient to determine whether the network has acquired an operation over variables. If that was the case, then the network should have been able to distinguish other forms of identity, such as ABB vs. BBA. Altmann's (2002) report does not allow to address this question.

offer valuable statistical cues that could distinguish XXY from YYX combinations. Note that the adoption of a feature matrix must be motivated by evidence, or else, a learning model will be unable to account for other aspects of phonological competence. Whether or not a change in the feature matrix is called for is a question that falls beyond the scope of this paper. Instead, we focus here on a more fundamental problem: Can such a solution work?

No doubt, incorporating a novel phoneme within the space of native Hebrew features may allow speakers to call upon statistical knowledge concerning familiar feature combinations. But in order for this solution to work, there must be a discernible association between the acceptability of root consonants and their feature similarity. The existence of such an association is the focus of our present investigation. To anticipate our conclusions, we show that a relationship between feature similarity and root acceptability indeed exists, but it is insufficient to account for the restrictions on identity at the segment level. In particular, we demonstrate that a feature-similarity account cannot capture the constraint on identical consonants at root final position. Accordingly, an account of the restrictions on identical root consonants must be formulated at the level of the segment. Because speakers can generalize this knowledge to novel phonemes, phonemes for which a segmental representation provides no useful statistical information, a generalization to novel phonemes implicates mental operations over variables.

2.3. A feature similarity account for the restrictions on segment identity

The idea that speakers constrain feature co-occurrence in the root morpheme has received ample support in the linguistic research. It has long been noted that Semitic constrains not only identical consonants but also consonants that share the same class of the place of articulation feature (i.e., homorganic consonants, see Greenberg, 1950). For instance, at root initial position, Hebrew limits not only the co-occurrence of identical velar consonants *kk* but also the co-occurrence of *kg*—homorganic (nonidentical) consonants that share the velar place of articulation. In fact, no such roots are attested (see Berent & Shimron, 2003, Table 1). In an influential paper, Pierrehumbert (1993) proposed that the co-occurrence of identical consonants may be due to their perceived similarity, captured in terms of their feature overlap and the distance among shared feature. Her analyses demonstrated that the Arabic lexicon limits the co-occurrence of perceptually similar consonants (for similar results, see Frisch, Broe, & Pierrehumbert, 2004; and Frisch & Zawaydeh, 2001 in Arabic, and Bender & Fulass, 1978, for Amharic; and Buckley, 1997, for Tigrinya). Pierrehumbert (1993) proposed that the constraint on similar (nonidentical) and identical consonants could be captured by a single constraint on perceived similarity. Segment identity is not separately represented or constrained. Instead, it is the limiting case of a single, stochastic constraint on perceived similarity.

The similarity account could be captured in either symbolic or associative terms. On the symbolic version, similar segments are undesirable because the grammar constrains identity among features. Each feature repetition incurs a constraint violation, such that the acceptability of any two phonemes is an inverse, monotonic function of the number of repeated features. Accordingly, identical consonants (e.g., *kk*, violating feature-identity constraint at both the place of articulation and voicing levels) are less acceptable than nonidentical homorganic consonants (e.g., *kg*, which violate the feature-identity constraint only at the place of articulation level). We consider this version to be symbolic because it appeals to a variable (any feature, X). The principal difference between the restrictions on feature similarity and segment identity concerns the domain of the restriction: The identity account restricts identity at the level of the full segment, whereas, on the similarity account, identity is restricted at the feature level. Both accounts, however, constrain identity. A more radical alternative is offered by an associationist version of the similarity hypothesis. On this view, similarity (either partial or full) is undesirable because features that share their place of articulation rarely cooccur—the identity of the place feature plays no role in this explanation. Both versions of the similarity hypothesis hold that (a) The constraint on segment identity is indistinguishable from the restriction on feature similarity; and (b) Identical segments (e.g., e.g., *kk*) are less desirable than nonidentical homorganic consonants (e.g., *kg*).

These claims are challenged by a second class of explanations we term "the identity hypothesis." The identity hypothesis holds that the restrictions on full segment identity differ from those applying to partial similarity. One version of this hypothesis is presented by McCarthy (1986, 1994). His analysis traces the restriction on segment identity and homorganicity to a common constraint, namely, the ban on adjacent identical elements (Obligatory Contour Principle, OCP). The restriction on segment identity reflects the application of the OCP at the full-segment level (the OCP total) whereas the restriction on non-identical homorganic consonants reflects the application of the OCP at the place of articulation level (the OCP place). Crucially, the constraint on segment identity is irreducible to the restriction on feature identity (i.e., partial similarity). Furthermore, roots with identical consonants are not necessarily less desirable than those with homorganic consonants. The contrast between the predictions of the

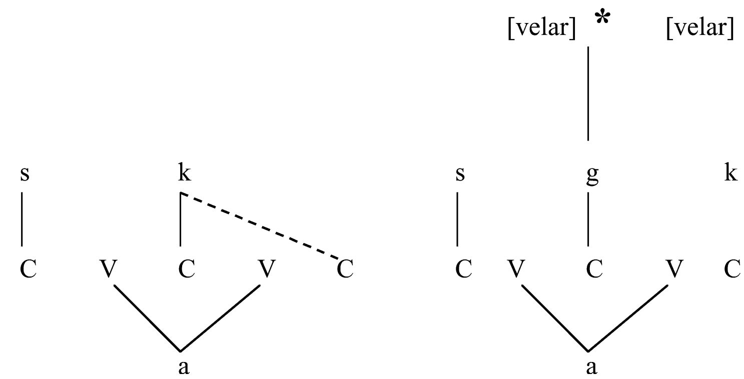

Fig. 1. OCP violations by homorganic vs. identical c2c3 consonants for the novel roots *skk* and *sgk*. Identical consonants in the root *skk* incur no OCP violations, whereas the homorganic consonants in *sgk* violate the OCP place (violations are marked by asterisks).

identity and similarity hypotheses is clearly evident at root final position.[2]

Compare the novel roots *skk* and *sgk*, for instance (see Fig. 1). McCarthy (1986) proposed that triliteral roots with final identity (e.g., the root *skk* in the verb *sakak*) are stored in the lexicon as a biconsonantal representation (e.g., *sk)*. Identity emerges during word formation. To form a word from the underling representation *sk*, it must be attached to the three consonantal slots in the word pattern in a left to right order. The third, empty, slot is next filled by spreading the second consonant, *k*, to the final position. Because forms such as *sakak* are generated by spreading a single consonant (i.e., they are not represented by adjacent identical segments), they do not violate the OCP. In contrast, forms such as *sagak* cannot be formed by spreading (since elements on the feature tier cannot branch, McCarthy, 1994). Accordingly, the homorganic root *sgk* must be represented by means of two adjacent elements on the place of articulation tier, thereby violating the OCP. Thus, root final homorganicity violates the OCP, whereas root final identity does not. Consequently, the identity hypothesis predicts that root final identity should be *more* desirable than root final homorganicity.

