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Experimental Evidence for Abstract Phonotactic Constraints[1]

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Abstract. This paper provides evidence for the psychological reality of a highly abstract phonotactic constraint within the verbal roots of Arabic, known as OCP-Place. In a novel root rating task, non-roots containing constraint violations were rated less acceptable than control non-violations. Ratings were also influenced by the lexical neighborhood density of the non-roots within the lexicon of occurring roots. Lexical characteristics of the non-root stimuli were controlled so that the difference between constraint violations and controls was not in the type frequency of consonants and consonant pairs involved, but instead a difference between a linguistically systematic and an accidental gap in the lexicon. In other words, the abstract constraint is a psychologically real factor in judging non-word acceptability.

Introduction

Generative and connectionist approaches to linguistic knowledge make different claims about the psychological reality of linguistic constraints. In distributed connectionist models, constraints are emergent properties of the set of lexical items and do not exist as independent mental entities. In formal generative grammar, constraints (or rules) are the core of linguistic knowledge and knowledge about individual lexical items is restricted to idiosyncratic information. This paper provides evidence based on a pilot experiment for the psychological reality of a highly abstract phonotactic constraint within the Arabic verbal roots. Our results are consistent with the generative approach, since we find evidence for an abstract phonotactic constraint which is independent of specific patterns in the lexicon. However, we find that lexical patterns influence acceptability judgments as well, as is predicted by a connectionist account.

In addition, our results are theoretically important because that we find lexical factors which have previously been examined only in English to have an influence in Arabic as well. In particular, we found that lexical neighborhood density (Goldinger, Luce, & Pisoni, 1989; Luce, 1986) influences acceptability ratings of non-words in Arabic.

Introduction to OCP-Place in Arabic

Morphology

The verbal roots of Arabic have a root-and-pattern morphology, and the underlying form of Arabic verbal roots is assumed to be a sequence of consonants, e.g., /k t b/. The canonical root contains three consonants. Vowels and a syllabic structure are provided by separate morphemes. This situation provides a rationale for segregating the consonants and vowels into separate autosegmental tiers (McCarthy, 1979), as in now famous examples such as kutib 'to be written', shown in (1).

(1)	consonantal tier:	k		t		b
		|		|		|
	skeletal tier:	C	V	C	V	C
			|		|	
	vocalic tier:		u		i	

Consonant Inventory

Arabic has a large consonant inventory, which includes nearly all of the consonants of English, as well as two series of consonants not found in English. The complete inventory is given in (2). The EMPHATIC consonants /T, D, S, Z/ are similar to the familiar English consonants /t, d, s, z/ but they are articulated with an additional constriction in the pharynx. The GUTTURAL consonants /χ, ʁ, ħ, ʕ, h, ʔ/ have place of articulation in the back of the throat, ranging from the uvula to the larynx. Their manner of articulation is considered to be APPROXIMANT by Catford's (1977) definition. The voiceless gutterals have a turbulent noise source which is absent in the voiced gutturals (see McCarthy, 1994, for an excellent summary of the phonetic character of the Arabic gutturals).

(2)	Labial	Coronal	Emphatic	Velar	Uvular	Pharyngeal	Laryngeal
		t	θ	k	q		ʔ
	b	d	ð	g			
	f	θ, s	ʃ		χ	ħ	h
		ð, z	ʒ		ʁ	ʕ	
		ʃ					
		l, r					
	m	n					
		w, y					

For most Arabic speakers the underlying velar /g/ is realized as [g], [dZ], or [Z]. However, for the purposes of the phonotactic constraint as it is reflected in the lexicon, this consonant patterns as a velar (McCarthy 1994). In the Levantine dialect which our participants speak, it is realized as [Z]. The possibility that this consonant would pattern differently in a behavioral experiment is not addressed here, but is an interesting topic for future research.

Phonotactics

Arabic has a well-known phonotactic constraint that restricts the set of allowable consonant sequences in roots based on place of articulation: Arabic roots rarely contain homorganic consonant pairs (Greenberg, 1950). This has traditionally been analyzed as a co-occurrence constraint, known as OCP-PLACE (McCarthy, 1986, 1988, 1994), which prohibits repeated place features within a verbal root.

The traditional approach to these co-occurrence restrictions is to divide the Arabic consonants into natural classes, with co-occurrence constraints applying within these classes. The major co-occurrence classes discussed by Greenberg and McCarthy are presented in (3). In their analyses, consonants in any one of these classes are claimed to co-occur freely with consonants from any other class, and within any class consonants tend not to co-occur, with two exceptions. First, the velars (3c) cannot co-occur with the uvular approximants {χ, ʁ}, though they can co-occur with the other gutturals. Second, among the coronal obstruents, there are far more roots containing one fricative and one stop than roots containing two fricatives or two stops. The phonological status of the glides {w, y} is unclear and they are typically excluded from analyses of OCP-Place. There may be a co-occurrence restriction between the glides and there is no evidence for a co-occurrence restriction between the glides and any other consonants (McCarthy 1994).

Major co-occurrence classes:

(3) a. Labials = {b, f, m}
b. Coronal Obstruents = {t, d, T, D, θ, ð, s, z, S, Z, ʃ}
c. Velars = {k, g, q}
d. Gutturals = {χ, ʁ, ħ, ʕ, h, ʔ}
e. Coronal Sonorants = {l, r, n}

Pierrehumbert (1993) demonstrated that the categorical statement of OCP-Place, based on the major co-occurrence classes, is incorrect. She showed that OCP-Place is gradient, and sensitive to the similarity of the homorganic consonants that are involved. For example, roots containing repeated identical consonants are never found (McCarthy, 1986), but roots containing homorganic stops and fricatives, e.g., /d s w/, are well attested.

More recently, Frisch, Broe, and Pierrehumbert (1997) developed a quantitative model of co-occurrence in Arabic based on a novel similarity metric for consonants. They analyzed the Arabic verb lexicon as approximated by a dictionary (Cowan, 1979; see Oldfield, 1966), categorizing consonants by similarity rather than major class. They expressed degrees of co-occurrence of consonants using the ratio of the observed number of consonant pairs in the dictionary (O) compared to the number which would be expected if consonants combined to form roots at random (E). Random combination was computed by multiplying the probabilities of consonant occurrence in each position in the root. For example, the expected frequency of the root /d s w/ is the product of the probability of /d/ in the first position times the probability of /s/ in second position times the probability of /w/ in third position times the total number of roots (2674 in Cowan, 1979).

Figure 1 shows the co-occurrence pattern (O/E) as a function of similarity for individual consonant pairs. The top figure is aggregate O/E for 'adjacent' consonant pairs (combinations of C1C2 or C2C3) and the bottom figure is aggregate O/E for 'non-adjacent' consonant pairs (combinations of C1C3). Both figures reflect the dependence of the co-occurrence constraint on similarity. As similarity increases, relatively fewer roots are found which contain consonant pairs of that similarity.

Insert Figure 1 about here

Note also that the constraint is weaker for non-adjacent consonants. Pierrehumbert (1993) explains the weakening of the constraint on interference in the perception of similarity for the more distant non-adjacent consonants (cf. Ericksen & Shultz, 1979; Massaro, 1970; Pisoni, 1973). For example, in the hypothetical root */d m t/, the medial /m/ provides interference in determining the similarity of /d/ to /t/. For more discussion of the influence of cognitive factors on phonology, see Frisch (1996). The non-categorical nature of the pattern in the lexicon is clearly evident in the gradient and cumulative effects of similarity and distance.