The findings of our earlier research, conducted using an off-line rating procedure support this prediction (Berent & Shimron, 2003). The following experiments further test the identity hypothesis using on-line lexical decision experiments. Experiment 1 examines unaffixed nouns whereas Experiments 2–3 examine verbs. The conclusion that the constraint on segment identity is inexplicable at the feature level would carry multiple implications. First, this conclusion is directly relevant for understanding the constraint on segment identity—a question that is central to phonological theory. Second, this outcome illuminates the role of operations over variables in accounts of linguistic productivity. Recall that the symbolic accounts of language predict that speakers can generalize grammatical constraints irrespective of the statistical properties of the lexicon. The observation of a restriction on segment identity despite controlling for the statistical co-occurrence of segments and features would suggest that this constraint is inexplicable by statistical properties captured at the segment level. Finding that the constraint on segment identity is inexplicable by feature similarity would further speak against statistical explanations couched at the feature level. Such results would offer strong support for linguistic accounts that incorporate a symbolic grammatical component that is autonomous from the lexicon.

3. Experiment 1

Experiment 1 compares the acceptability of nouns whose roots manifest either homorganic or identical consonants using a lexical decision task (see Table 1). Half of the materials presented in the experiment were existing nouns, whose roots manifest root final identity or no identity. Our primary interest concerns the

[2] At root initial positions, the predictions of the similarity and identity hypotheses are indistinguishable. For instance, compare the novel verbs *kakas* vs. *kagas*. Both forms include adjacent identical instances of the velar feature, hence, they each violate the OCP at the level of place of articulation. The full identity in *kakas* potentially incurs an additional violation at the level of the full segment (the root node). Thus, the identity hypothesis predicts that the full identity in *kakas* should clearly be ill formed, and potentially, less acceptable than the homorganicity in *kagas*. These predictions agree with those made by the similarity hypothesis. If feature similarity is unacceptable (either due identity of the place feature or its rare co-occurrence), then *kagas* and *kakas* should be both unacceptable. If acceptability is specifically a monotonic function of feature similarity (as predicted by the symbolic similarity account), then the full similarity in *kakas* should, in fact, be less acceptable than the partial similarity in *kagas*. Thus, the similarity and identity hypotheses converge to predict that full similarity (identity) and partial similarity should both be unacceptable root initially, and that identity is no more acceptable than similarity. Accordingly, the comparison of homorganicity vs. identity at root initial position cannot adjudicate between the two accounts.

Table 1
An illustration of the materials used in Experiment 1

	Nonwords	Words
Homorganicity	SiGuK	—
Identity	RiGuG	KiDuD (coding)
Control	GiDuN	KiShuT (decoration)

nonwords foils. These were novel nouns, constructed by inserting novel roots (i.e., a combination of three consonants that does not occur in any Hebrew root) in existing nominal word patterns. We expect the acceptability of the foils to impair their rejection (i.e., their classification as nonwords). Of interest is whether acceptability is sensitive to root structure. To address this question, we compared responses to three root types, arranged in matched trios. One member of the trio had identical consonants at the root's final position (e.g., *rgg*), another member had nonidentical homorganic consonants at the root's final position (e.g., *sgk*), and the control had no homorganic consonants (e.g., *gdn*). Members of all three root types were matched for their summed position bigram frequency as well as for the place of articulation of the identical/homorganic bigram (e.g., *rgg* and *sgk* both include velar consonants at C2C3 position). As a group, homorganic and identity members did not differ reliably on the co-occurrence of the place of articulation feature.[3] The co-occurrence of the place feature in roots with homorganic and identical consonants was lower than in the controls.

All accounts predict that roots with homorganic consonants should be less acceptable than controls (due to either OCP place violation, similarity or lesser frequency). The predictions of the similarity and identity accounts diverge with respect to roots with homorganicity vs. identity. The similarity account (on either its associationist or symbolic versions) predicts that roots with identical consonants should be no more acceptable than roots with homorganic consonants. Specifically, in view of the indistinguishable statistical properties of roots with homorganic and identical consonants, an associationist similarity account would predict no difference in responding to these types, whereas a symbolic similarity account (attributing acceptability to feature overlap) would predict that full identity is less acceptable than homorganicity. The prediction of the identity hypothesis (specifically, McCarthy's, 1986 proposal) is reversed: Because nonword foils whose roots manifest identity do not violate the OCP, they should be more acceptable (more difficult to reject) than foils with homorganic consonants (which do violate the OCP). A final prediction of this account concerns the comparison of the nonword foils with identity to the controls. Recall that on McCarthy's account, root final identity is formed by a grammatical operation that spreads a single consonant over two slots. Because such novel roots bear the signature of the grammar, they may be viewed as more wordlike, hence they should be more difficult to reject than frequency-matched controls.[4]

3.1. Method

3.1.1. Participants

Twenty-four University of Haifa students took part in the experiment. In this and all subsequent experiments, participants were native Hebrew speakers with normal or corrected vision. Participants in all experiments were paid $5 for their participation.

3.1.2. Materials

The materials consisted of 90 words and 90 nonwords. The words consisted of familiar Hebrew nouns. Half had identical consonants at the end of the root whereas the other half did not have identical consonants. The nouns were generated from three nominal word pattern (Piʔul, Paʔil, Poʔel, and Paʔol). The nonword foils were generated by inserting novel roots in the nominal word pattern PiʔuL. The foil roots were arranged in trios. One member of the trio exhibited root final homorganicity, the other member exhibited root final identity, and the third, control member consisted of three nonhomorganic radicals. Homorganic consonants were sampled from one of four natural classes defined after McCarthy (1994): coronal obstruent stops (t, d; a total of four roots), coronal obstruent fricatives (s,ʃ,c; a total of seven trios); labials (b, m, p; a total of six trios); velar stops (g, k; a total eight trios); gutturals (x, h, ʔ, ʕ, a total of two trios); and coronal sonorants (n, l, r; a total of three trio).[5] The

[3] Following the definition of homorganicity in McCarthy (1994), our calculations of co-occurrence at the place of articulation level distinguished between three sub-types of coronals (coronal obstruent fricatives, coronal stops and coronal sonorants). The remaining place features were labials, velars and gutturals (for further information, see Section 3.1).