The studies of Greenberg (1950), McCarthy (1986, 1988, 1994), Pierrehumbert (1993), and Frisch et al (1997) are all based on the statistical analysis of a dictionary as an approximation of a native speaker's lexical knowledge. They are therefore suspect on the grounds that the distribution of words in the dictionary is influenced by historical ancestry, and may not be a productive part of the grammar. Thus, the

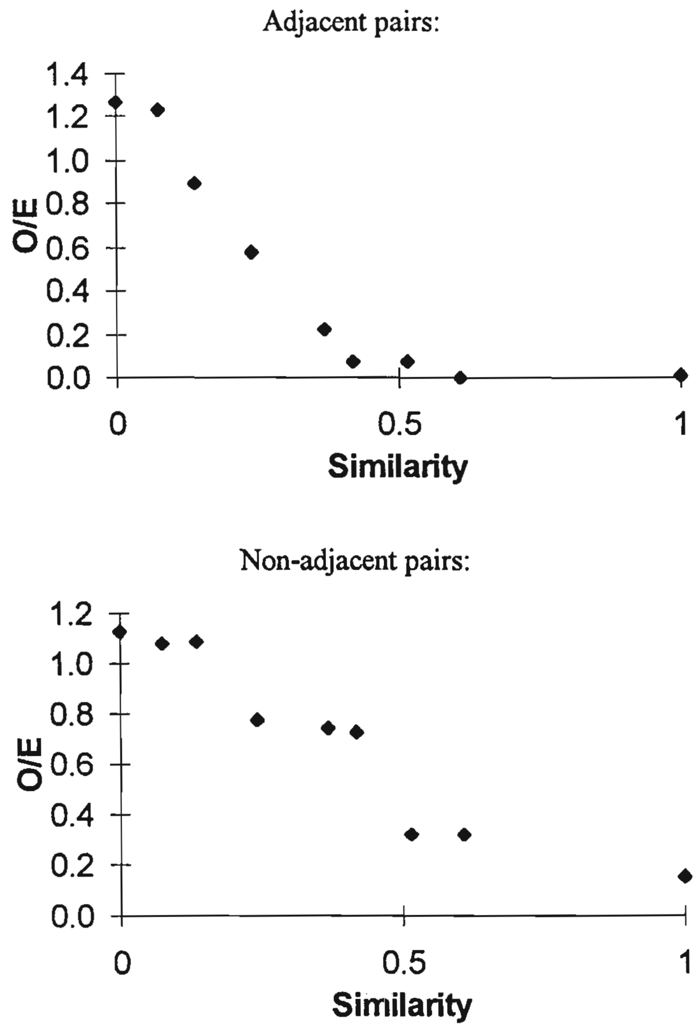

Figure 1. Aggregate O/E for adjacent consonant pairs (top panel) and non-adjacent consonant pairs (bottom panel) in the lexicon of Arabic verbal roots as a function of consonant pair similarity.

OCP-Place constraint may not be part of the synchronic grammar of native speakers. We conducted an experiment to test whether the characterization of the OCP-Place constraint from the dictionary studies accurately reflects the native speaker's implicit knowledge. This experiment also examined whether knowledge of the abstract constraint exists independently of the pattern of lexical items in the dictionary. In other words, are violations of the constraint less word-like than equally rare, but not phonologically regular, gaps in the lexicon.

Experiment

Previous research on acceptability judgments for non-words has found that acceptability ratings are influenced by the how much the non-word is like existing forms in the language (Greenberg & Jenkins, 1962; Ohala & Ohala, 1986). Recent work has quantified word-likeness using the expected frequency of the phonemes in the word. Acceptability ratings for CVC non-words in English are affected by the frequency of the VC combination in the lexicon (Treiman, Kessler, Knewasser, Tincoff, & Bowman, 1996). Vitevitch, Luce, Charles-Luce, & Kemmerer (1997) found analogous effects for consonant frequency in bisyllabic CVC.CVC sequences. Coleman & Pierrehumbert (1997) found the logarithm of the expected frequency of the entire word (where expected frequency was determined by independent combination of the positionally correct probabilities of the onsets and rimes) to be a good predictor of acceptability for a variety of English non-words. These studies all used the type or token frequency of the units which comprise the non-word as a measure of the expected probability of the non-word.

There is a second approach to word-likeness in the spoken word recognition literature which is based more directly on the similarity of a non-word to the set of existing words. The SIMILARITY NEIGHBORHOOD of a target word is the set of words which differ from the target word by at most one phoneme (either substituted, added, or deleted). The NEIGHBORHOOD DENSITY is the size of that set (Goldinger, Luce, & Pisoni, 1989). Luce (1986) and Luce & Pisoni (1998) found that the neighborhood density of a word/non-word influences accuracy and reaction time for a variety of perceptual tasks in English, including lexical decision. In an auditory lexical decision task, a participant must respond as quickly as possible to whether the stimulus is a word or not. Luce (1986) found that non-words in high density neighborhoods were less accurately identified as non-words than non-words in low density neighborhoods. He also found that reaction times for responses were longer for non-words in high density neighborhoods than for non-words in low density neighborhoods.

In order to test the influence of the OCP-Place constraint on acceptability, factors were controlled which influence acceptability and which are unrelated to the OCP constraint. The experimental stimuli were designed to match OCP violations with non-violations that were phonotactically equally probable and had the same number of lexical neighbors.

Stimulus Materials

All non-words in the experiment were non-existing three consonant verb roots. The set of 2764 existing three consonant roots from Wehr's dictionary of Arabic (Cowan, 1979) were used to compute lexical statistics for the non-word stimuli. This is the same dictionary which was used in the studies of Pierrehumbert (1993) and Frisch et al (1997). The stimuli were divided into two sets.

Stimulus Set 1 was designed for a three-way factorial ANOVA with expected frequency, neighborhood density, and OCP-Place violation as factors. The expected (type) frequency of a non-occurring three consonant sequence was computed by independent combination of the three consonants, as in Pierrehumbert (1993). For example, the expected frequency of */ʔ f z/ is

$$\text{Expected}(*/ʔ\ f\ z/) = P(/ʔ\ C\ C/) \times P(/C\ f\ C/) \times P(/C\ C\ z/) \times 2674$$

where P(/x y z/) is the probability of the sequence in the lexicon, and C is any consonant. In other words, the expected frequency is based on the product of the positionally correct phoneme probabilities.

Neighborhood density was computed by single phoneme substitution. In other words, the set of neighbors for a verbal root was taken to be the set of roots which differ by only one consonant. For example, the neighborhood density of */ʔ f z/ is

$$\text{Density}(*/ʔ\ f\ z/) = N(/ʔ\ f\ C/) + N(/C\ f\ z/) + N(/ʔ\ C\ z/)$$

where N(/x y z/) is the number of roots with the sequence in the lexicon, and C is any consonant. The density is equal to the number of roots which share two of the three consonants in the target root, and thus approximates the phonemic similarity of the target root to other roots.

It should not be surprising that expected frequency and neighborhood density are correlated over the entire lexicon. If a target root has many neighbors, then there are many other roots which contain the consonants in the target root and the expected frequency of the target root is relatively high. It is only possible to independently vary expected frequency and neighborhood density if the expected frequency and density is relatively low. Since OCP-Place violations tend not to occur, non-words containing OCP-Place violations are also of relatively low neighborhood density. In addition, expected frequency is correlated with word-hood (Pierrehumbert 1994, Frisch 1996), so non-words tend to have lower expected frequency than words. The stimuli were, on the whole, improbable sequences with few neighbors. The stimuli were grouped into two categories for each factor, as shown in Table 1 (mean values are shown in parenthesis). There were 160 total stimuli, 20 per three-way combination of categories.

Table 1

Three way categorization of stimuli in Stimulus Set 1.