[4] In principle, the same prediction could apply to our words with identical vs. nonidentical root consonants. But because we were unable to match these words on their meaning and token frequency, their comparison is not straightforward, and will not be discussed further.

[5] Because of the historical changes in the Hebrew phonemic system, the classification of several phonemes for place of articulation is uncertain. For instance, most Hebrew speakers no longer distinguish between the gutturals /ʕ/ and /ʔ/, a distinction that existed in Biblical Hebrew and was preserved in the orthographic transcription. Likewise, the phoneme /r/, historically a coronal sonorant, is currently pronounced as the uvular fricative /ʁ/ by most speakers (for discussion, see Berent & Shimron, 2003, Footnote 2). In view of these questions, our test of homorganicity effects avoided consonant sequences whose identity or place of articulation are uncertain. For instance, our homorganic roots did not include combinations of the phonemes /ʕ/ and /ʔ/. Likewise, we excluded homorganicity with the phoneme /r/. In contrast, the calculation of feature co-occurrence in our data base respected those historical distinctions, as these appear to have shaped the co-occurrence of consonants in existing roots, and they are also manifested in the orthography.

homorganic and identical trio members were matched on the place of articulation of homorganic consonant pairs. All trio members were matched on their summed positional bigram frequency. This measure was computed from a database including 1449 productive triconsonantal roots listed in the Even-Shoshan (1993) dictionary. We consider a root productive if it appears in at least one verbal form.The database lists the orthographic transcription of those roots. We determined the summed positional bigram frequency of each root by counting the number of root types that share this bigram in the database. The summed bigram frequency includes the counts for the C1C2 bigram, the final C2C3 bigram and the C1C3 bigram. The summed positional bigram frequency of the roots with homorganic, identical and nonhomorganic controls was 10.73, 10.93, and 10.70. These three means did not differ significantly ($F(2, 58) < 1$, MSE = .225), nor did any of the pairwise comparisons approach significance (all F's<1.2). We also calculated the statistical co-occurrence of the place of articulation in our materials by counting the number of roots in the database that exhibit that combination at the same root position. The co-occurrence of the place feature was examined in reference the five classes of homorganic consonants described above: labials, velar stops, gutturals, and the three sub-types of coronals (coronal obstruent stops, coronal obstruent fricatives, and coronal sonorants).[6] The summed frequency of the place of articulation feature was computed by adding the counts across C1C2, C2C3, and C1C3 positions. For instance, the place- feature frequency of *sgk* (a coronal fricative followed by two velars) was calculated by summing the number of roots that manifest a combination of a coronal fricative and a velar at the C1C2 position (42 roots), the number of roots with two velars at C2C3 positions (17 roots) and the number of roots with coronal fricative and a velar at C1C3 positions (48 roots). The summed frequency of the place of articulation feature in our materials was 108.87, 97.57, and 123.77, for homorganic, identical and control roots, respectively. Homorganic and identity roots did not differ reliably on their feature frequency ($t(58) = 1.79, p < .08$), and they were each less frequent than the control roots (for homorganic roots: $t(58) = 2.34$, $p < .03$, for identity roots: $t(58) = 4.15$, $p < .0002$).

To familiarize participants with the experimental task, they were first presented with a practice session. The practice included 10 word and 10 nonword trials. None of these materials was included in the experimental session.

[6] In view of the irregularity in the occurrence of the radicals /v/, /h/, and /y/ in Hebrew, these consonants were excluded from the feature frequency count. In all counts, the affricate /c/ was treated as a fricative.

3.1.3. Procedure

Each trial began with a fixation point, followed by a letter string presented at the center of the computer screen. Participants were asked to determine whether the letter string corresponds to a familiar Hebrew word and indicate their responses by pressing either the 1 or 2 keys (for word vs. nonword responses, respectively). Inaccurate and slow responses (RT>1500 ms) triggered a computerized warning message. Participants were tested individually.

3.2. Results and discussion

To eliminate the effect of outliers, we excluded from the response latency analyses all correct responses that fell 2.5SD above or below the mean. This practice resulted in the exclusion of 3.2% of the total correct responses.

3.2.1. Word responses

The analyses on target words did not reveal a reliable effect of root structure ($F_s(1, 23) = 5.98$, MSE = 296, $p < .03$; $F_i(1,44) = 2.10$, MSE = 4289, $p < .16$; $F_s(1,23) = 1.27$, MSE = .001, $p < .28$, n.s.; $F_i(1,44) < 1$, MSE = .014; for latency and accuracy, respectively). Responses to roots with final identity ($M = 690$ ms) did not differ reliably from roots with no identity ($M = 702$ ms). Likewise, response accuracy to roots with final identity ($M = 94\%$) did not reliably differ from those with no identity (93%).

3.2.2. Nonword responses

The effect of root structure on nonword foils was reliable in both response latency ($F_s(2, 46) = 29.94$, MSE = 915, $p < .0002$; $F_i(2, 58) = 12.25$, MSE = 3028, $p < .0002$) and accuracy ($F_s(2, 46) = 19.75$, MSE = .0024 $p < .0002$; $F_i(2, 58) = 8.90$, MSE = .0065, $p < .0005$). This effect was further evaluated by means of planned comparisons. The effect of homorganicity was modest (see Fig. 2): Roots with homorganic consonants did not differ reliably from controls in response latency ($t_s(46) = 1.01$, $p < .28$, n.s.; $t_i(58) < 1$), and only marginally so in response accuracy ($t_s(46) = 2.43$, $p < .02$; $t_i(58) = 1.55$, $p < .13$). The slight facilitation in the rejection of homorganic foils suggests that similarity is somewhat undesirable. Of primary intersect is whether feature similarity is sufficient to explain the acceptability of full segment identity. If root acceptability is determined by either the degree of feature similarity or the frequency of similar features, then full identity should be no more acceptable than partial similarity.