Frequency Category	Exp. Frequency	Density Category	Density	OCP Category
High Freq	0.12-0.25 (0.171)	Dense	11-20 (13.2)	OCP Violation
Low Freq	0.06-0.12 (0.068)	Sparse	1-10 (8.2)	No OCP Violation

Stimulus Set 2 was designed to test whether Arabic speakers' acceptability ratings differentiate SYSTEMATIC GAPS (due to the OCP-Place constraint) and ACCIDENTAL GAPS (chance gaps in consonant sequences with no systematic description). In this stimulus set, OCP-Place violations and control stimuli were balanced for expected frequency and neighborhood density as for Stimulus Set 1. In addition, the stimuli were balanced for the transitional frequency of their consonant pairs. Since OCP-Place violations tend not to occur, violating pairs are underrepresented in the lexicon. In each control, one consonant pair was highly underrepresented in the lexicon of Arabic, but did not form a natural class of examples with other underrepresented pairs. In other words, the controls contained accidental gaps while the OCP-Place violations were systematic.

OCP-Place violations were matched with non-violations that had the same transitional frequency of the C1C2, C2C3, and C1C3 consonant pairs. For example, for the non-existing root */m g t/ there are 3 roots of the form /m g C/, no roots of the form /C g t/ and two roots of the form /m C t/, where C is any consonant. The corresponding stimulus with an OCP-Place violation is /b S T/, which contains the emphatic coronal obstruent pair /S, T/. There are 3 roots of the form /b S C/, no roots of the form /C S T/ and two roots of the form /b C T/, where C is any consonant. There were 40 total stimuli, 20 violations and 20 non-violations.

Participants

Five native speakers of Levantine Arabic (including the second author) who are students at Indiana University, participated in the experiment. They were paid for their participation.

Methods

Stimuli were presented orthographically in Arabic. Stimuli were presented in infinitival form. The participants rated the non-words on a 1-7 scale (1 = impossible, 7 = sounds just like a verb of Arabic). All 200 non-words were rated in a single session, which took approximately 30 minutes. The verbs were presented in pseudo-random order, so that no two stimuli from the same category in either stimulus set appeared in sequence. Items from Stimulus Set 1 were randomly mixed with items from Stimulus Set 2.

Results: Stimulus Set 1

Analysis of variance of participants' ratings of the items in Stimulus Set 1 showed an extremely strong main effect for OCP-Place violation ($F = 79.1$, $p < 0.0001$). OCP-Place violations were rated much less acceptable than non-violations by all participants. There was also a main effect of density class ($F = 7.3$, $p = 0.007$). Non-words with higher neighborhood density were rated as more acceptable than non-words with lower neighborhood density by all participants. Frequency class was not a significant factor ($F < 1$), although the overall trend was in the expected direction. Non-words with higher expected frequency were rated slightly more acceptable than non-words with lower expected frequency.

There was also a significant interaction between density class and OCP-Place violation ($F = 4.6$, $p = 0.035$). For OCP-Place violations, the effect of density was reduced. This may have been a floor effect, because many of the OCP-Place violations were given the minimum rating of 1. The main effects of density and OCP-Place violation, as well as the interaction between the two, is shown in Figure 2. Expected frequency categories were collapsed in this figure since no effect of expected frequency was found.