The difference between homorganic and identical roots was highly significant. Contrary to the similarity account, however, roots with identical consonants resulted in significantly slower response latency ($t_s(46) = 7.18$, $p < .0001$; $t_i(58) = 4.45$, $p < .0001$) and more

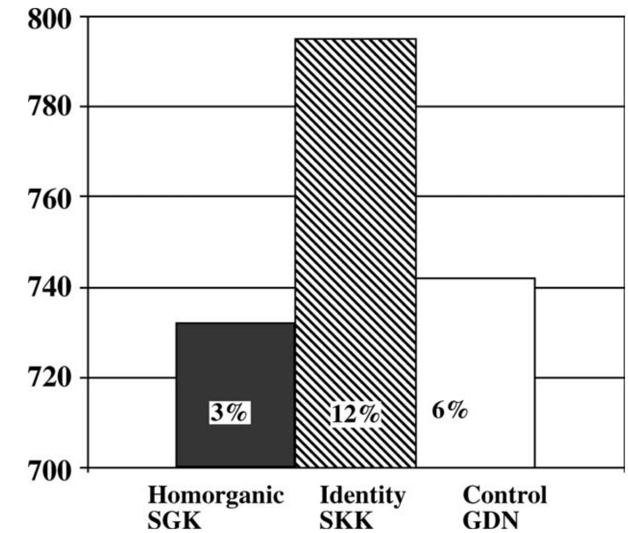

Fig. 2. Response latency (ms) and errors to the nominal foils presented in Experiment 1 as a function of root type.

errors ($t_s(46) = 6.23, p < .0001; t_i(58) = 4.17, p < .0001$) relative to homorganic consonants. In fact, roots with identical consonants yielded slower response latency ($t_s(46) = 6.08$, $p < .0001$; $t_i(58) = 4.10$, $p < .0001$) and an increase in errors($t_s(46) = 3.80$, $p < .0005$; $t_i(58) = 2.62$, $p < .02$) even when compared to dissimilar controls. The greater acceptability of roots with full similarity (identity) over either partial similarity (homorganicity) or no similarity (controls) is inconsistent with the symbolic similarity account. These results are also inexplicable by an associative similarity explanation: Roots with identical consonants were considered more wordlike than dissimilar controls or homorganic roots despite lower feature frequency (the difference was significant compared to controls, and marginally so compared to homorganic roots). However, these findings readily fit the identity hypothesis. Because the restrictions on identity differ from those on homorganicity, and because unlike homorganicity, identity does not violate the OCP, identity is more acceptable than homorganicity. Speakers' representation of full identity as the outcome of a grammatical operation further results in its perception as more wordlike, hence, more difficult to reject than controls (replicating the earlier results of Berent et al., 2001b).

4. Experiment 2

The findings of Experiment 1 suggest that the acceptability of nouns with identical consonants is inexplicable by the degree of feature similarity or the frequency of shared features. Although these results indicate that speakers specifically constrain full-segment identity, they cannot ascertain the domain in which identity is constrained. Our previous discussion attributes the constraint on identity and homorganicity to the location of the consonants in the root. In Experiment 1, however, the location of identity in the root was fully confounded with its word position: Root final identity was invariably word final. It is thus impossible to determine whether the restriction applies to the location of the consonants in the word or the root. To dissociate root from word structure, in Experiment 2, the same roots are inserted in a verbal pattern that is affixed (see Table 2). Accordingly, root final identity/homorganicity is now word internal. If the acceptability of identical/homorganic consonants in Experiment 1 is due to their position in the word, then the findings should not generalize when word position is altered. Conversely, if the restriction concerns root structure, then the findings should replicate despite the change in the position of the critical consonants and the grammatical class of the materials.

Table 2
An illustration of the materials used in Experiment 2

	Nonwords	Words
Homorganicity	SiGaKtem	—
Identity	RiGaGtem	LiKaKtem (you leaked)
Control	GiDaNtem	LiMaDtem (you taught)

4.1. Method

4.1.1. Participants

Twenty-three University of Haifa students took part in this experiment.

4.1.2. Materials

The materials consisted of 90 existing verbs and 90 novel verbs. The novel verbs (the foils) were generated by inserting the same root-trios employed in Experiment 1 in the verbal pattern Piʔel. The target words consisted of verbs in the verbal patterns Piʔel and Paʔal. Half of the target words included identical consonants at the root's end, whereas in the other half, the roots' final consonants were nonidentical and dissimilar. All the materials used in the experiment were suffixed. Prior to the experimental session, participants were presented with 20 practice trials, including an equal number of words and nonwords. The procedure was the same as in Experiment 1.

4.2. Results and discussion

To protect from the effect of outliers, we excluded from the response latency analyses all responses falling 2.5SD above or below the grand mean. This resulted in the exclusion of 2.55% of the total correct observations.

4.2.1. Word responses

The analyses on target words did not reveal a reliable effect of root structure. Responses to roots with final identity ($M = 705$ ms) did not differ reliably from roots with no identity ($M = 697$ms; $F_s(1,22) = 1.38$, MSE = 610, $p < .26$, n.s.; $F_i(1,44) < 1$, MSE = 2417). Likewise, response accuracy to roots with final identity ($M = 93.13\%$) did not reliably differ from those with no identity (90.91%; $F_s(1,22) = 3.64$, MSE = .0016, $p < .07$; $F_i(1,44) = 1.4$, MSE = .008, $p < .25$).

4.2.2. Nonword responses

A significant effect of root type was observed with nonword foils (for latency: $F_s(2,44) = 18.67$, MSE = 1133, $p < .0002$; $F_i(2,58) = 13.88$, MSE = 2160, $p < .0002$; for accuracy: $F_s(2,44) = 21.39$, MSE = .0045, $p < .0002$; $F_i(2,58) = 19.51$, MSE = .0063, $p < .0002$). Planned comparisons indicated a reliable effect of homorganicity (see Fig. 3): Roots with homorganic consonants were rejected faster ($t_s(44) = 3.89, p < .0004$; $t_i(58) = 2.92, p < .005$) and more accurately ($t_s(44) = 2.41$, $p < .03$; $t_i(58) = 2.35$, $p < .03$) than controls. The facilitation in rejecting homorganic roots suggests that they are relatively ill formed—a conclusion consistent with either the similarity or the identity account. The inspection of responses to roots with final identity allows us to distinguish among these explanations. Contrary to the predictions of the similarity account, roots with identical consonants (fully similar) were rejected slower ($t_s(44) = 6.03$, $p < .0001$; $t_i(58) = 5.26$, $p < .0001$) and less accurately ($t_s(44) = 6.47$, $p < .0001$; $t_i(58) = 6.19$, $p < .0001$) than roots with homorganicity (partial similarity). This finding suggests that identity is more acceptable than homorganicity. In fact, identity impaired responses even relative to controls (for latency: $t_s(44) = 2.14$, $p < .04$; $t_i(58) = 2.33$, $p < .03$; for accuracy: $t_s(44) = 4.06$, $p < .0002$; $t_i(58) = 3.83$, $p < .0004$), suggesting that nonwords with identical consonants are perceived as more wordlike. These results suggest that the acceptability of identity is clearly not an inverse, monotonic function of similarity: Identity (full similarity) is more desirable than homorganicity (partial similarity) or controls. Likewise, the acceptability of identical consonants is inexplicable by the frequency of their place feature, as the co-occurrence of place of articulation in identical roots was lower than controls, and indistinguishable from the homorganic roots. These findings suggest that speakers represent identity and constraint its position in a manner that is inexplicable by feature similarity.