Insert Figure 2 about here

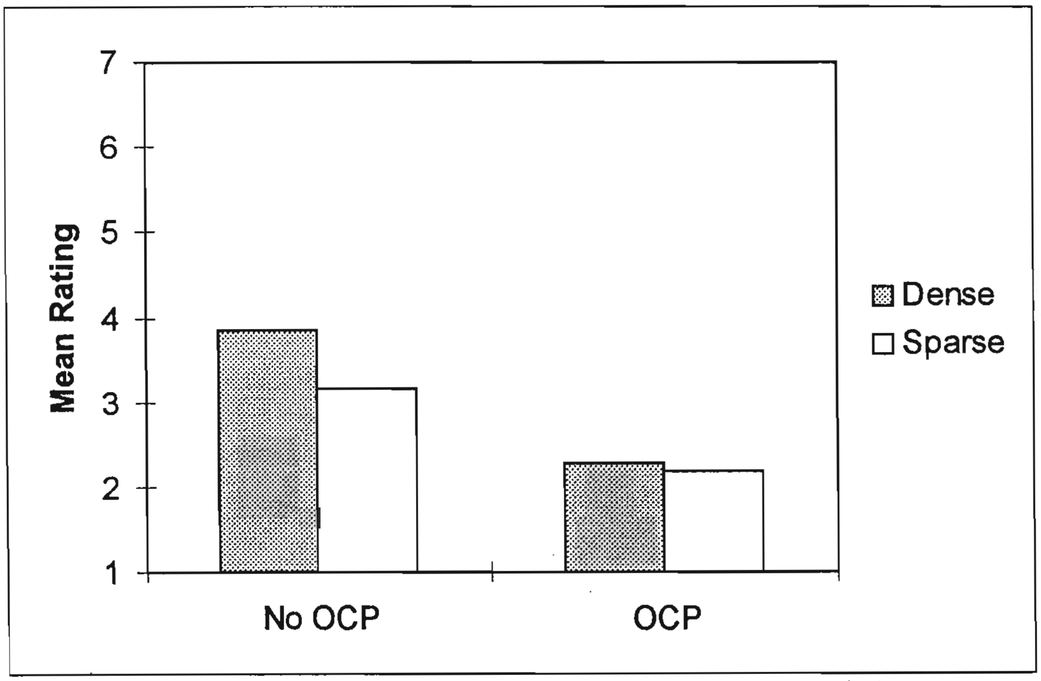

Figure 2. Mean ratings of non-violations and OCP violations by neighborhood density group. Violations were rated much less acceptable than non-violations. Lexical neighborhood density had a greater effect for non-violations. Non-violations from dense neighborhoods were rated much more acceptable than non-violations from sparse neighborhoods.

Results: Stimulus Set 2

Analysis of variance of participants' ratings with OCP-Place violation and participant as factors showed a main effect of OCP-Place violation ($F = 14.2$, $p = 0.0002$). OCP-Place violations were rated as much less acceptable than non-violations even though the non-violations were gaps in the Arabic lexicon. Mean ratings for each participant are shown in Figure 3. All five participants judged OCP-Place violations to be less acceptable than the control non-violations which contained accidental gaps.

Insert Figure 3 about here

Discussion

This experiment found lexical neighborhood density to have an effect on acceptability ratings. Previously, lexical neighborhood effects have only been observed in perceptual tasks in English. We have shown that neighborhood density has an effect on acceptability judgments, which is a linguistic task. Further, neighborhood density is a relevant characteristic of the lexicon of consonantal roots of Arabic. The Arabic lexicon is conceptually more abstract than the English lexicon, as the consonantal sequences are extracted from word forms containing both consonants and vowels, and some of the consonants in the word forms are not part of the root.

The much lower ratings for OCP violations versus non violations in Stimulus Set 1 provide some evidence for a psychologically real OCP-Place constraint in the grammar of Arabic speakers. When lexical factors like expected frequency of the consonant sequence in the verb and the number of phonological neighbors of the verb are taken into account, there is still a strong effect of violating the OCP-Place constraint on acceptability. However, while the stimuli were balanced for the overall neighborhood density of the words and the expected frequency of the phoneme combinations, there were still some differences in lexical characteristics between violations and non-violations in Stimulus Set 1. In particular, the violations tended to have one consonant pair, the pair which violated the OCP, which did not occur in other words in the lexicon. The neighborhood density was still balanced as the other consonant pairs in the word occurred more frequently. For the non-violations, this was generally not the case. Thus, based only on the results for Stimulus Set 1, it is possible that acceptability is not based on an abstract constraint, but rather on the transitional probability of the consonant sequences in the root.

Stimulus set 2 compared consonant pairs with equal transitional probability, half of which were accidental gaps, and half of which were systematic gaps (i.e. OCP-Place violations). The effects of the OCP-Place constraint were found even when lexical gaps were compared. Participants rated systematic gaps much worse than accidental gaps. Systematic gaps, which are the basis for linguistic constraints, have independent influence on acceptability judgments from lexical characteristics.