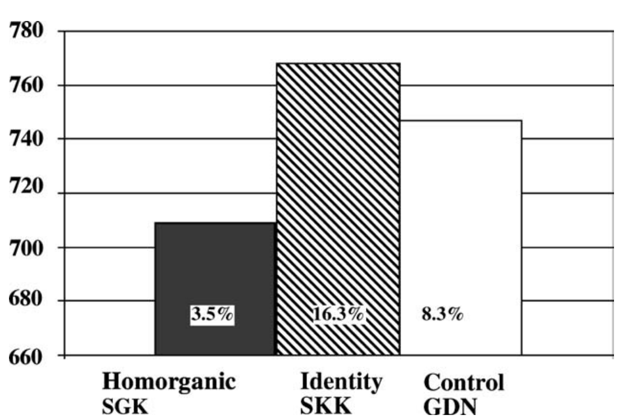

Fig. 3. Response latency (ms) and errors to the verbal foils presented in Experiment 2 as a function of root type.

5. Experiment 3

The convergence between speakers' responses to roots with identical vs. homorganic consonants across different word positions and grammatical classes (in Experiments 1–2) suggests that they constrain full identity in the root, an abstract morpheme. To secure the generality of these findings with respect to the surface position of identical/homorganic consonants in the word, Experiment 3 seeks to extend the previous results to one additional verbal classes. In this class, the root is not only suffixed (as in Experiment 2) but is also prefixed (see Table 3). The replication of the previous results for this word pattern would provide converging evidence that the constraint appeals to the root. Sensitivity to root structure under these conditions would also demonstrate that speakers decompose the root from the word pattern and constrain the structure of the root morpheme.

5.1. Method

5.1.1. Participants

Twenty-five students at Haifa University took part in this experiment.

5.1.2. Materials

The materials consisted of 90 words and 90 nonwords. The words were existing verbs in the verbal word pattern hitpaʔel. Half of the words had roots with final identity and half did not have identity. The nonwords were generated by inserting the set of 30 novel root trios, used in Experiments 1–2 in the same verbal pattern. In all verbs, the roots was "sandwiched" between a prefix and a suffix. Prior to the experimental session, participants received 20 practice trials, including 10 words and 10 nonwords. The procedure was the same as in Experiments 1–3.

Table 3
An illustration of the materials used in Experiment 3

	Nonwords	Words
Homorganicity	hiStaGaKtem	—
Identity	hitRaGaGtem	hitLaKaKnu (we leaked ourselves)
Control	hitGaDaNtem	hitLaMaDnu (we taught ourselves)

5.2. Results and discussion

To protect from the effect of outliers, we excluded from the response latency analyses all responses falling 2.5SD above or below the grand mean. This resulted in the exclusion of 2.63% of the total correct observations.

5.2.1. Word responses

The analyses on the responses to the target words did not yield a significant effect of root structure. Response latency to words with identical consonants ($M = 822$ ms) did not differ from words with no identity ($M = 824$ ms, $F_s(1, 24) < 1$, MSE = 1080; $F_i(1, 44) < 1$, MSE = 5837). Likewise, the slight advantage in response accuracy to words with identical consonants ($M = 90.04\%$) compared to those with no identical consonants ($M = 87.92\%$) was not reliable ($F_s(1, 24) = 2.74$, MSE = .002, $p < .11$, n.s.; $F_i(1, 44) < 1$, MSE = .0167).

5.2.2. Nonword responses

As before, nonwords yielded a robust effect of root structure in both the latency ($F_s(2, 48) = 13.89$, MSE = 2003, $p < .0002$; $F_i(2, 58) = 7.32$, MSE = 4565, $p < .002$) and accuracy ($F_s(2, 48) = 10.96$, MSE = .0038, $p < .0001$; $F_i(2, 58) = 3.83$, MSE = .0126, $p < .03$) analyses (see Fig. 4). Planned comparisons demonstrated a significant effect of homorganicity: Roots with homorganic consonants were rejected faster ($t_s(48) = 4.73$, $p < .0001$; $t_i(58) = 2.83$, $p < .007$) and more accurately ($t_s(48) = 4.67$, $p < .0001$; $t_i(58) = 2.76$, $p < .008$) than controls. Although homorganicity is undesirable, identity (full similarity) was more acceptable than homorganicity (partial similarity). Specifically, roots with identity resulted in a significant impairment in response latency ($t_s(48) = 4.37$, $p < .0001$; $t_i(58) = 3.64$, $p < .0006$) relative to homorganic roots. A similar trend emerged in response accuracy ($t_s(48) = 2.67$, $p < .02$; $t_i(58) = 1.56$, $p < .13$, n.s.). Unlike previous experiments, however, the rejection of roots with identity did not reliably differ from controls (for latency: $t_s(48) < 1$; $t_i(58) < 1$; for accuracy: $t_s(48) = 1.99$, $p < .06$; $t_i(58) = 1.19$, $p < .24$). Perhaps the overall delay in response latency in Experiment 3 (due to the opaqueness of the word pattern) allowed for a fuller analysis of the foils, which counteracted the difficulties incurred by the grammatical appearance of novel roots with final identity. Nonetheless, speakers distinguished both partial similarity (homorganicity) and full similarity (identity) from controls. The greater difficulties in rejecting root final identity relative to homorganicity suggests that the constraint on identical root consonants is inexplicable by their similarity. The replication of this pattern across experiments, despite marked differences in surface word structure, demonstrates that the constraint on identical consonants concerns the structure of the root, an abstract morpheme, rather than the word.