Conclusions and Future Directions

The present findings demonstrate that non-words which contain constraint violations are judged less acceptable than control non-violations. In addition, the difference between constraint violations and controls was not in the type frequency of consonants and consonant pairs involved, but instead was due to a difference between a linguistically systematic and an accidental gap in the lexicon. In other words, the constraint is a psychologically real abstraction and not only a reflection of the similarity space of lexical

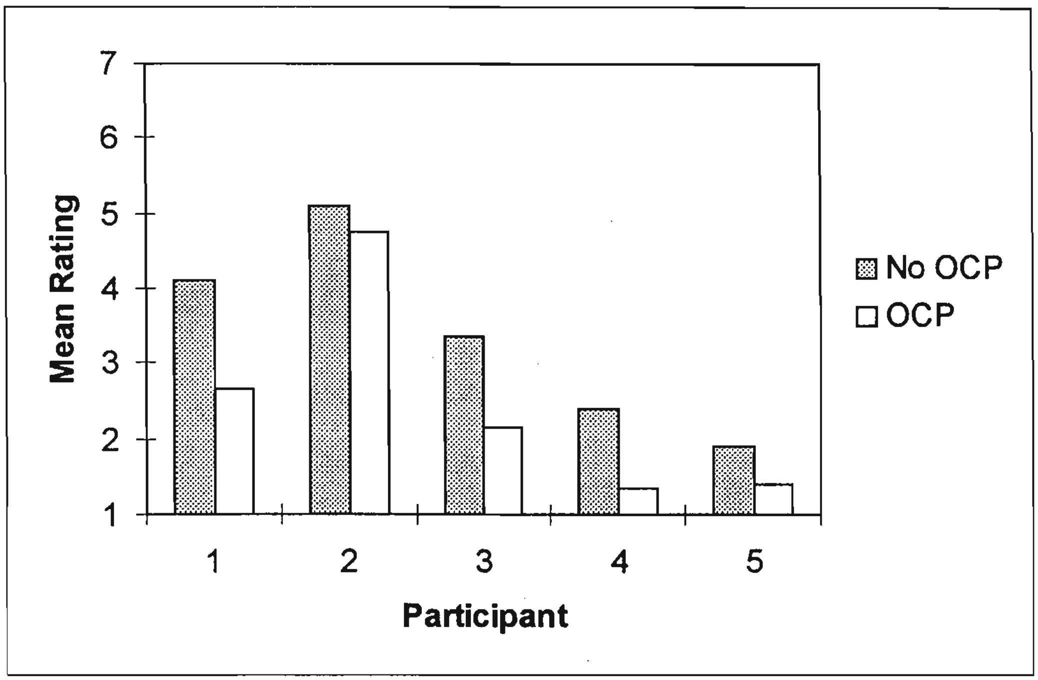

Figure 3. Mean ratings for each participant of stimuli with accidental (No OCP) or systematic (OCP) gaps. Systematic gaps were rated much less acceptable by all participants.

types. The existence of an abstract constraint supports the generative notion of linguistic knowledge as containing constraints abstracted from their lexical contexts.

Note, however, that these results are not inconsistent with connectionist or emergent approaches to language. What has been shown here is that Arabic speakers do know an abstract generalization about their language. This generalization is emergent from the pattern of lexical items (the generalization was observed by linguists examining the patterns over a dictionary, after all), and thus could potentially be learned by a connectionist system and need not be assumed to be innate. The point to be understood is that the system would have to be able to learn generalizations to the degree of abstraction generally assumed in linguistic theory.

We are currently analyzing data from the full version of this experiment, which used 30 participants living in Amman, Jordan. Preliminary results indicate that the OCP-Place effects are just as strong for these participants as they are for those who participated in the pilot experiment described earlier, and that these participants also differentiated accidental and systematic gaps just as reliably.

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