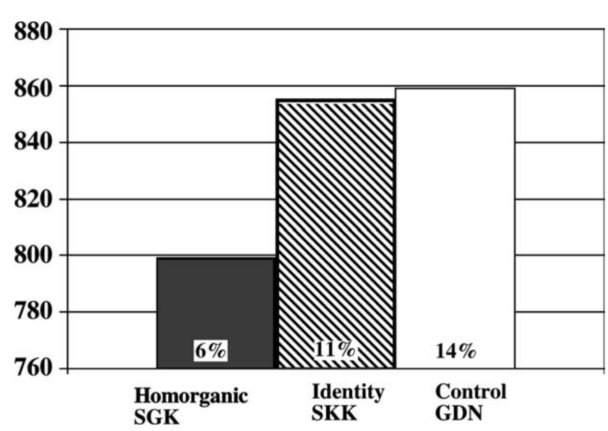

Fig. 4. Response latency (ms) and errors to the verbal foils presented in Experiment 3 as a function of root type.

6. General discussion

Experiments 1–3 examined whether the acceptability of identical consonants in the root is explicable by their feature similarity. The identity hypothesis states that the constraint on segment identity is irreducible to feature similarity. Specifically, McCarthy's (1986) account predicts that, at root final position, homorganicity, which violates the OCP, should be less acceptable than full identity, which escapes OCP violations. Conversely, the similarity hypothesis attributes the restrictions on identical consonants to their similarity, captured in terms of the degree of feature overlap (a symbolic version of the similarity hypothesis) or the frequency of feature-co-occurrence (an associationist version of the similarity hypothesis). Both versions of the similarity account predict that identical and homorganic consonants should each be unacceptable, and that the unacceptability of identical consonants should be at least as low as homorganic consonants.

Our results demonstrate that roots with identical consonants were more difficult to reject than roots with homorganic consonants. This finding suggests that identity is more acceptable than homorganicity, a conclusion that stands in direct opposition to the view that the acceptability of identical consonants is a monotonic function of their feature overlap. These outcomes are also inexplicable by the statistical properties of the materials: Roots with identical and homorganic consonants were matched for the co-occurrence of consonants, and they did not reliably differ in terms of the co-occurrence of homorganic features. The replication of these findings for both nominal (Experiment 1) and verbal (Experiments 2–3) word patterns, despite marked variations in surface word structure, indicates that speakers specifically constrain the position of identical consonants in the root: Root final identity (full similarity) is more acceptable than homorganicity (partial similarity), a conclusion that converges with off-line acceptability ratings (Berent & Shimron, 2003). In fact, not only was identity more acceptable than partial similarity—it was even more acceptable than controls. Replicating our previous results (Berent et al., 2001b), two of the three experiments demonstrated difficulties in rejecting roots with identical consonants relative to dissimilar controls. This finding is explained by the view of root final identity as the outcome of a grammatical operation (McCarthy, 1986). Because such roots bear the hallmark of the grammar, they are perceived as more wordlike, hence, they are more difficult to classify as foils.

Although our findings are incompatible with the similarity hypothesis as an account of the constraint on full segment identity, participants in our experiments were clearly sensitive to the perceived similarity among nonidentical segments. We do not question the adequacy of the perceived similarity account as an explanation for the acceptability of homorganic segments (Pierrehumbert, 1993). Indeed, Pierrehumbert (1993), Frisch et al. (2004) and Buckley (1997) mount compelling evidence favoring the stochastic similarity view over an inviolable constraint explanation for the acceptability of roots with partially similar consonants. Our critique strictly concerns the extension of this account to handle full segment identity.

Our results carry several implications. First, our findings suggest that Hebrew phonology constrains full-segment identity irrespective of similarity, and that the restriction on identical consonants operates in a long-distance manner, across intervening vowels and affixes. This conclusion constrains the class of possible grammars of Semitic morphology (for current optimality theory accounts of the constraint on identity, see Bat-El, 2002; Gafos, 1998; Rose & Walker, 2001). This conclusion also has some implications for theories of reading. Readers' sensitivity to the phonological features of novel printed words demonstrates that they assemble phonological structure from print, and that their representation specify feature information, at least at the place of articulation level (for converging results in English, see Lukatela, Eaton, & Turvey, 2001).

Additional implications of our results concern the scope of phonological generalizations. A central goal of a theory of language is to account for linguistic generalizations. Associationist and symbolic accounts of cognition offer radically different accounts for linguistic generalizations. Associative approaches attribute phonological generalizations to the statistical properties of stored lexical instances. Conversely, symbolic approaches attribute linguistic productivity primarily to a grammar, a mechanism that operates over variables. The assumptions regarding the mechanisms underlying the computational of novel forms have direct bearing on the scope of linguistic generalizations. The hallmark of a symbolic process is its ability to generalize across the board, irrespective of the statistical properties of specific test items or their similarity to training item. Whether or not speakers can generalize in such a fashion is a question that is crucial for understanding linguistic productivity.

Our current findings address this question. Replicating previous results (Berent et al., 2001b) , the findings from Experiments 1–3 demonstrate that speakers distinguish between roots with identical consonants and controls, matched for bigram frequency. Our current findings extend those earlier results by demonstrating that the restriction on identical consonants is inexplicable by the co-occurrence of the place of articulation feature. These findings suggest that the restriction on identical consonants generalizes irrespective of the statistical properties of phonemes or features in their lexicon, a conclusion that agrees with the predictions of the symbolic account.

A yet stronger evidence for the symbolic view could come from generalizations to novel phonemes–phonemes for which speakers lack relevant lexical statistical information altogether. Berent et al. (2002) demonstrated such generalizations. They showed that Hebrew speakers prefer XYY over XXY roots even when the identical consonants in question are foreign to the Hebrew inventory, and they never appear in either XYY or XXY forms. Berent et al. (2002) argued that their findings demonstrate the capacity to generalize phonological knowledge outside the phonological space of the language. A caveat in their argument is the possibility that the restriction on novel phonemes may be accommodated within the learners' feature space by tracking the co-occurrence of existing Hebrew features, especially place of articulation features. In order for this solution to work, however, the constraint on full segment identity must be explicable by the co-occurrence of the place feature. Our present findings speak against this possibility. The results demonstrate that the acceptability of fully identical consonants is inexplicable by the co-occurrence of the place feature or the degree of feature similarity. Thus, even if novel phonemes were accommodated within the feature space of Hebrew, it is doubtful that speakers could correctly learn the constraint on full segment identity from the co-occurrence of features. If the constraint on identical consonants must be represented at the segment level, then generalizations to novel phonemes must exceed the phonological space of the Hebrew language.

This conclusion brings us to the final, and, undoubtedly, most controversial implication of our findings: the link between the scope of linguistic generalizations and mental architecture. We pointed out that the ability to generalize outside the training space is the hallmark of symbolic architectures—such generalizations directly follow from the assumption that the mind operates over variables, a capacity that is innately specified in symbolic architectures. Whether the scope of linguistic generalizations indeed *requires* innate operations over variables has been the subject of much debate. Marcus (2001) demonstrated that popular connectionist networks that lack the innate capacity to operate over variables fail to generalize outside the training space. Several connectionist simulations have claimed to learn such generalizations in the absence of innate operations over variables. In each of these cases, however, Marcus (1998, 2001) either unveiled some principled limitations in the ability of such networks to generalize (Altmann & Dienes, 1999; Christiansen & Curtin, 1999; Dominey & Ramus, 2000, Model A), or demonstrated the implementation of operations over variables (Dominey & Ramus, 2000, Model B; Negishi, 1999; Seidenberg & Elman, 1999; Shultz, 1999).

We feel that the question concerning the scope of linguistic generalizations is separate from the question regarding their learnability. The main contribution of our results is in demonstrating that speakers' ability to generalize beyond the space of Hebrew phonemes is unlikely to be captured by the statistical co-occurrence of existing features. Although the learnability of such generalizations is still debated, in our interpretation, the existing evidence suggests that the mechanism governing operations over variables must be innately distinguished from the associative system. This conclusion directly speaks to a fundamental tenet of generative accounts of language, namely, the autonomy of the grammar from the lexicon. Our present results suggest that some aspects of phonological competence (a component of the grammar) appeal to the relationship among variables. If mechanisms governing such generalizations must be innately distinct from an associative system, then the grammar must be autonomous from the associative lexicon.

Several limitations of our conclusions must be noted. First, the conclusion that an account of linguistic productivity requires a symbolic computational mechanism does not imply that such a mechanism is sufficient to handle all forms of linguistic productivity. There are numerous demonstrations that speakers, including young infants, are sensitive to the statistical properties of lexical instances and their constituents, including features (e.g., Godrick, 2002), segments (e.g., Dell, Reed, Adams, & Meyer, 2000; Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993; Saffran, Aslin, & Newport, 1996) and morphemes (e.g., De Jong, Schreuder, & Baayen, 2000). Such observations indicate that the lexicon is an associative system, allowing for limited generalization by analogizing novel forms to existing instances (Pinker, 1999). Our results suggest that the associative lexicon is complemented by a second productive mechanism that generalizes by operating on variables (Marcus & Berent, 2003; Pinker, 1999). A second limitation of our conclusions concerns the ubiquity of symbolic generalizations. Our current findings can only assess the role of a symbolic mechanism in a single aspect of phonological competence. Our conclusions from phonology nevertheless converge with previous research demonstrating that various aspects of syntactic (e.g., Bornkessel, Schlesewsky, & Friederici, 2002), semantic (e.g., Lidz, Gleitman, & Gleitman, 2003), and morphological (e.g., Gordon, 1985; Marcus, Brinkmann, Clahsen, Wiese, & Pinker, 1995) knowledge are inexplicable by the statistical structure of the lexicon. Finally, our findings do not fully specify the nature of this symbolic mechanism. On the generative hypothesis, the grammar is not only symbolic and autonomous from the lexicon but it is also modular: It is innately constrained by principles that are language and species specific (cf. Chomsky, 1980; Fodor, 1983, 2000). Our findings support the computational autonomy of the grammar from the lexicon. Whether the grammar is modular is a question that falls beyond the scope of our investigation.

References

Altmann, G. T. M. (2002). Learning and development in neural networks—the importance of prior experience. *Cognition, 85*, B43–B50.

Altmann, G. T. M., & Dienes, Z. (1999). Rule learning by seven-month-old infants and neural networks. *Science, 284*, 977.

Bat-El, O. (2002). *Hebrew reduplication: The interpretation of forms with identical consonants.* Colloquium, Department of Linguistics, University of Southern California.

Bender, M. L., & Fulass, H. (1978). *Amharic verb morphology. A generative approach*. East-Lansing, MI: African Studies Center Michigan State University.

Berent, I., & Shimron, J. (1997). The representation of Hebrew words: Evidence from the obligatory contour principle. *Cognition, 64*, 39–72.

Berent, I., & Shimron, I. (2003). Co-occurrence restrictions on identical consonants in the Hebrew lexicon: Are they due to similarity? *Journal of Linguistics, 39.1*.

Berent, I., Pinker, S., & Shimron, J. (1999). Default nominal inflection in Hebrew: Evidence for mental variables. *Cognition, 72*, 1–44.

Berent, I., Everett, D., & Shimron, J. (2001a). Do phonological representations specify formal variables? Evidence from the obligatory contour principle. *Cognitive Psychology, 42*(1), 1–60.

Berent, I., Shimron, J., & Vaknin, V. (2001b). Phonological constraints on reading: Evidence from the obligatory contour principle. *Journal of Memory and Language, 44*(4), 644–665.

Berent, I., Marcus, G., Shimron, J., & Gafos, A. (2002). The scope of linguistic generalizations: Evidence from Hebrew word formation. *Cognition, 83*, 113–139.

Berent, I. (2001). Can connectionist models of phonology assembly account for phonology. *Psychonomic Bulletin and Review, 8*(4), 661–676.

Bornkessel, I., Schlesewsky, M., & Friederici, M. (2002). Grammar overrides frequency: Evidence from online processing of flexible word order. *Cognition, 87*, B21–B30.

Buckley, E. (1997). Tigrinya root morphology and the OCP. *U. Penn Working Papers in Linguistics, 43*, 19–51.

Chomsky, N. (1980). Rules and representations. *Behavioral and Brain Sciences, 3*, 1–61.

Christiansen, M. H., & Curtin, A. (1999). The power of statistical learning: No need for algebraic rules. In M. Hahn & S. C. Stones

(Eds.), *Proceedings of the Twenty first Annual Conference of the Cognitive Science Society* (pp. 114–119). Mahwah, NJ: Erlbaum.

Christiansen, M. H., Conway, C. M., & Curtin, S. (2000). A connectionist single-mechanism account of rule-like behavior in infancy. In *The Proceedings of the Twenty second Annual Conference of the Cognitive Science Society* (pp. 83–88). Mahwah, NJ: Lawrence Erlbaum.

De Jong, N. H., Schreuder, R., & Baayen, R. H. (2000). The morphological family size effect and morphology. *Language and Cognitive Processes, 15*, 329–365.

Dell, G. S., Reed, K. D., Adams, D. R., & Meyer, A. S. (2000). Speech errors, phonotactic constraints, and implicit learning: a study of the role of experience in language production. *Journal of Experimental Psychology: Learning, Memory and Cognition, 26*(6), 1355–1367.

Dominey, P. F., & Ramus, F. (2000). Neural network processing of natural language: I. Sensitivity to serial, temporal and abstract structure in the infant. *Language and Cognitive Processes, 15*(1), 87–127.

Eimas, P. (1999). Do infants learn grammar with algebra or statistics. *Science, 284*, 433.

Elman, J. (1993). Learning and development in neural networks: The importance of starting small. *Cognition, 48*, 71–99.

Elman, J., Bates, E., Johnson, M., Karmiloff-Smith, A., Parisi, D., & Plunkett, K. (1996). *Rethinking Innateness: A Connectionist Perspective on Development*. Cambridge, MA: MIT Press.

Even-Shoshan, A. (1993). Ha'milon ha'xadash [The new dictionary] Jerusalem: Kiryat Sefer.

Fodor, J. (1983). *The modularity of mind*. Cambridge, MA: MIT Press.

Fodor, J. (2000). *The mind doesn't work that way: The scope and limits of computational psychology*. Cambridge, MA: MIT Press.

Frisch, S. A., & Zawaydeh, B. A. (2001). The psychological reality of OCP-place in Arabic. *Language, 77*, 91–106.

Frisch, S., Broe, M., & Pierrehumbert, J. (2004). Similarity avoidance and the OCP. *Natural Language and Linguistic Theory* 22(1), 179–228.

Gafos, D. (1998). Eliminating long-distance consonantal spreading. *Natural Language and Linguistic Theory, 16*, 223.

Gafos, A. (1999). *The articulatory basis of locality in phonology*. New York: Garland publishers.

Godrick, M. A. (2002). *Patterns of sound, patterns in mind: Phonological regularities in speech production*. Unpublished doctoral disseration, Johns Hopkins University, Baltimore.

Gordon, P. (1985). Level ordering in lexical development. *Cognition, 21*, 73–93.

Greenberg, J. (1950). The patterning of morphemes in Semitic. *Word, 6*, 162–181.

Jusczyk, P. W., Friederici, A. D., Wessels, J., Svenkerud, V. Y., & Jusczyk, A. M. (1993). Infants' sensitivity to the sound patterns of native language words. *Journal of Memory and Language, 32*, 402–420.

Lidz, J., Gleitman, H., & Gleitman, L. (2003). Understanding how input matters: Verb learning and the footprint of universal grammar. *Cognition, 87*(3), 151–178.

Lukatela, G., Eaton, T., & Turvey, M. T. (2001). Does visual word identification involve a sub-phonemic level? *Cognition, 78*, B41–B52.

Marcus, G. (1998). Rethinking eliminative connectionism. *Cognitive Psychology, 37*, 243–282.

Marcus, G. (2001). *The algebraic mind: Integrating connectionism and cognitive science*. Cambridge, MA: MIT Press.

Marcus, G. F., & Berent, I. (2003). Are there limits to statistical learning? *Science, 300*, 53–55.

Marcus, G., Brinkmann, U., Clahsen, H., Wiese, R., & Pinker, S. (1995). German inflection: The exception that proves the rule. *Cognitive Psychology, 29*, 189–256.

McCarthy, J. (1986). OCP effects: Gemination and antigemination. *Linguistic Inquiry, 17*, 207–263.

McCarthy, J. (1994). The phonetics and phonology of Semitic pharyngeals. In P. Keating (Ed.), *Papers in laboratory phonology III* (pp. 191–283). Cambridge: Cambridge University Press.

McClelland, J. L., & Patterson, K. (2002). Rules or connections in past-tense inflections: What does the evidence rule out? *Trends in Cognitive Science*.

McClelland, J., & Plaut, D. (1999). Does generalization in infant learning implicate abstract algebra-like rules? *Trends in Cognitive Sciences, 3*, 166–168.

Negishi, M. (1999). Rule learning by seven-month-old-infants and neural networks. *Science, 284*, 875–875.

Pierrehumbert, J. (1993). Dissimilarity in Arabic verbal roots. In *Proceedings of NELS 23, GLSA*, Departments of Linguistics (pp. 367–381). Amherst, MA: University of Massachusetts.

Pinker, S. (1999). *Words and rules: The ingredients of language*. New York: Basic Books.

Pinker, S., & Ullman, M. (2002a). The past and future of the past tense. *Trends in Cognitive Science*.

Pinker, S., & Ullman, M. (2002b). Structure and combination, not gradedness, is the issue (Reply to McClelland and Patterson). *Trends in Cognitive Science*.

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

Rose, S., & Walker, R. (2001). *A typology of consonant agreement as correspondence.* Manuscript, University of San Diego and University of Southern California.

Rumelhart, D. E., & McClelland, J. L. (1986). On learning past tense of English verbs: Implicit rules or parallel distributed processing?. In J. L. McClelland, D. E. Rumelhart, & T. P. R. Group (Eds.), *Psychological and biological models: Vol. 2. Parallel distributed processing: Explorations in the microstructure of cognition* (pp. 216–271). Cambridge MA: Bransford Book, MIT Press.

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science, 274*(5294), 1298–1926.

Seidenberg, M. S., & Elman, J. L. (1999). Networks are not 'hidden rules'. *Trends in Cognitive Sciences, 3*, 288–289.

Shastri, L. (1999). Infants learning algebraic rules. *Science, 285*, 1673–1674.

Shultz, T. R. (1999). Rule learning by habituation can be simulated in neural networks. In M. Hahn & S. C. Stoness (Eds.), *Proceedings of the 21st Annual Conference of the Cognitive Science Society* (pp. 665–670). Mahwah, NJ: Erlbaum.

Van Orden, G. C., Pennington, B. F., & Stone, G. O. (1990). Word identification in reading and the promise of subsymbolic psycholinguistics. *Psychological Review, 97*, 488–522.